POST-MORTEM COMPUTED TOMOGRAPHY IN THE ASSESSMENT OF FATAL CHILD ABUSE

by

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Thesis submitted in fulfilment of the requirements for the degree:

DOCTOR OF RADIOGRAPHY

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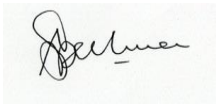
Declaration

I, Aladdin Speelman, hereby declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, the views expressed within this thesis are those of the author and do not represent the views of the Cape Peninsula University of Technology.



20 Feb 2022

Signed **Date**

Abstract

Introduction

The main purpose of forensic pathology is to determine the cause and manner of death of deceased persons, evaluate the fatality of injuries sustained, and methodically document, analyse and synthesise findings in a comprehensible way for presentation in a court of law. Worldwide, there has been a decline in autopsy rates due to cultural and religious objection to the conventional autopsy. Clinicians had to find alternative ways to establish the cause of death. The increased application of post-mortem imaging in forensic pathology has resulted in researchers exploring the suitability of both post-mortem Computed Tomography (PMCT) and post-mortem Magnetic Resonance Imaging (PMMRI) to establish the cause of death, determine injuries sustained and whether this imaging modality can replace the autopsy in certain cases. The main objectives of this research study were: to compare the degree of concordance between PMCT and the forensic autopsy in terms of the spectrum and anatomical location of injuries identified; to analyse the injury categories not readily diagnosed by both examinations; to ascertain whether PMCT can accurately establish the cause of death; and to explore whether selected forensic cases can undergo PMCT in the absence of the forensic autopsy.

Methods

Thirty children, all younger than 18 years with a history of suspected fatal child abuse or sudden unexplained death, underwent a whole-body PMCT examination using a 64 slice Computed Tomography (CT) scanner, followed by a forensic autopsy. All PMCT studies were reviewed independently by two paediatric radiologists (hereafter termed PMCT reviewers). Both reviewers were blinded to the forensic autopsy findings. The forensic autopsies were conducted by experienced forensic pathologists who were blinded to the PMCT findings. The radiology and forensic pathology reports were analysed using the International Classifications of Disease 10 codes for the respective injury types identified. Injury types identified were divided into five anatomical regions: head and neck; thorax; abdomino-pelvic cavity; spinal column and spinal cord; extremities and one miscellaneous group and comparisons made. Injury types were further grouped into nine common categories and also analysed. Percent agreement was used to establish the degree of concordance between PMCT and the forensic autopsy for injury types

diagnosed. The Cohen-Kappa statistic was used to measure interrater reliability between PMCT reviewers and the forensic autopsy to assign a cause of death.

Results

The forensic autopsy recorded 348 findings (mostly injuries) compared to 241 with PMCT resulting in a 69% agreement. The total combined number of findings observed by both the forensic autopsy and PMCT was 437. PMCT had an 86% agreement (n = 99/115) with the forensic autopsy for injuries within the head and neck, 60% for the thorax (n = 93/156), 53% abdomen and pelvis (n = 17/32), 93% extremities (n = 14/15) and 32% in the miscellaneous category (n = 7/22). The forensic autopsy had a 73% agreement (n = 8/11) with PMCT for spinal column and spinal cord injuries. PMCT had a total of 196 (45%) discrepant findings compared to 89 (20%) for the forensic autopsy. Discrepant findings were those injuries identified by one examination and not the other. Despite the high number of discrepant findings for PMCT, this modality was able to identify 89 additional injuries not recorded by the forensic autopsy.

When analysing injury categories, the forensic autopsy identified more haemorrhagic, hollow organ, large blood vessel, muscle, soft tissue and solid organ injuries compared to PMCT. Conversely PMCT identified more gas collections and skeletal injuries compared to the forensic autopsy. There was a good-to-perfect concordance between the forensic autopsy and PMCT for diagnosis of intracerebral haemorrhages (71%), lung collapse (83%), subarachnoid haemorrhages (SAH) (86%), haemothoraces (92%), rib fractures (97%), diastasis of skull bones (100%) and haemoperitoneum (100%). The forensic autopsy diagnosed more brain contusions (n = 0/8) brain laceration (n = 2/11) subdural haemorrhage (SDH) (n = 1/6) blood and gastric content aspirations (n = 1/11) lung haemorrhages (n = 1/14) lung parenchymal injuries (n = 6/27) cardiac injuries (n = 2/15) and abdominal organ injuries (n = 2/14). With PMCT more facial bone (n = 0/7) skull fractures (n = 26/38) (particularly orbital fractures) intraventricular haemorrhages (n = 2/8) brain compression/swelling (n = 3/7) pneumocephali (n = 0/13) and pneumothoraces (n = 3/20) were diagnosed.

PMCT showed perfect agreement (100%) with the forensic autopsy for assigning a cause of death for blunt force head injuries and very good agreement (91%) for gunshot injuries. PMCT further had good agreement (75%) with the forensic autopsy for establishing a cause of death in two fatal physical abuse cases. The mean percent agreement of PMCT for assigning the correct cause of

death for all 25 unnatural deaths in this study was 80%, suggesting a very good agreement with the forensic autopsy. There was 0% agreement between the forensic autopsy and PMCT for establishing the cause of death in five natural deaths. An incorrect cause of death was assigned with PMCT in one case. The Cohen Kappa statistic measuring interrater reliability for the cause of death rating assigned by the forensic autopsy and PMCT reviewers 1 and 2 was k = 0,624 (95% Confidence interval: 0.45 – 0.80; p = 0.00) and k = 0,582 (95% Confidence interval 0.41 - 0.76, p = 0.00) respectively. This implied a substantial and moderate level of agreement between the forensic autopsy and Reviewers 1 and 2 respectively. The interrater reliability between Reviewers 1 and 2 was k = 0.905, (95% Confidence interval 0.78 – 1.00, p = 0.00) suggesting a near perfect agreement.

Conclusion

This study confirmed that establishing the nature and anatomical location of injuries with PMCT for subjects, following traumatic deaths, is good but remains poor for natural deaths or unnatural deaths where no clear physical injuries are evident. PMCT is unable to assess organ pallor, measure free fluid; nor diagnose skin and mucosal injuries or establish organ weight. PMCT was unable to identify all entrance and exit gunshot wounds. Based on the number of discrepant findings for PMCT, and clinical and physical assessments not possible with this imaging modality, the findings of this study did not support the notion that PMCT can replace the forensic autopsy. PMCT should serve as an adjunct examination to forensic autopsies of children whose demise was due to suspected fatal abuse, irrespective of the initial manner of death. PMCT must therefore be routinely employed as a supplementary examination to the forensic autopsies in the assessment of suspected fatal child abuse.

Acknowledgements

1 My sincere appreciation to The Almighty Heavenly Father for the courage and infinite blessings during this research project and throughout my entire life.

2 I wish to express my sincere gratitude to my supervisors for their unwavering support and profound professional guidance during this research project:

2.1 Prof. Penelope Engel-Hills, Adjunct Professor, Faculty of Health and Wellness Sciences, Cape Peninsula University of Technology.

2.2 Prof. Lorna J. Martin, Professor and Head of Division, Forensic Medicine and Toxicology, Faculty of Health Sciences, University of Cape Town.

3 I further wish to extend my sincere appreciation and admiration to the following paediatric radiologists. Without their exceptional expertise and support, this study would not have been possible:

3.1 Prof. Rick van Rijn, Paediatric Radiologist, Department of Radiology, Emma Children's Hospital, Amsterdam and Amsterdam University Medical Center, Amsterdam, The Netherlands.

3.2 Prof. Amaka Offiah, Honorary Consultant Paediatric Radiologist, Sheffield Children's NHS Foundation Trust, Sheffield, and University of Sheffield, Sheffield, United Kingdom.

4 I also sincerely thank the following individuals and institutions:

4.1 Ms Clarene Francis (chief radiographer) and Mr Yaseen Brock (senior radiographer) who assisted me with the acquisition of the post-mortem Computed Tomography examinations. Your assistance was sincerely appreciated.

4.2 All the Forensic Pathology Officers, including Mr Carl Gordon, administrative staff: Mr Omar Galant, Ms Chantal Beukes, Ms Elrona Roberts and other staff of the Department of Forensic Pathology Services who assisted me during the data collection.

4.3 Mrs Valdiela Daries for correlating the ICD 10 codes for accuracy and consistency. Your support in this and other academic enveavours was as always, sincerely appreciated.

4.4 My family for their unreserved love and support. A special word of appreciation to my beloved sisters and brothers for all the support and care over the years: Prudence Davids, Emrald Speelman, Megan Speelman, Marcello Speelman, Ralton Benadie. I hope this work will make you proud.

4.5 My niece and nephews, Gavral Speelman, Vaughan Speelman and Anwell Davids. Thank you for your assistance with the tables and graphs and other tasks.

4.6 My dear friend, Marion Wilton-Williams: many thanks for the support with the initial formatting and technical editing. Your support at short notice was sincerely appreciated.

4.7 A special word of thanks to Dr Hilda Vember. Thanks for the continued encouragement over the years and believing in me. You gave me the courage to keep on walking.

4.8 My colleagues for their moral support and encouragement throughout this study.

4.9 My friends for their continued interest and encouragement.

4.10 Dr Jenny Wright for proof reading and editing of the thesis. Your vast expertise on the subject was deeply appreciated.

4.11 Prof Martin Kidd, Centre for Statistical Consultation, Department of Statistics and Actuarial Sciences at the University of Stellenbosch for support with the statistical analysis.

4.12 Dr Corrie Uys, Statistician and Manager, Centre for Postgraduate Studies, Cape Peninsula University of Technology for support with additional statistical analysis.

5 Special acknowledgement

I would like to acknowledge and honour the 30 children whose lives were sadly cut short. The majority through acts of brutal violence and others through neglect or disease. Without them this study would not have been possible.

6 The financial assistance received from the following grants is hereby acknowledged:

6.1 Cape Peninsula University of Technology University Research Fund.

6.2 Cape Peninsula University of Technology University Teaching Development Grant.

6.3 Cape Peninsula University of Technology University Capacity Development Grant.

7 Sections of this thesis appear in a publication entitled: *Speelman A et al., 2022. Postmortem computed tomography plus forensic autopsy for determining the cause of death in child fatalities. Pediatric Radiology, DOI: 10.1007/s00247-022-05406-7.* These sections were reproduced in this thesis with permission from Springer Nature and cited accordingly, where applicable.

Dedication

This thesis is dedicated in loving memory of my late parents:

Lorna and Daan (Wanie) Benadie

“By its very nature, the science of radiology solves mysteries as it reveals deep within the body, hidden secrets that are otherwise inaccessible to exposure”

B.G. Brogdon and J. Lichtenstein, 2011.

Cautionary note

This thesis contains information that may upset sensitive readers. The reader’s discretion is advised.

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LIST OF ABBREVIATIONS

2D	Two dimensional
3D	Three dimensional
5-HT	5-Hydroxytryptamine
AAP	American Academy of Pediatrics
ALARA	As low as reasonably achievable
AHT	Abusive head trauma
ATCM	Automatic tube current modulation
AVM	Arterio-venous malformation
CAMS	Child abuse-maltreatment syndrome
CD	Compact disc
CECT	Contrast enhanced Computed Tomography
CHC	Community Healthcare Centre
CM	Contrast media
CML	Classic metaphyseal lesion
CoD	Cause of death
CPUT	Cape Peninsula University of Technology
CR	Computed Radiography
CSA	Child sexual abuse
CT	Computed/Computerised Tomography
DAI	Diffuse axonal injury
DICOM	Digital Imaging and Communication in Medicine
DNA	Deoxyribonucleic acid
DOA	Dead on arrival
DR	Digital Radiography

DECT	Dual energy Computed Tomography
DSCT	Dual source Computed Tomography
EDH	Extradural/epidural haemorrhage
ESPR	European Society of Paediatric Radiology
ET	Endotracheal
ExSTRA	Examining Siblings to Recognise Abuse
FDP	Factitious Disorder by Proxy
FOV	Field of view
FPO	Forensic Pathology Officer
FPS	Forensic Pathology Service
GI	Gastro-intestinal
GSW	Gunshot wound
HIE	Hypoxic-ischemic encephalopathy
HIV	Human immunodeficiency virus
HRCT	High resolution Computed Tomography
HPCSA	Health Professions Council of South Africa
HPV	Human papillomavirus
HSV	Herpes simplex virus
Hu	Hounsfield unit
ICD 10	International Classification of Diseases, 10th revision
ICH	Intracranial haemorrhage
IIR	Iterative image reconstruction
ISFRI	International Society of Forensic Radiology and Imaging
ISPCAN	International Society for Prevention of Child Abuse and Neglect
ITBI	Inflicted traumatic brain injury
IVC	Inferior vena cava

IVH	Intra-ventricular haemorrhage
kV	Kilovolt
LODOX	Low dose X-ray
mA	Milliampere
mAs	Milliampere-seconds
MRI	Magnetic Resonance Imaging
MRA	Magnetic Resonance Angiography
MVA	Motor vehicle accident
NAI	Non-accidental injury
NAHI	Non-accidental head injury
OI	Osteogenesis imperfecta
PMCT	Post-mortem Computed Tomography
PMCTA	Post-mortem Computed Tomography Angiography
PMMRI	Post-mortem Magnetic Resonance Imaging
Rev	Reviewer
RTA	Road traffic accident
SAH	Subarachnoid haemorrhage
SAMRC	South African Medical Research Council
SAP	South African Police
SAPS	South African Police Services
SBS	Shaken Baby Syndrome
SCIWORA	Spinal cord injury without observable radiographic abnormality
SDH	Subdural haemorrhage
SIDS	Sudden infant death syndrome
SPA	Suspected physical abuse
SPSS	Statistical Package for the Social Sciences

SRFPS	Salt River Forensic Pathology Services
STI	Sexually transmitted infections
SUDI	Sudden unexplained death inquiry
SUID	Sudden unexpected infant death
SVC	Superior vena cava
UCT	University of Cape Town
UNODC	United Nations Office on Drugs and Crime
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
VIRTOPSY	Virtual autopsy
WC	Western Cape
WCG	Western Cape Government
WHO	World Health Organisation
WMA	World Medical Association

CHAPTER ONE

1.1 CHAPTER INTRODUCTION

The main purpose of forensic pathology is to determine meticulously the cause and manner of death in deceased persons, evaluate the fatality of injuries sustained, and to develop a forensic reconstruction based on such findings (Pomara et al., 2009). These findings are methodically documented, analysed and synthesised in a comprehensible way for presentation in a court of law (Pomara et al., 2009). During the forensic autopsy, the cranium, thoracic and abdominal cavity are usually opened, and organs dissected and inspected to determine the cause of death (Flach, Thali & Germarott, 2014a). However, the forensic autopsy extends beyond the anatomical dissection of the human body and may incorporate specialised supplementary examinations such as histology, microbiology, toxicology, biochemistry, deoxyribonucleic acid (DNA) analysis, dentistry, anthropology, evidence collection and photography, and may include conventional diagnostic imaging and or fluoroscopy (O'Donnell & Woodford, 2008).

Worldwide, there has been a decline in autopsy rates. This decline has, in part, been due to religious or cultural objection by families to the invasive and body scarring techniques evident in all autopsies (Sieswerda-Hoogendoorn & Van Rijn, 2010). Other factors that have contributed to the decline in autopsy rates are medical professionals being confident about the patient diagnosis at the time of death (Hinchliffe, Godfrey & Hind, 1994), and their reluctance to obtain informed consent for an autopsy from families or relatives of the deceased (Sinard, 2001), fear of litigation, misunderstanding by the family, as well as increased confidence in technologically advanced imaging studies (Newton et al., 2004).

Clinicians have therefore sought alternative ways to establish the cause of death. Cross-sectional imaging, using Post-mortem Computed Tomography (PMCT) and Post-mortem Magnetic Resonance Imaging (PMMRI), are thus suitable alternatives in some situations. Clinicians and parents of neonates and children who have died view cross-sectional imaging as more acceptable and less invasive alternatives to determine the cause of death (Arthurs, Hutchinson & Sebire, 2017). The increased application of post-mortem imaging has gradually evolved over time and has resulted in researchers exploring the suitability of PMCT and PMMRI to establish the cause of death, and whether these two imaging modalities can replace the autopsy in certain cases. This scientific exploration has led to a sharp increase in the application of these two imaging modalities in forensic pathology across the world.

The main objectives of the research study described in this thesis was to compare the degree of concordance between PMCT and the forensic autopsy for the diagnosis of a wide spectrum of injuries, as well as to establish the level of agreement in determining the cause of death in children who died as a result of suspected fatal child abuse and sudden unexplained deaths. Furthermore, this research study sought to determine the discordance between PMCT compared to the forensic autopsy for injury category diagnosis. Thirty subjects underwent a PMCT and a forensic autopsy examination. This thesis describes the injuries diagnosed with the forensic autopsy and PMCT in six categories consisting of five major anatomical regions and one miscellaneous category.

The next section will highlight some of the aspects that lead to the rise of PMCT imaging in forensic pathology.

1.2 THE RISE OF POST-MORTEM COMPUTED TOMOGRAPHY IMAGING IN FORENSIC PATHOLOGY

Computed Tomography (CT) technology has undergone rapid advances in the past two decades. These advances include the ability to acquire a full body CT scan in less than one minute, reconstruction of multi-planar sequences obtained from the axial data set, brought about by isotropic imaging, and three-dimensional (3D) volume-rendered images of the body (Rydberg et al., 2000; Aggarwal et al., 2002). The above technological advances have been recognised and adopted by radiologists and forensic pathologists alike to complement post-mortem investigations.

Pursuant to the above technological advances, various researchers at forensic and radiology institutions have been conducting clinical research to validate the agreement of PMCT and PMMRI with the autopsy to establish the cause of death (Filograna et al., 2010). Some researchers have, for example, explored the role PMCT can play as an adjunct to, or a replacement of the forensic autopsy. The promising results obtained by these empirical research studies thus far have resulted in PMCT becoming an integral part of post-mortem investigations in many forensic centres around the world (Filograna et al., 2010; Bryce, 2013). A review conducted by Baglivo et al. (2013) on the evolution of forensic radiology publications between 2000 and 2011 shows that research publications grew tenfold (a 1,225% increase) during this decade. This exponential growth has resulted in forensic radiology rising from an obscure entity to an indispensable component of forensic sciences (Baglivo et al., 2013).

Today, whole-body PMCT imaging, conducted prior to the forensic autopsy, is a widely established practice in many forensic institutions across the world (Baglivo et al., 2013). PMCT scanning, for example, is now an integral part of the workup of all admissions at the Victorian Institute of Forensic Medicine in Melbourne, Australia. All bodies admitted to this centre, undergo a PMCT examination (O'Donnell, 2010). The preliminary PMCT examination is used to decide whether or not an autopsy should be performed, following consultation with a forensic pathologist (Bedford, 2012; Baglivo et al., 2013).

Even though there is currently overwhelming evidence that PMCT can be used to determine the cause of death, in some settings, the validation of this imaging modality through empirical scientific evidence is still required to prove whether this imaging modality can completely replace the forensic autopsy on a wider platform (Higginbotham-Jones & Ward, 2014). Scientific evidence currently suggests that there is variable agreement between the forensic autopsy and PMCT for establishing the cause of death (Bryce, 2013). Some studies have shown that PMCT has a higher concordance for detection of skeletal or other trauma-related injuries, foreign bodies or air emboli, but a lower concordance for soft tissue injuries such as organ lesions, fatal haemorrhage, cardiac pathology, or fat embolism (Thali et al., 2003a; Sochor et al., 2008). In order for PMCT imaging to replace the forensic autopsy, it needs to show a high degree of concordance with results obtained via autopsy and must be able to assign the cause of death indisputably for most clinical scenarios.

The birth of the Virtual Autopsy (now termed Virtopsy) in Switzerland in 1998 has further revolutionised forensic imaging (Thali et al., 2003b). This application involves the acquisition of 3D photogrammetry and 3D colour-encoded optical surface scanning of the deceased, combined with 3D volume rendered CT imaging or Magnetic Resonance Imaging (MRI) or both, a post-mortem biopsy, or post-mortem Computed Tomography Angiography (PMCTA) to establish, inter alia, the cause of death (Dirnhofer et al., 2006; Thali et al., 2007).

The section that follows will describe the background to the research problem, the role of post-mortem imaging and the forensic autopsy in the diagnosis of fatal child abuse.

1.3 BACKGROUND TO THE PROBLEM

Child abuse is a regrettable and harmful social anomaly which occurs worldwide. Violence towards children has over centuries, been considered a serious social problem (Deltoff, 1994). According to Saayman (2001), South Africa is not exempt from this social iniquity. The extent of child abuse and neglect within developed Western society cannot be accurately calculated, due to many and varied reporting systems throughout the world (Ellis, 1997). Infants younger than six months old are subjected to child abuse and abusive head trauma at more than twice the rate of children 1 to 3 years old. Physical abuse amongst these infants is often missed, resulting in prolonged and additional injuries or death (Harper et al., 2014). It is thus evident that the younger the child, the higher the risk of abuse, and the greater the consequence in terms of neurological injury. This phenomenon will be discussed in greater detail in Chapter Two.

It is further postulated that, worldwide, a large number of child homicides are underreported, due to the lack of routine investigations and post-mortem examinations of child deaths, even in high income countries (Gilbert et al., 2009). This underreporting is further complicated by use of different terminology to classify child abuse e.g., child maltreatment, child battering, homicide and violent death. This variation in terms used often results in child abuse and neglect deaths being misclassified as drownings, burns, accidental injury or sudden death syndrome (Ellis, 1997). There is a lack of routine and reliable data sources in South Africa, particularly related to the prevalence and incidence of child abuse and neglect (Mathews & Martin, 2016). No single, accurate and complete data system for the evaluation of child mortality exists in South Africa (Reid et al., 2016). As an example, statistics collected and regularly provided by Statistics South Africa, as well as by the South African Police Service (SAPS), do not provide clear statistics on fatal child abuse and neglect, which hampers an accurate calculation of the magnitude of this problem. There is thus a paucity of information regarding current and historic statistics on child deaths, especially as a result of child abuse, at provincial and district level, in South Africa. This situation has negated the inclusion of updated statistics in this thesis.

The United Nations Office on Drugs and Crime (UNODC) estimated that in 2018 the South African homicide rate was 36,4% per 100 000 population compared to the world average of 5,8%. The homicide rate for South Africa is higher than the average for Africa (12,9%) per 100 000 of the population, or other developing economies such as Brazil, (27,4%), the Russian Federation (8.2%), India (3.1%) and China (0,5%) (UNODC, 2021). A study conducted in South Africa in 2009 showed that homicide was the leading manner of death, accounting for 36%

(n = 19,028/52,493) of all external causes, with the male homicide rate six times higher than for females (Matzopoulos et al., 2015). The higher mortality rate for males was attributed to sharp force injuries, such as stabbing and gunshot injuries, as well as blunt force injuries. Children are regrettably also affected by these high rates of violent crimes (Campbell et al., 2013).

The World Health Organisation (WHO) reports that global estimates suggest that annually, approximately 41,000 child homicides occur amongst children younger than 15 years (WHO, 2019). Infants and very young children (0 to 4 years) are at greatest risk; and the risk for this age group is more than double for children between 5 and 14 years (WHO, 2002). South Africa (including the Cape Metropole), has a high rate of child abuse, often ending in child homicide. A Child Death Review pilot study conducted in 2014 showed that gunshots (23%) and stab wounds (22%) were the leading causes of non-abuse-related homicide amongst children (Mathews & Martin, 2016). Firearm homicides are reported to be 10 times higher for adolescent boys than for girls (Pretorius & Van Niekerk, 2014). The ready availability of guns in urban areas is said to contribute to the high incidence of gun-related homicides amongst children (Gun Free South Africa, 2017). Considering major cities in South Africa, homicide is reported to be the highest in Cape Town compared to other cities such as Johannesburg, Durban, Pretoria and Port Elizabeth (Matzopoulos et al., 2014). Even though violence can occur amongst all socio-economic groups, it is more prevalent in lower socio-economic groups (Otwombe at al., 2015). Homicide rates in Cape Town are further well aligned with the geographical inequality of the city and are concentrated in poor neighbourhoods (Matzopoulos et al., 2020).

The child homicide rate in SA, is estimated to be 5,5 per 100,000 children, which is more than double the global rate of 2,4 per 100,000 children (Pinheiro, 2006; Mathews et al., 2013a; Mathews & Martin, 2016). About 44% of these homicides are due to child abuse and abandonment (neglect), with 74% of deaths occurring in children younger than 5 years of age (Mathews et al., 2013a). Local child homicide statistics suggest that three out of four children who die as a result of abuse when younger than 5 years, die as a result of fatal abuse by someone close to the child, such as a parent, guardian or carer (Mathews et al., 2013a). The South African National Child Homicide study has shown that about 1,018 child homicides were recorded in South Africa in 2009 (Mathews et al., 2013b). The above statistics suggest that large numbers of children in South Africa are exposed to child abuse annually, often with fatal consequences. This necessitates allocation of proper resources to address this social problem.

Furthermore, many low- and middle-income countries [including South Africa] do not collect or analyse statistics on child homicide, even though infant mortality is considered a key factor for the development and health standards of a country (Abrahams et al., 2016). Compounding the problem is that in many countries child homicides receive relatively little prioritisation with respect to public health policies; and research on the subject is rarely conducted, especially in low- and middle-income countries (Mathews et al., 2013a). In addition, South Africa lacks a coherent and systematic research strategy for assessing the degree and forms of violence to which children are exposed, which limits an appropriate response to address this social anomaly (Richter et al., 2018). Considering that violence is a major cause of child mortality in South Africa, it warrants the allocation of appropriate research funding and dedicated research studies (including imaging studies) to investigate this public health issue, so that proper policies and responses can be developed to curb this social injustice.

1.4 THE ROLE OF POST-MORTEM IMAGING IN FATAL CHILD ABUSE

Diagnostic radiographic examinations such as conventional X-rays, low dose X-ray (LODOX®) units and fluoroscopy, have been used in forensic pathology for many years to visualise and record findings in the living, as well as the deceased (Thali et al., 2003b; Higginbotham-Jones & Ward, 2014). The skeletal survey, for example, has been widely recognised as the mainstay for detection of skeletal injuries caused by non-accidental injury in both live and deceased children (American College of Radiology, 2020).

CT is widely used in the trauma setting and its usefulness in diagnosing injuries is well recognised (Van Rijn, 2009). The diagnostic capabilities of CT far exceed those of conventional diagnostic imaging. Even though the dose for CT imaging is significantly higher compared to conventional diagnostic imaging, the benefits far outweigh the risks (Power et al., 2016). CT allows exquisite anatomical detail of the human body. The increased use of PMCT in forensic pathology was therefore a natural and expected transition, given the excellent anatomical, multi-planar detail obtained of the human body. With the introduction of PMCT, PMMRI and PMCTA into forensic sciences, it is conceivable that conventional imaging methods, such as projection radiography and LODOX®, will become obsolete within the forensic setting in the next two decades. This presumption is based on the unparalleled benefits cross-sectional imaging provides, compared to conventional projection radiography, LODOX® imaging and fluoroscopy.

In forensic pathology globally, the four most applied imaging techniques which provide various imaging possibilities for the diagnosis of injuries or pathology, and establishing the cause of death are PMCT, PMCTA and PMMRI, and 3D surface scanning (Grabherr et al., 2017). PMCT offers a non-invasive means of exploration and can visualize internal organs in situ. PMCT examinations can be performed rapidly, offer visualisation of non-dissected areas, pose no risk such as infectious blood-related exposure for the forensic pathologist, offer considerable help in identification of victims, and are not destructive or invasive. PMCT further provides a bloodless display of anatomical and pathological detail for presentation during trial (Charlier et al., 2012). With the forensic autopsy, follow-up reviews of cases have to depend on written documents, and selected parts, or small specimens, retained for histological examination, because the remaining body tissues might have already been discarded (Cha et al., 2010). This is contrary to the case of PMCT images which can be recalled at any time and provide for intact topographical and anatomico-clinical reconstruction, years after organic remains will have decayed and disappeared (Thali et al., 2003a). PMCT is further useful for assessment of difficult-to-dissect areas, such as the cranio-cervical junction, spinal canal and small pelvis, shoulder girdle, larynx, face, and small vessels, such as lumbar or intercostal arteries (Flach et al., 2014a).

Skeletal fractures are the second most common sign of physical abuse in children, after soft tissue injuries such as bruises (Lonergan et al., 2003). External physical findings such as haematomas, or bruises, are not evident in the majority of child abuse cases (Van Rijn & Sieswerda-Hoogendoorn et al., 2012). In view of this, evidence of child abuse is often difficult to detect by surface inspection alone during forensic autopsies, and may therefore go unnoticed, hence post-mortem cross-sectional imaging plays an important role in delineating hidden evidence of child abuse (Oyake et al., 2006). Medical imaging has an important role to play in documenting the nature and extent of fatal injuries in abused children. Radiological imaging and related findings are therefore central to the diagnosis of the spectrum of abusive injuries, and to the subsequent prosecution of the perpetrators in the majority of cases (Brogdon, 2011). Documentation of unexplained or unusual injuries using radiology can be substantive evidence in the absence of any other medical signs and symptoms, such as bruising (The Society for Pediatric Radiology & National Association of Medical Examiners, 2004). Based on the above explanations, medical imaging is thus able to display inflicted injuries, even if no external signs of abuse are present. It can therefore be argued that, based on this principle, the role of post-mortem imaging in fatal child abuse will continue to have a central role in determining underlying abusive injuries.

1.5 THE ROLE OF THE FORENSIC AUTOPSY IN DIAGNOSIS OF FATAL CHILD ABUSE

The purpose of forensic pathology is to document systematically, analyse and explain scientifically the manner and cause of death, as well as the fatality of injuries sustained in an acceptable manner for the courts; and, where applicable, identification of the weapon of crime (Persson et al., 2008; Mohanty et al., 2011; Woźniak, Moskala & Rzepecka-Woźniak, 2015). In cases of child abuse, forensic medicine is the specialty that, over time, has mainly focused on the systematic classification and assessment of bodily injuries caused by such abuse (Jacobi et al., 2010). A vast majority of child deaths do have a cause attributed to them (Beck, 2014). Forensic pathology has four fundamental questions to answer, namely *"*who the person was, where they died, when they died and how they came by their death*"* (Rutty, 2007:21). The four aspects, Rutty is referring to in South Africa are the mandate of the Magistrate, as prescribed by the Inquest Act (South Africa, 1959). In answering the question as to what led to the demise of a child, Rutty described forensic pathologists as the "advocate[s] for the dead*",* who in some cases, have to use their professional judgment when deciding on the approach to follow when conducting a post-mortem investigation, regardless of the wishes of family who may (in some cases) be opposed to an invasive autopsy (Rutty, 2007:22).

The diagnostic autopsy examination in neonates, infants and young children usually includes a review of the clinical history (and scene findings, in cases of suspected unnatural deaths), prenatal or neonatal laboratory studies where relevant, and radiographic images (if available), as well as the differential diagnosis clinicians may have had prior to the demise of the child. The autopsy will include a physical external inspection of the body, as well as internal inspection following dissection of the three major cavities, i.e., the cranium, thorax and abdomen and pelvis (Fligner & Dighe, 2011). The autopsy report therefore serves as the only source of information depicting the physical state of the deceased person (Woźniak et al., 2015). In addition to providing clinically relevant information, paediatric autopsies also play a role in evaluating and improving the quality of medical care, as well as medical education (Newton et al., 2004).

Child abuse is now recognised as a discrete clinic-pathological entity with a spectrum of traumatic injuries that can result in severe debilitation or death. Fatal child abuse is the most extreme consequence of violence against children (Mathews & Martin, 2016). One variant of this spectrum is recognised by forensic pathology and is classified in some countries as child abuse-maltreatment syndrome (CAMS). CAMS is identified in both living and deceased subjects and has characteristic injuries that are time- and space-dependent, indicating [a single or] repeated

episodes of trauma (Pollanen et al., 2002). At autopsy, these children may have various injuries at different stages of healing, in addition to a recent fatal injury which has resulted in the ultimate cause of death. Older injuries are usually well healed or are in the healing phase, and do not contribute to the immediate cause of death (Pollanen et al., 2002). Whether a child's fatal injury is abusive is dependent solely on medical confirmation (obtained via the forensic autopsy) that the injury effects could, or could not, have been produced by the event described in the case history (Chadwick et al., 1991). The main purpose of the forensic autopsy, within the context of fatal child abuse, is to prove beyond a reasonable doubt, that the injury patterns observed during the forensic autopsy were the ultimate cause of death.

Many forensic pathologists feel that they have a duty to a deceased person, which is to ensure that the true cause and circumstances of the death be revealed (Cordner et al., 2001). Sedlak et al. (2006) hold the view that the role of law enforcement agencies focusing on child protection is not only to protect the child, but also to gather evidence, so the perpetrators can be identified and prosecuted successfully to ensure justice for victims. The forensic autopsy must ensure that the burden of proof as to a person's guilt or innocence is established; and, where relevant, that closure of such cases is brought to relatives of the deceased (Beck, 2014). Cordner and colleagues (2001:95) correctly pointed out that "nowhere in forensic pathology is it more difficult to discharge this duty than in child homicide*".*

Due to the varied sensitivity of PMCT in demonstrating evidence of abuse, there is a need to explore further the role of this imaging modality in the collection of such evidence. It is therefore in the interests of the child that evidence of abuse is established soon, justice is sought, and the perpetrator held accountable. Forensic imaging in this regard has a crucial supplementary role to play in documenting injuries sustained in order to uphold justice. The next section describes the research question, research aims and research objectives, as well as definitions relevant to this research study. The chapter will end with the legal requirements for a forensic autopsy, research rationale and the underlying motivation for conducting this research study.

1.6 RESEARCH QUESTION

The research question employed during this research study was: “What is the agreement between PMCT and the forensic autopsy in suspected abusive childhood deaths?

1.7 RESEARCH AIMS

The research aims were: to measure the concordance between PMCT and the forensic autopsy in determining the injury types sustained; establishing a cause of death and to assess whether selected forensic cases can undergo a PMCT, without the need for forensic autopsy, amongst children with a suspected clinical history of fatal abuse or sudden unexplained deaths.

1.8 RESEARCH OBJECTIVES

The research objectives were to establish:

- The degree of concordance between PMCT and forensic autopsy in terms of the spectrum and anatomical location of injuries diagnosed in suspected fatally abused children.
- The discordance between PMCT and the forensic autopsy for injury categories diagnosed.
- Under what circumstances PMCT can accurately establish the cause of death in fatally abused children.
- Whether selected cases can undergo PMCT in the absence of the forensic autopsy.

1.9 DEFINITION OF A CHILD

For the purposes of this research study, a child was defined as a person younger than 18 years of age, as defined by the Children’s Act 38 of 2005 (South Africa, 2005).

1.10 DEFINITION OF CHILD ABUSE

The WHO defines child abuse as all forms of physical and emotional ill-treatment that result in actual or potential harm to the child’s health, development or dignity. Five subtypes of abuse are

identified: physical abuse; sexual abuse; neglect, and negligent treatment; emotional abuse; and exploitation (WHO, 2014). The definition for neglect was for the purposes of this study expanded to include supervisory neglect.

1.11 DEFINITION OF FATAL CHILD ABUSE

For the purpose of this research study, fatal child abuse was defined as any act of physical and sexual abuse, neglect, or emotional ill-treatment, or exploitation, of a child at the hands of another person, that has resulted in the demise of a child.

1.12 LEGAL REQUIREMENTS FOR A FORENSIC AUTOPSY

In South Africa, two types of autopsies are recognised, namely an anatomical pathology autopsy and a medico-legal (forensic) autopsy. Anatomical pathology autopsies (also known as diagnostic autopsies) are conducted to establish the nature and extent of underlying natural disease such as cardiac disease, cancer or metabolic disease (Du Toit-Prinsloo & Saayman, 2012). Anatomical pathology autopsies are conducted in accordance with the Human Tissue Act (No. 65 of 1983) (South Africa, 1983). These autopsies not only enable the full investigation of the nature and extent of disease, complications and co-morbid conditions, but are useful for teaching students and conducting research. These findings can be used to inform clinicians as to the cause of death and, in this regard, are useful for clinico-pathological correlation. Permission from the next of kin is required to conduct an anatomical pathology autopsy (Du Toit-Prinsloo & Saayman, 2012).

Medico-legal autopsies are conducted for all unnatural causes of death. The medico-legal investigation (forensic autopsy) of unnatural deaths is a statutory requirement and mandated by the Inquest Act (No. 58 of 1959) in all deaths apparently occurring from unnatural causes (South Africa, 1959). The National Health Act (No. 61 of 2003) defines an unnatural death as any death due to physical or chemical influence, direct or indirect or related complications. Unnatural deaths include those that are considered natural but may have been the result of an act of commission or omission, or which might have been caused by criminal acts, or any death which is sudden and unexpected, unexplained or where the cause of death is not apparent (South Africa, 2003a). The purpose of such a medico-legal investigation, according to the National Health Act, is to establish the cause and circumstances of death and the nature of the injuries and disease processes which

may be present at the time of death (South Africa, 2003a). No permission from the next of kin is required for a medico-legal autopsy. For the sake of simplicity, the medico-legal autopsy will hereafter be referred to as a 'forensic autopsy'.

The Regulations Regarding the Rendering of Forensic Pathology Services, which were promulgated in terms of the National Health Act, further explain that, during a forensic autopsy, the forensic pathologist (or authorised medical practitioner), for the purposes of a medico-legal investigation, must conduct an internal and external examination of the body and may retain any internal organ or any part of, or any contents, such as fluid or tissue of the body, for evidentiary or diagnostic purposes (South Africa, 2003b; National Health Act, No. 61 of 2003. Regulation, 2018, No. R.359). Fluid, tissue, or objects removed from the body must be referred to an appropriate institution for further investigation for the purposes of establishing the cause of death and circumstances of the deceased, in order to advance the administration of justice (South Africa, 2003b; National Health Act, No. 61 of 2003. Regulation, 2018, No. R.359).

The research subjects selected for this research study all underwent a forensic autopsy, based on a history of having succumbed due to unnatural deaths. At the time of admission to the mortuary, all subjects had a history of suspected fatal child abuse, sudden or unexplained deaths which, according to the Inquest Act No. 58 of 1959, warrants a mandatory forensic autopsy (South Africa, 1959). The forensic autopsy was performed only after each subject underwent a whole-body PMCT examination.

1.13 RESEARCH RATIONALE

The overall aim of this research study was to measure the level of agreement of PMCT with the forensic autopsy in determining the cause of death amongst children with a suspected history of fatal abuse or sudden unexplained deaths. The term 'suspected fatal abuse' was used since a diagnosis of fatal child abuse cannot be assumed until the full post-mortem medico-legal investigation has been concluded. The objectives of this research study were to determine the degree of concordance between PMCT and forensic autopsy findings in terms of the spectrum and anatomical location of injuries diagnosed in suspected fatally abused children. The definition applied for the term 'spectrum' in this thesis refers to different injury types diagnosed within specific organs or anatomical locations. This research study also sought to determine the discordance between PMCT and the forensic autopsy for injury categories diagnosed during the forensic

autopsy and vice versa; and whether certain selected forensic paediatric cases can undergo a PMCT without the need for a forensic autopsy.

The theoretical untested assumption made prior to commencement of this research study was that, in a narrowly defined population of suspected fatally abused children, the application of PMCT may potentially yield a more robust and empirical analysis illustrating the usefulness of PMCT in relation to autopsy findings. The researcher sought to establish whether the use of PMCT in a group of suspected fatally abused children would yield a higher concordance between PMCT and the forensic autopsy findings. This assumption was made on the scientific and proven premise that PMCT has already been shown to be more sensitive for skeletal and traumatic injuries, but less so for soft tissue injuries (Krentz et al., 2016). At the design phase of this research study, it was postulated that a number of children who have been fatally abused will present with skeletal and traumatic soft tissue injuries. It was therefore conceivable that this narrow focus (applying PMCT imaging in this defined population of suspected child abuse cases) will lend an opportunity to assess whether this imaging modality will be more accurate compared to the forensic autopsy in the diagnosis of fatal inflicted injuries. In other words, this research study explored whether PMCT would render a higher concordance with the forensic autopsy in terms of establishing the spectrum of injuries, anatomical location thereof and injury types, and the subsequent cause of death in suspected fatally abused children. An additional purpose of this research study was to ascertain whether PMCT, for selected cases, can correctly determine the cause of death; or alternatively, indicate which clinical cases can confidently be selected for PMCT in place of the forensic autopsy.

Although the number of publications on the use of PMCT have grown steadily in the last two decades, the diagnostic agreement of post-mortem imaging compared to conventional autopsy has not yet been validated for all settings (Sieswerda-Hoogendoorn et al., 2014*).* What Sieswerda-Hoogendoorn et al., (2014*)* therefore emphasise, is the fact that even though the usefulness of PMCT in forensic pathology is undisputable in some cases, the exact diagnostic value it brings to all forensic pathology cases has not yet been validated and requires robust scientific evidence generated by empirical research. This validation was required, as the sensitivity and specificity of PMCT has not yet been established for all forensic settings, specifically in fatal child abuse. The exponential growth seen in forensic radiology worldwide, and related research studies described under Section 1.2 of this chapter, has not yet manifested in South Africa, and research studies

such as the one described in this thesis are therefore needed to provide research data for the local context.

Literature promoting the use of PMCT has, to date, focused mostly on trauma-related death, including head injury, neck injury caused by strangulation, drowning and the path and effects of bullet projectiles on the human body, mostly in the adult population (O' Donnell & Woodford, 2008). A review of the literature by the researcher has revealed that very few post-mortem imaging research studies using PMCT have been conducted amongst fatal child abuse cases, or even in other cases involving children. This observation is congruent with the above view expressed by O' Donnell and Woodford that the majority of forensic research studies published thus far have investigated the sensitivity of PMCT for natural and unnatural causes of death in mostly adults, with only a small number of studies including children (see Table 1.1). Because the focus of this thesis is on PMCT imaging, this table excludes PMMRI studies and case reports on children.

Table 1.1 Summary of research studies conducted to compare usefulness of PMCT to autopsy

Author(s)	Year of Publication	Title of research study	Population	Sample size (n)	Study Design	Manner of death
Shelmerdine et al.	2019	Diagnostic accuracy of Postmortem CT of children: A retrospective single-center study	Children	136	Retrospective	Natural and unnatural deaths
Ampanozi et al.	2017	Accuracy of non-contrast PMCT for determining cause of death	Adults	101	Prospective	Natural deaths
Van Rijn et al.	2017	The value of post-mortem computed tomography in paediatric natural cause of death: A Dutch observational study	Children	54	Prospective	Natural deaths
Arthurs et al.	2016	Comparison of diagnostic performance for perinatal and paediatric post-mortem imaging: CT versus MRI	Children	82	Prospective	Natural deaths
Kirchoff et al.	2016	Post-mortem computed tomography (PMCT) and autopsy in deadly gunshot wounds – a comparative study	Adults	51	Prospective	Unnatural deaths
Krentz et al.	2016	Performance of post-mortem CT compared to autopsy in children	Children	26	Retrospective	Natural and unnatural deaths
Scaparra et al.	2016	Detection of blood aspiration in deadly head gunshots comparing post-mortem computed tomography (PMCT) and autopsy	Adults	41	Retrospective	Unnatural deaths
Heinemann et al.	2015	Investigation of medical intervention with fatal outcome: The impact of post-mortem CT and CT angiography	Adults	200	Retrospective	Natural deaths
Sieswerda-Hoogendoorn et al.	2014	Post-mortem CT compared to autopsy in children; concordance in a forensic setting.	Children	98	Retrospective	Natural and unnatural deaths
Daly et al.	2013	Comparison of whole-body post mortem 3D and autopsy evaluation in accidental blunt force traumatic death using the abbreviated injury scale classification	Adults	21	Prospective	Unnatural deaths
Le Blanc-Louvry et al.	2013	Post-mortem computed tomography compared to forensic autopsy findings: A French experience	Adults and children	236	Prospective	Natural and unnatural deaths
Leth, Struckmann & Lauritsen	2013	Interobserver agreement of the injury diagnoses obtained by post-mortem computed tomography of traffic fatality victims and a comparison with autopsy results	Adults	67	Prospective	Unnatural deaths
Leth and Thomsen	2013	Experience with post-mortem computed tomography in Southern Denmark 2006–2011	Adults and children	900	Prospective	Natural and unnatural deaths
Makhlouf et al.	2013	Gunshot fatalities: Correlation between post-mortem multi-slice computed tomography and autopsy findings: A 30-months retrospective study	Adults	47	Retrospective	Unnatural deaths
Noda et al.	2013	Post-mortem Computed Tomography imaging in the investigation of nontraumatic death in infants and children	Children	38	Prospective	Natural deaths

Proisy et al.	2013	Whole-body post-mortem computed tomography compared with autopsy in the investigation of unexpected death in infants and children	Children	47	Prospective	Unnatural deaths
Schulze et al.	2013	Rib fractures at post-mortem computed tomography (PMCT) validated against the autopsy.	Adults and children	51	Prospective	Natural and unnatural deaths
Kasahara et al.	2012	Diagnosable and non-diagnosable causes of death by post-mortem computed tomography: A review of 339 cases	Adults and children	339	Prospective	Natural and unnatural deaths
Roberts et al.	2012	Post-mortem imaging as an alternative to autopsy in the diagnosis of adult deaths: A validation study	Adults	182	Prospective	Natural and unnatural deaths
Cha et al.	2010	Utility of post-mortem autopsy via whole-body imaging: Initial observations comparing MDCT and 3.0T MRI findings with autopsy results	Adults	5	Prospective	Unnatural deaths
Filograna et al.	2010	Computed Tomography (CT) virtual autopsy and classical autopsy discrepancies: Radiologist's error or a demonstration of post-mortem multi-detector computed tomography (MDCT) limitation?	Adult	1	Prospective	Unnatural deaths
Iwase et al.	2010	Evaluation of Computed Tomography as a screening test for death inquest	Adults	80	Prospective	Natural deaths
Ross et al.	2010	Multi-slice computed tomography (MSCT) of mountaineering casualties in the Swiss Alps – advantages and limitations	Adults	10	Prospective	Unnatural deaths
Aghayev et al.	2008	Post-mortem imaging of blunt chest trauma using CT and MRI	Adults	24	Retrospective	Unnatural deaths
Shiotani et al.	2008	Post-mortem computed tomography findings as evidence of traffic accident-related fatal injury	Adults and children	78	Prospective	Unnatural deaths
Sochor et al.	2008	Post-mortem Computed Tomography as an adjunct to autopsy for analysing fatal motor vehicle crash injuries: Results of a pilot study	Adults	6	Prospective	Unnatural deaths
Poulsen & Simonsen	2007	Computed Tomography as routine in connection with medico-legal autopsies	Adults	525	Retrospective	Natural and unnatural deaths
Yen et al.	2007	Post-mortem forensic neuroimaging: Correlation of MSCT and MRI findings with autopsy results	Adults	57	Retrospective	Natural and unnatural deaths
Levy et al.	2006	Virtual autopsy: Preliminary experience in high-velocity gunshot wound victims	Adults	13	Prospective	Unnatural deaths
Thali et al.	2003a	Virtopsy, a new imaging horizon in forensic pathology: Virtual autopsy by post-mortem Multislice Computed Tomography (MSCT) and Magnetic Resonance Imaging (MRI) – a feasibility study	Adults and children	40	Prospective	Natural and unnatural deaths
Thali et al.	2003b	Image guided virtual autopsy findings of gunshot victims performed with multi-slice computed tomography (MSCT) and magnetic resonance imaging (MRI), and subsequent correlation between radiology and autopsy findings	Adults	8	Prospective	Unnatural deaths

This review therefore provides evidence that at the time of completion of this thesis in March 2021 very few post-mortem imaging research studies were conducted focusing solely on the use of PMCT in children, more so in cases of unnatural death, such as fatal child abuse. Table 1.1 shows that, at the time of writing this thesis, to the author's knowledge, only seven studies (highlighted), were conducted using PMCT for determining the cause of death in children.

Some of the above listed studies have included adults and paediatric populations. The inclusion of both adults and children in the same study can be considered as a limitation, as the burden of disease, manifestation and radiographic appearance of pathologies are not always the same for adults and children, particularly the radiographic manifestations of physical child abuse. The research described in this thesis was therefore applied within a narrow context where the usefulness of PMCT was assessed in relation to 30 deceased children who had a suspected history of having been subjected to abuse, or had died suddenly or with unexplained cause. It was postulated that this narrow focus on suspected fatal child abuse would add to the body of knowledge regarding the concordance of PMCT with the forensic autopsy in determining the existence and nature of injuries in children, as well as determining the cause of death.

It is in the interests of both health care delivery and the growth of the radiology and radiography professions in South Africa that research studies such as this are conducted. At conceptualisation of this research study, it was postulated that this study might serve as a catalyst for much needed interdisciplinary skills development amongst radiographers, forensic pathologists and radiologists in South Africa. Because no PMCT or PMMRI examinations are currently conducted in forensic institutions in South Africa, it was also anticipated that this research study could encourage the roll out of cross-sectional forensic imaging and might even influence further education and training of radiographers, radiologists and forensic pathologists and stimulate specialisation, in forensic imaging.

1.14 ORIGINALITY AND MOTIVATION FOR THE RESEARCH STUDY

Based on recent advances in forensic pathology and imaging, there is an urgent need to enhance forensic radiology research and imaging practices internationally and in South Africa in particular. The conceptual framework and justification that underscores this research study was therefore based on the worldwide need for research in forensic imaging and in particular the lack of such research studies within the South African context. As explained in the previous section, there was

also a subsidiary need to narrow the application of PMCT in establishing the cause of death for a subgroup of unnatural deaths, in the case of suspected fatal abuse in children, as a contribution to knowledge building in this important aspect of forensic pathology.

This research study was, as far as could be ascertained, the first of its kind to be conducted in South Africa. A thorough literature search on 8 May 2014 and 25 October 2020, using the databases listed here, have shown that no masters or doctoral thesis has ever been completed on this topic:

- Navtech database.
- Union catalogue of theses and dissertations of South African universities.
- Dissertation abstracts international of the USA using the Proquest database.
- The NRF Nexus database System for Current and Completed theses and dissertations in South Africa (25 October 2020 only).

Furthermore, in May 2014 and on 25 October 2020, a thorough review of a large number of forensic journals, whose core business is to publish articles related to forensic or legal pathology and child abuse or related publications, did not yield any publications similar in focus and intent (see Addendum A1 for a list of journals consulted). The lack of publications on this topic in these journals, underscores the fact that this research study was unique and the first ever to be performed amongst suspected fatally abused children in South Africa. This research study is clinically justified. Section 1.3 above made reference to the fact that child homicides (which include child abuse), receive little attention in terms of public policy and research funding, especially in middle- and poor-income countries. South Africa also lacks a coordinated system for monitoring child homicides in order to devise strategies to respond to this social problem.

1.15 CHAPTER SUMMARY

This chapter has described the role of forensic pathology in South Africa in the investigation of unnatural deaths and, more specifically, fatal child abuse, and the rise of cross-sectional post-mortem imaging in forensic pathology. Other key aspects raised were the technological advances realised with CT, and how these advances have been translated into forensic pathology for the betterment of post-mortem investigations. Brief reference was made to various research studies that were conducted to validate the usefulness of PMCT in conjunction with forensic autopsies. It

was also highlighted that, even though there is overwhelming evidence that PMCT can determine the cause of death, this aspect has not been validated for all forensic scenarios. Brief mention was made of how the Virtopsy project has revolutionised forensic imaging by the use of cutting-edge, colour-encoded photogrammetry, and 3D volume rendered imaging with the use of PMCT. Other aspects highlighted were factors that led to a decline in autopsy rates, and how this decline led to the rise of cross-sectional imaging as a non-invasive alternative in determining the cause of death. This chapter also gave a brief overview of the role post-mortem imaging plays in establishing the cause of death in children.

Furthermore, this chapter provided child homicide statistics in South Africa. The associated lack of consolidated research studies on child homicide and how this negatively influences policy and required strategies to respond to this dire social problem, was also briefly presented. The role of the forensic autopsy in upholding justice in the context of fatal abuse was also briefly highlighted.

The research question, aims and objectives were discussed as an introduction to the core elements of this thesis. This chapter also stated the definition with respect to what 'constitutes a child' in South Africa, as well as the definition for child and fatal child abuse applied for the purpose of this research study. The chapter ended with a discussion of the research rationale and how the lack of post-mortem imaging publications in South Africa justified the execution of the research study. The originality of this study was also explained, as well as the need to validate the sensitivity of PMCT imaging for unnatural deaths amongst paediatric populations.

The section that follows gives a brief overview of the chapters that follows.

1.16 THESIS OVERVIEW

1.16.1 Chapter Two

This chapter will give an in-depth review of the literature with regard to the clinical presentation of physical abuse in children. Other aspects highlighted are the clinical presentation of emotional abuse, child neglect, as well as child sexual abuse. The reader is also familiarised with a lesser-known phenomenon known as Factitious Disorder by Proxy (previously known as Munchausen Syndrome by Proxy) and how this disease entity manifests in child abuse. Chapter Two further embarks on discussing a few of the many confounding clinical presentations which may simulate child abuse, as well as consequences of misdiagnosing child abuse.

1.16.2 Chapter Three

This chapter continues the review of the literature, focusing on a historical overview of post-mortem forensic imaging, as well as the advanced techniques possible with Virtopsy. The main body of this chapter explains the degree of concordance between the forensic autopsy and PMCT for the diagnosis of injuries in the major anatomical regions. Furthermore, a review ensues to highlight the level of agreement of PMCT with the forensic autopsy in establishing the cause of death and whether PMCT can replace the forensic autopsy. The chapter ends with a discussion on the advantages and disadvantages PMCTA holds for forensic pathology as well as the need for optimising PMCT imaging protocols and post-mortem imaging examinations.

1.16.3 Chapter Four

This chapter describes the research design and methodology of the study, including the data collection processes. The chapter starts by providing an overview of the two research sites used for data collection, the inclusion and exclusion criteria, and the patient care provided to subjects before, during and after PMCT examinations. The chapter also highlights how PMCT imaging reports and the forensic autopsy reports were recorded, analysed and coded and how internal validity was ensured for the recorded data. The chapter further present arguments against and for consensus reading when used within diagnostic imaging accuracy sudies. The chapter ends with a discussion on the ethical principles upheld during execution of the research project and explain why informed consent was waived for this study.

1.16.4 Chapter Five

The overall results of this study were too much for a single chapter and are in lieu of this, presented in two chapters. Chapter five presents the results of the study related to the first objective which set out to measure the degree of concordance between the forensic autopsy and PMCT for injury types identified. The chapter starts with presenting the initial manner of death categories recorded for all subjects, their sex and age range, time delay from admission to PMCT image acquisition. The body of this chapter describe the number of injuries identified with the forensic autopsy and PMCT within five anatomical regions namely the head and neck, thorax, abdomino-pelvic, spinal column and spinal cord as well as extremities. This chapter ends with a discussion on

miscellaneous injuries identified and those injuries for which a direct comparison could not be drawn between the forensic autopsy and PMCT.

1.16.5 Chapter Six

This chapter continues with a presentation of the results of the study related to the second, third and fourth objective of this study. The body of this chapter provides statistics on the degree of discordance between PMCT and the forensic autopsy for injury categories identified across the five anatomical regions. This chapter continues with statistics regarding the accuracy of PMCT to establish a cause of death in comparison with the forensic autopsy, using the evidential percent agreement and cohen kappa statistic measuring the interrater reliability. In addition, a detailed overview is provided of significant injuries seen with PMCT amongst three prominent 'cause of death' categories, as well as significant injuries not seen with PMCT within the five anatomical regions described. The chapter further ends with an overview of the number and type of supplementary examinations employed as part of the forensic autopsy, as well as the incidental findings diagnosed.

1.16.6 Chapter Seven

This chapter culminates in an indepth interpretation of the findings of this study. The reasons for the discordance between the forensic autopsy and PMCT for injury types diagnosed are also amplified. The chapter further considers arguments for and against PMCT replacing the forensic autopsy for certain clinical conditions. Other aspects discussed include the successes of this study, limitations identified during execution of the research study, as well as recommendations made for similar future research studies. This chapter further explains the contribution this study has made to the body of knowledge and the important role PMCT imaging play in managing and identifying child abuse. The chapter ends with the author's personal reflections on the future of post-mortem forensic imaging in South Africa and the implications thereof for health care management.

CHAPTER TWO

REVIEW OF THE LITERATURE: PART I

Historical overview of child abuse, common clinical presentations and conditions that mimic this disease entity

2.1 CHAPTER INTRODUCTION

Child abuse comprises five subtypes, namely physical abuse, sexual abuse, neglect and negligent treatment, emotional abuse, and exploitation (WHO, 2014). Published literature on child abuse as a disease entity, and the clinical characteristics it may present with, are extensive. This chapter commences with a brief historical overview of when child abuse was first documented. Thereafter, there follows a detailed discussion, drawing on the knowledge domains related to the clinical presentation of the five subtypes of child abuse. The chapter will end by highlighting some disease entities that may mimic physical child abuse and the consequences of misdiagnosing child abuse.

Child abuse can present in various forms in the clinical setting. The injury patterns of child abuse seen in live children, present in the same manner as those in deceased subjects. Due to limited published literature on fatal child abuse, this review focuses mostly on injury patterns in live children; however, the clinical manifestation thereof will be assumed to be same for fatal child abuse.

This thesis set out to assess the concordance of PMCT contrasted with the forensic autopsy for the assessment of fatal child abuse with a focus on fatal physical injuries. As stated in Chapter One, forensic pathology employs supplementary examinations, such as histology, microbiology, toxicology, biochemistry, DNA analysis, dentistry, anthropology, collection of evidence and photography (O'Donnell & Woodford, 2008). This literature review will exclude the use of supplementary examinations employed in forensic pathology for the assessment of fatal child abuse. Also, the radiographic appearances of child abuse obtained by using conventional imaging modalities such as Digital Radiography (DR) and Computed Radiography (CR) (previously known as projection radiography), LODOX® or Nuclear Medicine studies, will not be covered within this literature review, mostly to retain focus, but also because these modalities were not incorporated within this research study.

2.2 HISTORICAL OVERVIEW OF CHILD ABUSE

Throughout human history, abuse and killing of children have long been recognised as social phenomena (Matschke et al., 2009). Child abuse was first described in the year 900 by Rhazes, a physician from Perse, in a publication entitled *Dictionnaire d'hygiene et de salubrité,* which, translated, means 'Dictionary of hygiene and salubrity' (Labbé, 2005). Rhazes attributed hernias diagnosed in some children to intentional injuries. In 1651, Paulus Zacchias reported a case of a young boy suffering abusive head trauma inflicted by a tutor in Italy. In 1853, Adolphe Toulmache, a French forensic pathologist, reported a case of a four-year-old orphan girl who was whipped to death by her guardian. Sexual abuse was documented as early as 1856 by Toulmache who published a forensic study on sexual abuse in female children and teenagers (Labbé, 2005). Ambroise Tardieu is further credited as the first physician to describe, in 1856, all classical features of almost all forms of child abuse and neglect inflicted by parents (Labbé, 2005; Greeley, 2015). Tardieu was acknowledged for his work in the field of child abuse by having the sub-pleural petechial haemorrhages caused by mechanical asphyxia named after him as "Tardieu spots" (Knight, 1986, quoted by Ellis, 1997). In 1923, Burhans and Gerstenberger reported subdural haemorrhages (SDH) in five infants, four of whom also presented with associated retinal haemorrhages. Peet and Kahn, in 1932, described SDH which they attributed to trauma in nine infants, eight of whom had associated eye findings (Greeley, 2015).

John Caffey is widely recognised as the first radiologist to describe child abuse in infants. His landmark publication described unexplained skeletal fractures in six infants with SDHs. In this series, the six children presented with 23 skeletal fractures of the long bones, but with no history of trauma reported. Further, there was no radiographic or clinical evidence of skeletal disease that would have predisposed pathological fractures; and, in Caffey's argument, the majority of fractures occurred after the onset of SDHs (Caffey, 1946). In 1953, a British neurosurgeon, Norman Guthkelch, described 18 infants that had retinal haemorrhages, and he attributed the SDHs to birth injuries in half of the cases (Greeley, 2015). In 1962, Kempe, a paediatrician, and his colleagues, broadened the paradigm for child abuse after describing long bone fractures associated with SDH as a consequence of the "Battered Child Syndrome (Kempe et al., 1962; Greeley, 2015). Kempe posited that the ease and frequency with which a child is grabbed by his arms and legs make injuries to the appendicular skeleton the most common amongst victims of 'Battered Child Syndrome' (Kempe et al., 1962). This publication led to the implementation of laws that protected the rights of children, including making it compulsory to report child abuse cases in

the United States of America and the United Kingdom (Dawes, Bray & Van der Merwe, 2007; Paul & Adamo, 2014).

In 1968, Weston, a forensic pathologist, described SDHs diagnosed in 21 children, aged 1 to 5 years, following violent trauma such as being beaten with fists or sticks, or being swung and hit against stationary objects (David, 1999). Three years later, in 1971, Guthkelch reported SDH as a characteristic of the 'Battered Child Syndrome' and argued that the SDHs were caused by shaking. The brain injury was further complicated by a relatively large head and weak neck muscles that infants and toddlers have, which predisposes them to this injury (Guthkelch, 1971; Blumenthal, 2002). Other seminal work on physical abuse of children includes that of Kleinman et al. (1995) who reported the classic metaphyseal lesions (CML) in 31 fatally abused infants.

This historical overview shows that child abuse has existed for centuries. Acknowledgement also needs to go to the pioneers who were brave enough to use their professional judgment, and in some instances even challenge contemporary thinking at the time, to highlight different abuse patterns in children. Given the continued development of medicine and its related professional practices involving the diagnosis and management of child abuse, it is imperative that best practice in forensic pathology should also be developed and refined in order to enhance diagnosis of this disease entity. This research study set out to contribute to the body of knowledge by assessing the concordance of PMCT with the forensic autopsy in demonstrating injuries sustained in suspected fatal child abuse cases.

2.3. CLINICAL PRESENTATION OF PHYSICAL ABUSE IN CHILDREN

Child abuse can present in various ways and forms and can result in a plethora of injuries for the affected child. For example, child abuse may present in the form of a single injury but may also involve multiple injuries that all represent a particular type of abuse (Legano et al., 2009). Physical abuse occurs more commonly in children younger than two years of age; and, because of their age, trauma is perpetuated because these children cannot verbalise their symptoms, nor localise or indicate their pain (Offiah, 2012). This inability of infants to verbalise inflicted injury and associated pain hampers early diagnosis and management of physical abuse. In worst case scenarios, these children may not survive the traumatic episode as they succumb to the inflicted injuries (Offiah, 2012). Most forms of physical abuse can be diagnosed radiographically using conventional diagnostic imaging, or cross-sectional imaging such as CT and MRI.

The following clinical signs and symptoms are highly suggestive for physical child abuse:

- The clinical explanation is inconsistent with the nature and type of injury (Hoskote et al., 2003).
- A history that is unexplained, or an injury (event), that happened in the absence of witnesses (Mok, 2008).
- A sibling is blamed for the injury (Mok, 2008).
- Multiple and inconsistent explanations for the same injury (Offiah, 2012).
- The reported mechanism of injury is inconsistent with the child's age and development level. For example, a long bone fracture in a non-ambulant child is highly suggestive of physical abuse (Bandyopadhyay & Yen, 2002).
- Significant delay in seeking medical assistance, particularly for injuries (Hoskote et al., 2003).
- Multiple fractures at different stages of healing, which is considered to be the hallmark of physical abuse (Bandyopadhyay & Yen 2002; Offiah, 2012).
- Parents presenting with evasive or aggressive attitudes when questioned about the clinical history (Mok, 2008).
- Any evidence of neglect, such as non-organic failure to thrive (Mok, 2008).
- Lack of hygiene or care (Mok, 2008).
- Previously reported involvement of social welfare (Mok, 2008).
- Repeated visits to accident and emergency units (Mok, 2008).
- A rare form of child abuse is Factitious Disorder by Proxy, formerly known as Munchausen Syndrome by Proxy. This syndrome is caused by a mental illness in the caregiver or parent who will deliberately fabricate or induce illness or injury through poisoning, medication or physical injury (College of Radiographers, 2005). This disorder will be discussed in detail later in this chapter.
- Necklace calcification has been described as the result of fat necrosis following strangulation. The co-existent presence of necklace calcification and skeletal fractures is highly suggestive of child abuse (Carty, 1993).

The next section will describe the clinical and anatomical manifestations of physical abuse seen in live and deceased children. Where a discussion relates to the clinical presentation in live

children, the same inferences can be drawn regarding deceased children, as the injury pattern will arguably be the same.

2.3.1 Clinical presentation of bruises in abused children

Bruises are widely considered the most common clinical presentation of physical abuse (Legano et al., 2009). The Royal College of Paediatrics and Child Health (2016a) wrote that any part of the body may be vulnerable to bruising following physical abuse. Bruises, including ecchymoses, petechiae, and haematomas, may account for up to 40% of skin injuries (Baz & Wang, 2012). One study has shown that 89% of children diagnosed with physical abuse may present with bruises; however, up to 70% of children who were not subjected to physical abuse may also present with bruises, complicating diagnosis (Kemp et al., 2014). Another study has shown that abused infants younger than six months of age and presenting with one single bruise, may present with 60% additional non-bruise-related injuries (Harper et al., 2014). This indicates that children who present with a single bruise may have more underlying injuries, so a single bruise is not an indicator of a lower level of abuse. Not all bruises in children are necessarily a result of abusive behaviour of perpetrators (Kemp et al., 2014).

Atwal and colleagues (1998) conducted a study to establish the prevalence, distribution and pathological associations of external bruising in 24 children with fatal, non-accidental head injury. Within this study, 71% of the total number of bruises were new, external bruises, whilst 63% were old, external bruises. However, 21% of children (n = 5/24) had no external bruising at all. Important conclusions drawn from this study were that external bruising may be absent in children with fatal abusive intracranial injuries. These findings suggest that abused children may present with either new or old bruises, a combination of old and new bruises, or no bruises at all. This varying presentation complicates clinical diagnosis and requires a high index of suspicion amongst health care professionals. Distinguishing between bruises caused by intentional and non-intentional mechanisms can be complex and challenging, especially in mobile children (Kaczor et al., 2006). A high level of expertise is thus required to arrive at an appropriate diagnosis. Other skin manifestations of child abuse may include lacerations, abrasions, burns, bite marks, and traumatic alopecia (Kos & Shwayder, 2006).

Bruising over protected anatomical areas, such as the upper arms, medial and posterior thighs, the hands, trunk, cheeks, neck, ears, buttocks and genitalia, should raise suspicion of abuse,

particularly if such bruises are multiple and of varying age (Kos & Shwayder, 2006). The above-mentioned anatomical areas are not typically injured during falls or crawling, hence the higher suggestion for abuse (Kemp et al., 2014). Bruises in pre-mobile infants should therefore be considered highly suggestive of abuse. Such children may present with serious brain, skeletal and visceral injuries (Kos & Shwayder, 2006). PMCT has no role to play in the diagnosis of bruises, as imaging of the skin in 3D or natural colour, as is possible with the naked eye, is currently not possible with PMCT. However, as purported by Kos and Shwayder (2006), bruises can often be the only external evidence of underlying internal injuries, justifying medical attention and imaging. PMCT thus has a crucial role to play in documenting underlying abusive injuries.

2.3.2 Clinical presentation of burns in abused children

Intentional burns indicate a serious form of physical abuse and must be identified early to prevent further abuse to the affected child (Pawlik et al., 2106). Of all the forms of non-accidental injuries, burns are considered to be the most debilitating because of the long-term sequelae, including permanent deformity, loss of function, lifetime emotional harm, as well as mortality (Hodgman et al., 2016).

Burns caused by physical abuse are common and are reported to vary between 5,8% and 41% of child abuse cases annually (Hodgman et al., 2016; Pawlik et al., 2016). Burns and scalds are reported to be some of the most common causes of fatal child abuse (Maguire et al., 2008). Burns can range from a simple, isolated injury, to the involvement of large sections of the child's body (Pawlik et al., 2016). Burns result in destruction of the skin and subcutaneous tissue following the application of a physical agent such as heat, chemicals, or an electrical device (Legano et al., 2009). These agents are repeatedly held against the skin of the child, causing the underlying injury. Inflicted non-scald burns are mostly contact burns from domestic implements such as cigarettes, irons, hair straighteners, radiators and ovens. These burns most commonly occur on the dorsum of the hands, limbs and trunk, rather than on the palmar aspect such as those caused by accidental burn injuries involving touch (Gill & Falder, 2017). Inflicted burns are often multiple and may accompany additional injuries such as bruises, lacerations abrasions and bites (Maguire, Okolie & Kemp, 2014; Pawlik et al., 2016).

Neglect can, in some cases, be the cause of burns amongst children (Andronicus et al., 1998). One study showed that burns caused by neglect are far more prevalent than burns caused by

abuse (Chester et al., 2006). Neglect is more difficult to detect, given that there are various levels of intent, from a single episode of neglect to more repeated and deliberate instances of neglect (Chester et al., 2006).

In a large retrospective study Pawlik and colleagues (2016) found that scalds from child neglect were nine times more common than scalds from intentional injury. The most reported inflicted scald is forced immersion into hot water, which more often involves the lower limbs, buttock and perineum (Maguire et al., 2008; Gill & Falder, 2017). Forced immersion will present with a symmetrical pattern, with clear upper margins of the burn site consistent with the child being held still in hot water, compared to irregular edges and varied depth of burns found in accidental spill scalds (Gill & Falder, 2017). Forced immersion is also described as the glove and stock distribution and is highly suggestive of intentional scalds (Maguire et al., 2008).

When screening for inflicted burns, clinicians have to consider these points: whether the burns are consistent with the child's developmental stage; whether the pattern of the injury fits the mechanism or agent described; whether social services was previously involved; whether aspects such as lack of supervision or domestic violence were evident; or whether any previous burn injuries were reported. The presence of any unexplained, co-existent injuries is highly suggestive of child abuse (Maguire, Okolie & Kemp, 2014). As with bruises, PMCT has little role to play in imaging burns as a result of child abuse. However, where co-existing injuries are present, such injuries might be detected by PMCT.

2.3.3 Clinical presentation of skeletal fractures in abused children

Skeletal injuries are, after soft tissue bruises, the most common abuse-related injury (Lonergan et al., 2003). Fractures resulting from abuse have been described in almost every bone in the human body (Kemp et al., 2008; Kraft, 2011). There are a wide range of skeletal injuries that abused children may present with; however, the majority present with fractures of the extremities (Nor & Zainun, 2016). Certain fracture types, anatomical location and patterns are highly specific for abuse. These include fractures such as metaphyseal corner fractures in long bones, posterior rib fractures, fractures of the scapula, spine and sternum (Bandyopadhyay & Yen, 2002). The extremities are convenient 'handles' which can be used to grab, shake, swing or pull a child; and, for this reason, fractures of the extremities are the most common skeletal injuries (Brogdon, 2011). Diagnostically, the CML has a high specificity for inflicted injury and is the most commonly

encountered long bone injury in young infant fatalities. The most commonly encountered fractures in fatally abused children are these: the distal femur, proximal and distal tibia, and proximal humerii (Kleinman, 2008).

Paediatric bones have unique characteristics that determine fracture patterns. These unique features are important to consider when assessing injury, and the plausibility of the causal mechanism. For example, the periosteum of bones is much thicker in adults, resulting in less displacement of fracture fragments. Paediatric long bones are more porous and pliable due to their cartilaginous state, allowing absorption of greater amounts of energy before reaching the fracture threshold (Narain & Goldstein, 2016). This implies that paediatric bones must be exposed to significant external forces before they fracture. Unlike adult bones, the physis (epiphyseal cartilage) of children is the weakest part of the paediatric bone and so is more prone to shear in response to loading and torsional forces. Due to this, physeal injuries are common in skeletal immature paediatric bones (Narain & Goldstein, 2016).

Metaphyseal injuries often elude detection unless specifically sought via the use of skeletal surveys. Metaphyseal injuries are subtle, especially when acute, and require high definition projection radiography to ensure optimal diagnostic assessment (Kleinman et al., 1995). Histologically, the CML was reclassified by Kleinman and colleagues as a traumatic lesion as a result of shaking abuse, causing a complete shearing, or planar fracture (microfractures), that extends through the immature portion of the primary spongiosa of the metaphysis, and not an avulsion fracture, as previously reported by Caffey (Boal, 2008; Offiah & Hall, 2009). Midshaft transverse, spiral and oblique diaphyseal fractures of the femur and humerus are signs of inflicted injuries in the young infant (Boal, 2008). Chapter Three will discuss in detail the role PMCT plays in imaging the skeletal system in abused children.

2.3.4 Clinical presentation of dislocations in abused children

Children's bones are more pliable than those of adults; and the periosteum is stronger compared to adults, resulting in fewer dislocations and displaced fractures (Steyn, 2011). Joint dislocations may accompany a variety of injuries to the extremities, pelvis and spine. True joint dislocations are not often seen in child abuse cases. When dislocations are present, they are usually accompanied by severe trauma (Brogdon, 2011). True Salter Harris fractures are rare in non-accidental injury (NAI) compared to the incidence in accidental injuries and may be more evident

in younger abused children; and fracture separation of the epiphysis and dislocations have been reported (Rao & Carty, 1999). Dislocation of a secondary ossification centre is however not unusual (Brogdon, 2011).

The spinal column can also be subjected to dislocations. Spinal dislocations in abused children are rarely reported and this is thought to be the result of delay in seeking medical care, and incomplete clinical histories. Spinal fractures and dislocations may be occult, even if unstable (Kemp et al., 2006). Due to the mechanisms and force required to cause spinal dislocations, such injuries are highly suggestive of abuse, especially if the injury does not match the reported clinical history (Dudley & Garg, 2014). The effect of spinal dislocations has a greater morbidity and mortality in children (Brogdon, 2011). Compression, hyperflexion, or lateral flexion of the child's body caused by physical abuse may not only result in spinal compression fractures but may rupture the anterior spinal ligaments; and, in extreme cases, there is dislocation of the vertebral bodies (Carty, 1995). A sacral fracture dislocation in a two-month-old abused girl has also been reported (Lonergan et al., 2003). Atlanto-occipital dislocations, although rare, are often overlooked in the emergency setting (Pärtan et al., 2003). Dislocations, even though rare in children, are well visualised with PMCT.

2.3.5 Clinical presentation of skull fractures in abused children

Skull fractures are considered the second most common, non-accidental skeletal injury in physically abused children. These fractures may present as either simple or complex (Bandyopadhyay & Yen, 2002). Skull fractures represent a contact injury (Narain & Goldstein, 2016) and are found in as many as one third of abused children (Hsieh et al., 2015). Skull fractures in abused children do not follow specific patterns that are pathognomonic for abuse, and therefore have the same radiographic appearance as accidental skull fractures (Rao & Carty, 1999; Offiah & Hall, 2009). Simple skull fractures tend to be linear and do not cross suture lines, whilst complex skull fractures might be multiple, crossing suture lines, be displaced, communited, diastatic or depressed (Lowen & Reece, 2008).

Even though skull fractures may appear in any shape and form, complex fractures involving both sides of the cranium, multiple, depressed occipital, diastatic, and fractures in different stages of healing, are more common in NAI (Rao & Carty, 1999). The presence of a scalp haematoma may provide external evidence of a skull fracture. The haematoma may last for a variable length of

time, depending on the initial size thereof (Rao & Carty, 1999). Soft tissue swelling overlying a skull fracture is a result of a combination of the direct impact and bleeding from the site of the fracture (Offiah & Hall, 2009).

Radiographically, skull fractures may appear as linear or branching lucent areas with sharp margins, whilst diastasis presents as a skull bone separation > 3mm (Lonergan et al., 2003). The radiographic appearances of these fracture types on PMCT follows a similar pattern, especially when viewed on axial sequences or 3D reconstructions of the external skull. Arguably, these fracture types, as described above, will have the same pathological appearance during a forensic autopsy. In a systematic review conducted by Kemp and colleagues, the most common anatomical site for skull fractures was found to be the parietal bone, with linear skull fractures the most common fracture type (Kemp et al., 2008). Skull fractures, including the underlying brain injuries, are readily diagnosed with PMCT. This imaging modality is the best for demonstrating the relationship between disrupted or fractured cranial bones and underlying soft tissue injuries.

2.3.6 Clinical presentation of intracranial head injuries in abused children

Intracranial injuries caused by abuse may be fatal. Various terms are used in scientific literature to describe neurological injury caused by physical abuse. These terms are non-accidental head injury (NAHI), inflicted traumatic brain injury (ITBI), and whiplash shaken infant syndrome. Abusive head trauma (AHT) is the preferred term recommended by the American Academy of Pediatrics (AAP) used to describe head trauma caused by violent shaking (AAP, 2009b; Sieswerda-Hoogendoorn et al., 2012a). This will be the term used in this thesis. The above definition of AHT is also used by the Centers for Disease Control and Prevention and includes Shaken Baby Syndrome (Centers for Disease Control and Prevention, 2020).

AHT is defined as a skull or intracranial injury of an infant or young child (usually younger than five years of age) caused by inflicted blunt impact or violent shaking (Parks et al., 2012). No current statistics for AHT mortality in South Africa are available. The majority of AHT cases occur during the first year of life (Karibe et al., 2016). It is estimated that 14–40 per 100,000 children younger than one-year present with AHT annually; and 15–23% of cases die in hours or days following the incident (Sieswerda-Hoogendoorn et al., 2012a). Other neurological injuries associated with AHT include intracerebral haemorrhage, parenchyma lesions, and hygroma (Sieswerda-Hoogendoorn

et al., 2012a). Death in these children as the result of AHT is less likely to be reported, resulting in substantial underreporting (Sieswerda-Hoogendoorn et al., 2012a).

Brain parenchymal injuries may be caused by every way imaginable. The three common types of parenchymal injuries are shear injury (acceleration-deceleration injury), contusion, and oedema (Lonergan et al., 2003). Shear injuries, also commonly known as diffuse axonal injury (DAI), may be diffuse or focal and occur when the brain parenchyma shears at the gray-white matter interface. This shearing injury disrupts the tissue interfaces which is likely to cause parenchymal injury (Fernando et al., 2008). Shear injuries often involve the subcortical white matter, corpus callosum, brainstem and internal capsule (Hsieh et al., 2015).

A shaking injury can be caused by forceful shaking of an infant head or by grasping the shoulders or chest with an impetus that changes the momentum and direction of the force, by acceleration or deceleration (Hsieh et al., 2015). Both direct and indirect forces can cause secondary injury, such as brain oedema, ischemia and, ultimately, herniation (Fernando et al., 2008). Oedema may be focal or diffuse, and commonly appears in non-accidental head injury. Strangulation, suffocation, post-traumatic apnoea, amongst others, may cause hypoxia which can lead to oedema (Lonergan et al., 2003). Manual strangulation can cause two types of neurological damage. One is hypoxic-ischemic encephalopathy (HIE), secondary to the compromise of blood flow from the common carotid artery. The other is SDH, caused by shearing of bridging veins if violent shaking accompanies the strangulation (Hsieh et al., 2015).

Cerebral contusion is a focal haemorrhage within the brain parenchyma (usually the brain cortex) and occurs as a result of direct contact injury. Contusions are rare in infants, are usually small and not easily diagnosed on CT imaging (Lonergan et al., 2003).

Blunt trauma to the head usually leads to an immediate impact effect. Pathologies that can occur include subgaleal haematomas, skull fractures, brain contusion and epidural haemorrhage (EDH) or SDH (Hsieh et al., 2015). SDH and subarachnoid haemorrhage (SAH) are common diagnostic findings in child abuse, with SDH the most common, whilst EDH is less common (Lonergan et al., 2003; Greeley, 2015). On CT, the SDH may appear along the interhemispheric fissure and over the convexities. Intracranial haemorrhages due to blunt trauma are often accompanied by brain oedema and white matter laceration causing raised intracranial pressure in the acute stage (Hsieh et al., 2015). CT may show thin layers of SDH which may be obscured by the beam-hardening effect, often seen in the posterior fossa. Small subacute and chronic SDH are difficult to detect,

owing to similar attenuation between the haematomas and the CSF of the brain. Studies done in Estonia (1997–2003) and in Switzerland (2002–2007) showed that CT demonstrated SDH in 77–89% of AHT cases respectively (Talvik et al., 2006; Fanconi & Lips, 2010). Two other studies, both conducted in Philadelphia, Pennsylvania (United States of America) showed that an autopsy reported SDH in AHT cases occurred between 92-100% of cases respectively (Duhaime et al., 1987; Brennan et al., 2009). Current statistics for SDH in AHT diagnosed with autopsy could not be found but might have escaped the author's attention. Whilst MRI is useful, CT imaging, due to its rapid image acquisition and widespread availability, is the preferred imaging modality for diagnosis of intracranial injury in AHT patients. The above-described abusive intracranial injuries are well demonstrated with PMCT, enabling detailed documentation and assessment thereof during forensic autopsy assessment.

2.3.7 Clinical presentation of ocular injuries in abused children

Ocular signs and symptoms in child abuse may manifest due to direct or indirect injury (Betts et al., 2017). The most common ophthalmologic finding in physical abuse is the presence of retinal haemorrhage (Levin, Luyet & Knox, 2016). The incidence of retinal haemorrhages in AHT is reported to be 85% (Levin, Luyet & Knox, 2016). Retinal haemorrhages in children with AHT are more likely to be bilateral, involve the pre-retina and intra-retinal layers, cover the macula, and extend to the periphery of the retina (Bechtel et al., 2004). The location of retinal haemorrhages, rather than the presence thereof, helps in distinguishing abusive from accidental head trauma (Bechtel et al., 2004). Unilateral and asymmetrical retinal haemorrhages may occur in about 3% and 20% of AHT cases respectively (Arlotti et al., 2007; Levin, Luyet & Knox, 2016). The severity of the retinal haemorrhages is directly related to the severity of the brain injury (Levin, Luyet & Knox, 2016).

Other abusive ocular injuries may include peri-orbital oedema, chemosis, subconjunctival haemorrhage, corneal epithelial loss, hyphaema, cataract and globe rupture (Betts et al., 2017). Other ocular injuries that may occur as a result of AHT include retinal folds and traumatic retinoschisis, vitreous haemorrhage, optic nerve sheath haemorrhages, papilloedema and anterior segment injuries (Levin, Luyet & Knox, 2016). A study conducted in Ontario, Canada, showed that, in cases where children had succumbed as a result of AHT, approximately 97% had

evidence of SDH in the optic nerve sheath, and there were retinal haemorrhages in 89% of the cases (Wygnanski-Jaffe et al., 2006).

2.3.8 Clinical presentation of oral injuries in abused children

The mouth is less frequently affected but is nonetheless an important anatomical site of trauma following physical abuse. Tooth fractures, avulsions, frenulum and labial lacerations, mucosal and palatal injury, and fractures of the mandible or maxilla (or both) may occur (Zolotor & Shanahan, 2011). A torn labial frenulum was previously widely recognised as pathognomic of physical abuse and are considered by some experts as the most common abusive injury to the mouth (Maguire et al., 2007). Current opinion, however, suggests that, in the absence of other trauma, a torn labial frenulum should be treated with caution, and warrants a full investigation, as this condition has also been seen in accidental trauma (Yu, Ngo & Goldstein, 2016).

A South African study showed that 59% of children subjected to physical abuse presented with facial injuries, and 11% with intra-oral injuries. In this study, the lips were the most frequently injured site (54%), followed by oral mucosa (15%), teeth (12%), gingiva (12%) and tongue (7%) (Naidoo, 2000). Oral injuries may include the lips, gums, tongue and palate, as well as intrusion or extraction of the dentition, bruising, laceration, and bites. The mechanisms described to cause oral injury include forced feeding, gagging, gripping and violent rubbing of, or a direct blow to, the upper lip (Maguire et al., 2007). Other forms of abuse might be burns in the mouth or lips caused by hot food, or the use of hot utensils (Kos & Shwayder, 2006).

In a systematic review conducted by Maguire et al. (2007), other oro-facial injuries caused by abuse included ulcer formation of the fauces, abrasions and bruises of the gingiva and tongue, recurrent oral bleeding, tearing of the pharyngeal wall, loose or missing teeth, and adult bite of the infant tongue. Forcible dental extraction of healthy teeth is another extreme form of abuse that can occur, whilst dental neglect may co-exist with any of the other pathologies already described (Maguire, 2010). Though uncommon, oral trauma and infections following sexual abuse may also occur. In such cases, palatal abrasions, petechiae, and ecchymosis may be seen (Yu, Ngo & Goldstein, 2016). A rare form of child abuse described by Krugman and colleagues (2007) showed four infants suffocated with baby wipes. Three of the four infants presented with posterior pharyngeal tears, whilst two passed away as a consequence of the wipes being forced into the

trachea. Co-existing injuries diagnosed in these four infants included the classic CML, skull fractures, a total of nine rib fractures, and scalp and hip contusions (Krugman et al., 2007).

2.3.9 Clinical presentation of thoracic injuries in abused children

Major intra-thoracic injuries caused by child abuse are rare. Visceral injuries within the thorax caused by abuse may include lung contusions, chylothoraces, cardiac lacerations and rupture (Ng & Hall, 1997). Chylothorax is an extremely rare complication of child abuse (Ichikawa et al., 2015). Chylothorax can be defined as the accumulation of chyle (lymphatic fluid) in the pleural cavity, usually as a result of injury to the thoracic duct (Snow et al., 2015). At writing up of this thesis, and as far as could be ascertained, only three cases describing chylothorax have been published (Green 1980; Guleserian et al., 1996; Ichikawa et al., 2015).

South Africa lacks up-to-date statistics for child mortality caused by violence or abuse. Penetrating thoracic injuries caused by gunshot and stabbing amongst children is rare within scientific literature, and even more so for abused children (Boleken et al., 2013). Penetrating trauma is usually intentional. A study in Kwazulu-Natal showed that, over a five-year review period, just under 10% of paediatric trauma cases (n = 164 children) presented with penetrating trauma: 73 gunshot wounds (GSW's), 70 stab wounds, and 21 non-intentional impalement injuries. In this study, 27% of the penetrating injuries occurred within the thorax (Khumalo-Mugabi et al., 2020). A review of gunshot injuries to children at the Red Cross Children's Hospital in Cape Town showed that, over a 10-year period, 163 children presented with gunshot injuries, with 10% of these affecting the thorax (Campbell et al., 2013).

Mortality is generally higher for penetrating injuries to the thorax than to the abdomen (Boleken et al., 2013). Thoracic injuries caused by GSW carry a higher mortality than stab wounds; and mortality is related to the severity of the intra-thoracic injury, rather than extra-thoracic wounds (Reinhorn et al., 1996).

Another rare case of intrathoracic injury, commotio cordis (cardiac concussion), is described by Baker, Craig and Lonergan (2003) in which the father of a seven-week male infant punched his child with a closed fist on the precordial chest, causing disruption of the electrical activity of the heart. Even though this injury is common in sport-related injuries, it is an uncommon finding in abused children. Commotio cordis should thus be considered in cases of sudden child fatality

where non-lethal chest injuries are present. Such injuries may provide markers of previously inflicted chest trauma or can be markers of acute signs associated with the fatal blow (Baker, Craig & Lonergan, 2003).

2.3.10 Clinical presentation of rib fractures in abused children

Rib fractures are widely considered as common skeletal indications of non-accidental injury and are considered to be a hallmark of physical abuse (Ng & Hall, 1998). Rib fractures in children younger than 3 years of age has a predictive value of 95% for abuse (Dwek, 2011). Abused children have significantly more rib fractures than children injured accidently (Darling et al., 2014). The reason why rib fractures in infants are highly suggestive of abuse is because the mechanism that causes the fracture is highly specific (Kemp et al., 2008). Rib fractures in non-abused children are rare due to the plasticity (cartilaginous status) of ribs which will only break when a certain threshold is reached (Lonergan et al. 2003). Rib fractures are caused by forceful squeezing of the infant's chest by adults and are associated with significant intrathoracic injuries, such as haemothorax, chylothorax, or pulmonary or cardiac contusions (Darling et al., 2014).

Fractures may occur in the anterior and posterior arch, as well as lateral aspects of the rib cage and are often multiple and bilateral (Cadzow & Armstrong, 2000; Lonergan et al., 2003). However, most rib fractures appear at the costovertebral junction, yet represent only 33% of the total number when compared to all other individual rib fracture sites (Boal, 2008). Fractures of the rib heads and costochondral junction are particularly difficult to diagnose (Kleinman et al., 1995).

Radiographically, rib fractures may appear as a lucency through the rib; and they may be difficult to detect when acute, incomplete, non-displaced, or when superimposed by other anatomical structures (Lonergan et al., 2003). Projection radiography has a low sensitivity for rib fractures when acute (Kemp et al., 2008). Rib fractures are easier to diagnose in the presence of callus formation, subtle periosteal reaction, asymmetry, or external evidence of injury such as soft tissue swelling (Ng & Hall, 1998). Callus formation, which increases detection of fractured ribs, is only detected approximately seven days after the initial injury (Erfurt et al., 2011). According to Offiah (2012), 80% of acute rib fractures may be missed on diagnostic images, such as skeletal surveys or chest radiographs, due to overlying lung and vascular markings. The role of PMCT for the detection of rib fractures will be discussed in Chapter Three. To increase the yield for diagnosing rib fractures, follow-up imaging is recommended 10–14 days after the initial injury (Anilkumar et

al., 2006). The use of dedicated mammography and cabinet X-ray systems for post-mortem diagnosis of rib fractures in infants has been advocated (McNulty et al., 2014).

At forensic autopsy, acute rib fractures are characterised by disruption of the bony cortex and subjacent bony trabeculae (Lonergan et al., 2003). Surrounding haemorrhage is often visible and the periosteum may be intact or disrupted. For forensic cases, the autopsy is still the gold standard for rib fracture assessment. However, rib fractures of the inner corticalis and buckle fractures can hardly be detected by autopsy without maceration, which is expensive and not viable in every autopsy (Glemser et al., 2017).

2.3.11 Clinical presentation of clavicular fractures in abused children

The clavicle is one of the most commonly fractured bones in children following accidental trauma but rare in the non-accidental injuries. Clavicular fractures are reportedly caused by physical abuse in only 2–6% of patients who present with clavicular fractures (Chapman, 2004). A study conducted in Worcester, Massachusetts, United States of America, amongst 31 fatally abused children, showed that, of the 165 fractures identified in the sample, only 1% of children (n = 2) had clavicular fractures (Kleinman et al., 1995). This is a very low incidence, compared to fractures of other bones caused by physical abuse, and underscores the rarity of this fracture type in abused children. Clavicular fractures are often detected as an occult injury in physically abused children (Day et al., 2006). Callus formation within a clavicle might sometimes result in an incidental (occult) finding of this fracture type (Bilo, Robben & Van Rijn, 2011). Abusive clavicular fractures tend to occur at the lateral end of the clavicle (Carty, 1995; Chapman, 2004). In abused children younger than three years of age, clavicular fractures display a midshaft fracture if caused by a direct blow, whilst traction to the arm will cause a fracture of the lateral end of the clavicle. Avulsion fractures of the lateral end of the clavicle are highly suggestive of abuse (Bandopadhyay & Yen, 2002). As is the case for other bone fractures, clavicular fractures at different stages of healing are highly suggestive of abuse (Thomsen et al., 1997; De Lange, Vege & Stake, 2007).

2.3.12 Clinical presentation of sternal fractures in abused children

Sternum fractures can be caused by a direct punch or blow to the sternum, or forceful compression of the thorax. Such a blow may result in a dislocation of the sterno-manubrial joint, or along the

cartilaginous edges of the sternal ossifying nuclei (Bilo, Robben & Van Rijn, 2011). Fractures of the sternum are rare in cases of child abuse, with the result that there is a paucity of publications on this injury type and imaging patterns (Ross & Juarez, 2014). Due to the rarity of sternal fractures in children under normal circumstances, the clinical presence thereof in a child is highly suggestive of abuse (Kleinman, 1990a). The pliability of the paediatric thorax makes the sternum resistant to deformation and hence resistant to fractures (Bilo, Robben & Van Rijn, 2011). Sternum fractures requires a high application of force, which underscores the specificity in the physical abuse setting (Erfurt et al., 2010). Since this fracture is difficult to diagnose on plain images obtained via skeletal surveys, the incidence of sternal fractures might be underdiagnosed (Bilo, Robben & Van Rijn, 2011).

Fractures of the sternum are equally well seen on CT in the living as well as the deceased (Christe et al., 2010). PMCT is especially useful for demonstrating areas difficult to visualise in plain images, such as fractures near the manubrium and costovertebral junction (Arthurs et al., 2017). It is conceivable that, when present, sternal fractures, due to their anterior anatomical location, are easy to diagnose at autopsy.

2.3.13 Clinical presentation of scapulae fractures in abused children

Fractures of the scapulae are rare due to the unique anatomy and the protective nestling of the scapula in many layers of muscle and connective tissue (Bilo, Robben & Van Rijn, 2011). Furthermore, scapular fractures are uncommon, given the significant force it requires to cause this fracture (Paddock et al., 2017). Hence, fractures of the scapula are considered highly suggestive of abuse (Offiah et al., 2009; Debelle, 2012). Without a plausible explanation or history of trauma, scapular fractures in children younger than two years is, in view of the above, highly suggestive of abuse (Bilo, Robben & Van Rijn, 2011). Most scapular fractures involve the acromion, but also occur commonly in the blade (Brogdon, 2011). Physical abuse may, in addition to causing a fracture of the acromion, also result in dislocation of the acromio-clavicular joint (Kleinman, 1990a; Bilo, Robben & Van Rijn, 2011). Fragmentation, or an avulsion fracture of the acromion, fracture of the coracoid, or other parts of the scapula, may present after indirect trauma, such as violent shaking, or pulling by the arm, or forceful pulling of the arms behind the back. Direct blows to the scapulae may cause a non-specific linear, or typical ‘star-burst’, fracture (Bilo, Robben & Van Rijn, 2011). Scapular fractures often co-exist with other pathologies, such as a fracture of the glenoid

cavity, clavicle, coracoid process, rib, proximal humeral fractures, as well as pneumo- or haemothoraces (Pierce & Bertocci, 2006; Bilo, Robben & Van Rijn, 2011). Scapular fractures therefore rarely occur in isolation in abused children. Conventional CT or PMCT can demonstrate complex scapular fractures with excellent clarity (Adamsbaum et al., 2010).

2.3.14 Clinical presentation of abdominal injuries in abused children

Abdominal blunt trauma is, after abusive head trauma, the second leading cause of fatal child abuse (Klevens & Leeb, 2010). Abusive abdominal injuries are potentially lethal and carry high mortality and morbidity rates (Lonergan et al., 2003; Raissaki et al., 2011). The mortality rate for children subjected to abusive abdominal injuries is reported to be between 30-53% and this mortality is often caused by delayed presentation or diagnosis (Raissaki et al., 2011).

Abusive abdominal trauma may go unnoticed in some cases due to the absence of external bruising, compounded by the relative pliability of the abdominal wall, even in cases of severe intra-abdominal injuries (Raissaki et al., 2011). Up to a quarter of non-accidental abdominal injury may occur with no abdominal wall bruising at presentation; and as up to 35% of abused children have no physical or radiographic evidence of abdominal trauma (Sheybani et al., 2014). The true extent of abusive abdominal injuries is therefore difficult to determine (Maguire et al., 2013).

2.3.15 Clinical presentation of abdominal solid organ injury in abused children

This section describes the injury patterns for the different abdominal organs and how these relate to physical abuse. A systematic review conducted by Maguire et al. (2013) has shown that every organ in the abdomen can be subjected to injuries in abused children. Blunt injury to the liver and small bowel, however, is more prevalent (Hilmes et al., 2011; Maguire et al., 2013). Compared to adults, children have a less muscular and thinner abdominal wall. The diaphragm is more horizontal, resulting in the liver and spleen being more anterior within the abdominal cavity, and less protected by ribs, making these two organs very vulnerable to blunt force (Maguire et al., 2013).

Liver lacerations are the most common solid organ injury type, with the left lobe of the liver being the anatomical section most commonly affected in abusive injuries (Herr, 2011). These liver lacerations are thought to be secondary to direct central abdominal blows (Malik & Faerber, 2018).

Liver lacerations may be associated with parenchymal or subcapsular haematomas; and, if the hepatic injury extends to the surface of the liver, or the hepatic capsule is disrupted, there may be an associated haemoperitoneum (Malik & Faerber, 2018).

Pancreatic injuries are a common occurrence in abused children and may occur secondary to blunt abdominal trauma to the upper abdomen (AAP, 2009a; Brogdon, 2011). Haematomas, lacerations, mesenteric injuries and post-traumatic stricture are frequently reported in abuse-related injuries (Lonergan et al., 2003). In severe cases, there may be pancreatic laceration or transection due to compression of the pancreas against the spine (Malik & Faerber, 2018). CT findings may appear as lacerations or transection (involving more than 50% of the gland) and may be indicated by indirect signs, such as pancreatic enlargement and poorly defined areas of contusion (Malik & Faerber, 2018). Lacerations, transection, and contusion may appear as linear or ill-defined areas of hypo-enhancement (Malik & Faerber, 2018).

Splenic injuries are, as with liver injuries, a common injury in children following blunt abdominal trauma (Shenoi et al., 2017). Splenic lacerations and contusions are less common than liver injuries and, on CT imaging, have a similar appearance to liver injuries. The imaging features for splenic injuries include lacerations, fracture haematomas, and rupture (Sheybani et al., 2014). Splenic lacerations can be linear or branching in appearance, and may present as hypodense areas, compared to the normally enhancing parenchyma (Malik & Faerber, 2018). There may be associated parenchymal or subcapsular haematoma which may appear as an area of hypo-enhancement. In contrast to peri-splenic fluid, a subcapsular haematoma will indent the splenic parenchyma (Malik & Faerber, 2018).

Adrenal haemorrhage has been described in abusive injuries and more commonly affects the right adrenal gland. It is seen in association with other abdominal injuries. Imaging appearances vary, depending on the stage of haemorrhage (Lindberg, 2012; Malik & Faerber, 2018).

2.3.16 Clinical presentation of abdominal hollow-organ injuries in abused children

Even though small-bowel injuries can occur in children due to accidental trauma such as road traffic accidents (RTAs) and falls, these injuries are significantly more common in abused children (Barnes et al., 2005). The duodenum is the most commonly injured hollow organ in abuse-related injuries and may be the first identifiable manifestation of abuse (Sheybani et al., 2014). The

mechanism of injury is compression of the bowel against the spine or results from shearing forces. The duodenum, being retroperitoneal in location, is more prone to compressive injuries (Malik & Faerber, 2018).

Other intestinal injuries include intra-mural haematoma, mostly occurring in the duodenum, and perforation, mostly at the jejenum (Dedouit et al., 2011). On contrast enhanced CT (CECT), the presence of free intraperitoneal fluid, mesenteric focal fluid, and duodenal wall thickening, with or without focal mass, suggests duodenal haematoma (Malik & Faerber, 2018). Bowel injuries may be accompanied by mesenteric tears or contusions. Disruption of the mesentery may lead to bowel ischaemia and eventual stricture formation (Sheybani et al., 2014). Intra-peritoneal or retroperitoneal air, and enteric contrast extravasation, are suggestive of bowel perforation (Malik & Faerber, 2018).

2.3.17 Clinical presentation of spinal injuries in abused children

Abusive spinal fractures are rare (Royal College of Paediatrics and Child Health, 2016b). There are thus limited scientific publications on this topic (Kemp et al., 2010). A study conducted by Kleinman et al. (2013) showed that, of the 441 skeletal surveys conducted amongst abused children, only 2% (n = 10/441) of children presented with a total of 25 spinal fractures. In the study of Kleinman et al., (2013) children presented with, inter alia, vertebral compression of the thoracic and lumbar region, a hangman's fracture, and two isolated sacral fractures. Even though the incidence of spinal fractures in abused children is rare, fractures can lead to long-term disabilities and even death (Kleinman, Kleinman & Savageau, 2004). Vertebral body fractures and subluxations correlate highly with abuse (Rooks et al., 1998).

2.3.18 Clinical presentation of cervical spine injuries in abused children

The incidence of cervical spine injuries in abused children, is estimated to be 15-19% (Baerg et al., 2017). Cervical spine injuries could be underreported due to insufficient imaging regimes, such as exclusion of the spine in AHT cases. Imaging of the full spine is therefore recommended in abused children with AHT (Choudhary et al., 2014). There is a high correlation between AHT and spinal cord injuries (Boal, 2008; McKinney et al., 2008). Up to 78% of children with AHT may present with ligamentous injuries (Choudhary et al., 2014). A forensic study has shown that 70%

of infant homicides had concomitant cervical spine pathology (Brennan et al., 2009). Occipito-cervical spine injury accompanied by AHT may lead to disordered breathing and may cause HIE (Choudhary et al., 2014; Baerg et al., 2017).

Spinal fracture dislocations in twin infants were only discovered after imaging showed radiographic evidence of multiple injuries, even though the physical and neurological clinical examination showed no evidence of abuse (Rooks et al., 1998). These missed injuries are more frequent and apparent following injury mechanism studies and autopsy (Baerg et al., 2017). Other rare cervical spine injuries that may occur are cervical spine EDH, and spinal SDH (Baerg et al., 2017). Autopsy is better able to distinguish between EDH and SDH, and show microscopic injuries, such as nerve root avulsion and stretch injuries (Baerg et al., 2017). There is a high correlation between projection radiography, CT and MRI of occipito-cervical ligamentous injury and hypoxic-ischemic brain injury. Cervical spine fractures appear radiographically as compression deformities of the vertebral body, often accompanied by end plate defects and avulsion injuries of the spinous processes (Boal, 2008).

2.3.19 Clinical presentation of thoracic and lumbar spine injuries in abused children

Very few publications exist on thoracic and lumbar spine injuries in abused children. For this reason, injuries within these two anatomical regions will be discussed together. A large review of skeletal surveys, and neuroimaging results of 751 abused children younger than 4 years, indicated vertebral body compression as the most common radiographic finding (n = 14) amongst children presenting with spinal injury. The majority of these injuries occurred in the thoracic and lumbar spine, with only two children presenting with fractures of the sacrum and coccyx (Barber et al., 2013). Hyperextension of the spinal column in a fatally abused child, resulting in a complete tear of the anterior longitudinal ligament of the spine, and diastasis of the vertebral bodies of lumbar vertebrae 1 and 2, have also been described (Dudley & Garg, 2014). Other abuse-related injuries that can occur in the thoraco-lumbar region are cord compression, contusion, tethering or fracture dislocation (Gabos et al., 1998; Kemp et al., 2010). One study showed that 44% (n = 8/18) of SDH in the spine amongst abused children may be clinically occult; and, in the majority of these cases, the haematoma pooled in the thoracic or lumbar spine (Koumellis et al., 2009).

2.3.20 Clinical presentation of spinal cord injuries in abused children

Violent whiplash shaking, often seen amongst Shaken Baby Syndrome (SBS) victims, results in hyperextension of the neck, causing stretch injury to the spinal cord, brainstem or vasculature, leading to respiratory compromise (Boal, 2008; McKinney et al., 2008). Spinal injuries in the past were rarely diagnosed in children with AHT and could be a consequence of these injuries not actively being sought in the clinical environment (Choudhary et al., 2014). The reason for the high rate of missed spinal injuries could be due to accompanying severe brain injury, which can mask spinal cord compromise (Koumellis, 2009). These co-existent cervical cord injuries are therefore often not clinically recognised and managed by clinicians, due to compromised neurological function (Feldman et al., 1997). The change in protocol to complete removal of the spinal cord and brain (en bloc) during autopsy has now led to an increase in the diagnosis of especially upper spinal cord injuries, which are in the majority (Choudhary et al., 2014; Baerg et al., 2017).

Radiographic evidence of severe spinal cord injury is often not noted in conventional imaging and is described as spinal cord injury without observable radiographic abnormality (SCIWORA). Spinal cord injuries are hence often diagnosed as an incidental finding among a larger spectrum of injuries (Gabos et al., 1998). MRI is considered the gold standard for any spinal cord injury; however, CT is a useful adjunct to delineate the extent of bony injuries. Radionuclide scans can add additional information and assist in diagnosis in some cases (Kemp et al., 2010; Royal College of Paediatrics and Child Health, 2016b).

2.3.21 Clinical presentation of pelvic fractures in abused children

Pelvic fractures amongst abused children are rare (Karmazyn et al., 2011). A large retrospective review of skeletal surveys conducted amongst 930 abused children revealed that only 1 child presented with pelvic fractures (0,001%), underscoring the rarity of these fractures (Karmazyn et al., 2011). The paediatric pelvis has more cartilage in the apophyses and triradiate cartilages and joints, which include the symphysis pubis and sacro-iliac joints, hence there is a greater degree of elasticity owing to its pliability (Johnson, Chapman & Hall, 2004). The paediatric pelvis can absorb a high level of energy (force) before fracturing, and skeletal injuries involving the bony pelvis indicate a greater degree of inflicted force (Johnson, Chapman & Hall, 2004). Most abusive pelvic fractures reported in the literature thus far occurred in the presence of additional skeletal

fractures or significant bodily injuries, providing evidence that pelvic fractures occur in significant traumatic episodes (Starling, Heller & Jenny, 2002).

Fractures of the pelvis may be caused by various types of injuries and present in various forms due to the complex anatomical composition of the pelvis. Fractures of the left pubic ramus, with multiple associated injuries and bilateral superior pubic rami fractures, have been described in two abused male infants respectively (Starling, Heller & Jenny, 2002). Fractures of the superior pubic rami and ischiopubic ramus can occur in cases of sexual abuse and may be the result of forceful restraint (Johnson, Chapman & Hall, 2014).

PMCT can demonstrate the extent and severity of complex pelvic fractures and joint spaces (Kraft, 2011). For example, the iliac bone is very difficult to examine during autopsy. It is for this reason that a CT of the pelvis is considered a more suitable examination for diagnosis of pelvic fractures compared to autopsy (Poulsen & Simonsen, 2007). PMCT will continue to play an important role in documenting pelvic injuries due to its ability to image anatomical areas that are difficult to dissect.

2.3.22 Shaken Baby Syndrome

SBS is broadly defined as the violent and repetitive shaking of an infant or toddler (mostly younger than two years of age), but may also occur in children up to five years of age, resulting in neurological damage such as SDH, retinal haemorrhage and, in some cases, SAH (Atwal et al., 1998; Le Roux-Kemp & Burger, 2014; Nadarasa et al., 2014). The violent shaking may cause a whiplash injury, especially since the rotation-acceleration strains on the brain happen symmetrically, because the child would be grasped by the chest or limbs symmetrically. This may also explain why these types of subdural haemorrhages more often occur bilaterally (Guthkelch, 1971). In severe cases, the toddler or infant may present with skeletal fractures; and, if the shaking was very violent, the injuries may also include metaphyseal, or cervical or lumbar spine fractures, or both (Nadasara et al., 2014). This violent shaking can cause severe disability or even death (Le Roux-Kemp & Burger, 2014).

Caffey, a paediatric radiologist, is credited with coining the term ‘Whiplash shaken infant syndrome’ (David, 1999; AAP, 2001; Le Roux-Kemp & Burger, 2014). Caffey published a landmark article in 1946 in which he described subdural haemorrhages diagnosed in six children;

these haemorrhages were accompanied by multiple skeletal fractures (Caffey, 1946; Le-Roux-Kemp & Burger, 2014). However, in 1974, Caffey popularised this disease by branding it 'Whiplash shaken baby syndrome' (AAP, 2001). Caffey posited that the whiplash shaking might be a result of violent abuse; and the shaking frequently resulted in permanent damage to the infant's brains and eyes, as well as caused metaphyseal avulsion lesions. The metaphyseal avulsion fragments occur as a result of indirect traction, stretching and shearing, acceleration and deceleration forces to the periosteum, and articular capsule caused by gripping (grabbing) or squeezing the infant or child by the extremities (Caffey, 1972; Caffey, 1974). Caffey also believed that whiplash shaking might also occur during normal handling of the child, such as tossing the child in the air, horse riding, and swinging a baby in a circle (Caffey, 1974).

Translational or rotational forces can cause a head injury. Translational forces that can occur during falls can produce linear movement of the brain and may cause a skull fracture in extreme cases. Rotational forces, however, can occur during shaking, and can cause the brain to turn on its own axis, or at its attachment to the brainstem (Blumenthal, 2002). Movement of the brain within the subdural space results in stretching and tearing of the bridging veins which extend from the cortex of the brain to the dural venous sinus (Guthkelch, 1971; Blumenthal, 2002). Haemorrhage can thus occur within the subdural space. Even if a small SDH is evident, it confirms evidence of shaking especially in the absence of a history of severe accidental head trauma (Blumenthal, 2002).

Injury patterns have evolved since the time of Caffey. Current opinion suggests that, during the shaking motion, if the infant or toddler is held by the chest, a pattern of fractures involving the rib head, tubercle, and cranium, such as bilateral, diastatic, depressed fractures that cross suture lines, may occur. If the child is held by the extremities, cranial injuries may be accompanied by extremity injuries, such as spiral diaphyseal fractures, subperiosteal haemorrhages and metaphyseal fractures, such as corner and bucket handle avulsion fractures (Caffey, 1974; Ross & Juarez, 2014). However, some schools of thought suggest that the primary brain injury caused by shaking is hypoxia, which can lead to cerebral oedema and raised intracranial pressure. Further neurological damage or death can occur as a result of ischaemia, causing a fall in cerebral perfusion pressure (Blumenthal, 2002). Diagnostic imaging such as CT and MRI, and radionuclide scanning, have enabled much earlier diagnosis of traumatic brain or skeletal injury (Lazoritz et al., 1997).

Clinical signs and symptoms of SBS are sudden onset of neurological abnormalities, such as poor feeding, vomiting, lethargy and irritability, or both, occurring for days or weeks; excessive sleep, epileptic seizures, muscular hypotonia, somnolence, coma, or death (Ellis, 1997; AAP, 2001; Blumenthal, 2002; Jacobi et al., 2010). Depending on the severity of clinical signs, caretakers may or may not seek medical attention; and these non-specific signs may erroneously be attributed to viral disease, feeding dysfunction, or colic. In such milder cases, signs may resolve without the true cause being established (AAP, 2001; Blumenthal, 2002). PMCT plays a significant role in the diagnosis of various forms of brain injury in children subjected to SBS.

2.3.23 Battered Child Syndrome

Kempe is widely recognised as the pioneer who developed the term ‘Battered Child Syndrome’ in 1962. This term is not commonly used now in modern literature. Kempe’s work was mostly based on the work of Caffey and colleagues and Caffey’s protégé, Frederick Silverman (Thomsen et al., 1997; Di Pietro et al., 2009). Kempe described this syndrome as evident in young children, mostly three years or younger, who were subjected to serious physical abuse in which subdural haematoma with or without skull fracture occurred. Accompanying injuries include skeletal fractures, often multiple, in different stages of healing, with multiple soft tissue injuries, poor skin hygiene, or malnutrition (Kempe et al., 1962). Due to the severity of the physical abuse, children may develop permanent neurologic injury or die (Kleinman, 1990a). The clinical manifestation may be due to one single episode or repetitive trauma. The child’s general health is below par compared to that of his or her peers. One common characteristic in many of these children is the discrepancy between the clinical history provided by the parents, and the clinical findings. The diagnosis of Battered Child Syndrome may be applied to any child showing evidence of SDH, bony fractures, failure to thrive, skin bruising and soft tissue swelling, or both, accompanied by sudden death, especially in cases where the clinical history provided does not concur with the injuries present (Ellis, 1997). The term ‘battered child syndrome’ has subsequently evolved into the clinical entity known as ‘the abused child’ (Atwal et al., 1998), extensively covered within this thesis. The term: Battered Child Syndrome is therefore no longer used as current terminology and variations of the term: ‘abused child’ or child abuse or suspected physical abuse are the more commonly used terms to describe abuse amongst children.

2.4 CLINICAL PRESENTATION OF EMOTIONAL ABUSE

Emotional abuse is sometimes also described as psychological abuse. The WHO defines emotional abuse as failure by a caregiver to provide an appropriate and supportive environment, including activities that have a negative effect on the emotional wellbeing and development of a child (WHO, 2002). Examples include restricting a child's movement, denigration, ridicule, threats, intimidation, discrimination and rejection (Runyan et al., 2002; WHO, 2002; Kraft, 2011). Emotional abuse is also the most difficult form of abuse to recognise in clinical practice (McDonald, 2007). This is, according to Speight (2006), also the area where the interventions of society are least successful. Very limited data exist relating to emotional abuse. One of the main reasons why emotional abuse is not well understood in South Africa is because it is not widely recognised as a health problem. More research is required to assess the extent thereof, and its disguise in other forms of abuse. The diagnosis of emotional abuse in children is often reliant on the discovery of other forms of abuse, such as physical or sexual abuse (The Centre for Crime Prevention and Justice, 2012).

There are several subtypes of emotional abuse: rejection, isolation, terrorising (instilling of terror), ignorance, psychological unavailability, corruption, and inappropriate expectation of, or demands on the child (McDonald, 2007). Emotional abuse involves extreme debasement of feelings, and may result in the child feeling inadequate, inept, uncared for and worthless. Such children learn to hide their feelings to avoid further harm and embarrassment (Troiano, 2011). Children who experienced chronic abuse and neglect in the first few years of life may live in a persistent state of hyper-arousal and dissociation, anticipating a threat from every direction. The ability of such children to benefit from social, emotional and cognitive experiences may be impeded; they often have a limited capacity for empathy; and, due to their dissociation, they may feel no emotional attachment to any human being (WHO & International Society for Prevention of Child Abuse and Neglect, ISPCAN, 2006). This section is included to complete the narrative of abuse in children. However, an in-depth discussion of emotional abuse and subtypes falls outside the scope of this thesis.

2.5 CLINICAL PRESENTATION OF CHILD NEGLECT

Sink et al. (2011) define neglect as failure to provide for the child's physical, emotional and educational needs. Manifestations of neglect may include inadequate care; failure to provide food,

clothing, and shelter; and the parent or caregiver delay in seeking medical help. Neglect occurs when parents or caregivers has adequate resources to meet the child's developmental needs but fails to do so (Runyan et al., 2002; The Centre for Crime Prevention and Justice, 2012). Neglect can be divided into three categories: inadequate care (also known as deprivation-of-needs-neglect); supervisory neglect (also known as environmental neglect); and medical neglect (Welch & Bonner, 2013). Supervisory neglect is defined as failure by the parent or caregiver to provide proper supervision or provide adequate safety (or both) for a child, particularly based on the child's age and abilities (Welch & Bonner, 2013).

It is noted that parental practices considered as normal by one parent, can be considered as abusive and neglectful by another. Each country has its own standards for care and neglect of children which are usually prescribed by law. In South Africa, the Children's Act (Act 38 of 2005) gives effect to the rights of children and sets out such principles related to the care and protection of children, including parental rights and responsibilities (South Africa, 2005). While cultures may vary in their definition of child abuse or neglect, abusive parents or caregivers demonstrate a set of behaviours which fall outside the realm of acceptable in any context (Madu, Idemudia & Jegede, 2002).

A large retrospective review on child fatalities in Oklahoma, United States of America, showed that child neglect constituted 49% (n = 372) of all child fatalities. About 38% (n = 141) of children in this study were under the age of 1 year; 18% (n = 67) included children aged 1 year; and 9% of children were 2 years of age. The most common cause of child neglect fatalities in this study was unintentional drowning at 24% (n = 89); this was followed by smoke inhalation following domestic fires at 13% (n = 50) and asphyxia caused by foreign objects obstructing the major airways accounted for 8,6% (n = 32) of the fatalities (Welch & Bonner, 2013). This study showed that children that are not properly supervised – who suffer supervisory environmental neglect – are at a significantly higher risk of death. Children of any age can die because of one solitary (acute) instance of supervisory neglect (Welch & Bonner, 2013).

It is evident from this discussion that neglect may result in different forms of risk to the affected child. The role of PMCT would be to document injuries sustained due to neglect. Such injuries may prove fatal.

2.6 CLINICAL PRESENTATION OF CHILD SEXUAL ABUSE

The Sexual Offences Act (Act 32 of 2007) broadly defines child sexual abuse as any act of sexual penetration, with or without a child's consent. Child sexual abuse includes a range of behaviours: sexual exploitation; sexual grooming; exposure or display or causing exposure of a child to child pornography; or using children for, or benefiting from, child pornography (South Africa, 2007). Prevalence studies of Child Sexual Abuse (CSA) show that both girls and boys experience high levels of victimization in most nations (Mathews et al., 2017). Global statistics suggest that 8-31% of girls and 3-17% of boys are victims of CSA.

Most intimate sexual contacts are committed by an offender known to the child, usually a family member or a close family friend. Much of the intimate sexual contact involves contact across, rather than into, genitalia or anus, leaving no forensic signs. Fewer than 10% of cases of sexual abuse present with physical signs upon clinical examination, therefore the clinical history is the most important part of the sexual abuse investigation (McDonald, 2007). The detection and confirmation of traumatic findings and the causes is an important diagnostic criterion in cases of suspected CSA (Erfurt et al., 2010).

Genital penetration for female victims leads to traumatic changes to the introitus, hymen or vagina. Anal abuse may lead to radial fissure and bruising of the peri-anal margin (Sunderland, 2002). A large study showed that 13,6% (n = 130/949) of sexually abused children also had co-existent physical injuries (Hobbs & Wynne, 1990). Injury patterns that may suggest sexually-motivated injuries include bruises, scratches and burns around the lower trunk and genitalia, thighs, buttocks and upper legs, including the knees. Pinch and grip marks are often evident where the child was held. Other CSA-associated injuries that have been documented in live children include these: extensive soft tissue injuries to the arms, legs and perineum; fractures of pubic rami and sacro-iliac joint; acute abdomen and pneumoperitoneum due to a ruptured rectum; and upper humeral epiphysis with extensive sub-periosteal bone formation (Johnson, Chapman & Hall, 2004). Physical findings diagnosed amongst 21 fatally abused children included healed or healing ano-genital injuries, and fresh ano-rectal injuries caused by blunt trauma (Pollanen et al., 2002).

Fatal sexual assault (also known as sexual homicide) is a killing that occurs during or after sexual assault. Sexual homicide is often obscured by the crime being reported as homicide rather than sexual homicide. This hampers collection of evidence, leading to underreporting or inconclusive data on actual statistics (Lawrence, 2004). One in ten child homicides in South Africa are identified

with an associated sexual crime (Abrahams et al., 2017). Results of an epidemiological study showed that of the 1,277 child homicides committed in South Africa in 2009, 8,7% (n = 104) were the result of sexual assaults (Abrahams et al., 2017).

2.7 FACTITIOUS DISORDER BY PROXY (MUNCHAUSEN SYNDROME BY PROXY)

Factitious disorder by proxy (FDP), previously known as Munchausen Syndrome by Proxy, is a disease defined as a behavioural abnormal pattern in which a caregiver creates, exaggerates or induces mental or physical illnesses in a child in order to gain the attention of health care professionals and others (Bertulli & Cochat, 2017). Often this falsification happens because the parent (or in loco parentis) wants to escape an unpleasant environment (Wadhera et al., 2013). Typical victims are four years or younger; there is no strong gender preponderance amongst victims. Birth mothers are the perpetrators in three out of four cases (Bertulli & Cochat, 2017); fathers are the second most common perpetrators. About 23% of perpetrators have a psychiatric diagnosis with depression, with unspecified personality disorder commonly present (Sheridan, 2003).

The child's clinical symptoms may depend on the medical knowledge or sophistication of the parents (Troiano, 2011). Perpetrators are recognised to have some form of professional medical training or a strong interest in health care (Sheridan, 2003). However, Yates and Bass (2017) argued that the finding of persons suffering from FDP having some medical training must be treated with caution, as some perpetrators have also been found to be pathological liars, therefore they could have been lying about having medical training.

This syndrome should be suspected when persistent or recurrent, unexplained illness affects a child, and when unusual signs and symptoms occur in the presence of only one caretaker (e.g., the mother) who often seems over-attentive, yet unworried (Wadhera et al., 2013). Acute signs and symptoms abate when the child is removed from the perpetrator (Sheridan, 2003). Children may even die as a result of induced illness, or medical procedures or therapies (Glaser, 2005; Hines, 2016; Bertulli & Cochat, 2017). Parents may force the child to ingest medications or poison which induces vomiting, diarrhoea, lethargy and sleepiness (Troiano, 2011). In other victims, the skin may be burnt, dyed, tattooed, lacerated or punctured to simulate acute or chronic skin lesions (Sheridan, 2003). Induced illness is responsible for more fatalities than illness fabrication (Yates & Bass, 2017). Whilst this disease entity is rare, it is important for health care professionals to be

cognisant of it, as it may result in debilitating and in some cases, fatal outcomes for the abused child. PMCT imaging has a role to play in documenting the consequential injuries sustained of this form of abuse.

2.8 CONDITIONS THAT MIMIC CHILD ABUSE

In the clinical setting, child abuse may present in various shapes and forms as highlighted in this chapter; however, there are many diseases that may mimic child abuse. The differential diagnosis for suspected child abuse can vary significantly and is often complex (Gregory, 1999; Metz et al., 2014). It is important to be aware that findings which appear to be related to child abuse might be related to other causes, such as accidental injury, pathological conditions, or even cultural practices, the results of which may appear similar to child abuse (Swerdlin, Berkowitz & Craft, 2007).

In many cases, determining whether a skin lesion is the result of abuse is not straightforward. Non-cutaneous mimics of physical abuse may be the result of diseases ranging from haematological disorders such as coagulopathies, to metabolic bone diseases, e.g., osteogenesis imperfecta, rickets or infectious disease (Metz et al., 2014). The skeletal variations that affect the metaphysis are the most important due to the close resemblance to the CML. The most important signs are the ‘step off’ configuration, the metaphyseal spur, as well as the metaphyseal beak (Chapman, 2008).

Research done by the ‘Examining Siblings to Recognise’ Abuse (ExSTRA) research network has shown that diseases that mimic abuse can be as high as 5% (n = 137/2,890). What further complicates diagnosis of abuse in infants and children is that, amongst those that do present with mimics of diseases, there may also be definitive signs of abuse, such as fractures. In other words, children with clear evidence of abuse may also present with diseases that mimic abuse (Metz et al., 2014; Srinivas & Moss, 2018). This confounding fact requires a high index of suspicion amongst health care professionals to ensure that, where abuse co-exists with mimics of child abuse due to disease, such incidences are identified and managed accordingly. For the sake of brevity, the section that follows will describe only those peritinent conditions that mimics child abuse.

2.8.1 Sudden unexpected death in infancy

Sudden Unexpected Death in Infancy (SUDI), also known as Sudden Unexpected Infant Death (SUID), is a term used to describe any sudden, unexpected death in infants (< 1 year), whether explained or unexplained (Weber & Sebire, 2009; Carrol & Wood, 2012). SUDI is considered by some authors as the commonest form of post-neonatal infant death. In a number of SUDI cases, post-mortem examination will reveal the cause of death; but, in the majority of cases, the cause of death remains undetermined (Proisy et al., 2013; Gorincour et al., 2015). Following detailed investigation, the cause of death in SUDI cases may be determined as being the result of medical causes, such as undiagnosed infections, congenital malformations, accidents, or inflicted injury (Garstang, Ellis & Sidebotham, 2015; Arthurs et al., 2017).

A study conducted in London, England, showed that only one-third of SUDI cases will have an identifiable, specific cause of death (Weber et al., 2008). Of the identifiable causes of death, the most common attributable aetiology is infection related. Of all the supplementary post-mortem investigations, histology sampling provides the most additional information to establish a cause of death (Weber et al., 2008). Of the SUDI cases that remain unexplained, some will occur in association with well-described risk factors for Sudden Infant Death Syndromes (SIDS) which include co-sleeping, soft bedding, parental smoking, drug use and socio-economic deprivation (Arthurs et al., 2017).

In the forensic setting, one of the main purposes of post-mortem investigations for SUDI is to identify any causes related to NAI (Proisy et al., 2013). In a small proportion of cases, where a crime may have been committed, it is important that such cases are identified and justice be served (Garstang, Ellis & Sidebotham, 2015). In such cases, autopsies should be conducted by a forensic pathologist and should include a detailed macroscopic examination, tissue sampling for histological assessment, a skeletal survey, and sampling for bacteriological, virological, metabolic and toxicological examinations (Weber & Sebire, 2009). Histological sampling is still the most helpful ancillary examination but is only able to demonstrate causes of death in about 40% of SUDI cases (Weber & Sebire, 2009). There is value for society in determining the causes of SUDI, as the learning generated from untimely deaths may help prevent future deaths (Garstang, Ellis & Sidebotham, 2015). Despite a high throughput of cases seen by pathologists around the world, SUDI remains poorly understood; and investigation of SUDI deaths today is still a challenging area for medical practitioners (Arthurs et al., 2017).

2.8.2 Sudden infant death syndrome

SIDS is a diagnosis of exclusion and can be classified under the umbrella of SUDI. SIDS is defined as the sudden and unexpected death of an infant less than one year of age; death is related to a sleeping episode; and the death remains unexplained after a complete autopsy, a comprehensive death scene investigation, and a review of the child's clinical history (Paterson, 2013). The pathogenesis of SIDS is not entirely known but is thought to involve three complex aetiologies involving multiple and simultaneous factors. The three factors suggested includes an underlying vulnerability in the infant (e.g., infection or congenital abnormality); a critical developmental period (e.g., first year of life); and exogenous stressors (e.g., prone sleep) (Paterson, 2013). The three factors are described by Weber and Sebire (2009) as the 'triple risk hypothesis'. This triple risk model suggests that normal infants do not die only when having an underlying disease process; and the model may explain why only a few infants placed prone during sleep die of SIDS (Paterson, 2013).

Epidemiological associations have shown that the following aspects have been considered risk factors for SIDS: male gender predominance; winter season at the time of demise; prematurity; genetic predispositions through important inflammatory, innate and adaptive immune responses; polymorphisms; pre- and post-natal exposure to smoke; lower social status; prone sleeping on bacterially-contaminated surfaces; and alcohol use during pregnancy (Tfelt-Hansen et al., 2011; Paterson, 2013; Goldwater, 2017). Of note is that even though SIDS deaths can occur across all strata, a large proportion of cases occurs amongst socially deprived families (Leach et al., 1999).

Some theories suggest that a major subset of SIDS results from abnormalities in serotonin 5-Hydroxytryptamine (5-HT) and related neurotransmitters in regions of the lower brainstem; there is then a failure of protective homeostatic responses to life-threatening challenges during sleep (Paterson, 2013). Other studies have indicated that the gene variants that affect different elements of 5-HT neurotransmission may be the cause of such pathogenesis or abnormalities in SIDS. However, these theories are inconclusive, do not enjoy consensus support amongst experts and are unlikely to play a major role in the pathogenesis of the medullary 5-HT abnormalities observed in SIDS (Paterson, 2013).

Haynes et al. (2017) have shown that infants that died due to SIDS had an elevation in serum 5-HT levels when compared to control cases. Their study provided a blood biomarker for peripheral 5-HT abnormalities in SIDS that expanded the brain stem theory and supported the

suggestion that SIDS is most likely a 5-HT disorder related to an unknown underlying vulnerability, as posited within the triple-risk model alluded to earlier. The brainstem and peripheral abnormalities in 5-HT pathway markers suggest a key function for 5-HT metabolism in SIDS (Haynes et al., 2017).

Milat et al. (2009) have shown that, at a molecular level, there appears to be evidence that suggests that long-QT genetic variations may be the cause of death in 10% of SIDS cases. These long-QT genetic variants may constitute the cause of death themselves, or they may predispose the affected infant to arrhythmia but only in the presence of one or more risk factors for SIDS. If autopsy fails to establish the cause of death, supplementary investigations should include molecular screening, including that of major long-QT genes, as this could possibly reduce the number of unexplained SIDS cases (Milat et al., 2009).

Despite decades of research studies and significant funding spent on SUDI research worldwide, the cause(s) of SIDS still evades researchers (Goldwater, 2017). Forensic post-mortem imaging is therefore used to assess any foul play, such as child abuse, within the SIDS setting, to provide a possible explanation for such unexpected death (Goldwater, 2017).

2.8.3 Osteogenesis imperfecta

There are various skeletal abnormalities that may mimic skeletal trauma in infants and young children. One of the most well-known conditions is that of osteogenesis imperfecta (OI). This condition must be considered in the differential diagnosis in cases of suspected child abuse where abnormal bone fragility or multiple fractures are evident (Ablin et al., 1990). OI is a heterogenous group of disorders that control collagen biosynthesis and is the most common inherited disease that predisposes infants and children to skeletal fractures (Christian & States, 2017). In OI, connective tissue has abnormal quality and quantity of type I collagen. There are four major types of OI (Ablin et al., 1990); however, discussion of these four types falls outside the scope of this thesis. OI can be diagnosed with the use of DNA collagen analysis (Wardinsky, 1995). Other clinical features may include ligamentous laxity, hypermobility of joints, easy bruising, constipation, hyperplastic ears, abnormal thermoregulation, and mitral or aortic valvular disease (or both) (Ablin et al., 1990).

2.8.4 Mongolian spots

Mongolian spots, also formally known as congenital melanocytosis, are benign blue marks and are a common appearance in infants with highly pigmented skin but may also appear in Caucasians (Prasad & Tully, 2017). Mongolian spots are usually present at birth or appear within the first few weeks after birth and may disappear during early childhood. These spots appear as macular blue-grey patches of uniform colour (Prasad & Tully, 2017). Mongolian spots are characterised histologically by the presence of spindle-shaped melanocytes within the dermis due to a failure of these melanocytes to migrate from the dermis to the epidermis (Gregory, 1999; Prasad & Tully, 2017). These blue marks may give the impression of soft tissue injury or bruises secondary to physical abuse. The common anatomical location of these spots includes the buttocks, back and posterior aspects of the extremities. Mongolian spots are consistent in colour, have well demarcated borders and tend to disappear with age (Wardinsky, 1995).

2.8.5 Phytophotodermatitis

Phytophotodermatitis is a phototoxic reaction that takes place when a section of the skin that has come into contact with certain plants (such as lemon, carrot, parsley, fennel and dill) is exposed to direct sunlight. The reaction is thought to be mediated by furocoumarins, organic chemical compounds produced by a variety of plants, which are liberated when the plant is crushed (Marcos & Kahler, 2015). The reaction may present as blisters, linear streaking patterns, or finger- and handprints. When the skin is exposed to ultraviolet radiation, the furocoumarins initiate hyperpigmentation, a form of acute dermatitis evidenced by erythema or vesicle formation (Gregory, 1999). Phytophotodermatitis may resemble partial thickness burns in some patients; it may mimic child abuse, especially where no obvious history can be provided for the cause of the burns (Hill et al., 1997).

2.8.6 Gastromalacia

Gastromalacia is described as a post-mortem autolysis (autodigestion) of the soft tissue of the stomach that can result in gastric perforation which presents radiographically as pneumoperitoneum. This entity, caused by an autolytic rupture of the stomach wall due to endogenous enzymes, is devoid of any vital reactions (Usui et al., 2013). Even though rare in

radiology literature, this entity is well recognised by forensic pathologists, but less so by forensic radiologists (Laczniak et al., 2011; Usui et al., 2013). If not correctly confirmed by forensic autopsy, this disease may result in a misdiagnosis of abusive blunt abdominal trauma in infants or children. The first case of gastromalacia was described in the 18th century by John Hunter and is associated with some intracranial disorders of various types. The disease is thought to be facilitated by bacteria and is not considered to be an inflammatory response of the affected gastric wall or adjacent peritonitis. At autopsy, this disease is well recognised as a post-mortem grey discoloration, and soft tissue consistency of the thinned, usually fundus gastric tissue, adjacent to the perforation site, accompanied by a lack of vital reactions such as haemorrhage or mucosal inflammation (Laczniak et al., 2011). Even though the fundus has been described as the most common anatomical site for autodigestion, gastromalacia may also affect the distal oesophagus which may lead to perforation into the left pleural cavity (Usui et al., 2013).

2.8.7 Anatomical variants that mimic physical abuse

Coronal clefts are physiological variants which may be mistaken for a traumatic vertebral compression fracture. Coronal clefts occur because of stunted ossification of the vertebral bodies during foetal development. Coronal clefts are defined as radiolucent bands of hyaline cartilage between a ventral and dorsal ossification centre and are usually located in the centre of the vertebral body or, on occasion, slightly posteriorly. Coronal clefts mostly occur in the lumbar spine, but may also affect the thoracic spine, and are best visualised on the lateral lumbar spine. Coronal clefts may involve single or multiple vertebrae and usually disappear as children grow up (Doberentz et al., 2014). Another anatomical variant that can mimic child abuse in the scapula is an ossifying nucleus. According to Bilo, Robben and Van Rijn (2011), the accessory ossifying nucleus at the end of the acromion may sometimes mimic a fracture. A genuine fracture will have a sharp edge and callus formation when healing. Anatomical variants within the pelvis include that of ischiopubis synchondrosis. On plain radiographs, a normal radiolucent or expanded ischiopubis synchondrosis may be misinterpreted as a fracture (Ablin et al., 1992).

2.9 CONSEQUENCES OF MISDIAGNOSIS

The previous section has shown that there are various conditions that may mimic child abuse. Child abuse might also be overlooked in infants because they cannot verbalise any pain or injury caused by physical abuse. Section 1.4 has further highlighted the important role imaging plays in the diagnosis of child abuse. Health care professionals involved in medical imaging have an ethical and legal duty to identify and report child abuse so that affected children can be protected from further harm (Christian & States, 2017). The risk of misdiagnosis of child abuse is high for the affected child (Chadwick et al., 1991) and undiagnosed child abuse can ultimately result in the death of a child.

Health care professionals should do everything in their power to prevent repeated trauma; and the bias should be in favour of the child's safety. If inflicted injury is not proven when it exists, children may be left in the care of persons who injure them repetitively, sometimes with fatal consequences (Chadwick et al., 1991). Missed abusive injuries may thus result in the continuation of domestic abuse and, in some cases, even involve siblings (Wardinksy, 1995; Hoskote et al., 2003). Children should not be allowed to return to a hostile environment, even where a moderate risk of repetition exists (Kempe et al., 1962).

Health care professionals are sometimes caught between their ethical duty to suspect and report child abuse, and the fear of the consequences of a misdiagnosis (Kleinman, 1990b). If evidence of child abuse is overlooked, or a diagnosis of child abuse is wrongly assigned, both actions will have social and legal consequences for the child and caregivers (Christian & States, 2017). Although it is important to identify child abuse correctly when present, it is also important to consider the devastating implications when a medical disorder is mistaken for child abuse (Shur & Carey, 2015). False incrimination of the parents or caregivers may result in serious emotional or psychological trauma for both caregiver and child; and it may result in a child erroneously being removed from the parents (Wardinksy, 1995). In the worst-case scenario, innocent persons could erroneously be convicted of a crime (Bilo, Robben & Van Rijn, 2011; Chadwick et al., 1991). In some cases, incorrect removal of a child may result in huge financial expenses when parents or caregivers challenge the separation decision ordered by courts (Chadwick et al., 1991; Wardinksy, 1995).

Health care professionals thus need to show an understanding of injury epidemiology, injury mechanism, and consequences of child abuse (Christian & States, 2017). Some health laws in

the United States of America and the United Kingdom protect physicians against civil and criminal liability in the reporting of child abuse cases. These laws are there to protect the interests of the child. The South African Children's Act (Act 38 of 2005) is silent on the protection of health care professionals when reporting child abuse cases (South Africa, 2005). To the contrary, physicians may be exposed to lawsuits when unsubstantiated claims of child abuse are made in the absence of robust medical evidence (Kleinman, 1990). It is essential that health care professionals be familiar with those disease patterns which occur as a result of naturally occurring disease and accidental injury.

It is thus imperative for health care professionals to use epidemiological, clinical and laboratory data in a multi-disciplinary, consultative process, to confirm or refute the presence of child abuse (Christian & States, 2017). Familiarity with these variations, as well as the application of thorough medical and laboratory investigations, will enable proper medical diagnoses.

2.10 CHAPTER SUMMARY

This chapter gave a brief historical overview of child abuse and how this disease entity has manifested over centuries. The clinical presentations of physical abuse, emotional abuse, neglect and sexual abuse amongst infants and children were highlighted. This discussion has shown that the most common clinical signs of physical abuse are cutaneous lesions such as bruises, followed by skeletal fractures. The discussion has also highlighted that pre-verbal children, and those younger than two years of age, are at higher risk of child abuse. The chapter further demonstrated that neurological injuries are a major cause of morbidity and mortality in abused children, while those infants and children that survive neurological injuries often suffer debilitating consequences.

Diagnosis of child abuse is not a simple task. This chapter highlighted the need for health care professionals to maintain a high index of suspicion when encountering suspected child abuse. There are many diseases processes, or anatomical variants, that may mimic child abuse which complicate diagnosis. Child abuse assessment should therefore preferably be conducted by a multi-disciplinary team. These multi-disciplinary teams must use supplementary medical and laboratory examinations to confirm or refute the presence of child abuse. The consequences of misdiagnosing child abuse can have devastating long-term consequences for the child, the family, and the managing physician.

Chapter Three will provide a detailed literature review comparing the degree of concordance between PMCT and the forensic autopsy for the spectrum of injuries sustained during fatal abuse, as well as those not readily diagnosed with PMCT and the forensic autopsy. The chapter ends with a review, based on existing literature, as to whether PMCT can be used to replace the forensic autopsy.

CHAPTER THREE

REVIEW OF THE LITERATURE: PART II

Historical and current overview of post-mortem imaging, degree of concordance between PMCT and the forensic autopsy for traumatic injury diagnosis; establishing a cause of death with PMCT, use of PMCTA in forensics and the need for PMCT imaging protocol optimisation.

3.1 CHAPTER INTRODUCTION

This research study involved the use of PMCT imaging in the assessment of suspected fatal child abuse and sudden unexplained deaths. Chapter Three starts with a historical overview with respect to the introduction of post-mortem imaging. Thereafter follows a detailed review of the literature, relative to the four objectives of the research study, which includes: i) the degree of concordance between PMCT and forensic autopsy findings in terms of the spectrum and anatomical location of injuries diagnosed; ii) the discordance between PMCT and the forensic autopsy for injury categories diagnosed; iii) the circumstances under which PMCT can accurately establish the cause of death in fatally abused children; and iv) whether selected forensic cases can undergo PMCT in the absence of the forensic autopsy. The discussion will compare the sensitivity of PMCT to the forensic autopsy for the above four objectives, as described in current literature. The chapter continues by describing the contribution of the Virtopsy project[1] to forensic pathology. The chapter ends by discussing new developments currently being explored in PMCT imaging techniques, such as PMCTA, a procedure which will most likely become an integral part of cross-sectional forensic imaging in the near future as well as the need to optimize PMCT protocols.

[1] Refer to Section 3.3 for a detailed discussion about the Virtopsy project.

3.2 HISTORICAL OVERVIEW OF POST-MORTEM FORENSIC IMAGING

Medical imaging has long been used to document injuries for forensic purposes (Fligner & Dighe, 2011). Projection radiography has different diagnostic applications within forensic pathology and forms an integral part of forensic post-mortem investigations (Thali et al., 2003b; Higginbotham-Jones & Ward, 2014). In forensic clinical settings, where resources are scarce, projection radiography remains a valuable imaging modality (McNulty et al., 2014). The advantages of post-mortem imaging are well established and may be used to locate foreign bodies such as drugs or bullets, to identify fractures (in cases of child abuse, elderly abuse, or other trauma), to establish a person's biological age, and to support identification of unidentified victims by comparing antemortem imaging with post-mortem imaging (Thali et al., 2003b; Levy et al., 2006).

One of the first applications of post-mortem imaging in forensic pathology was the use of conventional X-rays to locate a bullet in the leg of a gunshot victim. This incident happened soon after the discovery of X-rays by Wilhelm Röntgen in 1895 (Baglivo et al., 2013) – the unit of radiation, 'roentgen', was named after him. On a winter's Christmas eve in 1895, George Holder shot one Mr Tolson Cunning in the leg. Attempts to locate the bullet clinically failed. The patient's wound healed but he remained symptomatic. X-rays of the lower leg of Mr Cunning (which took 45 minutes to expose) were later obtained, which showed a flattened bullet lying between the tibia and fibula. The X-rays were presented in court and this resulted in the subsequent conviction of Mr Holder (Brogdon & Lichtenstein, 2011). One year later, in April 1896, another early application of forensic imaging occurred, this time in a post-mortem context. It involved an incident in which a Mr Hartley in Lancashire, United Kingdom, shot four bullets into the head of his wife. X-rays were taken. Initially, only three of the four bullets could be identified on the two X-rays. The fourth bullet was later discovered by follow-up imaging conducted by Prof. Schuster, Professor of Physics (Brogdon & Lichtenstein, 2011). Subsequently, many other cases have been described in the literature.

PMCT, on the other hand, was first introduced to forensic sciences in the late 1970s by Wüllenweber, to document gunshot injuries (Baglivo et al., 2013; Flach et al., 2014b). Chapter One highlighted the fact that CT technology has undergone rapid technological advances in the past two decades: full body scans can be performed in less than one minute; and multi-planar sequences can be generated from the axial data sets (Rydberg et al., 2000). These technological advances led to a number of forensic pathologists and radiologists using advanced cross-sectional imaging technologies in forensic sciences in the early 2000s (Baglivo et al., 2013). The

introduction of PMCT and PMMRI in forensic pathology led to a sharp rise in research studies to validate the agreement of these imaging modalities in diagnosing fatal injuries, and to establish the cause of death (Filograna et al., 2010). The Virtopsy project in Switzerland gave impetus to cross-sectional imaging in forensic pathology, a development which will be described in more detail in Section 3.3. In view of the steep rise in the application of cross-sectional post-mortem imaging in various forensic centres across the world, some authors have advocated for forensic radiology to become a distinct sub-speciality of forensic pathology and radiology (O'Donnell & Woodford, 2008).

3.3 VIRTUAL AUTOPSY (VIRTOPSY)

The Virtopsy project has changed the forensic pathology landscape. Dirnhofer and Vock are credited with developing the Virtopsy project in Switzerland at the start of the new millennium (Baglivo et al., 2013). The Virtopsy project was founded and introduced first at the Institute of Legal Medicine at the University of Berne, Switzerland, in 2000 (Thali et al., 2003a).

The Virtopsy project combines the use of PMCT and PMMRI in a minimally invasive forensic autopsy for establishing the cause of death (Thali et al., 2003a). The system uses a combination of 3D body surface imaging methods which are merged with the PMCT, or PMMRI data, and 3D shape analysis (Schweitzer et al., 2014) (see Figure 3.1).

Thali and colleagues, in turn, are credited for coining the term 'Virtopsy', which is derived from the term 'Virtual Autopsy'. The primary aim of the Virtopsy project was to establish minimally invasive, routine post-mortem imaging methods to supplement and, in some cases, even replace the traditional autopsy (Thali, 2003a; Flach et al., 2014b).

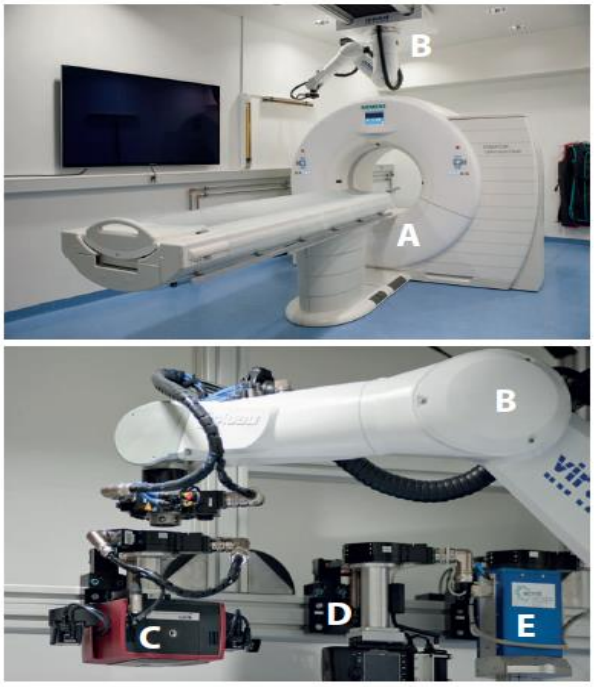


Figure 3.1 The Virtopsy system used for biopsies, comprising a 128 CT slice scanner (A) and robotic arm (B); and a 3D surface body scanner (C), a photographic mirror reflex camera (D) and a system to target and place biopsy needles (E). (Schweitzer et al., 2014). Photographs are used with permission from the Virtopsy Centre

The benefits the Virtopsy project offers to forensic investigations, include 3D photogrammetry and surface scanning for the documentation of patterned injuries (Baglivo et al., 2013). Others include material analysis, in which data are matched at a ratio of 1:1 to provide an accurate 3D geometry in the x, y and z-planes, which assists with scientific 3D reconstruction. Touch-free examination of hazardous bodies, e.g., those with contagious infective diseases, toxic substances and bodies infected with bio-hazardous substances as those caused by bioterrorism, can also be acquired (Schweitzer et al., 2014). The benefits that the Virtopsy project has brought to forensic pathology are well captured in the statement by Christe and colleagues who wrote: *"*Imaging revolutionised forensic medicine not only for diagnostic reasons, but also for medico-legal documentation that can be used in a court of law" (Christe et al., 2010:215).

3.4 DEGREE OF CONCORDANCE BETWEEN PMCT AND AUTOPSY FOR TRAUMATIC INJURY DIAGNOSIS

The field of forensic radiology has expanded rapidly in the last two decades, owing mostly to many empirical research studies being conducted. This section will highlight the degree to which PMCT is able to diagnose injuries in comparison with the forensic autopsy.

Many post-mortem forensic imaging research studies have shown that there is good concordance between PMCT findings and the forensic autopsy. The majority of these published studies used different research designs and methodologies, including subjects from different age groups and disease processes, as well as different causative mechanism of injuries, and hence natural and unnatural causes of death. It is therefore difficult to present a direct comparison of the level of agreement of PMCT in deceased children within existing literature.

In a systematic review conducted to compare PMCT findings to that of the autopsy, Scholing et al. (2009) concluded that the many differences in study protocols and methods employed in the research studies reviewed, hampered the interpretation of results; and a balanced comparison of the usefulness of PMCT to detect injuries in the forensic settings was therefore required. Furthermore, the lack of published research studies using paediatric populations only, also impeded a direct comparison in this regard. The sections that follow will compare PMCT findings with autopsy in mostly adult populations. Some studies did include children in their samples, and these will also be included in this review where they are found to be relevant.

Many studies have shown that both the autopsy and PMCT have strengths and weaknesses in establishing injuries sustained and in determining the cause of death. Even though autopsy techniques have been developed and improved over hundreds of years, certain parts of the body, such as the limbs, the back and the neck, are not routinely dissected during autopsy (Leth, Struckmann & Lauritsen, 2013). The forensic autopsy has certain limitations, such as an inability to reproduce findings, and restrictions on examining the whole body (Yen et al., 2007). Even though whole body PMCT allows visualisation of the complete human body, some injuries are missed by this imaging modality. Leth, Struckmann and Lauritsen (2013) found a 59% agreement between PMCT and autopsy for diagnosis of pathological findings. In the same study, PMCT was able to find 21% of injuries not detected by autopsy, whilst 20% of injuries detected by autopsy were not seen with PMCT. This implies that the false negative findings for both examinations were similar within this study. The review that follows will describe in detail the limitations for both PMCT

and the autopsy for the diagnosis of certain injuries. The tables presented in this chapter demonstrate which examination was superior to the other for different injury types only for the articles reviewed. The summation has not taken into account statistical significance or confidence intervals for the findings and subsequently each examination's superiority or inferiority has not been proven. This therefore represents which examination demonstrated more injury types per anatomical area for the publications reviewed and these summations must thus be interpreted with caution and within context.

3.4.1 Degree of concordance between PMCT and autopsy for intracranial injury diagnosis

It is often difficult to distinguish between EDH and SDH on PMCT if there is a long delay between the time of death and acquisition of the PMCT (Poulsen & Simonsen, 2007). Poulsen & Simonsen, (2007) therefore believe that PMCT imaging must be obtained as soon as possible after the demise of the deceased, so not to influence the diagnosis of these two intracranial haemorrhages.

Makhlouf and colleagues (2013) reported that 17 SAHs were diagnosed by autopsy, whilst 16 of the 17 cases were diagnosed using PMCT. Similar findings were shown by Daly et al. (2013) where 18 SAHs were diagnosed with autopsy, compared to 16 of the 18 using PMCT. Leth and Thomsen (2013) found that traumatic SAHs were diagnosed equally with both PMCT and autopsy, i.e., 34 SAHs were diagnosed with both examinations. However, in this same study, 14 additional traumatic SAHs were diagnosed by autopsy alone, as they were not seen with PMCT. PMCT was therefore unable to diagnose almost one-third of traumatic SAHs which were readily diagnosed by autopsy (Leth & Thomsen, 2013).

In the same study, Leth and Thomsen (2013) showed that PMCT had a perfect concordance with the forensic autopsy for diagnosis of SDH, as 17 were diagnosed with both examinations. In a smaller study by Daly et al. (2013), PMCT was found to be inferior for the diagnosis of SDH and was able to demonstrate only two SDHs compared to four diagnosed by autopsy. Similar findings were shown by Le Blanc-Louvry et al. (2013), where 14 SDHs were diagnosed with autopsy compared to eight diagnosed with PMCT. Poulsen and Simonsen (2007) found that three SDHs smaller than 3 mm were all missed with PMCT. The latter finding implies that PMCT is less sensitive for the detection of SDH, and even more so for SDHs smaller than 3 mm.

Le Blanc-Louvry and colleagues (2013) showed that the autopsy identified more EDH, as 11 in total were diagnosed at autopsy, compared to seven with PMCT. However, Leth and Thomsen (2013) have shown perfect concordance for the diagnosis of EDH, as both examinations diagnosed three in total, albeit in a very small number of cases.

Intraventricular haemorrhages are a common finding in traumatic brain injuries. PMCT was shown to identify more intraventricular haemorrhages compared to the autopsy, as 19 cases identified with PMCT were not diagnosed by autopsy (Yen et al., 2007). Maklouf et al. (2013) showed that brain contusion was best diagnosed with autopsy, as four cases were diagnosed, compared to zero using PMCT. For the diagnosis of soft tissue injury of the brain, autopsy had a better diagnostic yield. For example, Sochor and colleagues showed that autopsy was able to diagnose two cerebral contusions not diagnosed with PMCT (Sochor et al., 2008), whilst Le Blanc-Louvry et al. (2013) found that the number of cerebral contusions diagnosed with PMCT (n = 13) was similar to that diagnosed with autopsy (n = 12).

Cerebral oedema is one of many acute neurological signs in AHT (Carty, 1997). CT is the imaging modality of choice and is highly specific for the detection of secondary changes such as cerebral oedema in AHT (Dubowitz & Bennett, 2007; Kraft, 2011). In the study conducted by Le Blanc-Louvry et al. (2013), 116 cases of cerebral oedema were demonstrated by autopsy, compared to 110 diagnosed by PMCT. In the same study, PMCT diagnosed more pneumocephali, as 25 cases were identified compared to zero with autopsy. Daly and colleagues (2013) showed that PMCT was able to demonstrate nine subarachnoid pneumocephali, compared to none diagnosed at autopsy. In a similar vein, Makhlouf et al. (2013) demonstrated 20 pneumocephali diagnosed with PMCT, compared to zero diagnosed at autopsy.

Table 3.1 provides a summary of the degree of concordance for the number of intracranial injuries diagnosed with PMCT compared to the forensic autopsy. The colour coding in the table is used to indicate which examination identified more injury types compared to the other.

Table 3. 1 Degree of concordance between PMCT and autopsy for intracranial injury diagnosis

Injuries	Authors	PMCT findings (n =)	Autopsy findings (n =)	Degree of concordance
SAH	Makhlouf et al., 2013	16	17	94%
	Daly et al., 2013	16	18	88%
	Leth & Thomsen, 2013	37	48	77%
	Le Blanc-Louvry et al., 2013	24	28	86%
SDH	Leth & Thomsen, 2013	17	17	100%
	Daly et al., 2013	2	4	50%
	Le Blanc-Louvry et al., 2013	8	14	57%
	Poulsen & Simonsen, 2007	0	3	0%
EDH	Le Blanc-Louvry et al., 2013	7	11	64%
	Leth & Thomsen, 2013	3	3	100%
Intra-ventricular haemorrhage	Yen et al., 2007	19	0	0%
	Makhlouf et al., 2013	0	4	0%
Cerebral contusion	Sochor et al., 2008	0	2	0%
	Le Blanc-Louvry et al., 2013	13	12	92%
Cerebral oedema	Le Blanc-Louvry et al., 2013	110	116	95%
Pneumocephalus	Le Blanc-Louvry et al., 2013	25	0	0%
	Makhlouf et al., 2013	20	0	0%
	Daly et al., 2013	9	0	0%

Diagnostic rating	Colour
Autopsy superior	
PMCT superior	
Equal concordance	

Table 3.1 highlights that, for the studies reviewed, both types of examination had shortcomings in the diagnosis of neurological injuries. In some studies, both PMCT and autopsy missed certain categories of injuries. For the diagnosis of SAH, autopsy diagnosed more in four studies: In those four studies, 18 SAHs were not diagnosed with PMCT when compared to the autopsy. In three studies, the autopsy diagnosed more SDH as a total of 10 SDHs were missed with PMCT compared to the autopsy, whilst one study showed perfect concordance between autopsy and PMCT for this injury type.

Four EDHs were not diagnosed by PMCT, indicating that with autopsy more of these injuries were diagnosed. One study showed a perfect concordance between the autopsy and PMCT for the diagnosis of EDH. Given that this study had a small sample size, the findings must be interpreted with caution. For the diagnosis of intra-ventricular haemorrhages, in two studies, PMCT identified more compared to the autopsy. In total, PMCT was able to diagnose 15 more intra-ventricular haemorrhages compared to autopsy. For diagnosis of cerebral contusion, autopsy diagnosed one more case compared with PMCT. For diagnosis of cerebral oedema, in one study, autopsy was able to diagnose six more cases than PMCT. For diagnosis of pneumocephalus, PMCT identified 54 cases not seen at autopsy.

3.4.2 Degree of concordance between PMCT and autopsy for extracranial head injury diagnosis

Various anatomical structures external to the cranium can be injured as a result of child abuse. The next section will highlight some of the more common and high-risk head injuries seen in child abuse. When forensic pathologists examine deceased persons externally for trauma, the evaluation includes findings such as abrasions and lacerations of the skin, and gunshot entrance and exit wounds (Yen et al., 2007). Other extracranial injuries that may occur include injuries of the scalp, orbits, mouth, and neck structures. Chapter Two described some of the injuries that can be observed in abusive injuries of these structures. Very few studies draw comparisons between PMCT and the forensic autopsy for extracranial injuries. The literature suggests that there is a poor concordance between PMCT findings and autopsy for soft tissue injuries of the scalp (Jeffery, 2010). Yen et al. (2007) have shown that with PMCT, only one scalp abrasion was diagnosed out of 18 cases. In the same study, only 13 out of 20 haemorrhages of the temporal muscles were diagnosed with PMCT compared with the autopsy (Yen et al., 2007). This poor concordance is

thought to be due to PMCT's inability to display adequately soft tissue injuries involving the skin or underlying soft tissue. Extra-cranial head injuries diagnosed with the forensic autopsy in the present study included caput succedaneum, cephalohematoma, subgaleal haemorrhage, scalp bruising or haemorrhage. PMCT will according to Yen et al. (2007) remain of little forensic value for the diagnosis of extra-cranial head injuries. This shortcoming of PMCT imaging will remain for the foreseeable future until post processing options enable proper colourful display of the extra-cranial skin and soft tissue.

Table 3.2 Degree of concordance between PMCT and autopsy for extracranial head injury diagnosis

Injuries	Authors	PMCT findings (n =)	Autopsy findings (n =)	Degree of concordance
Head abrasions	Yen et al., 2007	1	18	6%
Haemorrhage: temporal muscles	Yen et al., 2007	13	20	65%

Diagnostic rating	Colour
Autopsy superior	

Table 3.2 shows that, for the two studies reviewed, autopsy identified 17 head abrasions which were not diagnosed with PMCT. The autopsy diagnosed seven more haemorrhages of the temporal muscles, compared with PMCT.

3.4.3 Degree of concordance between PMCT and autopsy for skull fracture diagnosis

The position and morphology of fractures to the skull are regularly assessed by forensic pathologists to differentiate between falls and blunt force trauma (Jeffery, 2010). Not all cranial fractures are demonstrated by PMCT. Yen and colleagues found that autopsy identified more skull fractures. In their study, 24 skull fractures were diagnosed with autopsy, compared to 18 using PMCT (Yen et al., 2007). Poulsen and Simonsen (2007) have shown that with PMCT, nine cranial fractures close to the petrous part of the temporal bone were not diagnosed. However, PMCT is better able to demonstrate the relationship of bone fragments for comminuted skull fractures

(Thomsen et al., 2009). Daly and colleagues, however, showed a perfect concordance between PMCT and autopsy for the diagnosis of base of skull fractures. In their study, nine base of skull fractures were diagnosed with both PMCT and autopsy (Daly et al., 2013).

Table 3.3 Degree of concordance between PMCT and autopsy for skull and facial fracture diagnosis

Injuries	Authors	PMCT findings (n =)	Autopsy findings (n =)	Degree of concordance
Skull fractures	Poulsen & Simonsen, 2007	0	9	0%
	Le Blanc-Louvry et al., 2013	38	37	97%
	Yen et al., 2007	18	24	75%
Base of skull fractures	Daly et al., 2013	9	9	100%
	Le Blanc-Louvry et al., 2013	24	26	92%
Facial bone fractures	Daly et al., 2013	10	4	40%
	Le Blanc-Louvry et al., 2013	38	26	68%
Maxilla fractures	Yen et al., 2007	7	0	0%
Mandibular fractures	Yen et al., 2007	3	0	0%
Temporo-mandibular joint fracture	Krentz et al., 2016	1	0	0%

Diagnostic rating	Colour
Autopsy superior	
PMCT superior	
Equal concordance	

3.4.4 Degree of concordance between PMCT and autopsy for facial bone fracture diagnosis

Similar to skull fractures, facial bone fractures can occur due to blunt force or penetrating trauma to the face. The face is, for cosmetic and ethical reasons, not routinely opened during autopsy. When facial bone fractures are not accompanied by external visible deformation or crepitation, they can easily be missed during autopsy (Yen et al., 2007). Facial bone fractures are more readily diagnosed during the forensic autopsy where there are dislocations (Poulsen & Simonsen, 2007). Krentz et al. (2016) have shown that one facial bone fracture involving the temporo-mandibular joint, was diagnosed with PMCT, but not with the autopsy. Similarly, Daly and colleagues demonstrated that with PMCT, six facial bone fractures were diagnosed compared to four diagnosed with autopsy (Daly et al., 2013). In the same study, three more occipital condyle fractures were diagnosed using PMCT compared to autopsy (Daly et al., 2013). PMCT ability to diagnose more facial bones fractures was also evident in a study conducted by Yen et al. (2007) in which seven maxillary fractures and three mandibular fractures were diagnosed with PMCT, but not detected at autopsy.

Table 3.3 shows that, for the five studies reviewed, there was variation in concordance between PMCT and the autopsy for the diagnosis of skull fractures. Autopsy diagnosed 16 more skull fractures compared to PMCT. However, in one study, a 100% concordance was seen between PMCT and autopsy for base of skull fractures and, in another study, a near perfect concordance for the same injuries. Autopsy was able to diagnose two more base of skull fractures compared to PMCT in one study. PMCT diagnosed more facial bone fractures in all five studies. For the two studies combined, autopsy failed to diagnose a total of 29 facial bone fractures.

3.4.5 Degree of concordance between PMCT and autopsy for neck injury diagnosis

One of the major pitfalls of PMCT in traumatic death is the inability to detect the cause of death in cases such as strangulation, hanging or throttling. These injuries to the neck have forensic significance in homicide investigations. In a study conducted by Kasahara et al. (2012) 17 cases of strangulation, one case of hanging and 10 cases of throttling were considered undiagnosable due to the inability to visualise cervical muscle injuries or lymph node haemorrhage with PMCT. These are findings easily diagnosed with autopsy. For hyoid bone fractures, concordance between PMCT and autopsy was almost perfect in the study conducted by Le Blanc-Louvry et al. (2013).

Within the study, six hyoid bone fractures were diagnosed with the autopsy, whilst five such fractures were diagnosed with PMCT. Even though PMCT is able to demonstrate fractures of the hyoid bone, MRI scanning is suggested, as PMCT alone, cannot reliably show whether such fractures occurred before or after death, as well as showing areas of associated soft tissue haemorrhage (Jeffery, 2010).

Table 3.4 Degree of concordance between PMCT and autopsy for neck injury diagnosis

Injuries	Authors	PMCT findings (n =)	Autopsy findings (n =)	Degree of concordance
Hanging	Kasahara et al., 2012	0	1	0%
Throttling	Kasahara et al., 2012	0	10	0%
Strangulation	Kasahara et al., 2012	0	17	0%
Hyoid bone fractures	Le Blanc-Louvry et al., 2013	5	6	83%

Diagnostic rating	Colour
Autopsy superior	

Table 3.4 underscores PMCT's inability to diagnose soft tissue injuries of the neck. In the two studies reviewed, overall, PMCT was unable to diagnose 29 injuries to the neck; yet PMCT's ability to diagnose bony injury is evident in the fact that, in Table 3.4, only one less hyoid bone fracture was diagnosed with PMCT compared to the total for autopsy, albeit with a small sample. The next section compares injuries of the thoracic cavity, as diagnosed by autopsy and PMCT.

3.4.6 Degree of concordance between PMCT and autopsy for thoracic injury diagnosis

Even though most injuries within the thorax are very well demonstrated by conventional CT, this imaging modality has some drawbacks for certain injuries. These will be highlighted in the section below. The interpretation of radiologic pulmonary findings in deceased persons remains challenging, mostly because it is difficult to distinguish between normal post-mortem findings and

existing pathological findings. This problem is exacerbated by aspects such as lack of inspiration, and position-dependent-findings in the lungs (Germerott et al., 2010).

In the trauma setting, haemothoraces and pneumothoraces are often consequences of penetrating injuries to the lung, or penetrating rib fractures. Makhlouf and colleagues found a perfect concordance between PMCT and autopsy for the diagnosis of haemothoraces. In their study, 19 haemothoraces were diagnosed with both PMCT and autopsy (Makhlouf et al., 2013). Daly and colleagues, however, found a dissimilar result: PMCT demonstrated eight haemothoraces, compared to only four with autopsy (Daly et al., 2013). Krentz et al. (2016) have shown that two haemothoraces detected at autopsy were not diagnosed using PMCT. These studies have shown that PMCT and autopsy had mixed results for the diagnosis of haemothoraces.

PMCT was shown to diagnose more pneumothoraces. For example, Makhlouf et al. (2013) diagnosed 18 pneumothoraces with PMCT, compared to seven with autopsy. Thomsen et al. (2009) demonstrated a similar finding as four pneumothoraces were not seen at autopsy in their study. In two of these cases, the pneumothoraces were accompanied by a mediastinal shift which is generally difficult to diagnose at autopsy (Thomsen et al., 2009). In this same study, PMCT was able to diagnose 18 gas emboli compared to zero diagnosed at autopsy. This suggests that with PMCT more gas emboli were diagnosed when compared to the autopsy (Thomsen et al., 2009).

Daly and colleagues found a 100% concordance between PMCT and the autopsy for lung lacerations, having diagnosed six with both examinations (Daly et al., 2013). In a smaller study, Sochor et al. (2008) found that two lung contusions were diagnosed by both PMCT and autopsy. However, Poulsen and Simonsen (2007) diagnosed 25 contusions with autopsy, compared to only four with PMCT.

As far as could be ascertained, there are not many cardiac injuries documented in scientific forensic radiology publications, but there are some for cardiac disease. Krentz et al. (2016) showed that autopsy identified one cardiac infarction not seen with PMCT. This cardiac infarction was diagnosed with autopsy in a 33-month infant, caused by intramyocardial haemorrhage. Poulsen and Simonsen (2007) have shown that, for cardiac rupture, PMCT showed 100% concordance (n = 11) with autopsy, whilst cardiac hypertrophy within the same study was better diagnosed by autopsy (n = 181 vs 158) compared with PMCT.

Detecting signs of aspiration is of high forensic relevance, as it clarifies whether an injury occurred pre- or post-mortem, and whether it was the primary factor in, or a contributing factor to the cause of death (Scaparra et al., 2016). Blood found deep in the bronchial tree is accepted as a sign of blood aspiration, whereas blood found in the large bronchi cannot be distinguished as blood resulting from resuscitation manoeuvres, or post-mortem flow of material into the respiratory tract (Scaparra et al, 2016). One study has shown that PMCT was able to demonstrate the anatomical location of aspirated blood (in the major airways) in 71% of cases (n = 29/41) compared with the forensic autopsy (Scaparra et al., 2016). A different study has shown that PMCT detected more fluid in the airways, demonstrating a total of 192 cases with PMCT, compared to 131 at autopsy (Le Blanc-Louvry et al., 2013).

Literature suggests that more diaphragmatic injuries are detected at the autopsy compared to PMCT. Makhlouf and colleagues (2013) showed that 12 diaphragmatic injuries were diagnosed at autopsy, compared to only three using PMCT. Interesting to note is that, in the same study, thoracic wall injury was almost equally well seen with the autopsy (n = 18) when compared to those diagnosed with PMCT (n = 19) (Maklouf et al., 2013).

PMCT can readily demonstrate fluid collections in the thoracic cage, and enable quantification thereof (Leth, 2011). PMCT is, however, unable to distinguish between fluid types, such as a hydrothorax, pyothorax and haemothorax, which are readily diagnosed at autopsy (Poulsen & Simonsen, 2007). A study conducted by Poulsen and Simonsen (2007) found that more free fluid was detected in the thorax with PMCT (n = 108) compared to 81 cases diagnosed at autopsy. The same authors noted that the fluid collections detected with PMCT were small and were the result of putrefaction, which could explain why more were detected at PMCT in this study (Poulsen & Simonsen, 2007). Forensic pathologists are able to see free fluid when present in the thorax as this is usually visible with the naked eye (Martin[2], 2020).

PMCT was shown to diagnose more pleural fluid compared to the autopsy. For example, Le Blanc-Louvry et al. (2103) showed that PMCT demonstrated more pleural fluid collections (n = 75) than

[2] Martin, L.J. 2021. Personal communication. Jan. 2021. Professor and Head of Division, Forensic Medicine, Faculty of Health Sciences, University of Cape Town, Cape Town, South Africa. (According to the institution's referencing guidelines, personal communication is listed in-text but not in the list of references).

autopsy (n = 55). The same study showed that with PMCT more pericardial effusions (n = 25) were diagnosed compared to autopsy (n = 16).

Table 3.5 Degree of concordance between PMCT and autopsy for thoracic injury/pathology diagnosis

Injuries	Authors	PMCT findings (n =)	Autopsy findings (n =)	Degree of concordance
Lung contusion	Poulsen & Simonsen, 2007	4	25	16%
	Sochor et al., 2008	2	2	100%
Lung laceration	Daly et al., 2013	6	6	100%
Haemothorax	Makhlouf et al., 2013	19	19	100%
	Daly et al., 2013	8	4	50%
	Krentz et al., 2016	0	2	0%
Pneumothorax	Makhlouf et al., 2013	18	7	39%
	Thomsen et al., 2009	4	0	0%
	Le Blanc-Louvry et al., 2013	57	0	0%
Gas embolism	Thomsen et al., 2009	18	0	0%
Thoracic wall injury	Makhlouf et al., 2013	19	18	95%
Pulmonary oedema	Le Blanc-Louvry et al., 2013	123	119	97%
Pulmonary wounds	Le Blanc-Louvry et al., 2013	11	24	46%
Pleural fluid	Le Blanc-Louvry et al., 2103	75	55	73%
Fluid in airways	Le Blanc-Louvry et al., 2013	192	131	68%
Pericardial effusions	Le Blanc-Louvry et al., 2103	25	16	64%
Endocardial haemorrhage	Krentz et al., 2016	0	1	0%
Intraventricular haemorrhages	Daly et al., 2013	6	1	20%

Cardiac rupture	Poulsen & Simonsen, 2007	11	11	100%
Fluid thoracic cavity	Poulsen & Simonsen, 2007	108	81	75%
Blood aspiration	Scaparra et al., 2016	29	41	71%
Diaphragmatic injury	Makhlouf et al., 2013	3	12	25%

Diagnostic rating	Colour
Autopsy superior	
PMCT superior	
Equal concordance	

Table 3.5 shows that, for the studies reviewed, PMCT identified more thoracic injuries or pathologies in 11 studies, compared to six studies in which autopsy identified more. In the studies reviewed, there were four studies in which a perfect concordance was seen between the two examinations. PMCT, overall, diagnosed 72 more pneumothoraces. Autopsy diagnosed more pulmonary injuries such as lung contusion as 21 more cases were diagnosed compared to PMCT, and nine more for diaphragmatic injuries. PMCT diagnosed more gas emboli, having detected 18 cases not diagnosed at autopsy. PMCT has been shown to be poor for lung parenchymal injuries mostly because these soft tissue injuries are usually not well seen on PMCT as presented in studies by Adelman et al. (2108), Mishra et al. (2018) and Le Blanc-Louvry et al. (2013).

Table 3.5 indicates that, for the studies reviewed, PMCT identified 20 more cases of pleural fluid, and 61 more cases of fluid in the airways. Nine more pericardial effusions were diagnosed with PMCT compared to autopsy and 27 more cases of free fluid within the thorax. The autopsy diagnosed 12 more blood aspirations compared to PMCT.

3.4.7 Degree of concordance between PMCT and autopsy for rib fracture diagnosis

Overall, compared to the forensic autopsy, PMCT has a lower sensitivity for rib fracture detection; however, incomplete rib fractures are best demonstrated by PMCT compared to autopsy (Schulze et al., 2013). PMCT is generally unable to detect rib fractures when no relevant joint dislocation or cortical discontinuity is present. PMCT is further constrained due to its inability to demonstrate associated soft tissue haemorrhage (Poulsen & Simonsen, 2007). Reattached fracture edges may

be invisible on PMCT, even with high resolution Computed Tomography (HRCT), as the thoracic cage maintains its stability and keeps broken ribs in their physiological position (Schulze et al., 2013). PMCT has a lower diagnostic yield for fractures of the antero-lateral ribs, numbers 2–7. The first rib and the lower ribs have muscle origins and these muscles may cause a displacement of fractured ribs, which may explain the higher detection rates in these sites, whether at autopsy or by PMCT (Schulze et al., 2013). Rib fractures located within the antero-lateral region may remain undetected if no physical stability testing was performed at autopsy; and the diagnosis of these rib fractures is further complicated if no fracture haematoma is evident (Schulze et al., 2013).

In a study by Daly et al. (2013), seven rib fractures were diagnosed with PMCT, compared to six with autopsy. Leth and colleagues found that 50 rib fractures were detected by autopsy compared to 49 using PMCT (Leth, Struckmann & Lauritsen, 2013). Another smaller study showed that PMCT identified more rib fractures: three were diagnosed with PMCT compared to only two at autopsy (Sochor et al., 2008).

Table 3.6 Degree of concordance between PMCT and autopsy for rib fracture diagnosis

Injuries	Authors	PMCT findings (n =)	Autopsy findings (n =)	Degree of concordance
Rib fractures	Le Blanc-Louvry et al., 2013	28	40	70%
	Daly et al., 2013	7	6	86%
	Leth, Struckmann & Lauritsen, 2013	49	50	98%
	Sochor et al., 2008	3	2	66%

Diagnostic rating	Colour
Autopsy superior	
PMCT superior	

Table 3.6 above shows that, for the studies reviewed, there were mixed results for the diagnosis of rib fractures by PMCT and autopsy. The study by Le Blanc-Louvry and colleagues showed that

PMCT missed a greater proportion of rib fractures, compared to the forensic autopsy (Le Blanc-Louvry et al., 2013).

3.4.8 Degree of concordance between PMCT and autopsy for abdominal injury diagnosis

Chapter Two has alluded to the fact that abdominal injuries in abused children are rare. However, abusive abdominal injuries have a high mortality rate (Raissaki et al., 2011). The liver is, due to its relative size, the most injured solid organ within the abdomen (Maguire et al., 2013). Autopsy in one study identified 11 liver injuries compared to six with PMCT (Maklouf et al., 2013). Similar findings were shown in another study where only two liver lacerations were diagnosed with PMCT, compared to five with autopsy, albeit with a small sample size (Daly et al., 2013). The ability of PMCT to detect organ laceration and contusion in the forensic setting is constrained, because contrast media are not readily administered due to the lack of blood circulation (Shiotani et al., 2008).

For diagnosis of splenic injuries, autopsy identified more compared to PMCT, as five splenic injuries were diagnosed with autopsy compared to one with PMCT (Makhlouf et al., 2013). However, in the same study, diagnosis of kidney injuries revealed a perfect concordance, demonstrating five cases with each examination, whilst slightly more haemoperitoneums (n = 11) were diagnosed by autopsy, compared to PMCT (n = 9) (Makhlouf et al., 2013). Free peritoneal fluid, or abdominal haematoma, is a common consequence of blunt abdominal trauma in abused children (AAP, 2009a; Dedouit et al., 2011). Free peritoneal fluid is clearly seen on CT imaging and ultrasound (AAP, 2009a). Small volumes of free fluid in the abdomen is generally difficult to diagnose on PMCT due to the large amount of air in the intestines, as well as putrefactive changes, and the large area of potential space where fluid can be scattered (Poulsen & Simonsen, 2007). It was thus not surprising that, in one study, free fluid within the abdomen was better seen in autopsy (n = 21) compared to PMCT (n = 14) (Poulsen & Simonsen, 2007).

Table 3.7 Degree of concordance between PMCT and autopsy for abdominal injury diagnosis

Injuries	Authors	PMCT findings (n =)	Autopsy findings (n =)	Degree of concordance
Liver injuries	Makhlouf et al., 2013	6	11	55%
	Daly et al., 2013	2	5	20%
Splenic injuries	Makhlouf et al., 2013	1	5	20%
Kidney injuries	Makhlouf et al., 2013	5	5	100%
Haemoperitoneum	Makhlouf et al., 2013	9	11	82%
Free fluid abdomen	Poulsen & Simonsen, 2007	14	21	67%
Solid organ injuries	Le Blanc-Louvry et al., 2013	10	47	21%
Hollow organ injuries	Le Blanc-Louvry et al., 2013	0	11	0%

Diagnostic rating	Colour
Autopsy superior	
PMCT superior	
Equal concordance	

Table 3.7 indicates that, for the eight studies reviewed, autopsy identified more abdominal injuries in six of the categories. Overall, autopsy diagnosed eight more liver injuries compared to PMCT. Four more splenic injuries were diagnosed with autopsy, and two more cases of haemoperitoneum. For kidney injuries, there was 100% concordance between PMCT and autopsy. The table shows that, overall, with autopsy, seven more cases of free abdominal fluid were detected; and, in total, 49 more cases of solid organ injuries, and 11 cases of hollow organ injuries, were diagnosed that were not seen with PMCT. These findings demonstrate that the autopsy demonstrated more solid abdominal organ injuries compared to PMCT.

3.4.9 Degree of concordance between PMCT and autopsy for pelvic injury diagnosis

As stated in Chapter Two, PMCT is a more convenient method for the exploration of fractures of the pelvis, compared to the forensic autopsy. For example, the hipbone is difficult to examine at autopsy (Poulsen & Simonsen, 2007). One study has shown that PMCT was able to demonstrate more pelvic fractures (n = 13) compared to autopsy (n = 9) (Le Blanc-Louvry et al., 2013). Similarly, Makhlouf et al. (2013), found that two pelvic fractures were identified with PMCT that were not diagnosed with autopsy (albeit a small sample size). Conversely, Poulsen and Simonsen (2007) found a perfect concordance between autopsy and PMCT for diagnosis of pelvic fractures. In the latter study, 20 fractures were diagnosed using both PMCT and autopsy. A different study showed a near perfect concordance between PMCT and the autopsy: 22 fractures were diagnosed at autopsy, compared to 23 with PMCT (Leth, Struckmann & Lauritsen, 2013). Contrary to these findings, Daly et al. (2013) showed that seven pelvic fractures were diagnosed by PMCT compared to only three at autopsy. A smaller study by Sochor et al. (2008) showed that four pelvic fractures were diagnosed with PMCT, compared to two at autopsy. In the same study, however, three sacro-ileal fractures were diagnosed at autopsy, compared to only two with PMCT.

Leth and Thomsen (2013) have shown mixed results for both autopsy and PMCT. In their study, a total of 50 pelvic fractures were diagnosed at both PMCT and autopsy. However, four additional pelvic fractures were diagnosed with PMCT, whilst one fracture diagnosed at autopsy was not seen at PMCT (Leth & Thomsen, 2013). Even though PMCT was unable to diagnose all pelvic fractures in their study, overall, this imaging modality had a higher yield compared to autopsy for the diagnosis of pelvic fractures.

Table 3.8 Degree of concordance between PMCT and autopsy for pelvic injury diagnosis

Injuries	Authors	PMCT findings (n =)	Autopsy findings (n =)	Degree of concordance
Pelvic fractures	Le Blanc-Louvry et al., 2013	13	9	69%
	Makhlouf et al., 2013	2	0	0%
	Poulsen & Simonsen, 2007	20	20	100%
	Leth, Struckmann & Lauritsen, 2013	23	22	96%
	Daly et al., 2013	7	3	43%
	Sochor et al., 2008	4	2	50%
	Leth & Thomsen, 2013	50	50	100%
	Leth & Thomsen, 2013	4*	0	* 4 Additional pelvic injuries identified not seen with autopsy
	Leth & Thomsen, 2013	0	1*	* 1 Additional pelvic injury identified not seen with PMCT
Sacro-ileum fractures	Sochor et al., 2008	2	3	67%

Diagnostic rating	Colour
Autopsy superior	
PMCT superior	
Equal concordance	

Table 3.8 indicates that, for the studies reviewed, PMCT identified more pelvic fractures in six of the seven studies; and it had a 100% concordance with autopsy in two other studies. Overall, PMCT diagnosed 15 more pelvic fractures compared to the autopsy. In one study, four additional fractures were diagnosed with PMCT that were not seen at autopsy, whilst, with autopsy, one additional fracture was diagnosed that was not seen with PMCT. It is thus evident that both examinations may miss certain pelvic fractures, even though the rate of misses appears to be lower for PMCT.

3.4.10 Degree of concordance between PMCT and autopsy for spinal column and spinal cord injury diagnosis

Spinal fractures are readily diagnosed using PMCT. Compared to all other imaging modalities, CT imaging is generally better suited to show complex spinal trauma (AAP, 2009a). Le Blanc-Louvry et al. (2013) have shown that PMCT detected more vertebral fractures (n = 20) compared to autopsy (n = 15).

Table 3.9 Degree of concordance between PMCT and autopsy for spinal column and spinal cord injury diagnosis

Injuries	Authors	PMCT findings (n =)	Autopsy findings (n =)	Degree of concordance
Spinal fractures	Le Blanc-Louvry et al., 2013	20	15	75%
Thoracic vertebra 8	Cha et al., 2010	0	1	0%
Atlanto-occipital fracture/dislocations	Daly et al., 2013	10	9	90%
Cervical vertebra 6	Daly et al., 2013	1	0	0%
Cervical vertebra 7	Daly et al., 2013	1	0	0%
Thoracic vertebra 3	Daly et al., 2013	1	1	100%
Spinal cord injury	Daly et al., 2013	1	2	50%
	Sochor et al., 2008	0	3	0%

Diagnostic rating	Colour
Autopsy superior	
PMCT superior	
Equal concordance	

Daly and colleagues (2013) had a similar finding where slightly more spinal vertebrae fractures (n = 13) were diagnosed with PMCT compared to autopsy (n = 10). In the same study, two spinal cord injuries were diagnosed with autopsy compared to only one with PMCT (Daly et al., 2013). In a different study, three spinal cord lacerations were diagnosed with autopsy, compared to none diagnosed with PMCT (Sochor et al., 2008). PMCT also failed to demonstrate a fracture of thoracic

vertebra number 8 which was confirmed with autopsy (Cha et al., 2010). These findings suggest that, at times, PMCT may fail to demonstrate certain spinal injuries, which is currently a shortcoming for this imaging modality.

Table 3.9 indicates that, for the four studies reviewed, PMCT identified eight more vertebral fractures compared to autopsy. However, one vertebral fracture was missed with PMCT. Autopsy had a higher diagnostic yield for spinal cord injuries compared to PMCT.

3.4.11 Degree of concordance between PMCT and autopsy for extremity fracture diagnosis

Extremity fractures in fatally abused children may be difficult to diagnose at autopsy, particularly if the lethal event occurred shortly before death and there is no evidence of soft tissue inflammatory reactions, callus formation and displacement. Haemorrhage of surrounding soft tissue may be mild, and so hardly visible during autopsy (Cattaneo et al., 2006). This suggests that, without any clear physical signs, fresh injuries of the extremities may be difficult to diagnose at autopsy.

PMCT is the best for diagnosing multiple and crushing extremity fractures, since this modality can demonstrate the fractures in situ (Poulsen & Simonsen, 2007). Also, compared to autopsy, PMCT provides a full overview of the extent of fractures when sometimes there are no external indicators of blunt force trauma to that area. PMCT is able to identify generally more extremity fractures than the autopsy (Leth & Thomsen, 2013). A comparative study by Daly et al. (2013) has shown that 18 skeletal injuries were diagnosed with PMCT compared to 14 seen with autopsy. Similarly, Le Blanc-Louvry et al. (2013) showed that PMCT diagnosed 55 extremity fractures, compared with 33 at autopsy.

Table 3.10 Degree of concordance between PMCT and autopsy for extremity fracture diagnosis

Injuries	Authors	PMCT findings (n =)	Autopsy findings (n =)	Degree of concordance
Extremity fractures	Daly et al., 2013	18	14	78%
	Le Blanc-Louvry et al., 2013	55	33	60%
Scapula fractures	Daly et al., 2013	2	0	0%

Diagnostic rating	Colour
PMCT superior	

Table 3.10 indicates that, for the three studies reviewed, PMCT diagnosed 28 more extremity fractures in total compared to autopsy.

3.4.12 Degree of concordance between PMCT and autopsy for solid organ and soft tissue injury diagnosis

The parenchyma of solid organs is often injured following an insult. Krentz et al. (2016) have shown that autopsy is able to detect more findings related to organ parenchyma. In their study, autopsy could identify organ parenchymal findings in 83% of cases (n = 65/78) compared to 63% (n = 49/78) using PMCT.

Autopsy is able to diagnose pale organs caused by exsanguination (Thomsen et al., 2009). Diagnosis of pale organs due to exsanguination is virtually impossible to diagnose using PMCT. The inability of PMCT to diagnose this critical forensic autopsy finding may have detrimental consequences for a criminal investigation, particularly where exsanguination was the cause of death. Furthermore, autopsy is better at demonstrating other organ pathology such as pulmonary oedema and stasis (Thomsen et al., 2009).

Soft tissue injuries following trauma can often be fatal. The forensic autopsy was shown to diagnose 25% more soft tissue injuries compared to PMCT, which is currently a shortcoming of PMCT (Sochor et al., 2008). Krentz and colleagues showed that the autopsy could diagnose

important soft tissue injury in 100% of cases (n = 35/35) compared to 77% (n = 27/35) when using PMCT (Krentz, et al., 2016).

Table 3.11 Degree of concordance between PMCT and autopsy for solid organ and soft tissue injury diagnosis

Injuries	Authors	PMCT findings (n =)	Autopsy findings (n =)	Degree of concordance
Organ parenchymal injuries	Krentz et al., 2016	49	65	75%
Soft tissue injury	Krentz et al., 2016	27	35	77%

Diagnostic rating	Colour
Autopsy superior	

As can be appreciated in Table 3.11, the study by Krenz et al., (2016), showed that the autopsy diagnosed more organ and soft tissue injury. Autopsy was able to diagnose 24 more organ parenchymal-related injuries in total, and eight more soft tissue injuries compared to PMCT. The findings of these two studies underscore the fact that PMCT is less sensitive for the diagnosis of soft tissue injuries, which is a current shortcoming of this modality.

3.4.13 Degree of concordance between PMCT and autopsy for gas collection diagnosis

Assessing PMCT images of the abdomen in deceased persons differs compared to assessing images of live subjects because of the putrefactive gaseous development, and changes seen post-mortem (Poulsen & Simonsen, 2007). Post-mortem gas begins within the first few hours after death which complicates establishing the origin thereof. Gas collections are often found in the cardiovascular system, and wound tracks (Thomsen et al., 2009). To interpret post-mortem gas correctly, it is important to know the usual anatomical distribution thereof on PMCT (Grabherr et al., 2017). Gas formation due to decomposition and putrefaction can be confusing and may lead to incorrect diagnosis if not fully understood (Bolliger et al., 2008; O'Donnell & Woodford, 2008). PMCT's ability to identify whether gas accumulation is traumatic or putrefactive assists in

determining the origins thereof and, ultimately, determining a cause of death (Higginbotham-Jones & Ward, 2014).

It remains challenging to detect the source of gas escape with PMCT, especially in the thoracic and abdominal cavity. Modern CT software enables tracking of the 3D path of pathological gas collections in soft tissues, which has advantages over autopsy (Heinemann et al., 2015). Diagnosing an air embolism during autopsy is even more difficult, as the heart must be punctured whilst submerged in water within the pericardial sac (Bolliger et al., 2008). If bubbles rise to the water surface, this confirms the presence of gas in the cardiac chamber. However, Bolliger et al. (2008) argue that the mere presence of gas in the cardiac chamber does not necessarily imply that this gas was embolised. Scholing and colleagues are of the view that diagnosis of gas embolism during autopsy is time consuming and is not performed on a routine basis in some forensic pathology centres, and therefore need frequent practice and education (Scholing et al., 2009). Establishing the presence of gas collections as part of routine forensic examinations, depends on case load of such centres. For example, submerging and puncturing the heart in water is routinely done in cases of penetrating chest trauma within forensic pathology centres in South Africa, especially those that serve as an academic training centre for registrar forensic pathologists (Martin, 2020).

3.4.14 Degree of concordance between PMCT and autopsy for vascular injury diagnosis

To date, little is known about the PMCT appearance of fatal haemorrhages. Some of the factors that can influence the interpretation of PMCT images are: the anatomy that can change dramatically in shape due to lack of blood circulation; blood elements that sediment out after the circulation ceases (a process known as lividity); and an intravascular clot that is seen as a normal change after death (O'Donnell & Woodford, 2008). In the absence of massive external bleeding, large volumes of blood in either the thoracic or abdominal cavity can be readily seen by CT imaging (Thali et al., 2003a). In cases of massive bleeding, the intense pallor of internal organs is a typical finding observed during autopsy, suggesting extensive haemorrhage, a diagnosis not identifiable on PMCT. This is currently a shortfall for PMCT (Thali et al., 2003a). PMCT is able to detect vessel injury owing to the presence of a surrounding haematoma, but specific vessel-related injury diagnosis cannot be made, unlike with the autopsy (Scholing et al., 2009).

Daly et al. (2013) have shown that, with PMCT, six cardiac intra-ventricular haemorrhages were diagnosed compared with only one with autopsy. However, in the same study, PMCT was inferior to autopsy for demonstrating large vessel laceration, as five were diagnosed with autopsy compared to one with PMCT (Daly et al., 2013). In another study by Sochor et al. (2008), four aortic lacerations were diagnosed at autopsy compared to two with PMCT. Le Blanc-Louvry et al. (2103) showed that PMCT was inferior for diagnosis of vascular rupture, as 18 were diagnosed at autopsy, compared to four with PMCT.

Table 3.12 Degree of concordance between PMCT and autopsy for vascular injury diagnosis

Injuries	Authors	PMCT findings (n =)	Autopsy findings (n =)	Degree of concordance
Large vessel lacerations	Daly et al., 2013	1	5	20%
Aortic laceration	Sochor et al., 2008	2	4	50%
Vascular rupture	Le Blanc-Louvry et al., 2013	4	18	22%

Diagnostic rating	Colour
Autopsy superior	

As can be appreciated in Table 3.12, in all three studies reviewed, autopsy diagnosed more vascular injuries. Table 3.12 further shows that overall, autopsy diagnosed 20 more vascular injuries compared to the PMCT. The above findings suggest that the forensic autopsy in these studies were shown to be better in diagnosing vascular injuries.

3.4.15 Degree of concordance between PMCT and autopsy for gunshot injury diagnosis

Both PMCT and autopsy are able to demonstrate the number and location of entrance wounds and direction of bullet tracks. For example, PMCT enables identification of bullet tracks through soft tissue; these tracks are often accompanied by linear areas of gas and metallic fragments along the path of the bullet. To this effect, PMCT can convey information with respect to the direction of the bullet and may inform the cause of death (Higginbotham-Jones & Ward, 2104). Autopsy can also determine the direction of the bullet, and its association with the cause of death

(Rainio et al., 2001). Makhlouf and colleagues (2013) showed that PMCT was able to diagnose 69% (n = 63/91) of penetrating entrance GSW's, which was equal to that observed at autopsy. The diagnosis of exit wounds, using PMCT within the same study, was inferior to autopsy. A total of 52% of exit wounds (n = 36/69) could be identified using both PMCT and autopsy. However, autopsy could identify a total of 45% additional exit wounds (n= 31/69) not identified with PMCT, underscoring autopsy's ability to identify exit wounds by physical inspection. In the same study, PMCT was able to demonstrate bullet tracks in 72% (n = 62) of wounds. However, PMCT is unable to link bullet tracks in victims who have been shot multiple times, which is a shortcoming (Makhlouf et al., 2013).

Table 3.13 Degree of concordance between PMCT and autopsy for gunshot injury diagnosis

Injuries	Authors	PMCT findings (n =)	Autopsy findings (n =)	Degree of concordance
Penetrating entrance wounds	Makhlouf et al., 2013	63	63	100%
Exit wounds	Makhlouf et al., 2013	36	36	100%
	Makhlouf et al., 2013	0	+31	Additional injuries identified
Wound tracks	Levy et al., 2006	68	78	87%

Diagnostic rating	Colour
Autopsy superior	
Equal concordance	

Table 3.13 indicates that, for the two studies reviewed, there was a perfect concordance between autopsy and PMCT for diagnosis of penetrating entrance wounds in 63 cases and exit wounds in 36 cases. However, autopsy was able to diagnose 31 additional exit wounds not diagnosed with PMCT. Autopsy was able to diagnose more wound tracks, having diagnosed 10 more, compared to PMCT.

The above sections have shown wide variation in the performance of the forensic autopsy and PMCT as described in scientific literature. A detailed explanation as to why the large variations

occur, falls outside the scope of this literature review. Whilst it is worth noting that the number of injuries listed in some studies were small, the presence thereof is totally depended on the manner of death and the number and type of injuries sustained by the subject. These injuries can never be predicted before a study and are not a reflection of poor study design or diagnoses. Injuries caused by hanging, throttling and strangulation often lead to soft tissue injuries of the neck which are poorly seen at PMCT. In the review of the literature, it was highlighted that the ventricular system of the brain is often disturbed during the autopsy and for this reason, intraventricular haemorrhages are often not diagnosed at the forensic autopsy. There are sometimes inherent nuances that make some injuries impossible to diagnose during PMCT or the forensic autopsy. For example, a subdural haematoma smaller than 3mm is difficult to see on PMCT imaging, but well seen during the forensic autopsy. Some injuries are more readily seen on PMCT and not during the forensic autopsy mostly because some anatomical areas are not routinely dissected. The above two reasons, in some scenarios, can explain why these injuries are poorly or not seen either at forensic autopsies or PMCT. This large variation described above must be seen within the context of the strengths and weaknesses of each examination, per injury type which is sometimes exacerbated by the number of injuries present. Chapter Seven will highlight some reasons why some injuries are not well seen with either the forensic autopsy or PMCT.

3.5 PMCT AS AN IMAGING MODALITY TO ESTABLISH THE CAUSE OF DEATH

The next section will discuss a review of the literature related to the third objective of the research study aimed at assessing whether PMCT can confidently establish the cause of death in fatally abused children. Even though most of the discussion will focus on PMCT findings compared to those for autopsy results in adults, only some inferences from the discussion can be made for children. These inferences are necessitated by the lack of peer-reviewed, comparative publications for paediatric populations and their different disease/injury profiles.

Establishing the cause of death of a deceased person is integral to forensic pathology. The manner of death can be due to natural or unnatural causes. The Regulations regarding the Rendering of Forensic Pathology Services define unnatural death as any death caused by physical or chemical influence, whether direct or indirect, or as a related complication; deaths which would normally be considered a result of natural causes, but which have been the result of an act of commission or omission; deaths which may be the result of criminal activity; any sudden

and unexpected or unexplained death; or where the cause of death is not apparent (National Health Act, No. 61 of 2003. Regulation, 2018, No. R.359). The manner of death is usually assessed by taking into consideration the scene findings, witness reports, external inspection of the body, and autopsy. The cause and mechanism of death are usually informed by a combination of the scene findings, as well as an external and internal examination (Ruder et al., 2011). Forensic pathology reports are therefore medico-legal documents of objective observations made during the post-mortem examination and may be used in a court of law (Adams, 2008).

Substantial progress has been made over the past two decades using cross sectional post-mortem imaging within forensic pathology. Even though PMCT has limitations, this modality can influence the diagnosis with regards to the manner and cause of death (Van Rijn & Leth, 2017). Across various studies, PMCT's agreement with the forensic autopsy to determine the cause of death is reported to range between 6 and 70%. This large variation can be ascribed to heterogeneity in study populations, methodological differences in executing research studies, as well differences in case mix, and definitions used to define cause of death (Ampanozi et al., 2017).

If PMCT is used to determine the cause of death, it should be able to confirm the following five concepts used in forensic autopsy, namely:

i) Atrium Mortis [which entails a] pathophysiological reconstruction and explanation of the cause of death.
ii) Relevant [recording of] forensic patho-morphologic findings in the bones, tissues and organs.
iii) Vital reactions elucidating the sequence of injury and death, by explaining whether an injury was received before or after death. This step is aimed at finding what happened to intact circulation (e.g. fatal haemorrhage, air and fat embolism, cutaneous emphysema, respiration e.g. aspiration). These findings are known as forensic vital reactions.
iv) Reconstruction of injuries with regards to force, biomechanics and dynamics.

v) Recapitulation and visualization of the atria mortis comprehensible to laymen and experts in a court of law, thereby allowing for objective evaluation of medico-legal

reports and just appreciation of a particular case (Thali et al., 2003a:1).

For this research study, only items i – iii above were investigated.

Leth and Thomsen (2013) found the agreement between PMCT and the forensic autopsy regarding the cause of death to be 66% (n = 425), including 14% (n = 91) in which the cause of death could not be determined by either examination. In cases where the cause of death could be established by PMCT, the agreement between PMCT and autopsy was even higher, and was determined at 94%. These figures excluded cases where the cause of death was established by toxicology. This is a significant finding, highlighting the high degree of concordance between PMCT and autopsy for determining the cause of death in these studies (Leth & Thomsen, 2013).

In addition, Leth and Thomsen (2013) found that the degree of concordance for determining the cause of death between autopsy and PMCT was as high as 85% when victims were involved in accidents. This was thought to be due to PMCT's ability to detect fractures and associated injuries with relative ease. The degree of concordance was therefore higher for injury deaths and lowest for natural deaths. This is a significant indicator which strengthens the original rationale of the research study covered by this thesis, as it implies that this focused comparative analysis of PMCT and autopsy findings in the fatal abuse setting may yield useful results, and possibly yield an even higher degree of concordance. In Chapter One, reference was made to the researcher's conjecture, at conception of this research study that fatally abused children will presumably have a large number of skeletal and associated traumatic injuries, rendering this comparative study appropriate for establishing the sensitivity of PMCT for determining the cause of death in unnatural deaths.

In another large study, Kasahara et al. (2012) (n = 339) was able to diagnose the cause of death with PMCT amongst only 7% of victims who died due to unnatural causes. This is a relatively low degree of concordance, compared to that of Leth and Thomsen (2013). In the same study by Kasahara and colleagues, diagnosing the cause of death with PMCT for trauma-related deaths (as a sub-category of unnatural deaths) was higher at 16% (n = 19/118) (Kasahara et al., 2012). These variations are evidence of the current inconsistencies in the degree of concordance (agreement) between PMCT and autopsy for determining the cause of death.

Yen et al. (2007) found that PMCT was able to correctly assign the cause of death for head trauma in 79% (n = 19/24) of cases in which brain injury was the primary cause of death. In a recent study,

Ampanozi et al. (2017) found that PMCT was able to assign the cause of death in 82% (n = 83/101) of cases, compared to the forensic autopsy. In their study, PMCT had a sensitivity and specificity of 82% and 97% respectively. PMCT and autopsy were unable to assign the cause of death in 8% (n = 8/101) of cases. Of these eight cases, histological and toxicological analysis was able to assign the cause of death in seven and one case respectively. This finding underscores the value of additional supplementary investigations being available during autopsy for establishing the cause of death.

PMCT is less accurate for determining the cause of death in natural diseases. In a large study, Roberts et al. (2012) found that PMCT had a 32% (n = 58) discrepancy rate with the autopsy for determining the cause of death. In their study, PMCT incorrectly assigned the cause of death in 32% of cases. In their study, PMCT was unable to correctly assign the cause of death for natural diseases such as coronary heart disease, pulmonary embolism, bronchopneumonia and intestinal infarction. Van Rijn et al. (2017) showed that PMCT was able to assign the cause of death in 13% (n = 7/54) of children who died of natural causes, compared with those diagnosed at autopsy. According to these authors, based on the CT findings, an autopsy of some children could have been avoided. The low sensitivity of PMCT in their study could have been ascribed to the heterogenous case mix (Speelman et al., 2022). For example, of the seven children for whom the cause of death could be determined by PMCT, two died because of cardiovascular disease, one because of infective disease, and four due to gastrointestinal tract disease (Van Rijn et al., 2017). The findings of their study also underscored PMCT's low diagnostic yield in determining the cause of death in natural deaths.

Kasahara et al. (2012) have shown that no cause of death could be assigned with PMCT for acute myocardial infarction in 88% (n = 15/17) of cases; 0% (0/8) for intracranial haemorrhage and 0% (n = 0/6) of pulmonary thrombo-embolism; and 0% (n = 0/5) for pneumonia. Proisy et al. (2013) found that PMCT had an 83% concordance (n = 15/18) with the autopsy for determining the cause of death. Autopsy was unable to assign the cause of death in 61,7% (n = 29/47) of cases, whilst PMCT could not assign the cause of death in 27/29 cases found undeterminable by autopsy (Proisy et al., 2013).

Iwase et al. (2010) have shown that the cause of death could be established using PMCT in 16% (n = 13/80) of cases, compared to the autopsy. According to the author's reading of the results of the study by Iwase and colleagues, the number of cases in which PMCT could establish the cause of death was as follows: brain haemorrhage (n = 4); SDH (n = 3); cardiac tamponade caused by

cardiac rupture or ascending aortic rupture (n = 3); SDH plus thoracic aortic rupture (n = 1); needle as a foreign object reaching the heart (n = 1); and tension pneumothorax (n = 1) (Iwase et al., 2010).

Kasahara et al. (2012) argued that PMCT is unable to diagnose the cause of death related to vital reactions such as tiny haemorrhages inside a brain contusion, spinal cord injury, or vascular injuries. In their study, PMCT was unable to assign the cause of death for asphyxiation in 82% (n = 31/38), burns in 100% (n = 35/35), hypothermia in 100% (n = 7/7), and causes of death as a result of medical negligence in 40% (n = 4/10) of cases. Determining the cause of death for asphyxiation caused by strangulation, hanging, or throttling with PMCT, is often hampered due to an absence of cervical muscle injuries, or lymph node haemorrhage (Kasahara et al., 2012).

As can be seen from this discussion, the degree of concordance between PMCT varies significantly amongst studies, even for the same injury classification. It should be noted that the disease profile between adults and children can vary. For example, children do not die of coronary artery disease as with many adults. Therefore, some references to the performance of PMCT in adults, for example cardiovascular disease, must be seen within context and may differ in children and vice versa. Scholing and colleagues concluded, after conducting a systematic review on 15 publications, that PMCT provided inconsistent evidence as a reliable alternative to autopsy for determining the cause of death (Scholing et al., 2009). The large variation was ascribed to these studies employing different study protocols and research methods, which hampered interpretation and direct comparisons between the results.

3.6 PMCT AS REPLACEMENT FOR THE FORENSIC AUTOPSY

This section will discuss a review of the literature related to the fourth research study objective aimed at determining whether certain forensic cases can be confidently selected to undergo PMCT in the absence of the forensic autopsy. Most of this discussion will be based on a review of the literature in adult populations due to the small number of available peer-reviewed publications involving children. However, as for objective three, inferences from the findings contained in these discussions may also be relevant for children.

For PMCT to equal the forensic autopsy, it must be able to answer all the questions related to the cause of death, and to the quantity and severity of injuries. During court cases, forensic imaging

must sustain a technically excellent image quality to enable the attorney representing the defence or victim, or for the court, to verify, confirm or exclude inquiries. PMCT must therefore be able to exhibit the same level of sensitivity to the forensic autopsy in determining a plausible cause of death (Flach et al., 2014b).

Leth and Thomsen (2013) argued that, if a day-to-day toxicology service is available, PMCT can confidently replace the forensic autopsy in 29% of all autopsies; and, if a toxicology service is not readily available, PMCT can replace autopsy in 15% of cases. Roberts and colleagues found that PMCT may replace the autopsy in about 34% of cases, depending on the level of confidence in the radiology findings obtained from PMCT (Roberts et al., 2012). Even though PMCT can assign the cause of death in some cases, this examination does not evaluate toxicological and biochemical causes of death and hence is not yet ready to replace autopsy overall (Roberts et al., 2012). Instead, a multi-disciplinary approach is recommended, where the pathologist and radiologist decide the best and most suitable examination, given the clinical or case history, for example, PMCT with a limited autopsy, including a physical examination, to screen for superficial signs of injury not diagnosed by imaging (Roberts et al., 2012).

In their study in 2013, Noda and colleagues showed that, in eight children in which the clinical diagnosis demonstrated an unknown cause of death, three cases of NAI could be identified with PMCT (Noda et al., 2013). Some experts believe that PMCT should be used in all cases of natural and unnatural deaths, as this modality has uncovered covert abuse-related injuries which cannot be diagnosed by surface inspection and history taking alone (Noda et al., 2013). PMCT will, according to Noda et al. (2013), be of significant help in diagnosing abuse in cases where parents refuse a conventional autopsy.

At the Victorian Institute of Forensic Medicine in Melbourne, Australia, PMCT is used as a routine adjunct to the forensic autopsy. If PMCT reveals a clear cause of death, such as a ruptured aortic aneurysm, and the circumstances of death are not deemed suspicious, recommendations are made to the coroner that an autopsy is not required, given the existing indication of a clear cause of death (O'Donnell, 2010). If the cause of death is not obvious on circumstantial grounds, but significant medical co-morbidities and non-suspicious circumstances are evident, and no clear cause of death findings emerge from PMCT, an autopsy might not be performed, provided this is accepted by family members and provided that the coroner is of the view that death was most probably the result of natural causes (O'Donnell, 2010). This practice is evidence that PMCT imaging has now become integral to forensic examinations in some forensic medical centres.

Scholing et al. (2009) are of the view that, due to inconsistent concordance between PMCT results and autopsy, PMCT is not yet ready to replace the autopsy. According to these authors, PMCT should be used as an adjunct to the autopsy, since it can diagnose additional injuries which are sometimes difficult to detect and are even overlooked at autopsy. The rapid development [and application] of post-mortem imaging is therefore set to continue (Van Rijn & Leth, 2017). Future research should explore the level of agreement of combining post-mortem investigations that best suit the forensic case in question. Van Rijn and Leth (2017) further postulate that, in future, difficult cases might undergo invasive autopsy following an enhanced algorithm with extensive histological and genetic testing, whereas some cases might satisfactorily be investigated with post-mortem cross-sectional imaging only (Van Rijn & Leth, 2017). Clearly, more research is needed to validate the agreement of PMCT with the forensic autopsy in establishing the cause of death before a clear case can be made that this imaging modality is ready to replace the autopsy. Further development of post-mortem imaging and research studies must be based on careful consideration of the current shortfalls of PMCT in determining the cause of death (Roberts et al., 2012). Another aspect to be considered is to ensure that PMCT research studies examine the same clinical case mixes which are routinely managed in forensic institutions. Similarly, larger studies need to be conducted to incorporate all anatomical-pathological or injury scenarios, as well as appropriate imaging protocols, to improve diagnosis for those cases where PMCT is currently showing a shortfall.

3.7 POST-MORTEM COMPUTED TOMOGRAPHY ANGIOGRAPHY

Whole-body PMCTA is a promising new development that shows potential to improve vascular, and soft tissue imaging, beyond what is currently possible with unenhanced PMCT. PMCTA has been conducted at some forensic institutions, even though wide use thereof is not yet current practice (Grabherr et al., 2014). Due to the lack of circulation in deceased persons, the radiological technique is different, and slightly complex compared to clinical practice (Ross et al., 2014). The PMCTA procedure is further time consuming, which hampers wide clinical application thereof in forensic pathology (Flach et al., 2014b). Despite the limited clinical uptake, PMCTA has been the focus of intense research. Most recent research projects to date were aimed at improving techniques and image quality (Grabherr et al., 2014).

PMCTA involves the cannulation of both the femoral artery and vein which get connected to a modified heart lung machine, after which a larger than usual volume of contrast media is

administered whilst maintaining pressure and monitoring flow (Haakma et al., 2017). The volume of contrast media administered for paediatric cases should be adapted, based on the habitus of the child (Flach et al., 2014b).

The main clinical indication for PMCTA is to assess vascular disease in cases of natural death, vascular injuries following trauma or post medical interventions (Grabherr et al., 2014). PMCTA allows for precise vascular and parenchymal localisation of pathologies and can add crucial diagnostic value to forensic pathology (Christine et al., 2013; Flach et al., 2014b). The greatest strength of this technique is to detect sources of haemorrhage, vascular stenosis and occlusions. The investigation of occlusions still requires further research, as in-vivo occlusions cannot currently be differentiated from occlusions with certainty due to post-mortem changes. PMCTA should only be done in cases where vascular lesions are expected to be the cause of death (Grabherr et al., 2014).

Current opinion suggests that, to enjoy the full benefit of PMCTA, a three-phase protocol should be employed which includes an initial unenhanced scan, arterial, venous, and dynamic phases (Grabherr et al., 2011). Multi-phase PMCTA has been shown to have greater sensitivity for soft tissue findings, such as small haemorrhages in the subcutaneous fatty tissue or muscular tissue (Christine et al., 2013).

3.7.1 Advantages of Post-mortem Computed Tomography Angiography

One of the main advantages of PMCTA is its ability to detect sources of haemorrhages, and the location of bleeding sources, because of the extravasation of contrast media. Even a small aneurysm in the Circle of Willis can now be diagnosed using PMCTA (Christine et al., 2013; Ross et al., 2014). PMCTA is also able to demonstrate the coronary arteries in situ, as well as fatal abnormalities such as severe stricture of a coronary artery, and depiction of the entire thoracic and abdominal aorta, including branches such as renal, celiac trunk and mesenteric arteries (Ross et al., 2014). PMCTA does not lead to motion artefacts during image acquisition due to lack of cardiac movement or respiration (Ross et al., 2014). PMCTA allows the diagnosis of vascular lesions without the disruption of anatomical structures evident during a routine forensic autopsy, as well as difficult-to-dissect areas such as the cranio-cervical junction and the small pelvis (Ross et al., 2014).

3.7.2 Disadvantages of Post-mortem Computed Tomography Angiography

One inherent limitation of routine PMCTA is its limited capability in visualising the entire vascular system and soft tissue structures. If the entire vascular system is not opacified during angiography, it may lead to false positive diagnoses, such as occlusion of vessels which were, in fact, not opacified with contrast media in the periphery (Grabherr et al., 2011). This procedure is less able to distinguish between antemortem or post-mortem thromboembolism. A study by Ross and colleagues showed that post-mortem clotting appears mostly in the right side of the heart, the pulmonary trunk and the great vessels, and more commonly in the venous vessels compared to the arterial vessels (Ross et al., 2014). The radiological diagnosis of pulmonary thrombo-embolism should be supported by biopsy findings of the clotted material, demonstrating ante-mortem thrombus (Ross et al., 2014). PMCTA was shown to have limitations for detection of non-occlusive, small arteriosclerotic lesions caused by fat deposits on the vascular wall, as well as small haemorrhages in arteriosclerotic lesions that do not reduce the vascular lumen of the coronary arteries. PMCTA may, in some scenarios, also result in a false positive diagnosis of pulmonary embolism caused by large post-mortem clots (Grabherr et al., 2011). In one study, PMCTA was unable to demonstrate bleeding into the vascular wall or ruptured atherosclerotic plaques that were too small to diagnose on PMCTA, but which were well seen at autopsy. A major shortcoming of PMCTA is its inability to visualise parenchymal haemorrhagic findings, which are well seen during the forensic autopsy (Christine et al., 2013).

3.8 THE NEED FOR PMCT IMAGING PROTOCOL OPTIMISATION

As alluded to in Section 1.2, PMCT has seen a growing application in forensic pathology which is set to continue in the near future. There is thus a strong need for PMCT protocol optimisation for mostly two reasons namely; reducing dose to the deceased and staff, as well as ensuring good image quality. In the section that follows, various references are made to CT as it relates to clinical imaging, however, the same arguments hold for PMCT. In live persons, the Image Gently campaign, promoted by a coalition of health care and professional organisations, aimed to raise awareness amongst health care professionals to adjust the radiation dose when conducting imaging in children. This campaign is dedicated to promote safe high quality paediatric imaging worldwide, including CT or PMCT (Image Gently, 2021). A similar programme exists for adults entitled *“Image Wisely”* which has the objective of lowering the amount of radiation dose employed

in justified medical imaging examinations and avoiding unnecessary dose-based imaging procedures (Image Wisely, 2021).

3.8.1 Dose reduction

There is widely held consensus that CT scans contribute to a large portion of the overall radiation exposure delivered during medical diagnostic procedures and may be 5-20% higher than projection radiography (United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR, Annex A; 2019). Estimates suggest that CT contributes 62% of all radiation doses from medical examinations (Rajiah, et al., 2020). There is thus a need to reduce radiation dose to live including deceased persons. If the dose is not kept to a minimum there is also an indirect risk to other health care professionals such as radiographers themselves and those accompanying patients within the CT scanner room. Radiation dose to patients undergoing CT examinations are influenced by a range of factors, which will be discussed in the sections that follow.

It is widely accepted practice that the dose employed in CT examinations in living patients should adhere to the as low as reasonably achievable (ALARA) principle (Parakh, et al., 2016). Even though there is no concern about radiation over exposure amongst the deceased undergoing PMCT examinations, it is the author's firm view that dose should, from an ethical perspective, also be kept to a minimum for this group and thus adhere to the same ALARA principle.

Justification, limitation and optimisation are three fundamental principles advocated by the Image Gently campaign that can be applied to reduce dose to children when conducting CT examinations (Image Gently, 2021). The benefit of subjecting patients to radiation as part of medical imaging examinations, should always outweigh the risk, underscoring the need to optimize CT protocols (Donnelly et al., 2001). Justification means the study should only be performed when clinically justified (or the benefit of undergoing the examination outweighs the risk to radiation exposure) (Nagayama, et al., 2018). Once justification has been met, appropriate adjustments to the scanning protocol (techniques and imaging exposure) must be made to ensure that the dose meets the ALARA standard (Nagayama, et al., 2018). Optimistion in the context of clinical or PMCT requires the images acquired to be of diagnostic quality for interpretation but acquired at exposure levels that reduce dose related risks to the patient and public (Strauss et al., 2010). CT or PMCT protocols should therefore always be adjusted based on the clinical question at hand (Strauss et al., 2010).

3.8.2 PMCT protocols

CT/PMCT imaging protocols serve as a guide for operators on how to conduct the best possible examination. This allows users to adhere to institutional guidelines and optimise the imaging request. A study amongst members of the European Society of Paediatric Radiology (ESPR) has shown that about 58% (n = 14/24) of forensic institutions, where paediatric post-mortem imaging studies are conducted, have a PMCT imaging protocol in place. However, one of the main outcomes of this study, showed that the development of an imaging protocol was an area that needed further development, especially to assist departments where no such imaging protocols exist (Arthurs et al., 2014). Pursuant on the latter, a consensus based paediatric PMCT imaging protocol was developed by the ESPR and the International Society of Forensic Radiology and Imaging (ISFRI). This protocol was published in 2019 and consists of 62 CT protocol parameters, covering all areas of paediatric PMCT imaging (Shelmerdine, et al., 2019). See Table 3.14 below.

Table 3.14 ESPR-ISFRI recommended PMCT imaging parameters for paediatrics

Imaging parameters*	**ESPR-ISFRI protocol[a]**	**Actual study[b]**
Coverage	Whole body (vertex to extremities)	Whole body (vertex to extremities)
kV	120	120
mAs	200 - 299	250 – 400*
Dose modulation	Off	On
Matrix	512 x 512	512 x 512
Scan field of view	Adjusted to patient's size	Scanner defined based on anatomical area scanned
Pitch	0.5 – 0.8	0.67 – 1.172
Tube rotation time	1	0.75
Slice thickness (mm) (detector collimation)	0.5 -1.0 mm	1 – 2 mm
Imaging approach	**ESPR-ISFRI protocol**	**Actual study**
Image interpretation	Radiologist	Paediatric radiologists
Image acquisition	Radiographer	Radiographer
Energy source	Single-source only	Single-source only
Image reconstruction (kernel/filter algorithm)	Soft tissue and bone (whole body) Brain (brain coverage) Lung (thoracic coverage)	Brain, lung, abdomen, vendor specific use of kernels
Image reformats	Coronal Sagittal Volume rendering	Coronal Sagittal Volume rendering

[a]ESPR-ISFRI PMCT imaging protocol developed by Shelmerdine et al., (2019)
[b] PMCT imaging protocol used in actual study
kV= kilovoltage
mAs = milliampere-seconds
*mAs in this study was influenced by the size of the subject

The following parameters all have an impact on dose; tube potential (measured in kilovolts), tube current (measured in milliampere), pitch, weighted CT dose index, volume CT dose index, dose length product and effective dose (Goske et al., 2011; Woo Goo, 2012).

3.8.3 Imaging techniques that support CT/PMCT protocol optimisation

There are various methods that can be employed to reduce dose to deceased persons when undergoing PMCT examinations but maintain image quality. The section that follows describe some of the important options.

3.8.3.1 Patient Positioning

Proper positioning of the patient within the scanner field of view is critical if proper milliamperage is to be obtained when using automatic tube current modulation (ATCM). Proper centering ensures that the high-intensity X-rays released by the beam, pass through the isocentre of the bowtie filter and therefore traverse the thicker central part of the human body, resulting in lesser dose to the thinner portions of the body (Kaza et al., 2014). Patients that are not positioned in the centre of the gantry (or field of view) (FOV) are therefore subjected to a higher dose to especially the peripheral parts of the body.

3.8.3.2 Scanning techniques

The advantages of axial or helical scanning in paediatrics needs to be carefully considered based on the clinical question. Helically acquired CTs enable multiplanar reconstruction of the images (Strauss et al., 2010). Use of a higher pitch reduces dose as less anatomy is subjected to radiation during helical movement of the X-ray beam, provided that other exposure parameters are not altered during the scan (Strauss et al., 2010). In CT, radiation risk is influenced by both the radiation dose the patient receives as well as the volume of the patient's body that is scanned. Limiting the surview and length of the CT sequences reduces dose (Strauss et al., 2010) and increases tube life. Even though some forensic centres do limited PMCT scans for some clinical cases, the majority of PMCT examinations employ whole-body scans (Rajiah, et al., 2020). Surviews (topograms) should ideally be acquired with a postero-anterior projection to reduce dose

to radiosensitive organs such as the male gonads, breast, thyroid and lens of the eye (Strauss et al., 2010).

3.8.3.3 Choosing exposure factors

Selection of exposure factors such as kilo-voltage (kV) and milli-ampere (mA) has a direct effect on patient dose and image quality. Increasing the kV increases the X-ray beam energy, resulting in improved penetrating power of the X-ray beam and reduced image noise (Strauss et al., 2010; Kaza et al., 2014). However, an increase in kV has an exponential effect on radiation dose. Increasing the kV from 120 to 140, with a constant mA, increase the effective dose by approximately 50%, unlike tube current that has a linear relationship to radiation dose (Strauss et al., 2010; Kaza et al., 2014). However, the tube voltage can be lowered for PMCTA especially if visualisation of contrast enhanced blood vessels or organs are the primary aim. Lowering the kV from 120 – 80 kV will result in the effective energy of the X-ray beam to be closer to the k-edge of iodine and will increase both image contrast and the contrast to noise ratio (Kaza et al., 2014). However, lowering of the kV in large patients results in an increase of image noise due to lowered X-ray beam penetration (Kaza et al., 2014).

3.8.3.4 Dose reduction strategies

Dose reduction strategies as a process of dose optimiation, should never be at the costs of image quality (Zhou et al., 2017). Poor image quality may obscure abnormalities and thus influence the ability to derive at a proper diagnosis. Dose saving protocols that can be used in CT are ATCM (such as z-axis dose modulation or x-y dose modulation), dynamic collimation and dose efficient detectors (Parakh et al., 2016). The z-axis dose modulation option uses the surview attenuation profile to select an appropriate mA for the complete CT sequence. The x-y dose modulation adapts the mA according to the patient x-y dimension (Kaza et al., 2014). The x-y dose modulation allows thinner portions of the body to receive lower exposure which translates into lower radiation dose for that anatomical area and vice versa, whilst still maintaining the same image noise. When using ATCM, some CT equipment enable the user to select the preferred image quality for each sequence. In other words, preferred image quality can be based on a predetermined reference

image or image noise estimate. The reference image is used to determine the preferred image quality after which the mA is adjusted based on the patient size and the resultant image will have an image quality closest to the reference image. Various vendors use different terms for the same functionality (Kaza, et al., 2014). As can be noted in Table 3.14, the ESPR-ISFRI guidelines recommends that ATCM be deselected when conducting PMCT examinations on children.

3.8.4 CT image quality

CT image quality is determined by various factors namely image noise, image contrast resolution, spatial resolution, artefacts, kernel used, slice thickness, display FOV and iterative reconstruction options (Woo Goo, 2012; Christianson, et al., 2014). Thinner CT slices result in higher dose to patients. For example, 2.5 mm slices can result in double the dose compared to 5 mm slices (Maldjian & Goldman, 2012). It is thus essential that CT images are acquired with thicker slices, except where subtle skeletal fractures are suspected, as thin slices will provide higher image resolution.

CT images acquired with high exposure factors will result in improved image quality but result in a higher radiation dose. Conversely, if exposure factors selected are suboptimal, noise will increase on subsequent CT images. Noise in CT is influenced by the number of X-ray photons falling on the detectors. If the number of X-ray photons falling onto the detector are too few, higher noise will be visible on such an image. Noise is the most important contributor to poor image quality (Zarb et al., 2010). Excessive noise interferes with image quality and subsequent image interpretation (Zarb et al., 2010).

3.8.5 CT artefacts

Artefacts can have a significant effect on the image quality up to a point that the CT images can be deemed undiagnostic (Barret & Keat, 2004). To optimise image quality, it is important to understand why artefacts occur, and how some can be prevented or suppressed. There are many factors that can result in image artefacts in CT. These common factors can be divided into four categories:

i) physics-based artefacts caused by errors in the physics processes integral in image acquisition,
ii) patient-based such as patient movement (usually not a factor in PMCT due to subject being deceased) or artefacts caused by metal objects within or around the clothing worn by live patients or the deceased, foreign objects such as retained bullets, needles and other in-situ medical devices,
iii) scanner-based artefacts caused by errors in scanner function, and
iv) image-reconstruction based artefacts (Barret & Keat, 2004).

The CT image-reconstruction based artefacts can be sub-divided into four groups namely:

i) streak artefacts (caused by inconsistence in a single measurement),
ii) shading (caused by groups of detectors deviating gradually from the true measurement),
iii) rings (caused by errors in individual detector calibration) and
iv) distortion (caused by errors in helical reconstruction) (Barret & Keat, 2004).

In-depth discussion of the causes of these artefacts falls outside the scope of this thesis. However, considering that deceased persons may present with many metal objects inside or within their clothing, radiographers involved in PMCT scanning, need to be familiar with the causes of such artefacts and how to minimise or reduce the effect thereof on the resultant images, as image artefacts may compromise image interpretation.

3.8.6 Iterative image reconstruction

Iterative image reconstruction (IIR) is a relatively new development in CT post processing functions which can be used to improve image quality. IIR allows the user to selectively identify and reduce image noise while maintaining image contrast and resolution (Kaza et al., 2014). IIR has two major advantages namely improving image quality without increasing the radiation dose and maintaining image quality at a lower dose (Kaza et al., 2014). The iterative process can be performed in the image domain, raw data domain or both. With statistical IIR options, variations in the projection data contributing to the image noise are identified and removed to produce an image with reduced noise after image acquisition (Kaza et al., 2014). In addition to reducing noise, IIR

comes at a cost. IIR can lead to reduced sharpness of the image, reduced sharpness of organ margins, smooth appearance of solid organs and reduced spatial resolution (Kaza et al., 2014). It is recommended that a moderate level of iteration is selected e.g. between 30-50% in order not to adversely affect image quality (Kaza et al., 2014). The use of IIR depends on the clinical request and cannot simply be applied in an attempt to reduce noise (Kaza et al., 2014).

One study has shown that CT protocol homogenisation and optimisation, with an iterative process that maintains image quality, resulted in a dose saving of between 23-58% for a range of CT sequences such as CT abdomen and pelvis (23%), renal calculus protocol (27%), CT chest for pulmonary embolism (38%), CT routine chest (44%) and CT bony pelvis (58%) (Rajiah, et al., 2020).

In the context of CT protocols optimisation, a close collaboration between the radiologists, forensic pathologist and radiographer should be maintained in order to realise the full potential of the various methods available to optimise CT protocols and examinations (Kaza et al., 2014).

3.8.7 The Hounsfield Unit

The Hounsfield unit (Hu) does not affect PMCT protocol optimisation but is an important tool to use in PMCT image interpretation. The Hu is a measurement of the attenuation coefficient of tissue when subjected to the X-ray beam during CT scanning (Bushong, 2013). The Hu can assume any value between -1,000 and + 3,000 and is useful for determining the density of tissue (or abnormalities). For example, a Hu of close to -1,000 will corresponds to air whereas a Hu of close to +3,000 correspond with bone (Bushong, 2013). CT readers (radiologists, forensic pathologists, clinicians and radiographers) can thus use the Hu, obtainable on all CT scanners, to determine the density of structures and differentiate the type of abnormalities present on CT images (Bushong, 2013). Knowledge of the use of Hu serves to improve CT/PMCT imaging interpretation which can play a role in respective patient/subject diagnosis.

3.9 CHAPTER SUMMARY

This chapter gives a historical overview of post-mortem imaging. It also highlights the variation in the degree of concordance between autopsy and PMCT for a range of injuries. Section 3.5 above

emphasised that this review dealt mostly with PMCT findings in adults and that there is a difference in the disease and injury profiles of children and adults. This is therefore a significant limitation of this review (exacerbated by lack of post-mortem imaging studies in children) and results discussed here for adults, might not, in all scenarios, be generalisable to children. This review highlighted that skeletal injuries had a higher diagnostic yield using PMCT, but a lower diagnostic yield compared to the autopsy for soft tissue, organ and parenchymal injuries. This discussion demonstrated that, even though the autopsy is considered the gold standard in determining the cause of death, some cases are found to be undetermined by autopsy. Similarly, PMCT was shown to have varied degrees of concordance relative to the autopsy for establishing the cause of death. The literature reviewed, and available evidence, suggest that PMCT is not yet able to replace the autopsy, mostly due to its weakness in establishing the cause of death in natural disease and surface injuries.

This chapter ended with a discussion on the need to optimise PMCT imaging protocols and the techniques that can be employed to enable this. Dose saving protocols should, in the author's opinion, and from an ethical perspective also be applied to the deceased. An understanding of these concepts will enable dose reduction and improve image quality, which are essential tools to use when conducting PMCT examinations. The next chapter describes the research design and methodology related to the research study, as well the ethical principles considered for this study.

CHAPTER FOUR

RESEARCH DESIGN AND METHODOLOGY

4.1 CHAPTER INTRODUCTION

This chapter describes the research design and methodology employed during the execution of this research study. The chapter starts with a brief overview of the functions of the Forensic Pathology Service (FPS) and its relationship with the South African criminal justice system. The following topics are also discussed namely subject selection (based on the inclusion and exclusion criteria); care of the research subjects before, during and after the PMCT image acquisition; the PMCT protocols and imaging parameters employed; and management and reporting of the PMCT images. Furthermore, the general principles applied, important aspects considered when conducting forensic autopsies in children, and the composition of a formal forensic pathology report, are also described. The chapter also describes how the data were prepared for analysis which includes an anatomical-injury categorisation, with the International Classification of Disease 10 (ICD 10) codification applied, and the steps taken to ensure internal validity of recorded data. The chapter also briefly explains the principles of consensus reading in diagnostic imaging studies, the advantages and disadvantages thereof, and the method used for data analysis for this study. The chapter ends with, firstly, a discussion of the ethical approval process followed; reasons for waiving of informed consent; the guiding ethical principles applied during execution of this study; and a brief overview of radiation dose in the deceased.

4.2 RESEARCH SITE 1: SALT RIVER FORENSIC PATHOLOGY SERVICES

Thirty bodies were recruited from the Salt River Forensic Pathology Services[3] (SRFPS). Children with a suspected history of suspected fatal child abuse or sudden unexplained deaths are, depending on their geographical location within Cape Town, routinely admitted to the SRFPS (Speelman, et al., 2022). As explained in Chapter One, the Forensic Pathology Services is mandated by the National Health Act (No. 61 of 2003) (South Africa, 2003b). The SRFPS is a

[3] Please note that permission has been granted by the SRFPS to reveal the name of this research site in this thesis.

branch of the Directorate of the Forensic Pathology Service of the Western Cape Government (WCG) located within the Western Cape Province, South Africa.

The SRFPS is mandated to investigate all unnatural deaths using forensic autopsies and post-mortem examinations. Services rendered by this facility include, inter alia, death scene investigations, identification of deceased persons, evidence collection, and provision of testimony in court cases and judicial reports (National Forensic Pathology Service Committee, 2011). Additional services conducted by the SRFPS include blood alcohol concentration assessment and toxicology which are referred to the Forensic Chemistry Laboratory (managed by the National Department of Health). In addition, the SRFPS conducts DNA analyses which are processed at the Forensic Sciences Laboratory (which is managed by the SAPS). The Forensic Sciences Laboratory conducts a host of forensic laboratory services, especially examination of physical exhibits, the results of which are mostly used to solve crimes committed (SAPS, 2020). In many respects, the SRFPS works closely with the criminal justice system which include the SAPS, the National Prosecuting Authority, and the Department of Justice (South Africa. Department of Health, 2020); and it provides scientific evidence used in solving criminal investigations. The SRFPS is one of two large forensic pathology institutions within Cape Town and has a dual function, namely rendering services to the WCG, as explained earlier in this section, as well as serving as a training facility for forensic pathology registrars undergoing training within the Faculty of Health Sciences, University of Cape Town (UCT). PMCT was not routinely used as a supplementary examination to the forensic autopsy and ethics permission was required to conduct these imaging studies. This aspect is discussed under Section 4.22 of this Chapter.

4.3 RESEARCH SITE 2: RADIOLOGY IMAGING PRACTICE

The SRFPS had no CT scanner installed so all PMCT examinations were conducted at a private radiology practice. The subjects were transported to the radiology practice in a mortuary vehicle. All Forensic Pathology Officers (FPOs) who were responsible for transporting the bodies underwent a training session regarding the manner and route to be used for transfer of the bodies to the radiology practice. The FPOs received an explanation of the function of, and safety precautions applicable to the CT scanner, including transfer of the body onto and off the scanner bed. Upon arrival of the body at the hospital, the researcher accompanied all FPOs to the radiology

site and back to the FPS vehicle. This research study was therefore conducted with close cooperation between the researcher, the SRFPS and the radiology practice concerned.

4.4 STUDY POPULATION

The study took place in Cape Town, the second largest city in South Africa, with an estimated population of 3,7 million residents (South Africa. Department of Statistics, 2021). This city consists of large urban and peri-urban areas with many formal and informal dwellings.

There are eight health districts located within the City of Cape Town's municipal boundaries. The SRFPS serves the Western Metro, as can be appreciated from Figure 4.1. This facility admits both adults and children who succumbed to unnatural deaths caused by violence, homicide, suicide, accidents (such as drowning or dog bites) and neonatal or foetus abandonment. Other cases admitted involve one or more of these: deaths following local or general anaesthesia (following general or dental surgery); sudden, unexplained deaths in adults or children (e.g., SUDI/SIDS also known as 'cot death'); and death due to neglect by medical or care professions (National Forensic Pathology Service Committee, 2011; South Africa. Department of Health, 2020). During the study period, 2016-2018, this facility admitted 3,649, 3,879 and 4,037 persons respectively per annum (Martin, 2021)[4]. Given that children are regularly admitted to this facility for a variety of reasons, it was easy to draw a suitable sample from this population. Children were selected and enrolled in cases where the scene findings were highly suggestive of suspected child abuse, sudden or unexplained deaths, including the five subcategories listed in Section 1.10 of Chapter One.

[4] Martin, L.J. 2021. Personal communication. Annual admissions, 26 Jan. 2021. Professor and Head of Division, Forensic Medicine, Faculty of Health Sciences, University of Cape Town, Cape Town, South Africa. (According to the institution's referencing guidelines, personal communication is listed in-text but not in the list of references).

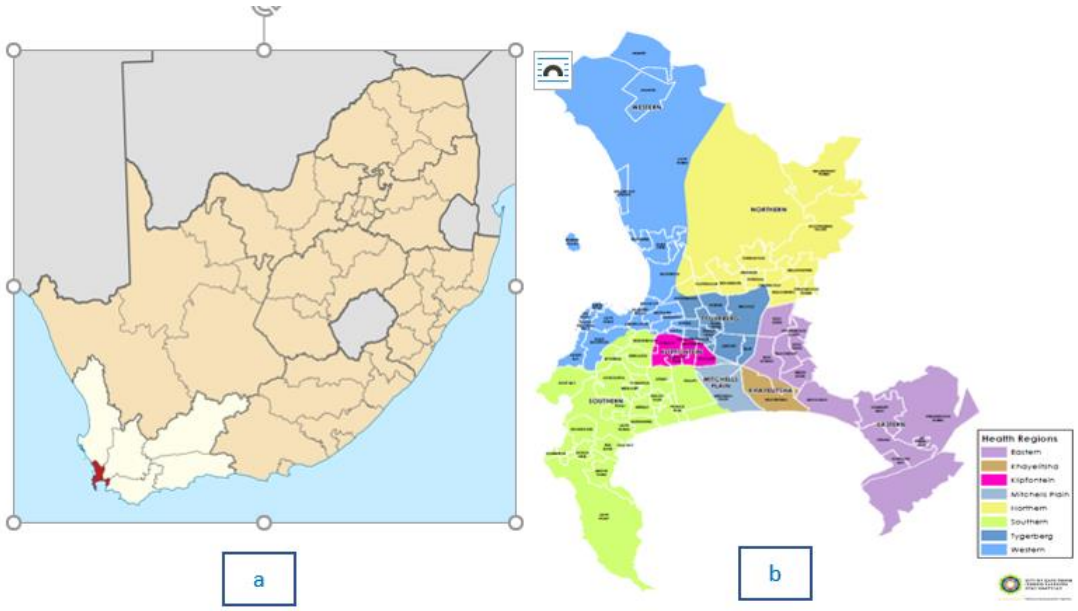


Figure 4.1 (a) Map showing location of City of Cape Town (red area) in South Africa (Wikimedia Commons, 2021); and (b) Health districts of City of Cape Town, showing location of Metro West (light blue region), the location of the research site (City of Cape Town, 2021)

4.5 THE RESEARCH DESIGN

This research study employed a prospective, descriptive, diagnostic imaging comparative research design within a quantitative research domain, where comparisons were made between the results of the forensic autopsy and a whole body PMCT examination. This research study was prospective in design, as the PMCT examinations were acquired as subjects meeting the inclusion criteria were admitted to the forensic pathology facility. All subjects enrolled first underwent a whole-body PMCT, then a forensic autopsy examination. In South Africa, in cases of unnatural death, a medico-legal investigation of death is mandated by the Inquest Act (Act 58 of 1959) which provides for a complete autopsy without consent. The forensic autopsy for all research subjects was therefore mandatory and conducted in accordance with the Inquest Act 58 of 1959 (South Africa, 1959).

4.6 SAMPLE SIZE

The Central Limit Theorem was adopted for determining the sample size for this research study (LaMorte, 2020). The Central Limit Theorem can be defined as a condition where the sampling distribution approaches normality as the number of samples taken increases (Bowling, 2010). In

other words, the distribution of the sample means will be nearly normally distributed, whatever the distribution of the measurement amongst the individuals, and will get closer to a normal distribution as the sample size increases (Campbell & Machin, 2002). Based on the Central Limit Theorem, as defined by LaMorte (2020), a sample size of 30 subjects was considered adequate. Considering that the study employed a non-probability sample of convenience, a power analysis for this study was not done. As a secondary consequence of collecting data prospectively, the sample size of 30 facilitated completion of the study within the time constraints for completion of this doctoral degree.

4.7 SUBJECT SELECTION

The South African definition of ‘a child’, the WHO definition for ‘child abuse’ and ‘fatal child abuse’ (described in Sections 1.9, 1.10 and 1.11 of Chapter One) were applied for this study. All children (hereafter referred to as ‘subjects’) admitted to the SRFPS between 4 July 2016 and 26 June 2018 and who met the entrance criteria, were enrolled consecutively, until the sample size of 30 was reached (Speelman et al., 2022). The details of each body admitted, all scheduled to undergo a forensic autopsy at the SRFPS, were recorded daily on an allocation list. This allocation list is used for internal administrative processes within the SRFPS facility. The following information was recorded for all admissions on this allocation list: i) the deceased admission number (Speelman et al., 2022), which is an alphanumeric number that indicates the Province, the facility, the chronological annual case number and the year of admission, i.e., i) WC/011/2018; ii) age; iii) sex; iv) clinical history, for those referred from a hospital; or v) scene findings, for those referred by the SAPS. In (i), WC refers to the Western Cape Province, and 11 is the facility number for the Salt River Forensic Pathology Services, allocated by the WCG Health Forensic Pathology Service. Other details included on the daily allocation list were, inter alia, the date on which the body was received at the facility, scheduled date for the forensic autopsy, suspected initial manner of death, and name of the forensic pathologist scheduled to perform the post-mortem examination. The researcher was given access to this list for screening purposes. This information was used to determine which children met the inclusion criteria for the research study.

4.7.1 Inclusion criteria

The following criteria were used to include subjects for this research study:

- Any child where exogenous factors, with a strong suspicion of suspected child abuse, (whether physical or otherwise), were the cause of death.
- Any child who had died due to suspected neglect or abandonment.
- Any child who had died because of suspected sexual abuse.
- Any child who met the criteria for SUDI.

4.7.2 Exclusion criteria

The following criteria were used to exclude subjects not suitable for this research study:

- Subjects whose demise was because of endogenous diseases, for example, cardio-vascular disease, pneumonia, or malignant disease.
- Underdeveloped foetus.
- Children who had died of unnatural causes, such as occupants of road traffic accidents (RTA)[5] or accidental drowning, where it was deemed by the researcher that the cause of death was not indicative of neglect or abuse, but accidental.
- Extreme putrefaction, decomposition or charred cadavers, as it would have impeded radiological interpretation of the PMCT examinations.
- Skeletal remains.

4.8 CARE OF THE SUBJECT BEFORE AND AFTER THE PMCT SCAN

Once a subject was deemed suitable for inclusion, the mortuary was contacted telephonically to ascertain two aspects, namely: whether the subject was available, and ready for the PMCT

[5] This definition excluded young children under the age of 10 years of age who were killed as pedestrians. These children were considered by the researcher as not being properly supervised and fitted the definition of child neglect.

examination; and whether a forensic pathology vehicle was available to transport the body to the radiology department. The bodies were not embalmed and were stored in a standard refrigerated environment at -5° Celsius prior to the PMCT examination.

Once the subject was ready, the radiology department was contacted telephonically to ascertain whether scanning of the subjects could be accommodated, taking into consideration their own daily scheduled CT cases. Most PMCTs were performed between 17:00 and 18:00 to minimise interference with the patient management of the radiology department. The route taken to transport the bodies from the mortuary vehicle to the radiology department was the shortest and least intrusive.

To protect the privacy of the deceased and to minimise contamination of the scanner bed, all bodies were scanned in a CT compatible body bag. All bodies were transported to the radiology department by a dedicated team of experienced FPOs. The FPOs were all WCG Health employees attached to the SRFPS and were aware of the medico-legal requirements pertaining to ensuring continuity of evidence whilst transporting the body. All subjects were under the complete care and supervision of FPOs whilst in transit and during the PMCT examination. At no time, therefore, did the researcher and radiographers take medico-legal control of the body. To preserve potential evidence and to ensure continuity of evidence, no alteration of the body was made, such as removal of clothes, shoes, medical devices or other personal belongings (where present). Positioning of the body during the PMCT did not require significant manipulation, which allowed the researcher to maintain the integrity of the body. The body was, for the same reason, not removed from the body bag at any given time.

These measures were taken to ensure that the integrity of the forensic autopsy, which was conducted after the PMCT examination, was maintained. The researcher and the FPOs carefully transferred all bodies manually from the forensic pathology trolley onto the scanner bed. All care was taken not to cause any damage to the body during this transfer: so as not to cause unintentional injuries. For older subjects (between 5 and 17 years), the researcher routinely placed his hand underneath the head and neck of the subject to provide support of these body parts during the transfer onto and off the scanner bed.

4.9 PMCT SCANS ACQUISITION

All subjects were scanned using a Philips Brilliance 64 slice, multi-detector CT scanner, Philips Medical Systems, Best, the Netherlands. All subjects underwent a whole body PMCT scan. The topogram sequence started about 3 cm superior to the vertex and ending about 3 cm below the feet (Speelman et al., 2022). The bodies were positioned in a supine position, with the head face up, and with the arms situated next to their body, or over the abdomen, depending on the degree and status of rigor mortis. The following protocols were routinely applied for children at the research site:

Table 4.1 PMCT imaging parameters used for different subjects

Age	Imaging parameter	Head/Neck	Thorax	Abdominal pelvic	Extremities
1 day–5 year	**kV**	120	120	120	120
	mAs	400	250-400	250-400	250-400
	Slice thickness	2 – 3 mm	2 - 3 mm	2 - 3 mm	2 - 3 mm
	Slice increment	1 mm	1 - 1.5 mm	1 - 1.5 mm	1 – 1.5 mm
	Collimation	0.625 mm	0.625 mm	0.625 mm	0.625 mm
	Pitch	0.67	1.078 - 1.172	1.078 - 1.172	1.078 - 1.172
	Tube rotation time	0.75 sec	0.75 sec	0.75 sec	0.75 sec
	Kernel	UB Filter	B Filter	B Filter	B Filter
6–14 years	**kV**	120	120	120	120
	mAs	400	250-345	250-345	250-345
	Slice thickness	2 – 3 mm	2 - 3 mm	2 - 3 mm	2 - 3 mm
	Slice increment	1 mm	1 - 1.5 mm	1 - 1.5 mm	1 – 1.5 mm
	Collimation	0.625 mm	0.625 mm	0.625 mm	0.625 mm
	Pitch	0.67	1.078 - 1.172	1.078 - 1.172	1.078 - 1.172
	Tube rotation time	0.75 sec	0.75 sec	0.75 sec	0.75 sec
	Kernel	UB Filter	B Filter	B Filter	B Filter
16–17 years*	**kV**	120	120	120	120
	mAs	400	250-345	250-345	250-345
	Slice thickness	2 – 3 mm	2 - 3 mm	2 - 3 mm	2 - 3 mm
	Slice increment	1 mm	1 - 1.5 mm	1 - 1.5 mm	1 – 1.5 mm
	Collimation	0.625 mm	0.625 mm	0.625 mm	0.625 mm
	Pitch	0.67	1.078 - 1.172	1.078 - 1.172	1.078 - 1.172
	Tube rotation time	0.75 sec	0.75 sec	0.75 sec	0.75 sec
	Kernel	UB Filter	B Filter	B Filter	B Filter

kV = kilovolt
mAs = milliampere-seconds
* No 15-year-old subject was enrolled in study.
(Speelman et al., 2022) Reproduced with permission from Springer Nature

The maximum scan length possible with this Philips CT scanner was 1,500 cm in the z-direction. Some subjects were scanned with a single sequence, from head to toe, whilst other subjects were scanned using two overlapping sequences.

All bodies were scanned using the same CT scanner. All subjects were scanned between 24 and 60 hours after admission to the mortuary. Bodies admitted to the mortuary over a weekend, public holiday, or after hours were, for logistical reasons, scanned on the following working day.

The PMCT examinations were performed by two research assistants who were both experienced radiographers employed by the private radiology practice. For medico legal reasons, the researcher was not permitted to conduct the PMCT scans himself, as he was not an employee of this radiology practice. However, all PMCT scans were conducted under the direct supervision of the researcher. Once the PMCT was completed, the body was transferred safely back onto the mortuary trolley. The researcher would then accompany the FPOs to the forensic pathology vehicle parked on the lower floor (a reserved service floor) within the basement of the research site, to which only staff have access. Hereafter, the body was transported back to the SRFPS.

Multi-planar reconstructions in the axial, coronal and sagittal plane and 3D reconstructions were performed for all subjects (Speelman et al., 2022). No dental reconstructions were done for any of the subjects, as the software for post-processing was not available on the scanner. No contrast media was administered, nor tissue sampling conducted for any of the subjects during the PMCT examination.

4.10 MANAGEMENT OF THE PMCT IMAGES

Each subject was assigned a study number (which consisted of a combination of a mortuary admission number plus a chronological study number) between 1 and 30, plus the year in which the subject passed away. A typical study number for a subject would therefore read as follows: WC/11/01/2017. The year in which the subject passed away was used to prevent confusion in the event that another research subject was allocated the same admission number, in lieu of the research study and PMCT scans being conducted over two years. The PMCT images were stored and saved in dedicated password-protected folders on the server of the radiology department. Only the researcher and the research assistants had access to these folders.

Table 4.2 Sequences and multiplanar reconstructions obtained for different subjects

Sequences and reconstructions obtained for subjects < 5 years	Sequences and reconstructions obtained for subjects > 5 years
Full body topograms: • Lateral full body topogram • AP full body	Topograms consisting of: • Lateral skull • AP thorax and abdominal pelvic cavity • AP pelvis and lower extremities
3D volume rendered sequence showing external surface of head	3D volume rendered sequence showing external surface of head
3D volume rendered sequence showing bony window of head	3D volume rendered sequence showing bony window of head
3D volume rendered sequence showing bony window of the skeleton	
Axial sequence of the brain	Axial sequence of the brain
Coronal sequence of the brain	Coronal sequence of the brain
Sagittal sequences of the brain	Sagittal sequences of the brain
Axial sequence of the thorax, abdominal pelvic cavity and lower extremity	Axial sequence of the thorax and abdominal pelvic cavity
Coronal sequence of the thorax, abdominal pelvic cavity and lower extremity	Coronal sequence of the thorax, abdominal pelvic cavity
Sagittal sequence of the thorax, abdominal pelvic cavity and lower extremity	Sagittal sequence of the thorax, abdominal pelvic cavity
	Axial sequence of the pelvis and lower extremities
	Coronal sequence of the pelvis and lower extremities
	Sagittal sequence of the pelvis and lower extremities

Images were saved on a compact disc (CD) using Digital Imaging and Communication in Medicine (DICOM) compatible software, then inserted into a dedicated squared, paper-based envelope by the research assistants, after which they were handed over to the researcher. DICOM is the international standard that all medical images and related information must meet, such as format and quality, in order for the images to be exchanged for clinical use (The Medical Imaging Technology Association, 2020). The images only contained the study number of the subject and

PMCT imaging parameters (see Figure 4.2 below for a sample of a whole-body topogram of Subject 17). The subject's true identity (i.e., full name and surname) was not known to the researcher, nor to the research assistants, and was thus not recorded on any of the PMCT images. The CDs were stored in a lockable cabinet in the office of the researcher. Only the researcher had access to this cabinet.

Figure 4.2 Whole body lateral topogram in a four-year old (Subject 17) showing subject number

The images were then downloaded from the CD and uploaded onto a folder on a password-protected desktop computer based in the researcher's office. From there, the images were uploaded to the researcher's personal Microsoft OneDrive (cloud) in DICOM format, using a RadiAnt DICOM viewer 4.6.5. The images were uploaded to the Microsoft OneDrive in the same order that they were saved by the research assistants. The researcher's Microsoft OneDrive was password-protected, and only the researcher had access to this drive.

Once uploaded onto the cloud, a link was created to the OneDrive folder which was sent to the two radiologists (hereafter, named 'the reviewers') by electronic mail. To preserve security, access to the OneDrive folder was only granted for one month to allow the reviewers adequate time to review the images. Access to this folder would then lapse after the expiry date of the link. Anonymity of the subjects' identities were maintained: no personal names, hospital numbers

(where applicable) or identity numbers of the deceased were recorded, nor stored on the PMCT images. Confidentiality of the images reviewed by the reviewers via the Microsoft OneDrive was maintained as the images contained only the subject study number and name of the radiology practice. Furthermore, confidentiality was maintained as only the reviewers had access to the link, and no names or any identification could be linked back to the subjects. Furthermore, special software was required to review the PMCT images on a computer screen, lending an additional security layer for review of the PMCT images.

4.11 EXPERT REPORTING OF THE PMCT IMAGES

Two expert and very experienced board-certified paediatric radiologists served as reviewers of the PMCT images. Both reviewers had, at the time of the data collection, 20 and 14 years of experience in post-mortem imaging and reporting (Speelman et al., 2022). The reviewers had access to dedicated software to interpret the PMCT images. This software enabled options such as zoom, window adjustment, measurement options which include concepts such as length, angles, measurement of angles, rotation or flip of images, windowing in terms of converting the images into lung, bone, soft tissue, brain, chest or negative window. Cine options and annotation of images were also possible.

The reviewers were asked to provide, independently, a written report for each of the PMCT examinations. The report had to be written in electronic format on a report form design by the researcher (see Addendum A2).

This information was recorded on the radiology report form: the study number of each subject; the age; sex; and the scene findings, or case history related to the initial manner of death. The two reviewers reviewed each subject's image sets independently and systematically; and they were only aware of the clinical history or scene findings of each subject. The completed radiology reports were saved in a file created for each subject on the desktop computer of the researcher.

The radiologists had to record the type of injuries present, the anatomical location thereof, as well as the cause of death for each subject. All completed radiology reports were sent by the reviewers to the researcher by electronic mail.

4.12 THE FORENSIC AUTOPSY

The National Code of Guidelines for Forensic Pathology Services in South Africa prescribes a detailed set of activities which must be followed for each medico-legal post-mortem examination of an unnatural death. Please refer to Addendum A3 for the Standard Operating Procedures for all unnatural deaths (including cases of suspected child abuse).

Prior to the forensic autopsy, and as part of the evidence collection, the forensic pathology officers who collect deceased bodies will take scene scripts, take a history from relatives or witnesses, as well as photos and videos of the scene, where required. The forensic pathologist, in compiling his or her findings, has access to all of this information and may, in addition, also consult with family, may phone police and, before the full autopsy, conduct an external examination of the body (National Health Act, No. 61 of 2003. Regulation, 2018, No. R.359).

An experienced forensic pathologist, employed by the WCG Health FPS and stationed at the SRFPS mortuary, performed the forensic autopsy according to the aforementioned standard protocols after the PMCT examination (Speelman et al., 2022). The forensic autopsy protocols are aligned with international guidelines such as the National Association of Medical Examiners (2005) and Home Office, The Forensic Science Regulator, Department of Justice and the Royal College of Pathologists, (2012). The forensic autopsy was not influenced, nor dictated to, by the PMCT results, and was performed as part of the routine undertakings of the SRFPS. The forensic pathologists knew the clinical history, or scene findings for each subject but were not aware of the PMCT results (Speelman et al., 2022). The extent of the dissection was decided by the forensic pathologist on a case-by-case basis. Because the PMCT images were acquired as part of a research study, the radiology reports were not made available to the forensic pathologists at any time during the research project.

4.13 THE FORENSIC PATHOLOGY REPORT

The forensic pathology report is a medico-legal document which forms an integral part of the forensic autopsy and is compiled after the medico-legal investigation has been completed. As per the standard recommended report guideline, the forensic pathologist records in a detailed written report all pathological findings, including the type and location of injuries, culminating in the cause of death (see example of a template autopsy report form that is used to write this report in Addendum A4).

For readers not familiar with paediatric forensic autopsies, the researcher has compiled a list of aspects that forensic pathologists routinely describe in a typical forensic autopsy report for all unnatural deaths (see Addendum A5). This document therefore excluded assessments of natural deaths by forensic pathologists, and the reporting thereof may thus differ for such cases. Please note that this list is based on aspects contained in the final forensic autopsy reports of the 30 subjects enrolled for this research study and is by no means exhaustive.

The forensic pathology report is compiled in the form of an affidavit which is commissioned by a Commissioner of Oaths and can thus be introduced as evidence in court.

The researcher manually recorded verbatim the findings of the final forensic pathology report for each subject in a Microsoft word document. The forensic pathology findings were recorded consistent with the categories and content contained in the complete and final pathologist report. The recording of the forensic pathology findings is discussed in more detail in the next section. These records of the forensic pathology reports were typed and stored on the researcher's personal laptop, in an individual folder created for each subject. The reason for recording and storing these reports on a personal laptop was for security and confidentiality reasons, as no photocopies or electronic mailing of the final forensic autopsy reports could be made at the forensic pathology facility. The manual recording of the final forensic pathology reports onto a personal laptop was thus the only feasible alternative. This laptop was password protected to ensure access control of these reports and the related PMCT images. As alluded to before, no names or personal details of the deceased were recorded, nor the names of the forensic pathologists, as this was not required for the execution of this research study, so the required level of confidentiality, anonymity and privacy of all subjects and the forensic pathologists was maintained. The forensic pathology reports were later transferred from the laptop to the relevant subject's folder and stored on a desktop computer in the researcher's office.

4.14 ANATOMICAL INJURY CATEGORISATION

As stated before, 30 subjects underwent a whole-body PMCT followed by a complete forensic autopsy. The injuries observed for each subject during the forensic autopsy were copied from the final written forensic pathology report. The forensic pathology reports described findings according to anatomical regions, such as head and neck, thorax, abdomen, spine, upper and lower extremities (Speelman et al., 2022). Other data recorded from the forensic pathology reports

included the chief post-mortem findings and schedule of observations at the time of the forensic autopsy. These included the general physical features of the deceased, the status of secondary post-mortem changes, external appearances of the body, and condition of the limbs. The completed forensic pathology reports included findings of supplementary examinations, such as histology, toxicology, DNA analysis, LODOX®, and conventional projection radiography, amongst others (Speelman et al., 2022). Addendum A4 contains a blank forensic pathology report, itemising the various aspects covered within a forensic pathology report.

The results for both the forensic autopsy and the PMCT examinations were recorded on an Excel spreadsheet, termed 'the Master spreadsheet' (see sample, Addendum A6, Parts 1– 3). This master spreadsheet comprised the following column headings: subject study number (e.g., 01–30); WC number; type of examination (i.e., forensic autopsy); separate and complete PMCT results for Reviewers 1 and 2; and the perceived cause of death, recorded with both the forensic autopsy and by Reviewers 1 and 2. In other words, the injuries recorded during the forensic autopsy, or by both reviewers, were recorded separately for each anatomical area, where relevant. The injuries recorded with PMCT and the forensic autopsy were copied in the same order on this Excel spreadsheet, as displayed in the blank forensic pathology report. Due to the size of this Excel sheet, not all headings are displayed in Addendum A6, parts 1–3.

Injuries diagnosed in the head and neck were recorded according to the following sub-categories: scalp, skull, intracranial contents, orbits, nasal and aural cavity, mouth, tongue and pharynx, neck structures including the thyroid, hyoid bone, laryngeal cartilage and larynx.

Injuries within the thorax were recorded according to the following subcategory headings: thoracic cage and diaphragm; mediastinum and oesophagus; trachea and bronchi; pleural cavity; lungs; heart and pericardium; and large blood vessels.

Injuries within the abdomen were recorded according to the following sub-categories: peritoneal cavity; stomach and contents; intestines and mesentery; liver, gallbladder and biliary passages; pancreas; spleen; adrenals; kidney and ureters, urinary bladder and urethra; pelvic wall; and genital organs.

Injuries relevant to the spinal vertebrae and spinal cord were recorded according to the following sub-categories: spinal column and spinal cord respectively. Injuries relevant to the appendicular skeleton were recorded according to upper and lower extremities respectively. In addition,

LODOX® findings, where applicable, were recorded, as well as incidental findings diagnosed with the forensic autopsy.

4.15 RECORDING OF PMCT RADIOLOGICAL FINDINGS

The radiological findings diagnosed on the PMCT examinations were copied from each radiology report and recorded separately on the Excel master spreadsheet, using the same anatomical injury categorisation described earlier for the forensic autopsy. The injuries diagnosed by both reviewers were recorded in two separate rows, one for each reviewer. Injuries diagnosed by reviewer 1 were denoted as 'PMCT 1', and for reviewer 2 as 'PMCT 2', for each of the 30 subjects (see sample in Addendum A6, Part 2). Incidental findings and congenital anomalies were also recorded separately for both reviewers.

4.16 ICD 10 CODIFICATION

The data related to the injuries diagnosed for each subject were extrapolated into a second spreadsheet entitled 'Injuries and ICD 10 codes (see sample in Addendum A7, Parts 1–2). This second spreadsheet was created to assign the ICD 10 code for all injuries. Each ICD code was assigned in accordance with the 2016 International Statistical Classification of Diseases and Related Health Problems (10th revision, Volume 1, 5th edition) Tabular list, as well as the alphabetical list of the 2016 International Statistical Classification of Diseases and Related Health Problems, 10th revision, Volume 3, 5th edition (WHO, 2011). These codes were aligned to the data recorded on the forensic autopsy and radiology reports (Speelman et al., 2022). The ICD 10 codes for all injuries were recorded in a separate column adjacent to the descriptive injury findings on this spreadsheet. Some injuries may appear in more than one category in the alphabetical list. This list was used as the primary source for extracting ICD 10 codes, based on appropriate modifiers or qualifiers for each injury; and, for each injury, the Tabular lists were used to determine the correct category or subcategory within this allocation. The researcher did not use the Abbreviated Injury Scale nor the Injury Severity Score because these classifications were not routinely used at the research site.

4.17 FINDINGS EXCLUDED

The ICD 10 codes were used for the final data analysis and were recorded to identify significant findings. Non-significant findings were thus not recorded for data analysis. Examples of non-significant findings excluded for the forensic autopsy examinations were the type and colour of fluid within the pericardial sac, the condition of the capsule of the liver or spleen, and description of, for example, frothy oedematous fluid found within the trachea. Non-significant findings, excluded for the PMCT examinations included the location and number of any bony fragments, following a bony injury or gunshot wound. In addition, normal post-mortem changes, such as loss of grey-white matter differentiation of the brain parenchyma, as well as lung consolidation – even though significant in living subjects – were considered as normal post-mortem changes and were excluded. Furthermore, all PMCT findings that were recorded as suspected or unsure by the reviewers were considered as uncertain findings and therefore excluded.

4.18 ENSURING INTERNAL VALIDITY OF DATA

Only the researcher copied and recorded the forensic autopsy and radiology reports, ensuring standardisation of how the findings were recorded. Once all possible ICD 10 codes used in this study had been identified, a separate alphabetical list of all injuries, each with its associated ICD 10 code, was drawn up in a Word document to ease cross-reference and to ensure consistency and internal validity of data recorded (see Addendum A8). This cross-reference was done to ensure that the ICD 10 codes allocated for a particular injury were consistent across all anatomical regions and for all subjects.

Once all injuries for both the forensic autopsy and the PMCT examination had been assigned an ICD 10 code on the ‘Injuries and ICD 10’ Excel spreadsheet, a research assistant was asked to scrutinise for consistency the ICD 10 codes in conjunction with the International Statistical Classification of Diseases and Related Health Problems Tabular list and Alphabetical list codes. This was done to maintain internal validity of the ICD 10 codes assigned for each injury, and to enhance robustness of the raw data. Where inconsistencies were noted, such errors were corrected, as per the tabular list.

4.19 CONSENSUS READING WITHIN DIAGNOSTIC IMAGING ACCURACY STUDIES.

In radiology literature, there are various methods researchers can use to report results of diagnostic imaging accuracy studies. In post-mortem diagnostic imaging accuracy studies, consensus reading is one of the methods commonly applied, where PMCT results are compared with those of the forensic autopsy (Daly et al., 2013; Ampanozi et al., 2015; Scaparra et al., 2016). With consensus reading, two radiologists review the same set of images, come to a consensus, and eventually record the findings as if only one observer had read the images (Bankier et al., 2010).

Other methods involve the use of average scores of reviewers (Bankier et al., 2010). With this method, the results can simply be averaged; or the researcher can select the scores of the reviewer scoring the highest in the study; or select the scores of the most experienced reviewer; or count each reviewer as a single study within a study; or randomly select the results of a particular reviewer. Each method has its advantages and disadvantages (McGrath et al., 2017). An average score does not favour the expert reviewer and takes into account variability in expertise and misjudgements of interpretation, as evident in the clinical setting. Using the average score of reviewers, however, may obscure heterogeneity of inter-observer variability. Conversely, if the results of only one, or the results of the best reviewer, are selected, this may overestimate the accuracy of diagnostic imaging tests. There are currently no established guidelines regarding which method ought to be used (McGrath et al., 2017).

In the present study, a modified version of consensus reading was applied. For this method, the findings of both reviewers were recorded separately and afterwards the combined results were compared against those of the forensic autopsy. The reviewers therefore did not sit together and reach a consensus finding for each injury, unlike in traditional consensus readings. Where the same injury was recorded by both reviewers, such a finding was only counted as one injury for the combined totals. Where an injury was observed by only one reviewer, such a finding was considered valid and counted.

Consensus reading of diagnostic imaging accuracy studies is not fool proof and has several flaws. The first flaw is that it does not reflect clinical practice, as it is seldom done (Bankier et al., 2010). Reviewers within diagnostic imaging accuracy studies possess different cognitive, visual and perceptual abilities. These differences influence the accuracy of the imaging modality, rather than

the modality itself. Consensus reading records the majority interpretation, but does not record these variations (Obuchowski, 2004). Reporting inter-observer variability further assists in assessing the generalisability of the imaging modality to clinical practice (McGrath et al., 2017). A second criticism of consensus reading is that this system encourages group thinking, in the sense that it forces the reviewers (radiologists, in this context) to modify their opinions to reflect what they believe the others want them to think, which Bankier et al. (2010) aptly describe as 'a pseudo-consensus'. A third flaw is that, in a group, readers of lesser levels of experience could be overshadowed by dominant or more experienced reviewers, resulting in the more experienced or dominant reviewers making all the decisions by themselves. For purposes of this study, combining the total scores of the two reviewers (as a modified consensus) was considered the most suitable option for this study.

4.20 COMPARING THE FORENSIC AUTOPSY AND PMCT AS TWO SEPARATE EXAMINATIONS

The forensic autopsy could not be considered as the gold standard against which to measure PMCT performance. The rationale for this is that studies have shown that the forensic autopsy may at times not diagnose all injuries, which implies that all such injuries diagnosed with PMCT, must be considered as false-positives (Jackowski, 2013). It is for this reason that both examinations were considered as two separate measuring instruments which were compared to each other (Adelman et al., 2018). Section 7.3 in Chapter Seven provides more background to this aspect.

4.21 THE USE OF PERCENT AGREEMENT

The percent agreement for each injury type was also calculated between the forensic autopsy and PMCT using a modified consensus reading method as explained above. Where a percentage was found with a decimal, the percentage was rounded off to the nearest whole number. The interpretive scale used for the percent agreement was based on the scale used by Lee and colleagues (2016) (see Table 4.3).

Table 4.3 Interpretive scale for percent agreement
(Adopted from Lee et al., 2016)

Value of agreement	Strength of agreement
0%	None
1%–20%	Very poor
21%–40%	Poor
41–60%	Moderate
61–80%	Good
81%–99%	Very good
100%	Perfect

The Cohen Kappa statistic (k) was calculated to measure the interrater reliability for the cause of death rating as assigned by the forensic pathologist and Reviewers 1 and 2. The strength of agreement in Table 4.4 below was used to measure interrater agreement.

Table 4.4 Cohen Kappa statistic and strength of agreement categories
(Adopted from Landis & Koch, 1977)

Kappa Statistic	Strength of Agreement
< 0.00	Poor
0.00–0.20	Slight
0.21–0.40	Fair
0.41–0.60	Moderate
0.61–0.80	Substantial
0.81–1.00	Almost perfect

4.22 ETHICAL CONSIDERATIONS AND PERMISSIONS

Ethical approval to conduct this study was sought from and granted by the following Research Ethics Committees:

- Research Ethics Committee, Faculty of Health and Wellness Sciences, at the Cape Peninsula University of Technology (CPUT) (see Addendum A9)
- Human Research Ethics Committee, Faculty of Health Sciences at UCT (Speelman et al., 2022) (see Addendum A10)

Ethical approval was renewed yearly upon expiry of the previous ethics certificate. Ethical approval was thus in place for the full duration of the data collection period. Research site permission to conduct the study within the SRFPS was granted by the Western Cape Health Research Committee of the WCG (see Addendum A11). The Provincial Department of Health is an entity of the WCG which is the custodian of all state health facilities in this province, one of which is the SRFPS. In addition, research site permission to conduct the PMCT scans within the private radiology practice was granted by the Netcare Research Operations Committee of Netcare Management (Pty) Limited (see Addendum A12). Netcare Management (Pty) Limited is the owner of the private health care facility where the PMCT scans were acquired.

4.22.1 Waiving of Informed consent

PMCT examinations are not part of the routine undertakings of the SRFPS. However, pursuant to this, and prior to the commencement of the study, it was felt necessary to request a waiving of informed consent for the PMCT examinations for three reasons. The first reason was as follows: All subjects enrolled for this study died because of suspected unnatural deaths, which made the forensic autopsy mandatory, in accordance with the South African Inquest Act (South Africa, 1959). A forensic autopsy is different to a normal anatomical autopsy in the sense that, where the cause of death is suspicious, litigious, or unnatural, a formal medico-legal inquest into the cause of death needs to be conducted. The body may not be released before or until the forensic pathologist is satisfied that a complete investigation has been done and that all examinations, including specimen collections, have been adequately performed; and that the scientific identification is complete (National Forensic Pathology Service Committee, 2011).

Because forensic autopsies are legal requirements, no informed consent to conduct the autopsy is required from parents (National Health Act, No. 61 of 2003. Regulation, 2018, No. R.359). The forensic pathologist, after reviewing the case findings, has the right to conduct any medical procedure or test, or both, including imaging of such a body which he or she might deem necessary. The acquisition of PMCT examinations therefore fell within the purview of the forensic pathologist.

The second reason was because informed consent was not needed for the PMCT imaging, approaching parents for informed consent was not needed and avoided any further potential distress of affected parents. A third reason was that there was potentially a chance that parents or legal guardians, who might have been responsible for the demise of their child, would choose not to enrol their child out of fear of being found guilty of the fatal assault. Waiving informed consent was therefore a means of safeguarding the inclusion of all eligible children and obviate refusal of potentially guilty parents or legal guardians.

De Clercq et al. (2014) wrote that the participation of children in research is subjected to greater scrutiny because of their inability to provide informed consent, as they are considered a vulnerable group. It can be argued that this scrutiny is equally relevant for deceased children. The Helsinki Declaration, as well as the Guidelines of the Council for International Organisations of Medical Sciences, has brought about additional safeguarding of children by framing the enrolment of children in research around two fundamental ethical pillars, namely the scientific necessity of the research in question, and a minimal risk burden (De Clercq et al., 2014). The proposed research project met these criteria, since the emerging role of PMCT in forensic imaging is only now being explored, particularly in children who succumbed to unnatural deaths. In addition, the risk for children participating in this study was low. Further, the benefits to be gained from this study far outweighed any risks. In view of these arguments, and the sensitivity of the research study, informed consent, which is usually required for research studies (in this case, a whole body PMCT), was waived by the Human Research Ethics Committee, Faculty of Health Sciences, UCT.

4.22.2 Guiding ethical principles applied for the research study

Overall, the Helsinki Declaration principles served as the guiding ethical standards for this study. This section describes all applicable ethical standards observed and upheld during execution of

the research study. In addition, the study conformed to some of the General Ethical Guidelines for Health Researchers of the Health Professions Council of South Africa (HPCSA, 2016).

The following Helsinki principles were upheld during the research study:

Principle 7:

> "Research that promotes and ensures respect for all research subjects and protect their health and rights" (World Medical Association, WMA, 2013:1).

This principle was evident in the fact that all subjects were handled with respect, and no subject was harmed during execution of the research study (WMA, 2013). All PMCT scans were conducted in a secure room and behind closed doors. All subjects were scanned in a closed body bag to protect their identity.

Principle 8:

> "The principal purpose of research should be to generate new knowledge" (WMA, 2013:1).

This principle is evident in the fact that the application of PMCT within a forensic setting is a new and emerging field within forensic pathology, and thus generates new knowledge. This research study added new knowledge to the existing body of knowledge around post-mortem imaging in children. This principle is also aligned with the HPCSA General Ethical Guidelines for Health Researchers which, with regard to the principle of beneficence, states that the benefits of the research must outweigh the risks to research participants (HPCSA, 2016). The benefits of this study far outweigh the risks to subjects within this study.

Principle 18:

> "Researchers should not conduct research if they are not confident that the risks have been adequately assessed" (WMA, 2013:2).

During the execution of this research study, there were minimal risks for research subjects, the researcher and research assistants (WMA, 2013:6). The only potential risks were that the identity of deceased subjects could be disclosed, or that the continuity of evidence could not be maintained during execution of the research study. However, the subjects' identities were protected as no personal information of any one was required nor recorded for the purposes of this research study. Continuity of evidence was maintained, as no alteration to the body or removal of evidence

occurred at any time during the study when the subject was not within the geographic location of the designated medicolegal facility. This principle is also aligned with the HPCSA's principle of non-maleficence, which state that risks and harms to participants must be minimised (HPCSA, 2016).

Principle 20:

> **"**Medical research with a vulnerable group should only be conducted if such research is responsive to the health needs or priorities of this group and cannot be conducted in a non-vulnerable group" (WMA, 2013:2).

It can be argued that deceased children are a vulnerable group. However, the research study conducted speaks to the health needs of fatally abused children, making them central to this research study. The study also provided valuable answers with respect to the usefulness and constraints of PMCT imaging in fatally abused children, an aspect which will be addressed in Chapter 7.

Principle 24:

> "Privacy and Confidentiality" (WMA, 2013:3).

All reasonable steps were taken to uphold the privacy of research subjects and to protect their personal information (WMA, 2013). No personal details of subjects were recorded or required for the purpose of this study. Moreover, the researcher also kept the forensic pathologists' and radiology reports on a password-protected desktop computer. The CDs on which the PMCT images were recorded were kept in a lockable cupboard in the office of the researcher.

Research ethics are guided by four key principles, namely autonomy, beneficence, non-maleficence and justice (Jahn, 2011). The National Health Research Ethics Council of South Africa support health-related research provided it is underpinned by the core values of respect, scientific merit, integrity, justice and beneficence. The ultimate goal of all ethical principles is to protect the rights, safety and welfare of research subjects, especially vulnerable individuals. (South Africa. Department of Health, 2015). Children's rights, due to their unique vulnerability, are protected by various international and national standards. Children enrolled in research studies arrive with rights, and always retain such rights (Bell, 2008). This is even more so beyond life. There appears to be a paucity of scientific publications on research on deceased children. Deceased children are, undoubtedly, a vulnerable group, and so require special protection and

care when enrolled in research studies. It is therefore critical that imaging research studies, as described in this thesis, set out to uphold and protect the rights of deceased children, in accordance with national and international ethical norms. The previous section highlighted how, in the quest to advance scientific knowledge involving post-mortem imaging, the ethical principles upheld during the study safeguarded the interests of research subjects,

4.23 RADIATION DOSE IN THE DECEASED

The South African Medical Research Council (SAMRC) Guidelines on the use of radiation and bio-hazards state that in all research projects, the use of radiation exposure should be based on Good Clinical Practice (SAMRC, 2002). These guidelines, however, were written in the context of applying radiation dose to live research participants. It is still assumed that most of these guidelines can be applied to the deceased. All applicable radiation safety principles, such as the ALARA principle, where the dose must be kept as low as possible, were upheld during this research study. The anticipated risk of radiation dose to the deceased was zero. The PMCT protocols used during the research study were the same as those used for live subjects.

4.24 CHAPTER SUMMARY

This chapter described the research design and methodology that was employed for the research study. Thirty subjects under the age of 18 years underwent two examinations: a whole-body PMCT examination, followed by a forensic autopsy. Considering that all subjects died due to suspected unnatural deaths, the forensic autopsy was mandatory, in accordance with the South African Inquest Act (South Africa, 1959). The PMCT images were reviewed by two expert paediatric radiologists. Continuity of evidence was maintained during PMCT image acquisition, as no alteration of any evidence on the body occurred during imaging. The forensic autopsies were conducted by consultant or specialist forensic pathologists, according to international protocols. This chapter also describes the ethical principles upheld during execution of the research study. The next chapter will describe how the collected data were analysed.

CHAPTER FIVE

RESULTS: PART 1

5.1 CHAPTER INTRODUCTION

The overall results of the study were too much for one chapter. In lieu of this, the results discussed in this chapter are aligned with research objective one which set out to measure the degree of concordance between PMCT and the forensic autopsy in terms of the spectrum and anatomical location of injury types diagnosed. The results related to the remaining three research objectives will be discussed in the Chapter Six. Chapter five starts with an explanation of these aspects: the initial manner of death categories assigned to each subject at the time of their demise, their respective sex and age ranges; time delay from admission to PMCT acquisition; and an outline of how the results are presented. The number of injuries identified within the anatomical regions of the head and neck, thorax, abdomen and pelvis, spinal column and spinal cord as well as extremities diagnosed with both the forensic autopsy and PMCT is presented mostly in tabular form. This chapter ends with a discussion on miscellaneous injuries identified as well as those injuries for which no direct comparison could be drawn between the forensic autopsy and PMCT.

5.2 INITIAL MANNER OF DEATH CATEGORIES

For each research subject admitted to the relevant mortuary, an initial manner of death classification was used to record the way in which deceased persons were presumed to have succumbed to their disease or injury. The initial manner of death classification is a provisional statement and is used at the research site as the presenting feature and thus not the final cause of death, as the latter is only confirmed once the forensic autopsy has been concluded. This initial manner of death classification can therefore naturally differ to the final cause of death (or manner of death) as determined by the forensic autopsy.

There were nine initial manner of death categories for all 30 subjects, as illustrated in Figure 5.1. Two categories had more than one classification. The double classification for some initial manner of death categories was for subjects where FPOs, based on the scene findings at the time of death, could not clearly categorise the manner of death due to confounding or inconclusive circumstantial evidence. This bar graph indicates that gunshot wound (n = 11) was the category

with the highest number of subjects enrolled, followed by SUDI (n = 7) and road traffic accidents (RTA) pedestrians (n = 4).

The SUDI classification involved cases where a sudden and unexplained manner of death was apparent, often involving a relatively healthy infant. Chapter Two Section 2.8.1 provides a detailed discussion of the SUDI context. The RTA pedestrian category involved children younger than 10 years of age who succumbed to a fatal RTA, mostly as a result of supervisory neglect. Supervisory neglect was, for the purposes of this study, considered one of the sub-categories used to define child abuse. Concealment of birth (abandonment) in this study, refers to cases where new-borns were deliberately dumped shortly after birth, presumably by the mother.

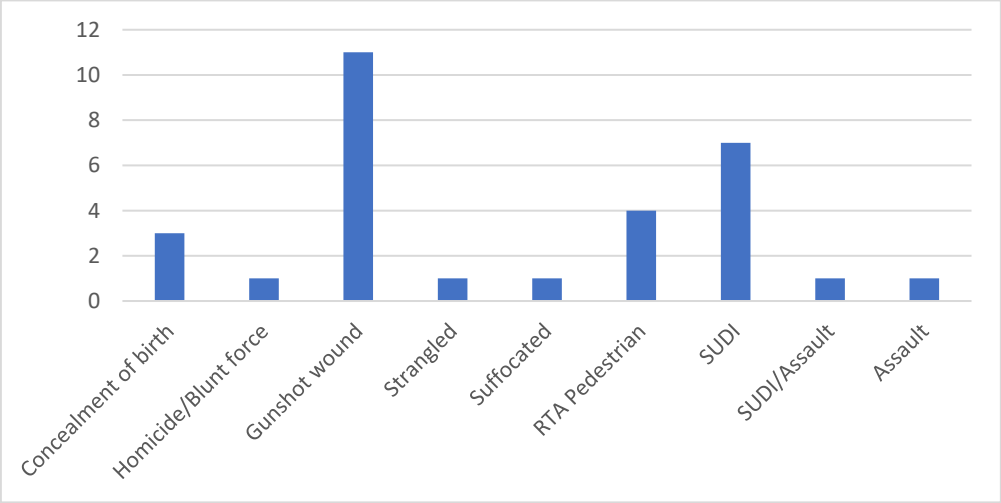


Figure 5.1 Initial manner of death classification for all subjects shows that Gunshot wound had the highest number of admissions, followed by SUDI and RTA pedestrian (Speelman et al., 2022). Reproduced with permission from Springer nature

There was a wide variation in the initial manner of death categories for the 30 subjects. Except for Gunshot wound and SUDI, all other categories had a maximum of four cases or less enrolled for the study. This variation had an impact on the number of cases enrolled for a particular category. The low number of cases per initial manner of death category, resulted in a lower number of injuries per anatomical area, which negated significance testing of the results. However, the large variation in initial manner of death categories did allow assessment of PMCT performance across a wider case mix of deaths often seen at a busy forensic institution.

5.3 SEX AND AGE RANGE OF SUBJECTS

There was strong male preponderance among the subjects enrolled in this study. Of the 30 subjects enrolled, 80% (n = 24) were males and 20% (n = 6) were females (Speelman et al., 2022), as illustrated in Figure 5.2.

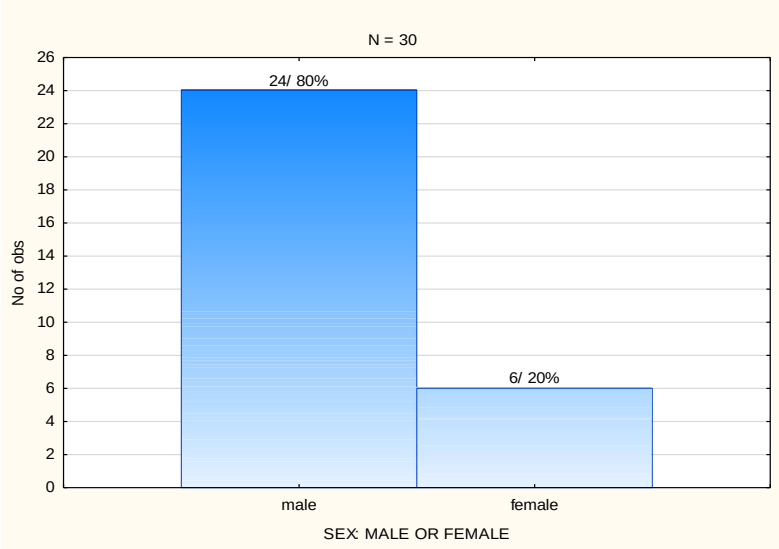


Figure 5.2 Ratio of male versus female subjects enrolled

The mean age for all subjects enrolled was 6,2 years (range: 1 day to 17 years) (Speelman et al., 2022). The mean age for the Gunshot wound category was 14 years (range: 4-17 years). Subjects enrolled under the SUDI manner of death classification had a mean age of 0,9 months (range 1 month to 3 years). For subjects enrolled under RTA pedestrians, the mean age was 4 years (range: 17 months to 9 years). All four of these subjects were unaccompanied minors under 10 years of age, three of which were pedestrians. The remaining child in this category was driven over when a car was in reverse motion in the driveway of her parent's home.

Table 5.1 Sex and age distribution for initial manner of death classifications

Initial manner of death	No. of subjects	No. of males	No. of females	Age range	$\bar{x}$ age
Concealment of birth	3	1	2	1 day	1 day
Homicide/Blunt force	1	1	0	6 years	6 years
Gunshot wound	11	10	1	4–17 years	14 years
Strangled	1	1	0	1 day	1 day
Suffocated	1	1	0	3 years	3 years
RTA Pedestrian	4	2	2	1,5–9 years	4 years
SUDI	7	6	1	1 month to 3 years	0,9 months
SUDI/Assault	1	1	0	18 months	18 months
Assault	1	1	0	19 months	19 months
Total	**30**	**24**	**6**	**1–17 years**	**$\bar{x}$ = 6,2 years**

5.4 TIME DELAY FROM ADMISSION TO PMCT ACQUISITION

For this research study, 50% of subjects (n = 15) were scanned within one day after admission to the mortuary, with a mean of 1,7 days (median 1,5 days and range 1–5 days) (see Figure 5.3). Thirty-seven percent (n = 11) of subjects were scanned within two days after admission. Seven percent of subjects (n = 2) were scanned three days after admission, whilst one subject each (3%) was scanned four and five days respectively after admission to the mortuary. Putrefaction can affect the diagnostic quality of PMCT images. The majority of subjects (87%) (n = 26) were thus scanned within two days after admission. The majority of PMCT images were, due to this relatively short time delay, not affected by putrefaction, and were overall of good diagnostic quality. The time delay between admission and performance of the forensic autopsy and the time delay between the acquisition of the PMCT and the forensic autopsy, was for the purpose of this study, not calculated. These time delays were not essential to the outcome, nor the results of the study.

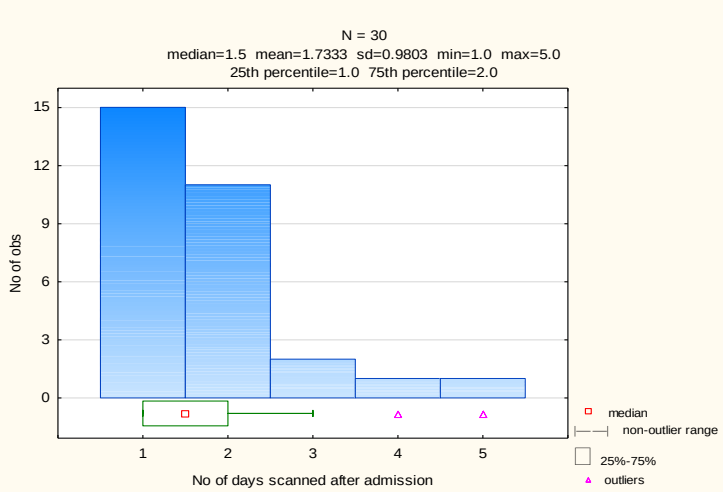


Figure 5.3 Time delay in days for PMCT acquisition

5.5 PRESENTATION OF THE RESULTS

Injuries were divided into injury types and injury categories. The total number of injuries diagnosed amongst all subjects was divided into five anatomical regions – head and neck, thorax, abdomen and pelvis, spine, extremities – and one miscellaneous group. The total number of injuries for each anatomical region was calculated based on the sum of injuries diagnosed for individual injury types during the forensic autopsy and PMCT. Percent agreement was calculated to determine the level of agreement between the forensic autopsy and PMCT for the respective injury types identified per anatomical region.

Percent agreement is an acceptable form of data analysis used by many experts in forensic diagnostic imaging studies (Leth & Ibsen, 2009; Scholing et al., 2009; Kasahara et al., 2012; Le Blanc-Louvry et al., 2013; Leth, Struckmann & Lauritsen, 2013; Krentz et al., 2016). In order to calculate percent agreement, the PMCT scores of reviewers 1 and 2 were calculated separately and added as one total which was compared with the number of injuries diagnosed with the forensic autopsy. This was considered as a modified version of consensus reading, described under Section 4.19 in Chapter Four.

The next few sections present the number of injuries diagnosed with the forensic autopsy and combined scores for PMCT for each anatomical region as well as the percent agreement between the two examinations. As alluded to before, the forensic autopsy was not considered the gold standard, as not all injuries were recorded by the forensic autopsy. Instead, both examinations

were considered as separate measuring methods (examinations). Where the forensic autopsy scored more injuries compared to PMCT, these results were used to calculate the percent agreement for PMCT. At times, percent agreement was also calculated for the forensic autopsy in cases where PMCT scored more injuries compared to the forensic autopsy.

5.6 TOTAL NUMBER OF FINDINGS FOR THE FORENSIC AUTOPSY AND PMCT

The forensic autopsy recorded a total of n = 348/437 findings which represents 80% of possible findings compared to n = 241/437 with PMCT, representing 55% of all possible findings for all 30 subjects. See Table 5.2 below. The PMCT injury totals were calculated by counting the number of injuries identified by both reviewers in the same subject as one injury. Where an injury was identified in a subject by only one of the two reviewers, such an injury too was counted as one injury. These findings included mostly injuries and some minor abnormalities including congenital. PMCT had a discrepancy rate of 45% (n = 196/437) compared to 20% (n = 89/437) for the forensic autopsy for the total combined findings. Discrepancy rate here refers to findings (diagnoses) made by one examination, not recorded by the other. Refer also to Addendum B1 for a complete breakdown of the discrepant findings.

Table 5.2 Number of injuries diagnosed per anatomical region, percent (%) agreement and discrepant findings

Anatomical regions and miscellaneous category	Forensic Autopsy n (%)	PMCT* n (%)	% agreement FA vs PMCT
Head and neck	115 (33%)	99 (41%)	86%
Thorax	156 (45%)	93 (39%)	60%
Abdomen and pelvis	32 (9%)	17 (7%)	53%
Spinal column and cord	8 (2%)	11 (5%)	73%
Extremities	15 (4%)	14 (6%)	93%
Miscellaneous	22 (6%)	7 (3%)	32%
Total	**348 (80%)**	**241 (55%)**	**69%**
Discrepant findings	**89 (20%)**	**196 (45%)**	**-**
Combined no of findings	**437**	**437**	**-**

***** This includes combined number of injuries diagnosed by Reviewers 1 and 2
Values in parenthesis reflect number of injuries as a percentage for overall number of injuries diagnosed per examination. Percentages were rounded to the nearest whole number

5.7 NUMBER OF INJURIES DIAGNOSED PER ANATOMICAL REGION

All injuries were divided into six groups consisting of five major anatomical regions, plus one miscellaneous group, resulting in 82 injury types. As can be appreciated in Table 5.2, the forensic autopsy recorded the majority of injuries (45%) (n = 156/348) in the thorax, followed by head and neck injuries (33%) (n = 115/348). For PMCT, more injuries (41%) (n = 99/241) were recorded in the head and neck, followed by 39% (n = 93/241) within the thorax. Significantly fewer injuries were diagnosed in other anatomical regions such as the abdomen and pelvis (9% vs 7%) (n = 32/348 vs 17/241) extremities (4% vs 6%) (n = 15/348 vs 14/241) and spinal column and cord (2% vs 5%) (n = 8/348 vs 11/241) for the forensic autopsy and PMCT respectively. The number of injuries diagnosed for the miscellaneous category was 6% vs 3% (n = 22/348 vs 7/241) of injuries for the forensic autopsy and PMCT respectively.

Due to the small number of injuries diagnosed per anatomical region, statistical significance of these results could not be calculated and hence only the percent agreement is reported for this section of the results. Based on the interpretive scale for percent agreement (Table 4.3, Chapter Four), there was very good agreement between the forensic autopsy and PMCT for the diagnosis of injuries within the head and neck (86%); moderate agreement for injuries within the thorax (60%) and abdomen and pelvis (53%). There was very good agreement for injuries within the extremities (93%); and good agreement (73%) for the spinal column and spinal cord.

Tables 5.3 to 5.8 that follow illustrate the number of injuries for each anatomical region and miscellaneous category, as diagnosed during the forensic autopsy and with PMCT. In the next few sections, the number of injuries (n) recorded for the forensic autopsy and PMCT will be compared followed by the percent agreement in parenthesis.

5.8 NUMBER AND TYPE OF INJURIES DIAGNOSED WITH THE FORENSIC AUTOPSY AND PMCT IN THE HEAD AND NECK

5.8.1 Intracranial and extracranial injuries

The injuries diagnosed within the head and neck were divided into six sub-categories, as can be appreciated by examining Table 5.3. As stated before, these sub-categories were aligned to those included within the forensic autopsy report. The total number of injuries diagnosed within the head and neck was the second highest overall recorded for the forensic autopsy and highest for PMCT. A total of 53 intracranial injuries were diagnosed with the forensic autopsy compared to 49 for PMCT (n = 49/53) (92%). A total of four extracranial injuries were diagnosed with forensic autopsy compared to zero with PMCT (n = 0/4) (0%). Nine different injury types affecting the brain and meninges were evident. Six of these injury types involved the brain parenchyma and were grouped into brain compression or swelling[6], brain contusions, brain lacerations, brain oedema, intracerebral haemorrhages, and pneumocephalus.

Pneumocephalus can occur inside and outside the brain parenchyma but, for ease of analysis, was considered here as a finding affecting the brain parenchyma. The three remaining injuries comprised two sub-meningeal haemorrhage types, namely, SAH, SDH, as well as intraventricular haemorrhages.

Brain contusions and brain lacerations occur as a result of injury to the brain parenchyma. Some subjects presented with multiple injuries to the brain. In this study, brain contusions and brain lacerations were counted for each individual injury. For example, for cases where the pathologists diagnosed lacerations in different parts or different lobes of the brain, these were counted as separate entries. Conversely, findings such as brain oedema, where present, were counted as one observation per subject.

More cases of brain compression or swelling, were diagnosed with PMCT (n = 3/7) (43%) compared to the forensic autopsies. More brain contusions (n = 8/0) (0%) brain lacerations (n = 2/11) (18%) and more cases of brain oedema (n = 5/11) (45%) were diagnosed with the

[6] In this context, brain compression or swelling, represented a compressed brain stem or cerebellum with or without tonsillar herniation, as identified by the forensic pathologists, or effacement or obliteration, of the ventricles on PMCT images of the brain.

forensic autopsies compared with PMCT. Unless small, SDH haemorrhages are relatively easy to diagnose on PMCT images. Surprisingly, only one SDH was diagnosed with PMCT (n = 1/6) (17%) compared with the forensic autopsy. There was an almost equal number of SAH (n = 6/7) (86%) diagnosed by the forensic autopsies and PMCT.

Following penetrating injury to the skull, a pneumocephalus can present inside the brain parenchyma, or between the outer surface of the brain and inner skull table. Understandably, PMCT diagnosed more pneumocephali (n = 0/13) (0%) compared to the forensic autopsy as this abnormality cannot readily be diagnosed with the forensic autopsy. More intracerebral haemorrhages (n = 5/7) (71%) and intraventricular haemorrhages (n = 2/8) (25%) were diagnosed with PMCT compared to the forensic autopsy. No EDH was diagnosed in any of the 30 research subjects by either the forensic autopsy or PMCT imaging.

Overall, the results show that the forensic autopsies diagnosed more injuries compared to PMCT in five of the nine injury types. The five injury types were brain contusions, brain lacerations, brain oedema, SAH and SDH. With PMCT imaging, more brain compressions or swelling, intracerebral haemorrhages, intraventricular haemorrhages, and pneumocephali were diagnosed compared to with forensic autopsies. A deeper analysis shows that the forensic autopsy and PMCT each diagnosed more injuries than the other in three of the six categories affecting the brain parenchyma.

Based on the interpretive scale for percent agreement Table 4.3, Chapter Four, there was moderate agreement (43%) between the forensic autopsy and PMCT for the diagnosis of brain compression or swelling; no agreement (0%) for brain contusion; very poor agreement (18%) for brain lacerations; and moderate agreement (45%) for brain oedema. For intracerebral haemorrhages, there was good agreement (71%) between the forensic autopsy and PMCT, but poor agreement (25%) for the diagnosis of intraventricular haemorrhages; very poor agreement (17%) for the diagnosis of SDH; very good agreement (86%) for SAH; and no agreement (0%) for the diagnosis of pneumocephali.

5.8.2 Skull and face

A total of 30 skull and facial injuries were diagnosed with the forensic autopsy compared to 49 with PMCT (n = 30/49) (61%). Skull and facial bone fractures are common radiographic and clinical

findings following trauma to the head. There were injuries of several different skull areas (including the base of skull) and facial bones amongst subjects. In this study, for the sake of simplicity, fractures of skull bones and base of skull were combined under one entity, namely, skull fractures. Overall, more skull fractures were diagnosed with PMCT compared with the forensic autopsy (n = 26/38) (68%). In addition, with PMCT, seven facial bones fractures (n = 0/7) (0%) were diagnosed, compared to zero with the forensic autopsy.

Based on the interpretive scale for percent agreement, there was perfect agreement (n = 4/4) (100%) between the forensic autopsy and PMCT for the diagnosis of skull bone diastasis; and good agreement (68%) for the diagnosis of skull fractures; but no agreement (0%) for facial bone fractures.

5.8.3 The scalp

A total of 15 scalp injuries were diagnosed with the forensic autopsy compared to one with PMCT (n = 1/15) (7%). With the forensic autopsy, more scalp injuries were diagnosed (n = 0/12) (0%) compared to those diagnosed with PMCT, as well as for subgaleal haemorrhages (n = 1/3) (33%). Based on the interpretive scale for percent agreement, for the scalp findings, there was no agreement (0%) between the forensic autopsy and PMCT for the diagnosis of scalp injuries; and there was poor agreement (33%) for subgaleal haemorrhages. The poor agreement was a result of only one subgaleal haemorrhage being diagnosed with PMCT.

5.8.4 Oral cavity and pharynx

Nine oral and pharyngeal injuries were diagnosed with the forensic autopsy compared to zero at PMCT (n = 0/9) (0%). More injuries were diagnosed with the forensic autopsy compared to PMCT in the case of the pharynx (n = 0/4) (0%) tongue (n = 0/3) (0%) and tonsils (n = 0/2) (0%). Based on the interpretive scale for percent agreement for this category, there was no agreement (0%) between the forensic autopsy and PMCT for any of these injuries, as none of were diagnosed with PMCT.

5.8.5 Neck structures

Only four injuries were recorded for neck structures. These included four recorded by the forensic autopsy compared to zero with PMCT (n = 0/4) (0%). The forensic autopsy diagnosed two lacerations of the carotid arteries (n = 0/2) (0%) and internal jugular veins (n = 0/2) (0%) compared to zero diagnosed with PMCT. All four of these injuries were the result of gunshots to the neck. Based on the interpretive scale for percent agreement, there was no agreement (0%) between the forensic autopsy and PMCT.

Table 5.3 Head and neck injuries diagnosed with the forensic autopsy and PMCT

Head & Neck	Injuries	FA (n =)	Combined score for PMCT (n =)	% agreement: FA vs PMCT
Intracranial	Brain compression/ swelling	3	7	43%
	Brain contusion	8	0	0%
	Brain laceration	11	2	18%
	Brain oedema	11	5	45%
	Intracerebral haemorrhage	5	**7**	**71%**
	Intraventricular haemorrhage	2	8	25%
	Pneumocephalus	0	13	0%
	SAH	7	**6**	**86%**
	SDH	6	1	17%
	Sub-total	**53**	**49**	**92%**
Extracranial	Haemorrhage optic nerves	2	0	0%
	Injury parotid glands	2	0	0%
	Sub-total	**4**	**0**	**0%**
Skull & face	Diastasis skull bones	4	**4**	**100%**
	Fracture facial bones	0	7	0%
	Fracture skull bones (including skull base)	26	**38**	**68%**
	Sub-total	**30**	**49**	**61%**

Scalp	Subgaleal haemorrhage	3	1	33%
	Injury scalp	12	0	0%
	Sub-total	**15**	**1**	**7%**
Oral cavity & pharynx	Injury pharynx	4	0	0%
	Injury tongue	3	0	0%
	Injury tonsils	2	0	0%
	Sub-total	**9**	**0**	**0%**
Neck	Laceration: carotid artery	2	0	0%
	Laceration: internal jugular vein	2	0	0%
	Sub-total	**4**	**0**	**0%**
	Total	**115**	**99**	**86%**

FA = Forensic autopsy

5.9 NUMBER AND TYPE OF INJURIES DIAGNOSED WITH THE FORENSIC AUTOPSY AND PMCT IN THE THORAX

The majority of injuries diagnosed amongst the 30 subjects occurred within the thorax, mostly affecting the lungs and heart. The injuries were grouped into seven sub-categories, as reflected in Table 5.4. There was a large variation in the number and type of injuries diagnosed between the forensic autopsy and PMCT for this anatomical region. A total of 75 injuries and some other abnormalities within the lungs and airways were recorded by the forensic autopsy compared to 15 with PMCT (n = 15/75) (20%). It is further evident that the PMCT diagnosed significantly fewer injuries involving the heart (n = 6/16) (38%), mediastinum (n = 0/8) (0%) and diaphram (n = 0/2) (0%). An equal number of injuries were diagnosed within the thoracic cage (n = 34/34) (100%) whilst more injuries involving the pleural cavity were diagnosed with PMCT (n = 17/38) (45%).

5.9.1 Lungs and airways

A deeper analysis shows that with the forensic autopsy more parenchymal injuries of the lungs were diagnosed compared to PMCT. As can be noted in Table 5.4, lung parenchymal injuries diagnosed included lung haemorrhages (n = 1/14) (7%) lung injury (n = 6/27) (22%) and lung

congestion (n = 0/9) (0%) (the latter considered as lung abnormalities). Lung injuries in this study represented lung damage due to any perforating or penetrating injury, laceration, and cavities caused by gunshot wounds or localised lung contusion.

Even though lung collapse is easily discernible on PMCT, the forensic autopsy diagnosed one more case (n = 5/6) (83%) compared to PMCT. Based on the interpretive scale for percent agreement, there was very good agreement (83%) between the forensic autopsy and PMCT for the diagnosis of lung collapse; poor agreement (33%) for subpleural bleb and lung atelectasis (25%). For the rest of the injury types involving the lung and major airways, there was either no, or very poor agreement between the forensic autopsy and PMCT.

5.9.2 Heart, mediastinum and large blood vessels

A total of 16 injuries and other abnormalities were diagnosed with the forensic autopsy within the heart compared to 6 with PMCT (n = 6/16 (38%). There were eight injuries (n = 0/8) (0%) diagnosed within the mediastinum and four injuries (n = 0/4) (0%) of the major blood vessels at the forensic autopsy compared to zero with PMCT. With respect to injuries of the heart, more heart haemorrhages (n = 2/8) (25%) were diagnosed with the forensic autopsies compared with PMCT. The eight heart haemorrhages were grouped together due to the small number observed: there were four haemopericardiums, one focal haemorrhage, and three petechial haemorrhages of the heart muscle. Similarly, more heart lacerations were diagnosed with the forensic autopsies (n = 0/5) (0%) and mediastinal haemorrhage (n = 0/7) (0%) compared to PMCT. The five heart lacerations consisted of four pericardial sac lacerations, and one interventricular septum laceration. All heart lacerations in this study occurred as a result of gunshot injuries. Two heart valve perforations (n = 0/2) (0%) diagnosed with the forensic autopsy were missed with PMCT. More heart displacements (also known as mediastinal shift) were diagnosed with PMCT (n = 1/4) (25%) compared to the forensic autopsies. Two perforations to the thoracic aorta (n = 0/2) (0%) one perforation each of the superior pulmonary artery (n = 1 vs 0 = 0%) and superior vena cava (n = 0/1) (0%) diagnosed with the forensic autopsies, were not seen with PMCT.

Based on the interpretive scale for percent agreement, there was poor agreement (25%) between the forensic autopsy and PMCT for the diagnosis of heart displacement and heart haemorrhages (25%); and no agreement (0%) for heart lacerations, heart valve perforations and perforations of the thoracic aorta, superior pulmonary artery and superior vena cava.

5.9.3 Pleural cavity

A total of 17 findings were diagnosed within the pleural cavity by the forensic autopsy compared to 38 with PMCT (n = 17/38) (45%). In this study, haemothoraces and pneumothoraces were all a consequence of penetrating trauma to the lungs and pleura. Overall, for the three injury types involving the pleural cavity, more injuries were diagnosed with PMCT than the forensic autopsy. Significantly more pneumothoraces (n = 3/20) (15%) and one more haemothorax (n = 11/12) (92%) and more pleural effusions were diagnosed with PMCT (n = 3/6) (50%) compared with the forensic autopsy. Based on the interpretive scale for percent agreement, there was very good agreement (92%) between the forensic autopsy and PMCT for the diagnosis of haemothoraces; moderate agreement (50%) for pleural effusions; and very poor agreement (15%) for diagnosis of pneumothoraces.

5.9.4 Thoracic cage

A total of 34 injuries to the thoracic cage were diagnosed with both the forensic autopsy and PMCT (n = 34/34) (100%). One more rib fracture (n = 32/33) (97%) was diagnosed with the forensic autopsy than with PMCT. One more fracture of the sternum (n = 1/2) (50%) was diagnosed with PMCT. Based on the interpretive scale for percent agreement, there was very good agreement (97%) between the forensic autopsy and PMCT for the diagnosis of rib fractures and moderate agreement (50%) for the diagnosis of sternal fractures.

5.9.5 The diaphragm

Two diaphragmatic contusions were diagnosed with the forensic autopsy compared to zero with PMCT (n = 0/2) (0%). The diaphragm was injured in two subjects following blunt trauma to the thorax and abdomen, and one case following physical abuse. Based on the interpretive scale for percent agreement, there was no agreement (0%) between the forensic autopsy and PMCT for the diagnosis of diaphragmatic contusions.

Table 5.4 Thoracic injuries/findings diagnosed with the forensic autopsy and PMCT

Thorax	Injuries	FA (n =)	Combined score for PMCT (n =)	% agreement FA vs PMCT
Lungs and airways	Traumatic aspiration: Blood	8	1	13%
	Traumatic aspiration: Gastric content	3	0	0%
	Bronchus injury	1	0	0%
	Haemorrhage lung	14	1	7%
	Lung atelectasis	4	1	25%
	Lung collapse	6	**5**	**83%**
	Lung congestion	9	0	0%
	Lung injury	27	6	22%
	Subpleural bleb	3	1	33%
	Sub-total	**75**	**15**	**20%**
Pleural cavity	Haemothorax	11	**12**	**92%**
	Pleural effusion	3	6	50%
	Pneumothorax	3	20	15%
	Sub-total	**17**	**38**	**45%**
Heart	Displacement of heart	1	4	25%
	Haemorrhage heart	8	2	25%
	Laceration heart	5	0	0%
	Perforation heart valve	2	0	0%
	Sub-total	**16**	**6**	**38%**
Major blood vessels	Perforation thoracic aorta	2	0	0%
	Perforation superior pulmonary artery	1	0	0%
	Perforation superior vena cava	1	0	0%

	Sub-total	**4**	**0**	**0%**
Mediastinum	Haemorrhage mediastinum	7	0	0%
	Haemorrhage thymus	1	0	0%
	Sub-total	**8**	**0**	**0%**
Thoracic cage	Fracture rib	33	**32**	**97%**
	Fracture sternum	1	2	50%
	Sub-total	**34**	**34**	**100%**
Diaphragm	Diaphragm contusion	2	0	0%
	Sub-total	**2**	**0**	**0%**
	Total	**156**	**93**	**60%**

FA = Forensic autopsy

5.10 NUMBER AND TYPE OF INJURIES DIAGNOSED WITH THE FORENSIC AUTOPSY AND PMCT IN THE ABDOMEN AND PELVIS

Injuries affecting anatomical organs and other structures within the abdominal cavity were divided into four sub-categories, as seen in Table 5.5. Injuries affecting the pelvis were divided into two sub-categories. A higher number of injuries within the abdomen and pelvis (n = 17/32) (53%) were diagnosed with the forensic autopsies, compared to PMCT. As for the injuries of the thorax, there was also a large variation between the injury findings observed during the forensic autopsy and PMCT for this anatomical region.

5.10.1 Solid abdominal organs

A total of 14 injuries to the solid abdominal organs were diagnosed with the forensic autopsy compared to two with PMCT (n = 2/14) (14%). All injuries to solid abdominal organs within this study involved the parenchyma of adrenal glands, spleen, pancreas, kidney and liver. More liver lacerations (n = 1/4) (25%) were diagnosed during the forensic autopsies than with PMCT. In the trauma setting, injuries to the pancreas are usually well seen. In this study, however, three injuries of the pancreas (n = 0/3) (0%) diagnosed with the forensic autopsy were not seen with PMCT. Injuries to the stomach are not usually well demonstrated with CT. PMCT showed a low diagnostic

yield for abdominal solid organ injuries which is congruent with the low diagnostic yield for solid thoracic organ injuries. Based on the interpretive scale for percent agreement, there was moderate agreement (50%) between the forensic autopsy and PMCT for the diagnosis of one kidney injury, and poor agreement (25%) for liver lacerations. There was no agreement (0%) between these two examinations for injuries to the adrenal glands, pancreas and spleen respectively, with the forensic autopsy having diagnosed injuries in all these organs.

5.10.2 Abdominal and pelvic hollow organs

A total of eight hollow abdominal organ injuries were diagnosed with the forensic autopsy compared to zero with PMCT (n = 0/8) (0%). In this study, injuries to the duodenum and bladder, were the consequence of physical abuse in two male infants. The forensic autopsy diagnosed two injuries (n = 0/2) (0%) to the stomach, three in the duodenum (n = 0/3) (0%) and bladder (n = 0/3) (0%) respectively which were not diagnosed with PMCT. Based on the interpretive scale for percent agreement, there was no agreement (0%) between the forensic autopsy and PMCT for the diagnosis of any of the hollow abdominal or pelvic organ injuries.

5.10.3 Peritoneal cavity

Only three peritoneal cavity abnormalities were diagnosed with the forensic autopsy compared to nine with PMCT (n = 3/9) (33%). This finding is congruent with the findings of the thorax and diaphragm, where PMCT diagnosed more injuries within the pleural cavities. Based on the interpretive scale for percent agreement, there was perfect agreement (n = 3/3) (100%) between PMCT and the forensic autopsy for the diagnosis of haemoperitoneum, and no agreement (n = 0/3) (0%) for pneumoperitoneum and ascites respectively. Understandably, pneumoperitoneum is not diagnosable during the forensic autopsy and could explain the lower percent agreement for this radiological diagnosis.

5.10.4 Bony pelvis

A total of three injuries to the bony pelvis were diagnosed with the forensic autopsy compared to six with PMCT (n = 3/6) (50%). The pelvis was the least injured anatomical region for all subjects.

One fracture to the ischium was diagnosed with both the forensic autopsy and PMCT (n = 1/1) (100%). One more fracture of the symphysis pubis (n = 1/2) (50%) was diagnosed with PMCT than with the forensic autopsy. One hip dislocation (n = 0/1) (0%) was diagnosed during one forensic autopsy not seen with PMCT. One fracture of the ilium (n = 0/1) (0%) was diagnosed with PMCT but not with the forensic autopsy. One subject presented with three superficial soft tissue injuries of the penis and anus (n = 0/3) (0%) all of which were diagnosed during the forensic autopsy, but not with PMCT. All three of these superficial injuries were a result of physical abuse. Based on the interpretive scale for percent agreement, there was moderate agreement (50%) between the forensic autopsy and PMCT injuries involving the bony pelvis, but no agreement (0%) for superficial injuries involving the genitals.

Table 5.5 Abdominal and pelvic injuries diagnosed with the forensic autopsy and PMCT

Abdomen	Injuries	FA (n =)	Combined score for PMCT (n =)	% agreement FA vs PMCT
Solid abdominal organs	Injury: adrenal gland	3	0	0%
	Injury: kidney	2	1	50%
	Injury: pancreas	3	0	0%
	Injury: spleen	2	0	0%
	Laceration liver	4	1	25%
	Sub-total	**14**	**2**	**14%**
Hollow abdominal and pelvic organs	Bladder injuries	3	0	0%
	Duodenum contusion	3	0	0%
	Stomach contusion	2	0	0%
	Sub-total	**8**	**0**	**0%**
Peritoneal cavity	Ascites	0	3	0%
	Haemoperitoneum	3	**3**	**100%**
	Pneumoperitoneum	0	3	0%
	Sub-total	**3**	**9**	**33%**

Major blood vessels	Perforation abdominal aorta	1	0	0%
	Sub-total	**1**	**0**	**0%**
Pelvis	**Injuries**	**FA (n =)**	**Combined score for PMCT (n =)**	**% agreement FA vs PMCT**
Bony pelvis	Fracture acetabulum	0	1	0%
	Fracture ischium	1	**1**	**100%**
	Fracture symphysis pubis	1	2	50%
	Fracture ilium (involving SI joint)	0	1	0%
	Hip dislocation	1	0	0%
	Morel-Lavelée lesion[7]	0	1	0%
	Sub-total	**3**	**6**	**50%**
Genitals	Injury: genitals superficial	3	0	0%
	Sub-total	**3**	0	0%
	Total	**32**	**17**	**53%**

FA = Forensic autopsy

5.11 NUMBER AND TYPE OF INJURIES DIAGNOSED WITH THE FORENSIC AUTOPSY AND PMCT IN THE SPINAL COLUMN AND SPINAL CORD

A total of five injuries to the spinal column were diagnosed with the forensic autopsy compared to 10 with PMCT (n = 5/10) (50%). Injuries to the spinal column and cord were divided into four sub-categories (see Table 5.6). After the pelvis, this anatomical region presented with second lowest number of injuries. More spinal fractures (n = 5/10) (50%) were diagnosed with PMCT than with the forensic autopsy. More fractures were diagnosed within the thoracic spine (n = 3/7) (43%) than

[7] Morel-Lavelée is a closed traumatic soft tissue, degloving injury where the hypodermis is separated from the underlying fascia following a shearing force to soft tissue (Scolaro, Chao & Zamorano, 2016).

the rest of the spinal column. The thoracic spinal fractures were all the result of gunshot injuries to the thorax and are directly associated with the higher number of injuries observed within the thorax.

Three spinal cord transections were diagnosed with the forensic autopsy compared to one with PMCT (n = 1/3) (33%). One spinal cord transection was diagnosed with PMCT and the forensic autopsy in the same subject and involved the spinal cord at cervical vertebra 1 level. Based on the interpretive scale for percent agreement, there was moderate agreement (50%) between the forensic autopsy and PMCT for the diagnosis of spinal column injuries; and poor agreement (33%) for spinal cord transections.

Table 5.6 Spinal column and spinal cord injuries diagnosed with the forensic autopsy and PMCT

Spinal column	Injuries	FA (n =)	Combined score PMCT (n =)	% agreement FA vs PMCT
Cervical spine	Cervical spine 1 fracture (C1)	0	1	0%
	Cervical spine dislocation (C1)	1	0	0%
	Cervical spine 2 fracture (C2)	0	2	0%
Lumbar spine	Lumbar spine	1	0	0%
Thoracic spine	Thoracic spine	3	7	43%
	Sub-total	**5**	**10**	**50%**
Spinal cord	Spinal cord transection	3	1	33%
	Sub-total	**3**	**1**	**33%**
	Total	**8**	**11**	**73%**

FA = Forensic autopsy

5.12 NUMBER AND TYPE OF INJURIES DIAGNOSED WITH THE FORENSIC AUTOPSY AND PMCT IN THE EXTREMITIES

A total of 11 upper extremity fractures were diagnosed with the forensic autopsy compared to nine with PMCT (n = 9/11) (82%). Four lower extremity fractures were diagnosed with the forensic autopsy compared to five with PMCT (n = 4/5) (80%) as can be appreciated in Table 5.7. The

overall agreement between the forensic autopsy and PMCT for all extremity fractures was 93% (n = 14/15). Extremity fractures are a common occurrence in physically abused children, gunshot injuries, or RTA. Scapular fractures are rare in children (Paddock et al., 2017). In this study, two scapular fractures were diagnosed in a gunshot victim, and one diagnosed in a physically abused child.

Table 5.7 Extremity injuries diagnosed with the forensic autopsy and PMCT

Extremities	Injuries	FA (n =)	Combined score for PMCT (n =)	% agreement FA vs PMCT
Upper extremity	Humerus fracture	3	**4**	**75%**
	Metacarpal fracture	2	**0**	0%
	Scapula fracture	2	**3**	**67%**
	Radius fracture	3	**2**	**67%**
	Ulna fracture	1	0	0%
	Sub-total	**11**	**9**	**82%**
Lower extremity	Fibula fracture	1	**1**	**100%**
	Metatarsal fracture	1	2	50%
	Tibial fracture	2	**2**	**100%**
	Sub-total	**4**	**5**	**80%**
	Total	**15**	**14**	**93%**

FA = Forensic autopsy

The extremity fractures diagnosed during the forensic autopsies included those that were diagnosed during physical inspection of the body and with the LODOX® system or conventional projection radiography. Based on the interpretive scale for percent agreement, there was very good agreement (82% and 80%) between the forensic autopsy and PMCT for the diagnosis of upper and lower extremity fractures respectively. When comparing the overall number of extremity fractures identified, there was an almost perfect agreement (93%) between the forensic autopsy and PMCT for this injury diagnosis.

5.13 MISCELLANEOUS INJURIES

Some injuries diagnosed with both the forensic autopsies and PMCT could not be categorised under any of the anatomical regions previously discussed (see Table 5.8). A total of 22 miscellaneous injuries and other abnormalities were diagnosed with the forensic autopsy compared to seven with PMCT (n = 7/23) (30%). A total of 12 retained bullets were identified with both the forensic and PMCT (n = 12/12) (100%).

Six cases of soft tissue oedema (n = 1/6) (17%) were diagnosed during the forensic autopsies compared to one with PMCT. Similarly, more muscle injuries (mostly haemorrhages into muscle tissue) (n = 1/4) (25%) were diagnosed with the forensic autopsy compared with PMCT. More skin injuries (n = 5/9) (56%) were diagnosed with the forensic autopsy compared to PMCT. Skin injuries represented injuries such as disruption of the skin surface (diagnosed with PMCT) or skin damage following GSW diagnosed during the forensic autopsies. For the purposes of this study, skin abrasions were not counted as these are not diagnosable with PMCT. Based on the interpretive scale for percent agreement, there was moderate agreement (56%) between the forensic autopsy and PMCT for the diagnosis of skin injuries; poor agreement (25%) for muscle injuries and very poor agreement (17%) for soft tissue oedema; and no agreement (0%) for soft tissue haemorrhages.

5.14 NON-COMPARATIVE FINDINGS

There were three sub-categories for which a direct comparison could not be made between the forensic autopsy and PMCT. This was due to these diagnoses being made by only one of the two examinations (see Table 5.8). PMCT diagnosed a total of 26 cases of air in blood vessels, which was thought to be the result of putrefaction. Understandably, these cases were not recorded during the forensic autopsy reports. However, an air collection presented in the ventricle of one subject; was based on the PMCT findings considered to be an air embolism. This case is later highlighted in Figure 6.13 in Chapter Six.

Another non-comparative finding was that of subcutaneous emphysema (surgical emphysema) which is well seen on PMCT imaging. This can be the consequence of underlying soft tissue damage following penetrating trauma or putrefaction. A total of 23 cases of subcutaneous emphysema were diagnosed with PMCT, but not diagnosed during any of the forensic autopsies. Conversely, a total of 81 cases of organ pallor were diagnosed with the forensic autopsy amongst

the 30 subjects. Pallor of organs was either the result of exsanguination or shock. Pallor of organs, which is a critical finding in forensic autopsies, is not identifiable with PMCT, hence a comparison could not be drawn for these findings (but is a critical consideration when comparing the two examinations).

Table 5.8 Miscellaneous injuries diagnosed with the forensic autopsy and PMCT

Miscellaneous (4)	**FA (n =)**	**Combined score for PMCT (n =)**	**% agreement: FA vs PMCT**
Haemorrhage soft tissue	3	0	0%
Skin injuries	9	5	56%
Muscle injury	4	1	25%
Oedema soft tissue	6	1	17%
Total	**22**	**7**	**32%**
Non-comparative findings	**FA (n =)**		
Air blood vessels	1	26*	-
Pallor organs	81	0*	-
Subcutaneous emphysema	0	23*	-
Foreign bodies	**FA (n)**	-	-
Retained bullet	12	12	**100%**

FA = Forensic autopsy
* Percent agreement not calculated for these findings

With relative ease, PMCT is able to identify bullets or shrapnel following gunshot injuries. In this study, 12 bullets were retrieved from the 11 subjects who sustained fatal gunshot injuries, while 12 retained bullets were diagnosed on PMCT images by both reviewers, resulting in very good agreement between these two examinations.

5.15 CHAPTER SUMMARY

The results of this study showed that 80% of subjects included in this study were males with a mean age of 6,2 years for all subjects combined. A total of 87% of subjects were scanned within two days after admission to the SRFPS rendering the PMCT image quality diagnostic for radiological interpretation. The forensic autopsy recorded 348 findings (mostly injuries) compared to 241 identified with PMCT. PMCT showed an 86% (n = 99/115) agreement for injuries identified within the head and neck, 60% (n = 93/156) for the thorax, 53% (n = 17/32) for the abdomen and pelvis, 93% (n = 14/15) extremities and 32% (n = 7/22) in the miscellaneous category. The forensic autopsy had a 73% (n = 8/11) agreement with PMCT for spinal column and spinal cord injuries. The next chapter described the results as it relates to the remaining three objectives of this study.

CHAPTER SIX

RESULTS: PART 2

6.1 CHAPTER INTRODUCTION

This chapter continues with a presentation of the results of the study relative to the following three research objectives: the discordance between PMCT and the forensic autopsy for injury categories diagnosed; under which circumstances PMCT can accurately establish the cause of death; and whether selected cases can undergo PMCT in the absence of the forensic autopsy. Furthermore, this chapter compares the cause of death categories assigned by the forensic autopsy and PMCT for all subjects. The chapter continues further with a description of the number of significant injuries seen with PMCT, supported with cross-sectional images for some, as well as those significant injuries not seen within the five anatomical regions as described. The chapter ends with a description of the number of supplementary examinations employed during the forensic autopsies, factors impacting on PMCT image quality including image artefacts, as well as incidental findings identified with both examinations.

6.2 DISCORDANCE BETWEEN PMCT AND THE FORENSIC AUTOPSY FOR INJURY CATEGORIES DIAGNOSED

This section describes the results related to the second objective which set out to compare the discordance between the forensic autopsy and PMCT for injury categories diagnosed. Discordance in this section will refer to those injuries/abnormalities identify with one examination, but not by the other. The injury types described earlier were further grouped into similar categories. For example, pneumothoraces, pneumoperitoneum and pneumocephalus were grouped under the category of gas collections. Similarly, all extremity and spinal fractures diagnosed within the skeleton were grouped under skeletal injuries. A total of nine injury categories were compiled. These are displayed in Figure 6.1 below. A detail breakdown of the number of discrepant findings across the nine categories for both examinations can be found in Addendum B1. Addendum B2 provides a detailed breakdown of the discrepant findings with respect to the number of injury types not diagnosed by the two examinations across the nine injury categories.

6.2.1 Injury categories not diagnosed with the forensic autopsy

Figure 6.1 visually presents the number of injury types not diagnosed by the forensic autopsy and PMCT for each injury category. The forensic autopsy performed better than PMCT in seven of the nine categories compiled. Of the nine injury categories, the forensic autopsy did not diagnose all injuries in five of the nine categories (Addendum B1). As evident in this bar graph, the most common injuries not diagnosed with the forensic autopsy were gas collections (n = 33), followed by skeletal (n = 33), haemorrhagic injuries (n = 8), fluid collections (n = 7) and solid organ injuries (n = 7) respectively.

Under the category of gas collection, the forensic autopsy did not diagnose the following injuries: pneumothoraces (n = 17), pneumocephalus (n = 13) and pneumoperitoneum (n = 3). The second highest number of injuries not diagnosed with the forensic autopsy were skeletal injuries (n = 33). These injuries comprised skull (n = 12) and facial bone fractures (n = 7), whilst a small number of thoracic vertebrae fractures (n = 4) and others were also not diagnosed.

The fluid collections not diagnosed with the forensic autopsies included ascites (n = 3), pleural effusions (n = 3) and a haemothorax (n = 1). The haemorrhagic injuries not diagnosed with the forensic autopsy included intraventricular cerebral haemorrhages (n = 6) and intracerebral parenchymal haemorrhages (n = 2).

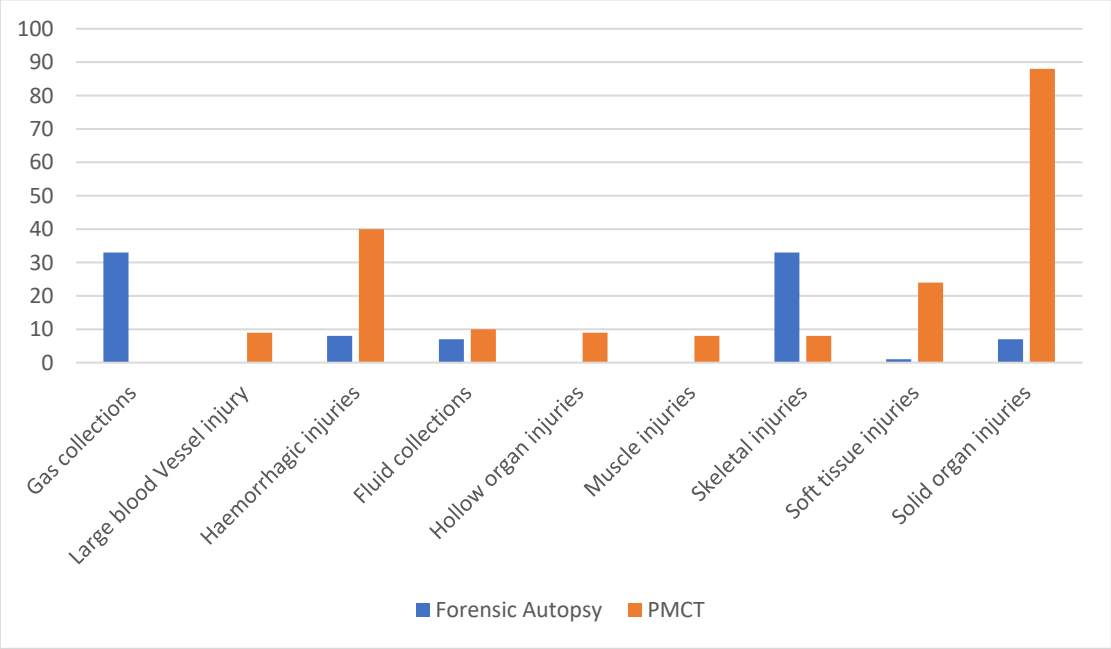


Figure 6.1 Number of injuries not diagnosed with forensic autopsy and PMCT per injury category

6.2.2 Injury categories not diagnosed with PMCT

PMCT did not diagnose all injuries in eight of the nine categories. As can be appreciated from Figure 6.1, The highest number of injuries not diagnosed with PMCT were solid organ injuries (n = 88) which inter alia, included lung injuries (n = 21), brain lacerations (n = 9), lung congestion (n = 9), brain contusions (n = 8), brain oedema (n = 6) and laceration of the heart (n = 5). The majority of the brain lacerations were caused by GSW. Addendum B2 provides a comprehensive breakdown of the injury types not diagnosed with this imaging modality.

The second highest number of injuries not diagnosed with PMCT were haemorrhagic (n = 40) which included, inter alia, haemorrhage of the lungs (n = 13), mediastinal haemorrhage (n = 7), heart muscle (n = 6), SDH (n = 5), as well as a small number of other haemorrhagic-related injuries.

The third highest number of injuries not diagnosed with PMCT was soft tissue injuries (n = 24) which included scalp injuries (n = 12), soft tissue oedema (n = 5), pharynx (n = 4) and superficial injuries of the genitals (n = 3). A total of eight muscle injuries were also not diagnosed with PMCT, which included the sterno-hyoid (n = 1) sterno-thyroid muscle (n = 1), sterno-cleidomastoid muscle (n = 1), contusion of the diaphragm, (n = 2), injuries to the tongue (n = 3).

The ten fluid collections not diagnosed with PMCT included traumatic aspiration of blood (n = 7) and aspiration of gastric content (n = 3) into the major airways. A number of large blood vessel injuries (n = 9) were also not diagnosed with PMCT. These injuries included perforation of the aorta (n = 3) carotid artery (n = 2) internal jugular vein (n = 2) superior vena cava (n = 1) as well as the superior pulmonary artery (n = 1). A total of nine hollow organ injuries not diagnosed with PMCT, included contusion of the duodenum (n = 3), bladder injury (n = 3), contusion of the stomach (n = 2) and one bronchus (n = 1). Other injuries not diagnosed with PMCT are displayed in Addendum B2.

6.3 THE ACCURACY OF PMCT TO ESTABLISH A CAUSE OF DEATH

One of the main functions of a forensic autopsy is to determine the cause of death. The third objective of this research study was to ascertain whether PMCT can be used with confidence to establish the cause of death. In addition to determining the type of injuries sustained, the reviewers were based on the PMCT findings, asked to provide a cause of death for each subject. The results related to this objective were thus derived from the causes of death assigned by the forensic

pathologists during the forensic autopsies, as well as the two PMCT reviewers. The cause of death ratings for the PMCT reviewers are reported here separately. The autopsy identified a total of 11 causes of death categories (see Table 6.1).

The first section that follows describes the level of agreement for the cause of death between the forensic autopsy and Reviewers 1 and 2. The second section describes the level of agreement, based on the Cohen Kappa statistic for cause of death agreement, between the forensic autopsy and PMCT, including the confidence intervals for all three comparisons. These results are also reported individually.

The cause of death classifications of the forensic autopsies was used as the reference standard against which PMCT's agreement to determine the cause of death was measured. The reason for this was because of the forensic autopsy's ability to establish the cause of death with a high degree of certainty, and no false positives could be assumed.

Addendum B3 provides a comprehensive overview of all the cause of death categories, as attributed during the forensic autopsies, as well as those assigned by Reviewers 1 and 2 respectively.

The cause of death rating was separated into three broad categories of natural, unnatural and unknown deaths, as can be appreciated in Table 6.1. In this table the percent agreement between the forensic autopsy and Reviewers 1 and 2, for each of the cause of death categories, are shown within parenthesis. The overall level of agreement for assigning the CoD with PMCT for all three categories was 70% (n = 21/30) and 67% (n = 20/30) for Reviewers 1 and 2 respectively (mean 69%). For unnatural CoD's the percent agreement between the forensic autopsy and Reviewers 1 and 2 was higher at 82% (n = 18/22) and 77% (n = 17/22) respectively (mean 80%). Assigning a CoD with PMCT for traumatic deaths showed a higher percent agreement with the forensic autopsy. Reviewers 1 and 2 had a 90% (n = 18/20) an 85% (n = 17/20) percent agreement with the forensic autopsy respectively (mean 88%) (Speelman et al., 2022).

The cause of death category with the highest number of recordings at the forensic autopsy was gunshot injuries. This number is directly related to the number of subjects admitted for fatal gunshot injuries. The percent agreement for the cause of death rating between the forensic autopsy and both Reviewers 1 and 2 for gunshot injuries was very good at 91% (n = 9/11) (see Table 6.1). The next highest cause of death category at the forensic autopsy was that of blunt force head injury. For this category, there was a 100% (n = 6/6) agreement between the forensic

autopsy and both Reviewers 1 and 2 (Speelman et al., 2022). One subject was diagnosed during the forensic autopsy as having succumbed due to physical abuse. There was perfect agreement 100% (n = 1/1) between the forensic autopsy and both Reviewers 1 and 2 for this category, having assigned physical abuse as the cause of death for the same subject. There was perfect agreement (100%) (n = 1/1) between the forensic autopsy and reviewer 1 for severe abdominal and pelvic injuries as both the forensic pathologist and reviewer 1 considered this to be the cause of death for the subject concerned. The abdominal and pelvic injuries for this subject were the result of physical abuse in a three-year-old male (Speelman et al., 2022).

According to the forensic autopsies, five subjects succumbed to natural disease. Three of these subjects were diagnosed with pneumonia, one hypothermia and one mucolipidosis. An unknown cause of death was assigned by both reviewers for all five cases resulting in a 0% agreement with the forensic autopsy (Speelman et al., 2022).

No cause of death could be established with the forensic autopsy in three subjects admitted with an initial manner of death classification of concealment of birth (n = 2), and suffocation (n = 1). For these three unknown causes of death there was 100% agreement (n = 3/3) between the forensic autopsy and both reviewers (Speelman et al., 2022). In addition to the above stated unknown cases, both reviewers assigned an unknown cause of death in the following additional cases: haemorrhage from an unclamped umbilical cord (n = 1), hyperthermia (n = 1) and asphyxia (n = 1). Reviewer 2 could not assign a cause of death for one additional participant with severe abdominal and pelvic injuries (n = 1). See highlighted text in Addendum B3. An incorrect cause of death was assigned by Reviewers 1 and 2 in the same subject (Addednum B3: Subject 16) as a tension haemo-pneumothorax and fatal stab wound respectively. This subject was assigned a cause of death with the forensic autopsy as gunshot injury (Speelman et al., 2022).

In this study, one subject succumbed to hyperthermia which was considered an unnatural death caused by supervisory neglect. This subject disappeared for half an hour and was found locked in the boot of an abandoned car, which exposed the victim to excessive temperatures.

Table 6.1 Cause of death assigned with forensic autopsy and PMCT for all subjects

Cause of death category according to forensic autopsy	Cause of death: Reviewer 1: n (%)	Cause of death: Reviewer 2: n (%)
Unnatural cause of death category (n = 22)		
Asphyxia (n = 1)	0 (0%)	0 (0%)
Blunt force head injury (n = 6)	6 (100%)	6 (100%)
Gunshot injury (ies) (n = 11)	10 (91%)	10 (91%)
Haemorrhage from an unclamped umbilical cord (n = 1)	0 (0%)	0 (0%)
Hyperthermia (n = 1)	0 (0%)	0 (0%)
Physical abuse (n = 1)	1 (100%)	1 (100%)
Severe abdominal and pelvic injuries (Physical abuse) (n = 1)	1 (100%)	0 (0%)
Totals: Unnatural Deaths	**18/22 (82%)**	**17/22 (77%)**
Natural cause of death category (n = 5)		
Gastroenteritis (n = 1)	0 (0%)	0 (0%)
Mucolipidosis (n = 1)	0 (0%)	0 (0%)
Pneumonia (n = 3)	0 (0%)	0 (0%)
Totals: Natural deaths	0/5 (0%)	0/5 (0%)
Unknown cause of death category (n = 3)		
Unknown cause of death (n = 3)	***3 (100%)**	***3 (100%)**
False negative PMCT cause of death's assigned as unknown		
Unknown (include 5 natural and 4 unnatural deaths)	**8**	**9**
Incorrect cause of death assigned with PMCT		
Tension haemopneumothorax	**1**	-
Fatal stab	-	**1**
Overall cause of death agreement	**21/30 (70%)**	**20/30 (67%)**

Values within parentheses indicate percent agreement between reviewers and the forensic autopsy
** Cause of death correctly assigned as unknown in the same subject as with the forensic autopsy*
Speelman et al., 2022. Reproduced with permission from Springer Nature

The Cohen Kappa statistic (k) was calculated to compare interrater reliability for the cause of death rating between the forensic autopsy and the two PMCT reviewers. Table 6.2 illustrates the crosstabulations showing the cause of death rating between the forensic autopsy and reviewer 1. These crosstabulations were used to calculate the Cohen Kappa statistic for their interrater reliability.

Table 6.2 Cross tabulation showing cause of death rating between the forensic autopsy and reviewer 1.

Forensic Autopsy * Reviewer1 Crosstabulation								
		Reviewer1						Total
		Blunt abdominal trauma	Blunt force head injury	Child abuse (physical)	Gunshot injuries	Unknown	Tension haemo-pneumothorax	
Forensic Autopsy	Asphyxia- smothering.	0	0	0	0	1	0	1
	Blunt abdominal trauma	1	0	0	0	0	0	1
	Blunt force head injury	0	6	0	0	0	0	6
	Child abuse (physical)	0	0	1	0	0	0	1
	Gastro-enteritis	0	0	0	0	1	0	1
	Gunshot injuries	0	0	0	10	0	1	11
	Haemorrhage from unclamped umbilical cord.	0	0	0	0	1	0	1
	Hyperthermia	0	0	0	0	1	0	1
	Mucolipidosis	0	0	0	0	1	0	1
	Pneumonia	0	0	0	0	3	0	3
	Unknown	0	0	0	0	3	0	3
Total		1	6	1	10	11	1	30

Table 6.3 illustrates the crosstabulations for the cause of death rating between the forensic autopsy and reviewer 2.

Table 6.3 Cross tabulation showing cause of death rating between the forensic autopsy and reviewer 2.

Forensic Autopsy * Reviewer2 Crosstabulation							
		Reviewer2					Total
		Blunt force head injury	Child abuse (physical)	Gunshot injuries	Unknown	Fatal stab wound	
Forensic Autopsy	Asphyxia-smothering.	0	0	0	1	0	1
	Blunt abdominal trauma	0	0	0	1	0	1
	Blunt force head injury	6	0	0	0	0	6
	Child abuse (physical)	0	1	0	0	0	1
	Gastro-enteritis	0	0	0	1	0	1
	Gunshot injuries	0	0	10	0	1	11
	Haemorrhage from unclamped umbilical cord.	0	0	0	1	0	1
	Hyperthermia	0	0	0	1	0	1
	Mucolipidosis	0	0	0	1	0	1
	Pneumonia	0	0	0	3	0	3
	Unknown	0	0	0	3	0	3
Total		6	1	10	12	1	30

Table 6.4 illustrates the crosstabulations for the cause of death rating between reviewer 1 and reviewer 2.

Table 6.4 Cross tabulation showing cause of death rating between Reviewers 1 and 2.

Reviewer1 * Reviewer2 Crosstabulation							
Count							
		Reviewer2					Total
		Blunt force head injury	Child abuse (physical)	Gunshot injuries	Unknown	Fatal stab wound	
Reviewer1	Blunt abdominal trauma	0	0	0	1	0	1
	Blunt force head injury	6	0	0	0	0	6
	Child abuse (physical)	0	1	0	0	0	1
	Gunshot injuries	0	0	10	0	0	10
	Unknown	0	0	0	11	0	11
	Tension haemo-pneumothorax	0	0	0	0	1	1
Total		6	1	10	12	1	30

The Cohen Kappa statistic (red circle in Table 6.5) for the cause of death interrater reliability (also known as inter-observer agreement) between forensic autopsy and reviewer 1 was k = 0,624 (95% Confidence interval: 0.45 – 0.80; p = 0.00) implying a substantial agreement between forensic autopsy and reviewer 1 for the overall cause of death classifications (Speelman et al., 2022).

Table 6.5 Cohen Kappa statistic measuring interrater reliability between the forensic autopsy and reviewer 1

Symmetric Measures						
		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance	Exact Significance
Measure of Agreement	Kappa	.624	.090	7.800	.000	.[c]
N of Valid Cases		30				
a. Not assuming the null hypothesis.						
b. Using the asymptotic standard error assuming the null hypothesis.						
c. Cannot be computed because there is insufficient memory.						

The Cohen Kappa statistic (k) (red circle in Table 6.6) for cause of death interrater reliability between the forensic autopsy and reviewer 2 was k = 0.582 (95% Confidence interval 0.41 – 0.76,

p = 0.00) implying a moderate agreement between the forensic autopsy and reviewer 2 for the overall cause of death classifications (Speelman et al., 2022).

Table 6.6 Cohen Kappa statistic measuring interrater reliability between the forensic autopsy and reviewer 2

Symmetric Measures						
		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance	Exact Significance
Measure of Agreement	Kappa	.582	.090	7.235	.000	.[c]
N of Valid Cases		30				
a. Not assuming the null hypothesis.						
b. Using the asymptotic standard error assuming the null hypothesis.						
c. Cannot be computed because there is insufficient memory.						

The Cohen kappa statistic (red circle in Table 6.7) calculated to establish interrater reliability for cause of death rating between Reviewers 1 and 2 was k = 0,905 (95% Confidence interval 0.78 – 1.00, p = 0.00) implying a near perfect agreement (Speelman et al., 2022).

Table 6.7 Cohen Kappa statistic measuring interrater reliability between Reviewers 1 and 2

Symmetric Measures						
		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance	Exact Significance
Measure of Agreement	Kappa	.905	.062	8.065	.000	.[c]
N of Valid Cases		30				
a. Not assuming the null hypothesis.						
b. Using the asymptotic standard error assuming the null hypothesis.						
c. Cannot be computed because there is insufficient memory.						

6.4 CAN CERTAIN CASES BE SELECTED TO UNDERGO PMCT IN THE ABSENCE OF THE FORENSIC AUTOPSY?

The fourth objective of this research study was to ascertain whether certain forensic cases can be selected to undergo a PMCT, without the need for a forensic autopsy. Table 6.1 showed that there was a perfect agreement (100%) between the forensic autopsy and PMCT for the cause of death attribution for six blunt force head injuries; a very good agreement (91%) for eleven gunshot injuries; and perfect (100%) agreement for one case of fatal physical abuse. The results for the fourth objective were obtained by analysing and comparing the number of significant injuries diagnosed with the PMCT, as well as those significant injuries not observed with PMCT, with those of the forensic autopsy for subjects who died as a result of blunt force head injuries, gunshot injuries and cases of fatal physical abuse. The rationale was that, given the very good to perfect agreement for these three 'cause of death categories', the number of significant injuries seen, and those not seen, would provide a better indicator for determining whether such cases can be selected to undergo a PMCT, without the need of a forensic autopsy. These significant injuries seen and not seen by PMCT, are presented according to the same anatomical regions described earlier in this chapter.

The definition of 'significant injuries' was adopted from Velhamos et al. (2001). These authors define 'significant injuries' as all intracranial, thoracic or abdominal visceral injuries, vascular injuries and long-bone, facial, spinal and pelvic fractures, as these injuries can independently or in combination, result in the unnatural death of an individual (Velhamos et al., 2001). The above-mentioned injuries were analysed for all subjects who succumbed due to blunt force head injuries, gunshot injuries and physical abuse. The definition for 'significant injuries' was expanded to include skin injuries, as these have implications for forensic examinations, particularly in the context of fatal physical abuse.

It is a well-established fact that at times, both the forensic autopsy and PMCT for a variety of reasons, may not diagnose certain injuries. For this reason, the forensic autopsy and PMCT were treated as two separate measuring methods (examinations) rather than using the forensic autopsy as the reference standard for injury diagnosis. This aspect is discussed in greater length in Section 7.3 of Chapter Seven.

Addenda B4 and B5 provide a summary of the significant injuries that were diagnosed, and those not diagnosed, during PMCT imaging. These injuries were based on, and contrasted against,

significant injuries observed with the forensic autopsy for blunt force head injuries, gunshot injuries and fatal physical abuse only. This comparison is thus based on the forensic autopsy and PMCT injuries of this study and excludes other published studies. The rationale was that this analysis can be used in future as a basis to determine which forensic autopsies presenting with similar case histories can undergo PMCT, or not, without the need for a forensic autopsy.

PMCT provides exquisite images of the body not seen to the same degree at the forensic autopsy. As alluded to before, the following section thus uses PMCT images as the basis for describing the significant injuries seen with PMCT for the three ‘causes of death categories’ within this study.

6.5 PERCENT AGREEMENT BETWEEN THE FORENSIC AUTOPSY AND PMCT FOR GUNSHOT INJURIES, BLUNT FORCE HEAD TRAUMA AND PHYSICAL ABUSE

Figure 6.2 that follows shows that, even though the cause of death could be assigned by PMCT for gunshot injuries, blunt force head trauma and physical abuse, the identification of various injuries differed significantly amongst the respective anatomical regions. For identification of intracranial injuries, there was a 68% agreement between the forensic autopsy and PMCT, which suggests a good agreement. For the identification of skull and facial fractures, there was very good agreement (92%) between the forensic autopsy and PMCT. For the identification of scalp injuries, there was a very good agreement (80%) between these two examinations. There was also a very good agreement (89%) for the identification of injuries involving the spinal column and spinal cord. There was a moderate agreement for the identification of injuries involving the peritoneal cavity (50%) and pleural cavity respectively (48%). The agreement levels for the other anatomical regions was zero to poor. This suggests that there was no consistency in the level of agreement for the identification of injuries per the respective anatomical regions. More injuries were diagnosed with the forensic autopsy compared with PMCT across the majority of the anatomical regions, except for injuries involving the pleural cavity.

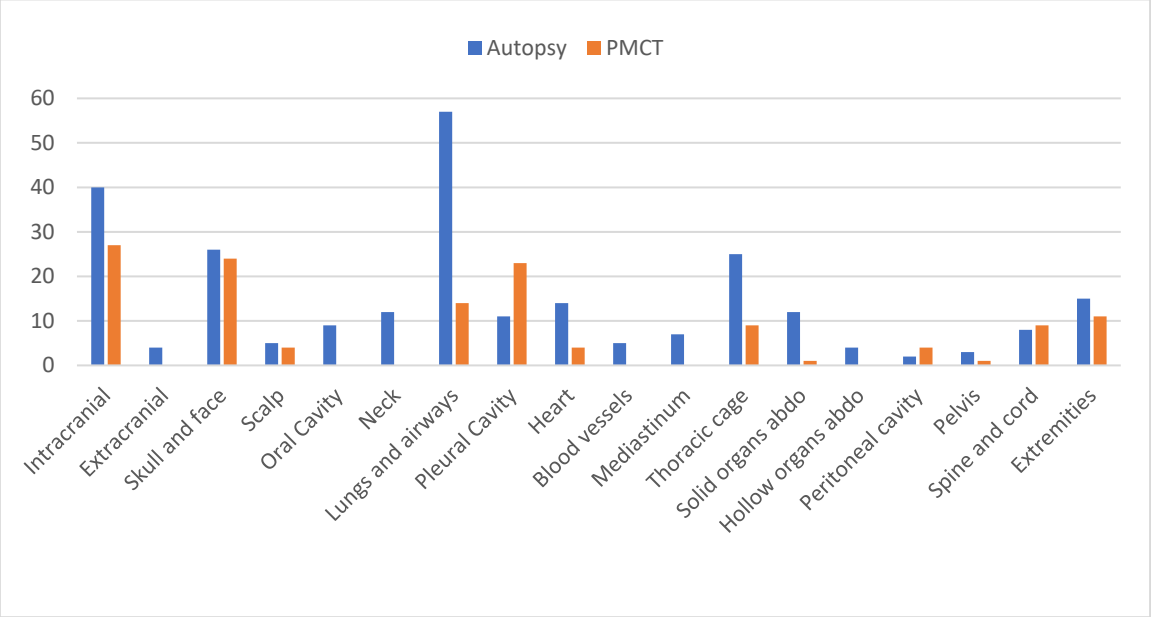


Figure 6.2 Comparison of number of injuries diagnosed per anatomical region for combined gunshot injuries, blunt force head injuries and physical abuse

6.6 IMAGING DISPLAYS POSSIBLE WITH PMCT

PMCT enables unparalleled cross-sectional imaging of the whole body. Topograms of the body acquired with each PMCT examination enable a broad overview of the condition of the body and may where evident, illustrate gross injuries. Post processing options enable 3D volume rendered display of the body surface or bony skeleton, as well as 2D display of the full body, as can be appreciated in Figure 6.3. Furthermore, a multi-planar display of human anatomy is possible from one axial data set. Besides MRI, no other diagnostic imaging modality allows this level of image quality and post processing options. In Figure 6.3 (a), an in-situ endotracheal (ET) tube, an intra-osseus needle located in the proximal right lower leg, as well as a disposable diaper, are visible. The only other diagnostic modality which enables a full body display, similar to the 2D antero-posterior view (image b, Figure 6.3), and which is also used in forensic pathology in South Africa, is the LODOX® system. Displaying 3D images of the surface of the body is not possible with LODOX® imaging. This is one of the major benefits PMCT provides for any forensic autopsy.

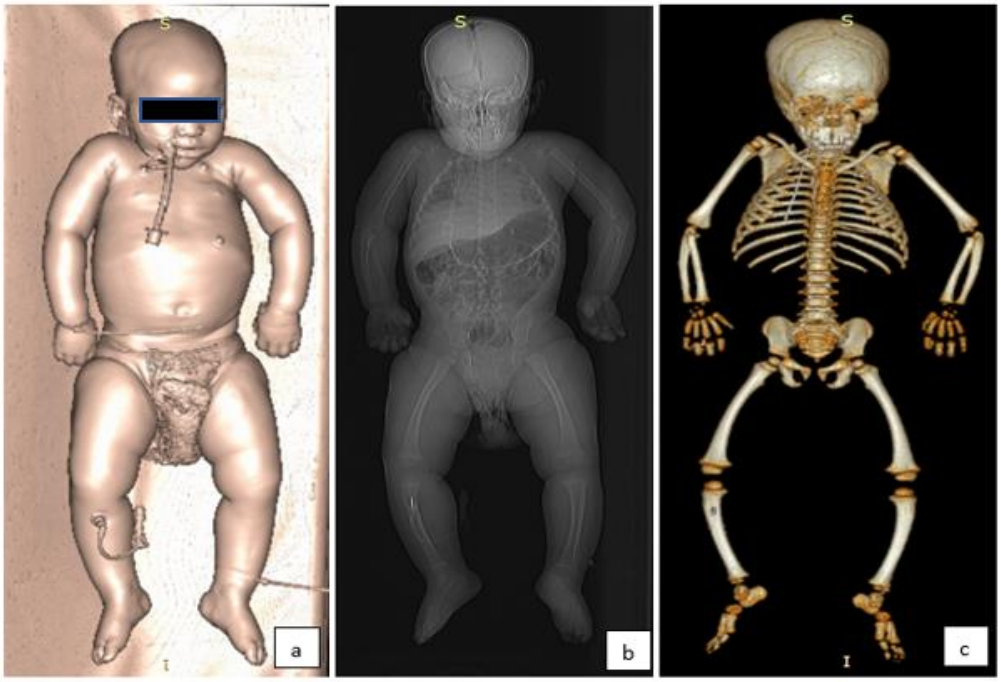


Figure 6.3 Topogram of 18-month male showing (a) 3D volume rendered view of the external body surface; (b) 2D antero-posterior topogram; and (c) 3D topogram of the bony skeleton of same subject (Subject 9)

PMCT also enables the multi-planar display of all body regions with the click of an icon. Removal of certain anatomy is also possible with a simple click. These are functions which enable exquisite display of the interior of the human body.

The next section will describe some of the significant injuries diagnosed with PMCT, amongst subjects who succumbed as a result of blunt force head injuries, gunshot injuries and physical abuse. These are the 'causes of death categories' where there was a moderate to perfect agreement between the forensic autopsy and PMCT. These injuries will be presented per anatomical region using multiplanar PMCT images of different subjects to support the discussion.

6.7 SIGNIFICANT HEAD AND NECK INJURIES SEEN WITH PMCT

PMCT images allows illustration of the skull and intracranial content in various shades of grey. The skull bone, due to its high density, forms a perfect intermediate border between the grey-white matter interface of the brain parenchyma and the external soft tissue planes of the skull. Addendum B4 provides an overview of the type and range of significant head and neck injuries diagnosed with PMCT across the three cause of death categories under discussion here.

A wide variety of skull fractures were diagnosed with PMCT across all three categories. These fractures included the occipital, frontal, temporal and parietal bones and orbits which were diagnosed in nine subjects across all three categories. Most skull fractures were observed in subjects who had sustained blunt force head trauma, with a smaller number observed in those who sustained gunshot injuries to the head. Figure 6.4 shows an undisplaced occipital bone fracture diagnosed in Subject 14. Marked swelling of the soft tissue of the head inferior to this fracture, is also evident on this image.

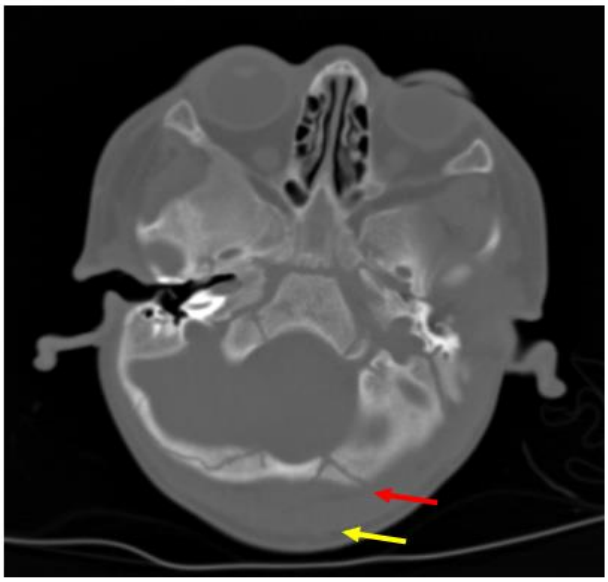


Figure 6.4 PMCT axial view of the skull in bony window showing occipital skull fracture (red arrow), as well as soft tissue swelling (yellow arrow) in an 18-month male infant who sustained physical abuse (Subject 14)

PMCT can display fractures of the base of skull with good resolution. A rare fracture of the clivus, as can be appreciated in Figure 6.5 was diagnosed in Subject 10 who sustained blunt force injuries to the head. This fracture was not diagnosed with the forensic autopsy. In the same figure, a parietal bone fracture can also be seen superiorly. This parietal fracture was also diagnosed during the forensic autopsy. Other calvarium injuries, well demonstrated with PMCT, included three skull bone diastases (not displayed here).

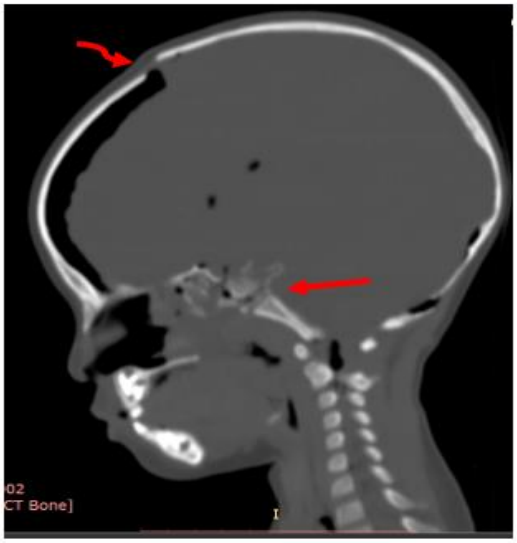


Figure 6.5 PMCT sagittal view of the skull in bony window showing rare fracture dislocation of the clivus (straight arrow) and skull fracture (curved arrow) in two-year-old infant driven over by a reversing car (Subject 10)

A number of facial bone fractures were diagnosed across the three categories which included the maxilla, mandible and nasal bone. Figure 6.6 shows a fracture of the maxilla in a subject who sustained fatal injuries following an RTA.

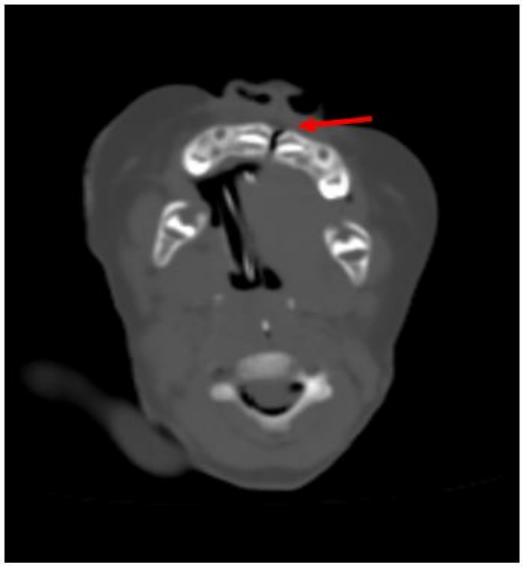


Figure 6.6 PMCT axial view of the head in bone window, showing midline fracture of the maxilla (see arrow) in an 18-month male infant involved in an RTA pedestrian (Subject 9)

Under normal clinical conditions, most intracranial haemorrhages are demonstrable on CT. In the present study, most of the common intracranial haemorrhages were well seen with PMCT, except for SDHs. The majority of these intracranial haemorrhages were diagnosed amongst subjects who sustained blunt force head injuries and gunshot injuries. Figure 6.7 (a) demonstrates intraventricular haemorrhages, as well as SAH (Figure 6.7 b) in the same subject who sustained fatal blunt force head trauma.

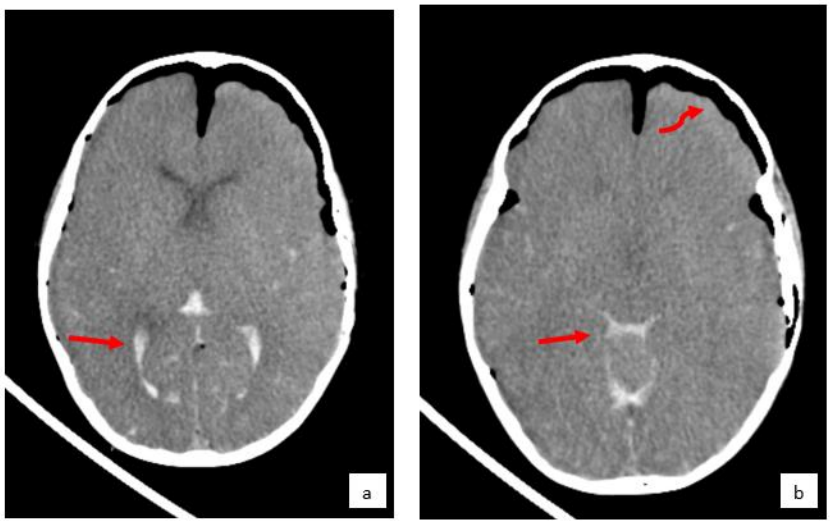


Figure 6.7 (a) Unenhanced PMCT axial view of the brain in five-year-old female who sustained blunt force head injury after RTA pedestrian incident, showing intraventricular haemorrhage (arrow); and (b) Unenhanced axial PMCT view in same subject showing SAH (straight arrow). Also note extensive pneumocephalus (curved arrow) (Subject 25)

Brain oedema, which is usually a sign of significant brain trauma, was diagnosed in six subjects, across all three categories. Brain oedema (or brain swelling) causes raised intracranial pressure and presents on PMCT images as either a loss of white-grey matter interface, effacement, or loss of gyri and sulci markings, or effacement of the four ventricles (see Figure 6.8). In this study, five subjects were diagnosed with raised intracranial pressure, the majority as a consequence of blunt head trauma. Pneumocephali was diagnosed in four subjects within the three cause of death categories.

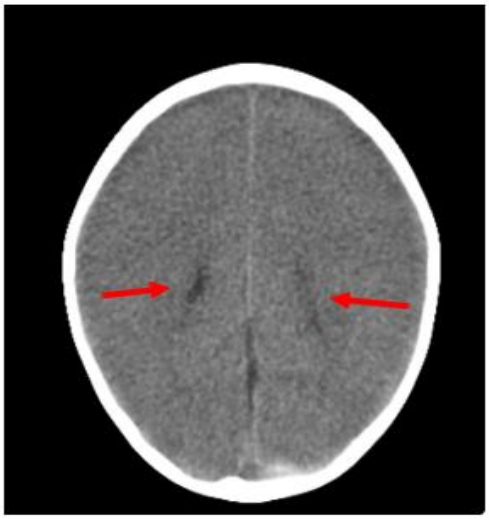


Figure 6.8 Unenhanced PMCT axial view of the head showing loss of grey-white matter interface, suggesting brain oedema in three-year-old male who sustained blunt force head trauma. Left and right lateral ventricles faintly visible (arrows) (Subject 11)

In four subjects, PMCT was able to demonstrate the location of three penetrating gunshot entrance wounds, as well as 10 retained bullets, all which were the result of gunshot injuries. No exit wounds could be determined with PMCT in any of the subjects who sustained gunshot injuries. PMCT also enabled identification of haemorrhage along one of the bullet tracks in one subject. Figure 6.9 shows a bullet track and retained bullets visible in a four-year-old female who succumbed to a fatal gunshot to the head (Subject 17).

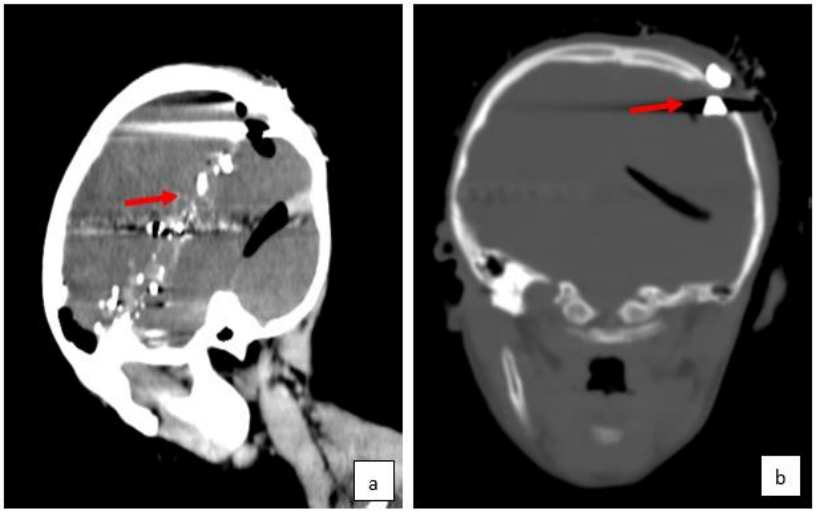


Figure 6.9 (a) Unenhanced PMCT sagittal view of the head showing bullet tract in a postero-anterior direction (arrow) in four-year-old female who sustained a single penetrating gunshot to the head; (b) Coronal view of the head in bone window (same subject) showing deformed left-sided bullet shell intracranially (arrow) and extracranially (Subject 17) (Speelman et al., 2022) Reproduced with permission from Springer Nature

6.8 SIGNIFICANT THORACIC INJURIES SEEN WITH PMCT

Various thoracic injuries can be diagnosed with PMCT, usually with exquisite detail. The varying densities of the different thoracic organs and anatomical structures result in superb contrast with PMCT imaging. In the present study, a wide range of thoracic injuries within the three categories were diagnosed amongst the subjects. Post-processing options possible with PMCT enable the display of CT images in lung windows, mediastinal and bony windows. This windowing enhances illustration and diagnosis of injuries across different grey scales. PMCT was effective in demonstrating a number of pneumothoraces and haemothoraces, most often evident in subjects who sustained gunshot injuries. Pneumothoraces were demonstrated in nine subjects who sustained blunt force head and gunshot injuries. In addition, a tension pneumothorax was also diagnosed in Subject 13 (Speelman et al., 2022). The majority of haemothoraces diagnosed with PMCT were bilateral and were mostly a result of gunshot injuries. Figure 6.10 provides an example of a bilateral haemo-pneumothorax.

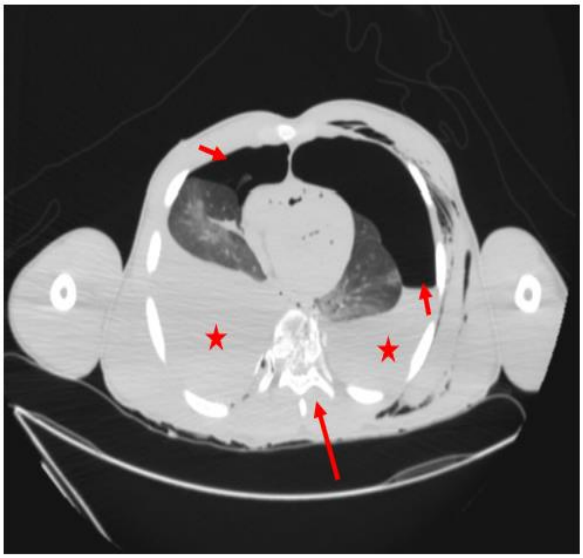


Figure 6.10 Unenhanced PMCT axial view of the thorax in lung windows, showing bilateral haemo-pneumothoraces (blood – stars) (air – short arrows), with a fractured thoracic vertebra (long arrow) in 16-year-old male who sustained multiple gunshot injuries (Subject 7) (Speelman et al., 2022) Reproduced with permission from Springer Nature

A tension pneumothorax can cause significant intrathoracic pressure resulting in mediastinal shift. In one such subject, PMCT was able to demonstrate mediastinal shift resulting in the heart and major blood vessels being displaced towards the right, as can be appreciated in Figure 6.11. In

this figure, the collapsed lung can also be observed. The lung collapse in this subject, was diagnosed at the forensic autopsy, but not the mediastinal shift and heart displacement evident.

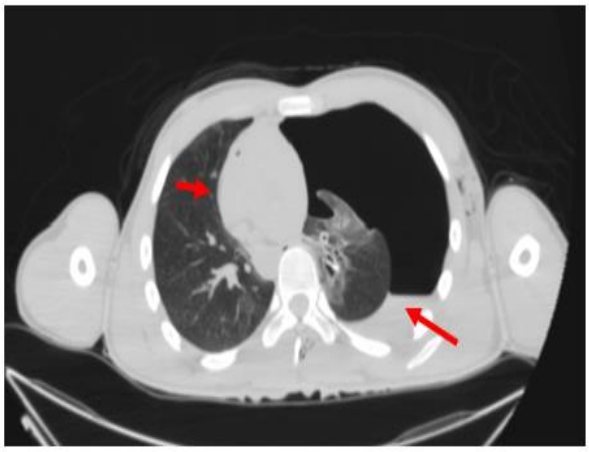


Figure 6.11 Unenhanced PMCT axial view of the thorax in lung windows showing large tension pneumothorax (long arrow), with heart displaced to the right (short arrow) caused by mediastinal shift in 17-year-old male that sustained multiple gunshot wounds (Subject 13)

Other significant lung injuries diagnosed with PMCT included four perforating wound tracts, and lung collapse in four subjects, all of which were the result of gunshot injuries (not displayed here).

The illustration of cardiac injuries by PMCT following trauma is critical to establish the manner and cause of death. As can be noted in Addendum B4, very few injuries involving the heart were demonstrated with PMCT. The only significant cardiac injuries diagnosed with PMCT, across the three categories, included two haemopericardiums. The latter were diagnosed in two subjects who sustained gunshot injuries to the thorax. Other abnormalities diagnosed with PMCT were four heart and mediastinal displacements which are not injuries in themselves but consequences of thoracic injuries (see example of a haemopericardium in Figure 6.12).

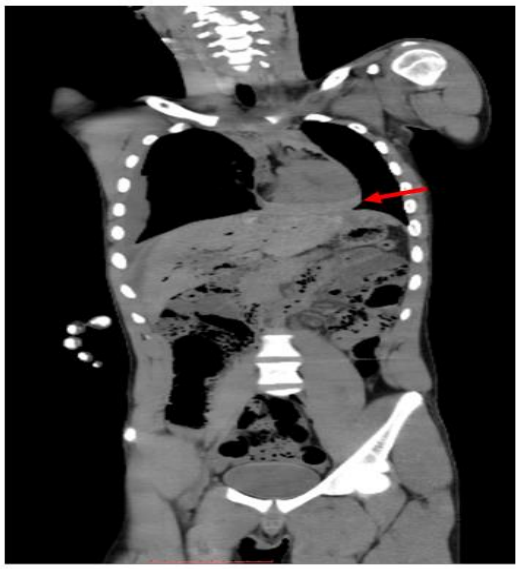


Figure 6.12 Unenhanced PMCT coronal view of the thorax and abdomen showing haemopericardium (arrow) in 16-year-old male who sustained multiple gunshot injuries (Subject 29)

As discussed earlier in Section 6.2.1, PMCT was able to demonstrate the location and volume of air and gas collections with excellent detail and precision. In the present study, PMCT demonstrated a collection of air in the right ventricle. This air collection was considered to be the consequence of an air embolism (see Figure 6.13). This air embolism was not diagnosed at the forensic autopsy.

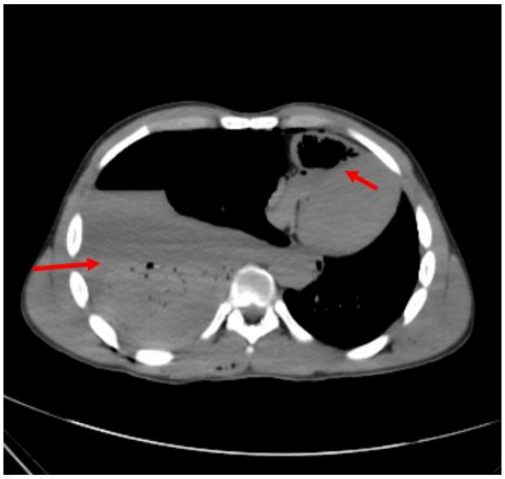


Figure 6.13 Unenhanced PMCT axial view of the thorax showing large right-sided haemothorax (long arrow), mediastinal shift, and air in right ventricle (short arrow), considered to be an air embolism, in 17-year-old male, (Subject 15) with a single gunshot wound to thorax. Mediastinal shift in this image is evident in the relative left-sided location of the heart

PMCT can further demonstrate the impact of gunshot injuries and resultant organ damage in the body. Interesting to note was that PMCT was also able to indicate the directionality of the bullets in two subjects who had sustained fatal gunshot injuries. In Figure 6.14, which is an unenhanced, coronal PMCT view of the thorax, the presence of thoracic vertebral fractures, as well as the directionality of the gunshot injury, can be appreciated. The oblique angle of the vertebral fractures, as well as the small bony fragments to the right of the thoracic vertebrae, is evidence that the bullet travelled in an infero-superior direction and exited the vertebral column on the right side (Speelman et al., 2022). Thus in some cases, PMCT enables the establishment of the angle at which the victim was shot. PMCT also enables establishment of ricochet trauma, where relevant (this finding is not displayed here).

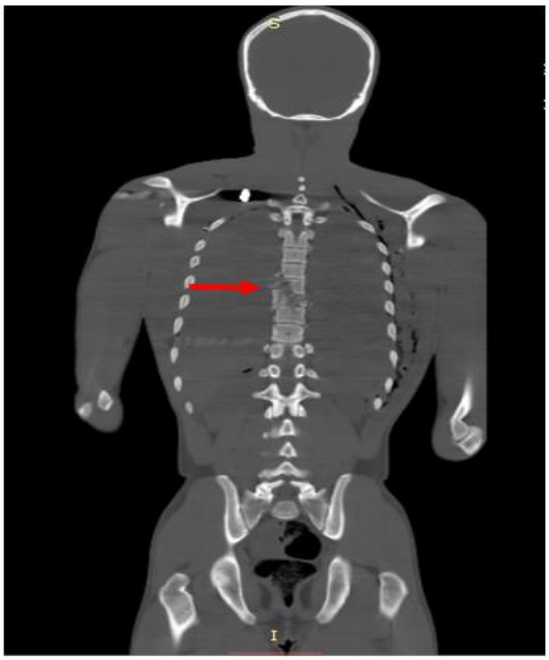


Figure 6.14 Unenhanced PMCT coronal view of the thorax and abdomen in bony window showing fractures of thoracic vertebrae 6 to 9 (arrow). Directionality of bullet is discernible by the obliquity of bullet track, as having travelled from left to right, and in an infero-superior direction, and confirmed by the bony fragments located lateral to the vertebral bodies in 16-year-old male with multiple gunshot injuries (Subject 7) (Speelman et al., 2022)
Reproduced with permission from Springer Nature

Rib fractures are a common finding caused by physical abuse, physical trauma or RTAs. In this study, a large number of rib fractures were diagnosed with PMCT imaging. Rib fractures were diagnosed in five of the 11 subjects who sustained gunshot injuries, whilst other rib fractures were diagnosed in two subjects who sustained fatal physical abuse (see samples of rib fractures in Figure 6.15).

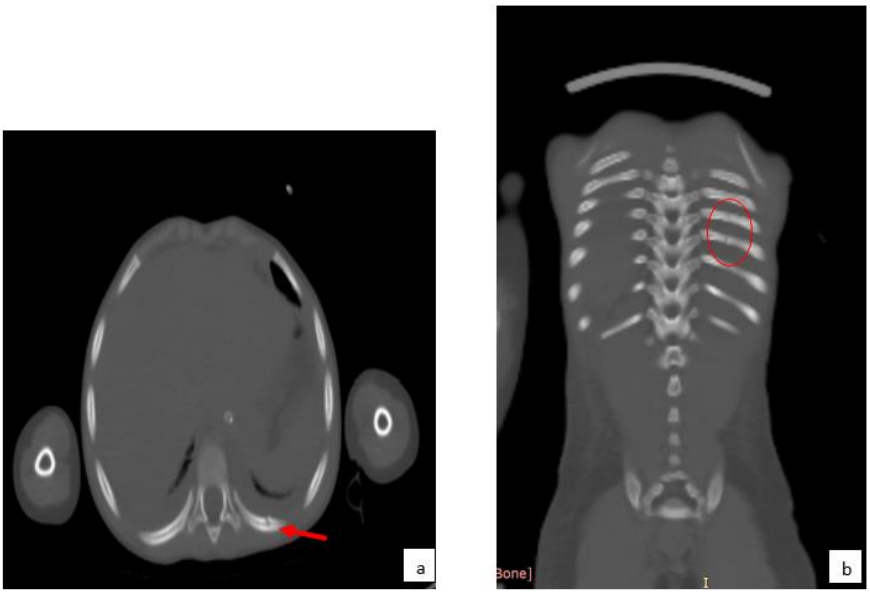


Figure 6.15 (a) Unenhanced PMCT axial view of the thorax in bony window, showing incomplete left dorsal rib fracture in three-year-old male who sustained physical abuse; and (b) PMCT coronal view of the thorax and abdomen in the same subject showing subtle left-sided dorsal rib fractures (red ellipse). These fractures were not detected at autopsy (Subject 11) (Figure a: Speelman et al., 2022) Reproduced with permission from Springer Nature

Sternal fractures are rare in children (Kleinman, 1990a; Ross & Juarez, 2014). Across the three categories under discussion here, two sternal fractures were diagnosed in two subjects who sustained gunshot injuries (see Figure 6.16).

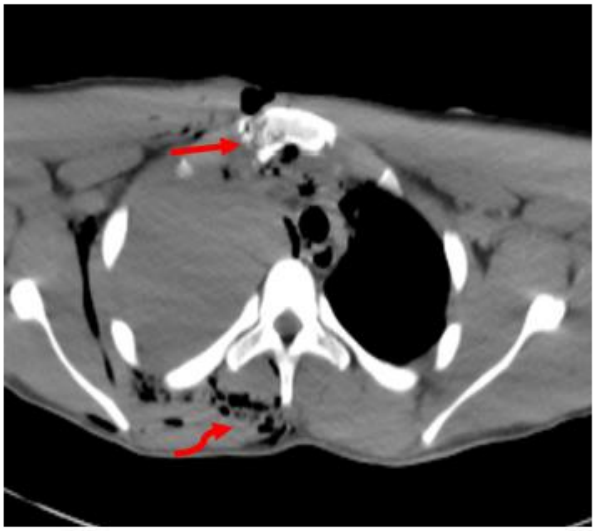


Figure 6.16 Unenhanced PMCT axial view of the thorax showing fractured sternum (straight arrow) in 17-year-old male following a single gunshot injury to the thorax (Subject 15). Extensive subcutaneous emphysema is also visible (curved arrow)

6.9 SIGNIFICANT ABDOMINAL AND PELVIC INJURIES SEEN WITH PMCT

Only seven significant abdominal injuries were evident across the three categories under discussion here. The majority of these injuries were diagnosed in subjects who had sustained gunshot injuries and physical abuse. These injuries included one case of haemoperitoneum, a laceration of the liver, and a bullet trajectory through the lower pole of the left kidney, all the consequence of gunshot injuries diagnosed in three subjects. Intra-abdominal haemorrhages were also diagnosed in two subjects, one in a subject who sustained a gunshot injury, and the other in a subject who sustained physical abuse (see example in Figure 6.17).

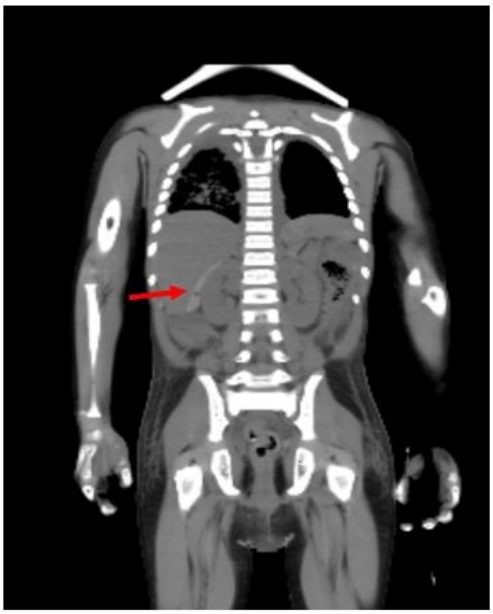


Figure 6.17 Unenhanced PMCT coronal view of the thorax, abdomen and pelvis showing right-sided haemoperitoneum located between liver and right kidney (red arrow) in three-year-old male who sustained fatal physical abuse (Subject 11) (Speelman et al., 2022) Reproduced with permission from Springer Nature

Two cases of pneumoperitoneum were diagnosed in two subjects. These were a result of gunshot injuries, suggesting an injury to a hollow viscus. Figure 6.18 shows the presence of free air in the abdomen, following an injury to a hollow viscus. One subject presented with free abdominal fluid following a gunshot injury (this finding is not displayed here).

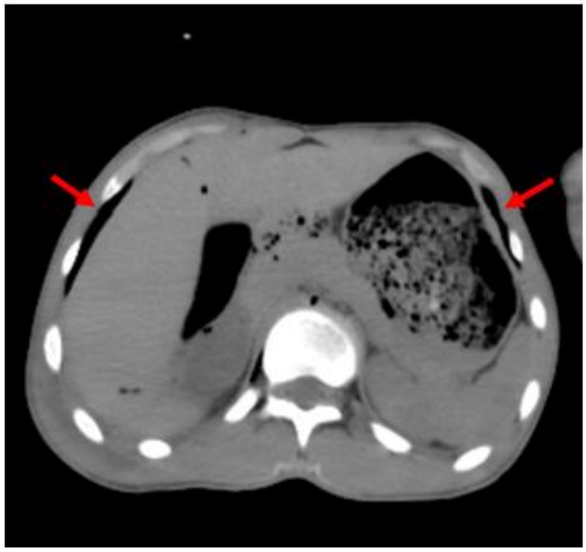


Figure 6.18 Unenhanced PMCT axial view of the abdomen showing pneumoperitoneum bilaterally (arrows) in 16-year-old male who sustained gunshot injury to the shoulder (Subject 26)

PMCT can sometimes reveal unusual findings. A rare finding, which was partially in keeping with that of a Morel-Lavallée lesion, was diagnosed in one subject (Subject 23) with multiple pelvic bone fractures following a pedestrian RTA (see Figure 6.19). From this image, it was not clear what substance caused the radiopaque appearance.

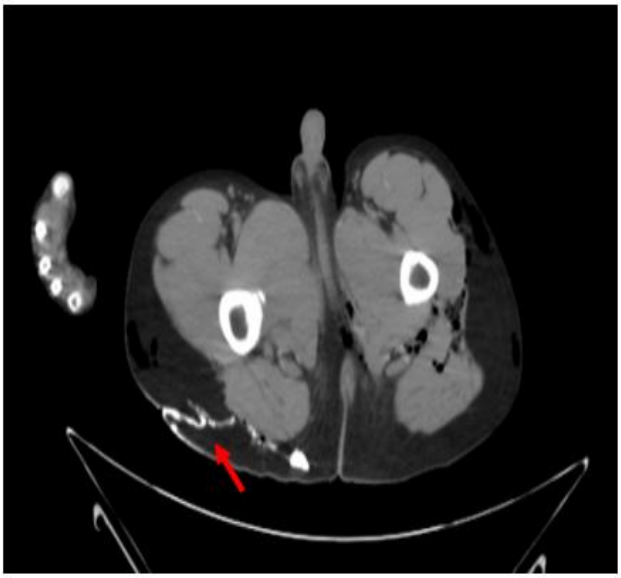


Figure 6.19 Unenhanced PMCT axial view of the pelvis presenting with a suggestive Morel-Lavallée lesion (arrow) of the soft tissue of the pelvis in a nine-year-old male pedestrian who sustained fatal injuries after being knocked over by a car (Subject 23)

6.10 SIGNIFICANT SPINAL COLUMN AND SPINAL CORD INJURIES SEEN WITH PMCT

Injuries to the spinal column (i.e., vertebral bodies and posterior vertebral arch) are usually well visualised with PMCT imaging. The majority of injuries to the spinal column diagnosed with PMCT across these three categories were spinal fractures, all the result of gunshot injuries. The fractures were mostly found within the thoracic and cervical vertebrae. In all cases, the fractures were the result of bullets traversing the vertebrae. Spinal cord transections are not easily discernible on PMCT imaging. However, one transection of the cervical myelum (at the level of C1) was demonstrated with PMCT in a subject who sustained gunshot injuries to the neck and thorax (see Figure 6.20).

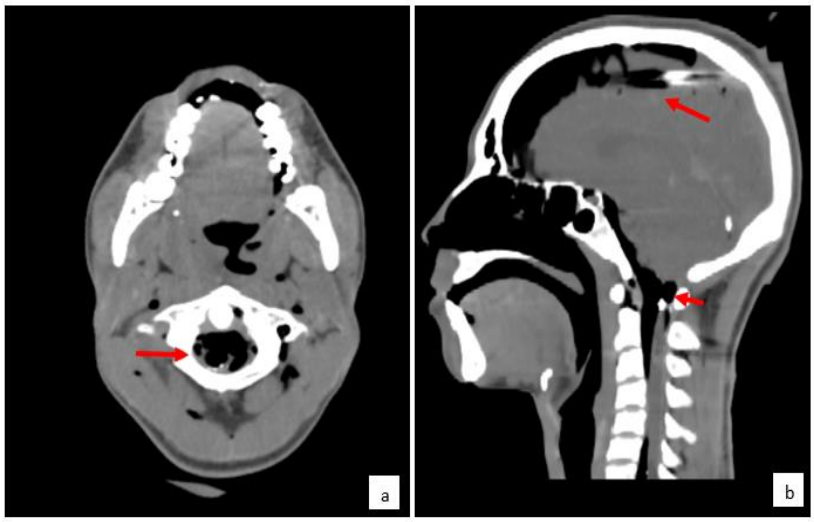


Figure 6.20 (a) Unenhanced PMCT axial view of the brain showing complete transection of the spinal cord at the level of 1st cervical vertebra (red arrow) in 17-year-old male who sustained multiple gunshot injuries; and (b) Unenhanced sagittal PMCT image of the head in same subject, showing transection of the spinal cord (short arrow) and bullet trajectory (long arrow) (Subject 13)

6.11 SIGNIFICANT EXTREMITY INJURIES SEEN WITH PMCT

In this study, fractures to the upper and lower extremity were found to be present across all three categories. An analysis of the radiological injuries revealed that in this study, PMCT was accurate in diagnosing nine extremity fractures caused by physical abuse in one subject. In Subject 14, PMCT demonstrated extremity injuries which were all skeletal hallmarks of physical abuse. These injuries included left humeral fractures in different stages of healing, as well as the classical metaphyseal lesion diagnosed at the left elbow. In addition, this subject was also diagnosed with a callus formation of the left proximal humerus, as well as bilateral proximal tibial fractures, also

in different stages of healing. For example, callus formation was also evident around the right proximal tibial bone (see Figure 6.21).

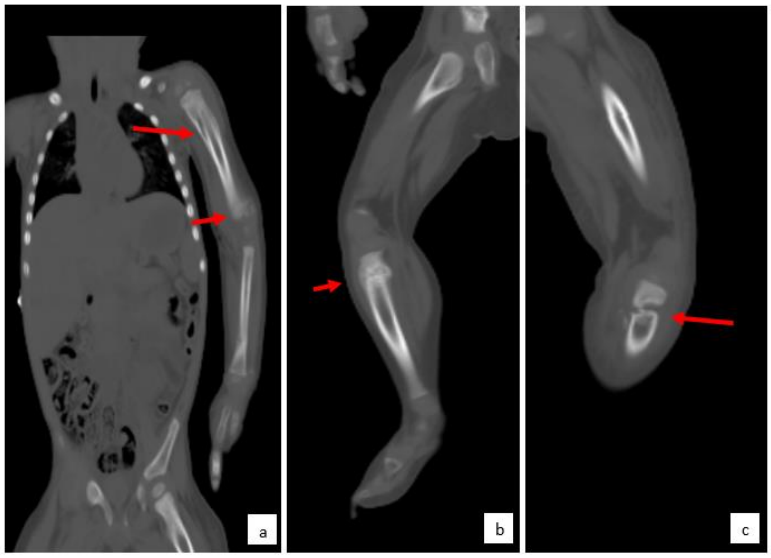


Figure 6.21 (a) Unenhanced PMCT coronal view of the thorax and abdomen, and left arm, demonstrating healing humeral fracture (long arrow) and classic metaphyseal lesion of left distal humerus (short arrow) in 18-month male infant who sustained physical abuse; (b) Sagittal view of right leg (same subject) showing proximal tibial fracture with callus formation (short arrow); and (c) Sagittal view of the left leg (same subject) showing proximal fracture of tibia (long arrow). Note that asymmetry of limbs was due to rigor mortis (Subject 14).

Four extremity fractures in subjects who sustained gunshot injuries were also diagnosed with PMCT within the three cause of death categories. Findings are not displayed here (see Addendum B4).

Further, PMCT also enabled the illustration of bullet tracks in Subjects 26 and 29 who were shot in the upper leg and forearm respectively. An example of an oblique bullet track involving the muscle of the left femur is evident in Figure 6.22. In another subject, ricochet trauma to the glenoid fossa (Subject 7) following a fracture to the scapula, as well as the presence of a retained bullet in the surrounding soft tissue of the upper arm, was also diagnosed. The directionality of a bullet involving an upper extremity injury was discernible in one case (Subject 29) where the bullet travelled from a postero-anterior direction through the left forearm (not displayed here).

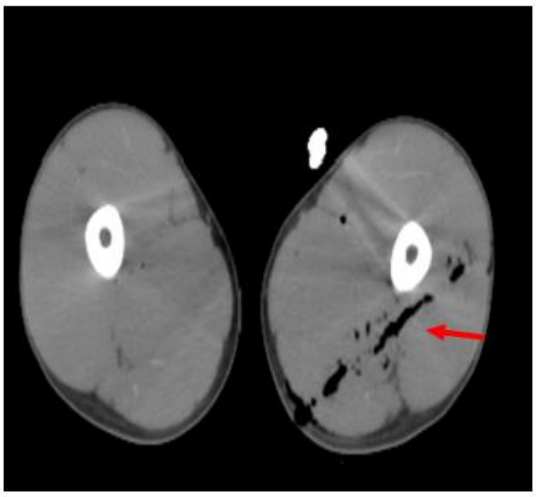


Figure 6.22 Unenhanced PMCT axial view of the femurs showing oblique bullet trajectory in 16-year-old male (red arrow). Directionality of the bullet could not be determined from this sequence (Subject 26)

6.12 RETAINED BULLETS SEEN WITH PMCT

The excellent contrast possible with some PMCT images enables exquisite identification and location of retained bullets and bullet fragments. The dense properties of bullets and bullet fragments cause these objects to appear as radiopaque structures on PMCT imaging. The exact anatomical location of bullets and bullet fragments is therefore relatively easy to assess on PMCT images. Even the smallest bullet fragments do not escape PMCT detection. Figure 6.23 shows the location of three bullets in a subject who sustained five gunshot wounds to the thorax. The retention of bullets for ballistic analysis has significance for the forensic autopsy and subsequent outcome, rendering PMCT imaging a useful tool for the location and identification of bullets or fragments.

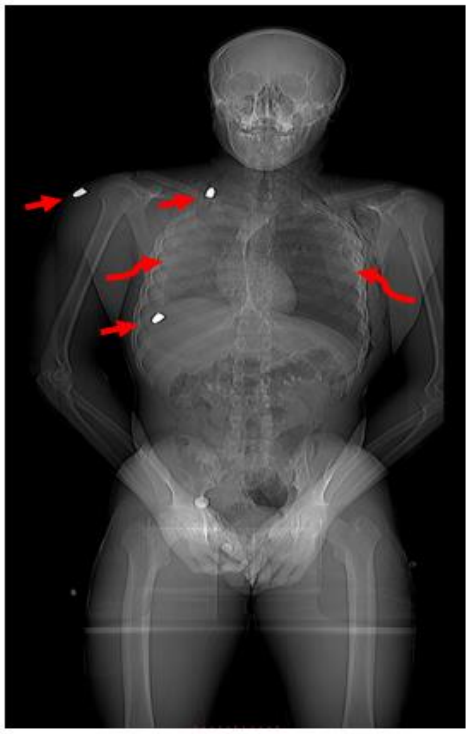


Figure 6.23 PMCT topogram showing three retained bullets (short arrows) in 16-year-old male who sustained five gunshot wounds. Bilateral haemothoraces were also evident on this topogram (curved arrows) (Subject 7)

6.13 SIGNIFICANT INJURIES OF THE HEAD AND NECK NOT SEEN WITH PMCT

The previous section dealt with significant injuries readily observed with PMCT imaging. However, this modality has many shortcomings. The following section describes some of the shortcomings which were evident in this study. These shortcomings derived from those injuries diagnosed during the forensic autopsy but not diagnosed with PMCT in the three cause of death categories for blunt force head trauma, gunshot injuries, as well as physical abuse. In addition, this section will also highlight some of the measurements done during the forensic autopsies. A summary of the injuries not readily diagnosed with PMCT in this study, and measurements performed, are listed in Addendum B5.

In this study, PMCT was not effective for diagnosis of subgaleal haemorrhages, scalp bruises, scalp abrasions and scalp lacerations. With reference to this discussion, these injuries were evident only in subjects who sustained blunt force head injuries and physical abuse. There are various types of subgaleal haemorrhages which may involve several layers of soft tissue that covers the cranium. In this study, subgaleal haemorrhages which were diagnosed in three different subjects during the forensic autopsy were not diagnosed on PMCT. Bruises and scalp lacerations

involving the skin, which indicates blunt force trauma, were not diagnosed with PMCT. Other scalp-related injuries that were not discernible with PMCT were scalp abrasions diagnosed in three subjects, all of whom had sustained blunt force head injuries. Similarly, two scalp lacerations diagnosed in two subjects who sustained blunt force head injuries were not diagnosed with PMCT.

Blunt or sharp trauma to the head may result in significant brain parenchymal contusions and lacerations. In addition, these injuries may also result in intracranial haemorrhages such as EDH, SDH, SAH or intracerebral haemorrhages. Section 5.8.1 of Chapter Five showed that PMCT was able to demonstrate some parenchymal brain injuries. However, superficial brain parenchymal injuries, such as superficial brain contusions, or brain lacerations, are not easily identifiable on PMCT imaging. In this study, PMCT was not able to diagnose cortical contusions of different areas of the brain in three subjects who succumbed as a result of blunt force head injuries. Similarly, in three subjects, brain lacerations involving different lobes of the brain were not discernible on PMCT imaging. One laceration of the dura mater was also not diagnosed with PMCT.

Subperiosteal blush haemorrhages, indicating injury to the skull bone, were diagnosed in one physical abuse subject during the forensic autopsy, but these were not discernible with PMCT. Brain matter can sometimes extrude from the cranial cavity following open skull fractures or gunshot injuries. In this study, the extrusion of brain matter, which is a sign of significant brain injury, was not diagnosed with PMCT.

Even though some soft tissue haemorrhages can be diagnosed with PMCT, in this study, soft tissue haemorrhages of the neck muscles were not diagnosed in three subjects who succumbed to blunt force head injuries and gunshot injuries.

6.14 SIGNIFICANT THORAX AND DIAPHRAGM INJURIES NOT SEEN WITH PMCT

Penetrating or perforating injuries caused by gunshots can cause significant damage to the lung and heart parenchyma, mediastinal structures and major blood vessels. Parenchymal injuries of the lungs were not discernible with PMCT in this study. For example, in the forensic autopsy, five lung contusions were diagnosed in five different subjects across all three categories, but these were not diagnosed with PMCT. The aspiration of blood or gastric content can compromise breathing and can be potentially fatal during a traumatic event. PMCT was able to demonstrate only one of eleven traumatic blood aspirations in subjects who sustained fatal gunshot injuries.

(see Figure 6.24). This suggests that PMCT was inferior to the forensic autopsy for the diagnosis of this injury type.

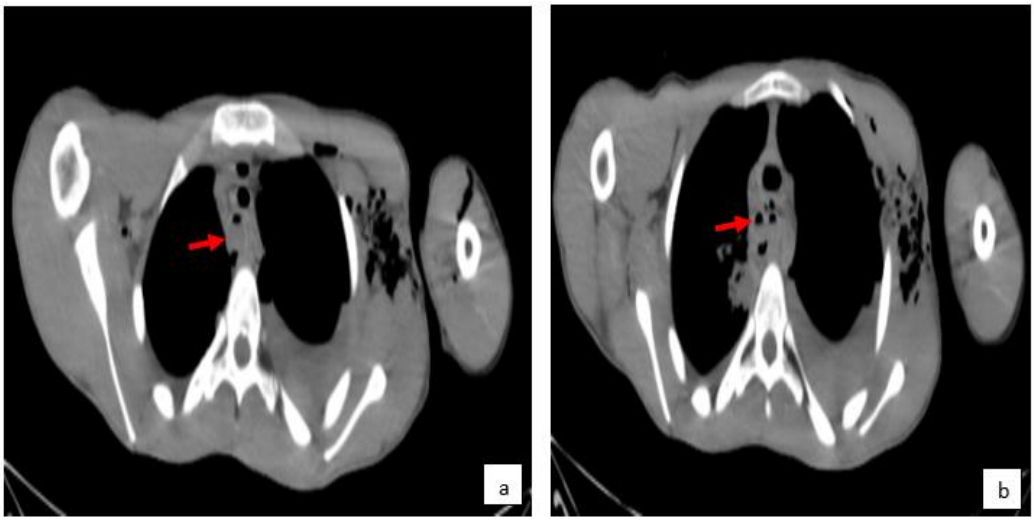


Figure 6.24 (a) Unenhanced PMCT axial view of the thorax showing blood in trachea evident by air-fluid level (arrow) in 16-year-old male; (b) Same subject as (a), showing air-fluid levels in main bronchus just below carina (arrow) (Subject 26)

Further, PMCT had shortcomings related to diagnosing focal haemorrhage of the mediastinum, atria and heart ventricles, sub-epicardial petechial haemorrhages, and sub-endocardial haemorrhages. None of these lesions were diagnosed with PMCT (see Addendum B5).

Pallor of organs is a critical observation made during any forensic autopsy. It is usually a sign of exsanguination or hypovolemic shock, especially where a subject has endured significant blood loss following a fatal injury. In the three categories under discussion here, pallor of the lungs and heart were diagnosed during the forensic autopsy amongst the five subjects who sustained fatal gunshot injuries. PMCT is currently not able to discern visual cues such as organ pallor.

An important activity conducted during a forensic autopsy is the measurement of free blood, or fluid in the pleural or thoracic cavity. The measurement of free fluid is done to assess the volume of blood loss prior to death or, in some cases, the presence of free fluid in the pleural cavity as either a pathological exudate or transudate. At autopsy, free fluid was measured in the pleural cavity, thoracic cavity and pericardium amongst nine subjects, most of whom had sustained gunshot injuries. A small volume of 10 ml of pleural fluid was also measured in one subject who had sustained physical abuse. The free fluid measured within the thoracic cavity varied between

100 ml to 1,500 ml of blood in the thorax (Addendum B5). One subject presented with 60 ml of blood in the pericardium following a gunshot injury. These measurements cannot routinely be performed during a PMCT examination.

6.15 SIGNIFICANT ABDOMINAL INJURIES NOT SEEN WITH PMCT

Blunt force or sharp abdominal trauma can affect various organs and structures, causing a plethora of injuries. In this study, the majority of significant injuries not discernible with PMCT within the abdomen across the three cause of death categories included contusion of the abdominal wall, duodenum, surrounding mesentery, peri-renal tissue, stomach, bladder and the testis. These injuries were diagnosed in two subjects who had sustained physical abuse.

Two spleen lacerations diagnosed in a subject who had succumbed as a result of blunt force head injuries, and another one of fatal gunshot injuries, were not diagnosed with PMCT. Soft tissue haemorrhages of the pancreas, peri-adrenal soft tissue, adrenal medulla, subcutaneous haemorrhage of the perineum, and haemorrhage within the spermatic cord of a male infant, were not discernible with PMCT. All the above haemorrhages occurred in the two subjects who had suffered fatal physical abuse.

As in the case of the thorax, assessment of abdominal organ pallor forms an integral part of forensic autopsies. The organs diagnosed with pallor across all three categories included the liver, kidneys, pancreas and spleen. Measurement of free fluid or blood within the peritoneal or retroperitoneal space is also routinely done as part of any forensic autopsy. Three subjects were also diagnosed as having 50–150 ml of free blood within the peritoneal cavity, as measured during the forensic autopsies. The measurement of free fluid within the abdomen is currently not possible with PMCT.

6.16 SIGNIFICANT SPINAL COLUMN AND SPINAL CORD INJURIES NOT SEEN WITH PMCT

Soft tissue injuries to the spinal cord are very difficult to discern with PMCT imaging. In section 5.11 of Chapter 5, reference was made to one transection of the spinal cord which was diagnosed with PMCT. However, two other spinal cord transections at the atlanto-occipital joint and thoracic vertebra nine level which were evident during the forensic autopsies were not diagnosed with

PMCT. In one infant that had sustained physical abuse, a small haemorrhagic staining of the spinal cord, corresponding to a lumbar vertebral fracture, was not diagnosed with PMCT.

6.17 SKIN INJURIES NOT SEEN WITH PMCT

Fresh and older injuries to the skin can present in the form of abrasions, bruises, scabs, scars or bite marks. Injuries involving damage to the layers of the skin and subcutaneous tissue can sometimes be diagnosed using PMCT. However, injuries such as abrasions, scabs and bruises are currently not discernible with PMCT imaging. Addendum B5 lists the various skin injuries noted in subjects who succumbed due to blunt force head trauma, gunshot injuries and physical abuse. As alluded to in Chapter Two, Section 2.3.1, certain bruises can be a sign of physical abuse and can be the only external physical manifestation of child abuse. Both subjects who succumbed to fatal physical child abuse within this study presented with numerous bruises which are not discernible with PMCT. Subject 14 also presented with numerous scars, bruises over the body and an adult bite mark on his skin, which were confirmed by a forensic odontologist as the bite marks of an adult (Speelman et al., 2022). Employing the service of a forensic odontologist is an example of the many supplementary examinations possible during forensic autopsies to assist in determining skin injuries and or the cause and manner of death.

Another shortcoming for PMCT in this study, was the location of entrance and exit gunshot wounds. Section 6.7 of Chapter 6 has highlighted that PMCT can locate the entrance wounds for some gunshot injuries. In the present study, directionality of bullets was not discernible for all cases, which has major forensic pathology significance. Furthermore, in the present study, the anatomical location of the majority of entrance and exit wounds could not be determined with PMCT (see Addendum B5). As part of the external examination of a deceased person, personalised skin signs such as tattoos, are used for identification purposes and so are routinely and meticulously recorded. In this study, three tattoos in three subjects who had all succumbed as a result of gunshot injuries, were recorded. The recording of such unique personal identifiers is currently not possible with PMCT.

6.18 SUPPLEMENTARY EXAMINATIONS USED WITH THE FORENSIC AUTOPSY

During this study, many supplementary investigations were employed as part of the forensic autopsy. Addendum B6 of this thesis gives an overview of the supplementary examinations conducted for each subject. The majority of subjects (77%) (n = 23/30) underwent whole-body LODOX® imaging prior to autopsy. Toxicology was the second most frequently employed supplementary examination at 37% (n = 11), followed by ballistics at 30% (n = 9) and histology at 27% (n = 8). Other supplementary examinations of subjects conducted included: DNA analyses, 13% (n = 4); pharmacology 10% (n = 3); a skeletal survey (0,7%) (n = 2); microbiology, 0,7% (n = 2); and virology 0.3% (n = 1). Toxicology was mostly done to establish the blood alcohol concentration, mostly in male subjects. Pharmacology is a screening test and was done to quantify the presence of drugs; and, if present, toxicology would be performed. Retained bullets and clothing of subjects who sustained gunshot injuries, were sent for ballistic analysis.

The implications of the above results for post-mortem imaging will be discussed in more detail in Chapter Seven.

6.19 PMCT IMAGE QUALITY AND IMAGE ARTEFACTS

Even though PMCT imaging is able to illustrate body injuries with exquisite detail, this modality does have some inherent constraints caused by some objects on/in the deceased and patient positioning. Metal objects such as bullets and those caused by clothing e.g. waist belts and shoes may compromise image quality at times. The majority of deceased persons wear clothing at the time of their demise and these may for medico-legal reasons, not be removed during imaging, which will remain an impediment for PMCT imaging. Figure 6.25 below provides an example of how image quality can be influenced by retained bullets.

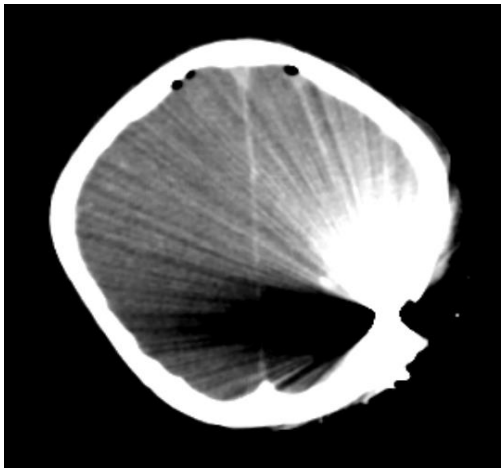


Figure 6.25 Unenhanced PMCT axial view of the brain in a 4-year-old female (Subject 17) with retained bullet in head. Streak artefacts are compromising image quality at this anatomical level and could obscure underlying injuries

Figure 6.26 below provide an example of how image quality can be influenced by streak artefacts caused by the subject's arms positioned next to the body during PMCT image acquisition. In live individuals the patient's arms would ordinarily be raised above the head to omit such streak artefacts.

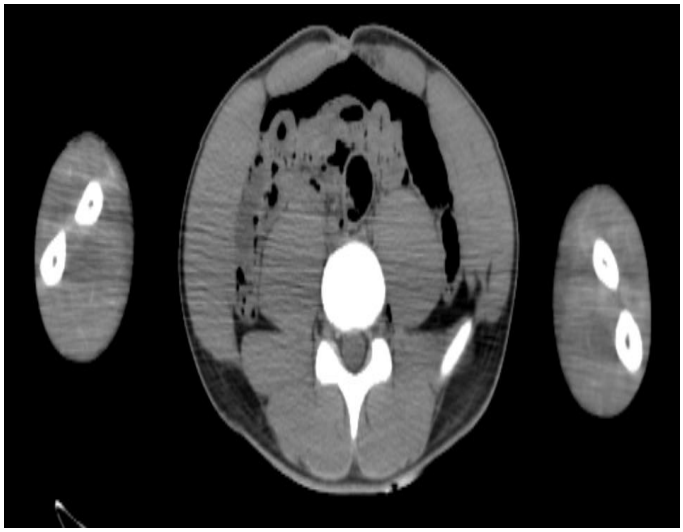


Figure 6.26 Unenhanced PMCT axial view of the abdomen in 16-year-old male (Subject 7) demonstrate streak artefacts caused by arms positioned next to the body

Figure 6.27 provides another example of streak artefacts caused by the waist belt of the subject worn during PMCT image acquisition.

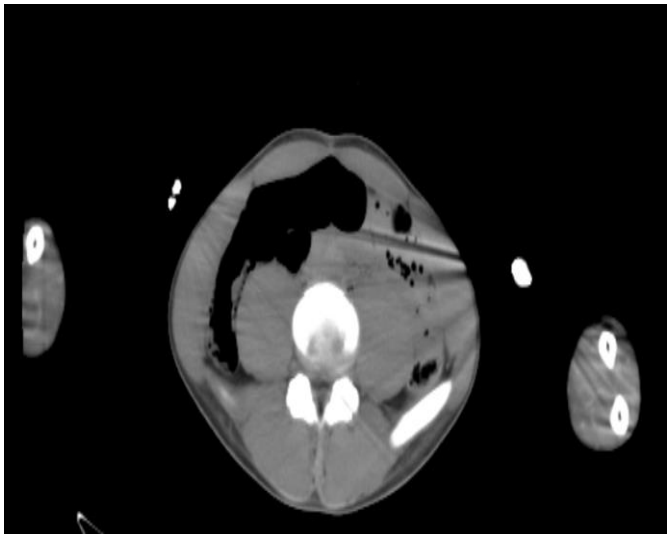


Figure 6.27 Unenhanced PMCT axial view of the abdomen in 16-year-old male (Subject 30) demonstrate streak artefacts caused by waist belt

The presence of shoes may also compromise measurement of the scan length particularly due the subject being in a body bag. The presence of shoes may also interfere with diagnostic PMCT image interpretation. Figure 6.28 below provides an example of the shoes on the feet of one subject. Image quality was not degraded in this case.

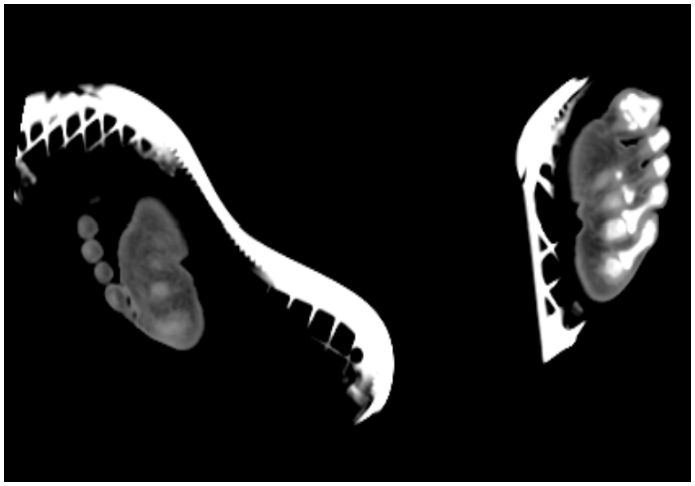


Figure 6.28 Unenhanced PMCT axial view of the feet of 16-year-old male (Subject 29) showing the sole of the shoes present

6.20 INCIDENTAL FINDINGS

A total of 19 incidental findings were noted during the study. As can be appreciated from Table 6.8, one subject was diagnosed with an umbilical hernia. Two subjects presented with an anatomical variant, having had only 11 pairs of ribs. Subject 11 also presented with bilateral accessory cervical ribs. Subject 6 presented with an Inca bone[8], whilst Subject 8 had a patent foramen ovale (Botalian duct). Subjects 5 and 8 each presented with a Mongolian spot, a dermatological variant which was diagnosed during the forensic autopsy. As stated in Section 2.8.4 in Chapter Two, Mongolian spots may mimic child abuse.

Forensic autopsies and PMCT can also sometimes reveal medical errors or malpractice. PMCT demonstrated an incorrectly positioned endotracheal tube located in the right main bronchus of three subjects. Subject 10 presented with a dilatation of the oesophagus, considered a rare incidental finding. Subject 8 (one-day-old female) was diagnosed with bullae within the lungs; whilst Subject 15 presented with a small cyst of the right lobe of the thyroid gland. Two subjects also presented with lymphadenopathy. For example, Subject 14 was diagnosed with cervical lymphadenopathy, whilst Subject 24 presented with hilar lymphadenopathy. Both adenopathies were only diagnosed at the forensic autopsy. Subject 14, based on radiological and forensic pathology evidence, presented with signs of physical abuse estimated to have occurred over an extended period; whilst Subject 24 presented with mucolipidosis and was a generally neglected infant. These lymphadenopathies were thus pathological in nature. The majority of incidental findings were identified with PMCT. Only three incidental findings had forensic significance which were those for Subjects 9, 11 and 25, where the ET tube was incorrectly placed in the right main bronchus. This implied that a medical error occurred as the ET tube should have been placed within the trachea just above the carina. The incorrect placement of the ET tube within the right main bronchus suggests that artificial ventilation could have been compromised to the left lung due to majority of air being pumped into the right lung. This places the affected lung at risk of collapsing.

[8] An inca bone is a triangular sutural bone found at the previous anatomical location of the posterior fontanelle and is one of the Wormian bones. It is a normal variant (Kabbani & Gaillard, 2020).

Table 6.8 Incidental findings diagnosed with forensic autopsy and PMCT

Incidental findings	Subject number	Subject age	Examination at which finding was observed:
Eleven pairs of ribs (unilateral)	1	1 month	PMCT (Reviewer 2)
Mongolian spots	1	1 month	Forensic autopsy
Umbilical hernia	2	5 months	PMCT (Reviewers 1 & 2)
Mongolian spots	5	3 months	Forensic autopsy
Six lumbar vertebrae	5	3 months	PMCT (Reviewer 2)
Eleven pairs of ribs (bilateral)	5	3 months	PMCT (Reviewer 2)
Inca bone	6	1 day	PMCT (Reviewers 1 & 2)
Bullae in lungs	8	1 day	PMCT (Reviewer 1)
Patent foramen ovale (Botalian duct)	8	1 day	Forensic autopsy and PMCT (Reviewer 1)
ET tube in right main bronchus	9	18 months	PMCT (Reviewer 1)
Dilatation of oesophagus	10	2 years	PMCT (Reviewer 1)
Accessory cervical rib (bi-lateral)	11	3 years	PMCT (Reviewer 1)
ET tube deep in right main bronchus	11	3 years	PMCT (Reviewer 1)
Eleven pairs of ribs (bi-lateral)	14	18 months	PMCT (Reviewer 2)
Cervical lymph adenopathy	14	18 months	Forensic autopsy
Thyroid cyst	15	17 years	Forensic autopsy
Septal defect	20	1 day	Forensic autopsy
Hilar lymphadenopathy	24	10 months	Forensic autopsy
ET tube in right main bronchus	25	5 years	PMCT (Reviewer 1)

6.21 CHAPTER SUMMARY

The results in this chapter showed that PMCT was able to identify some injuries, but not others. PMCT was able to identify skeletal trauma such as facial bones and skull fractures; gas collections such as pneumothoraces and pneumocephali; and fluid collections such as pleural effusions. However, PMCT did not perform well in demonstrating solid organ injuries, haemorrhagic injuries, as well as hollow organ and soft tissue injuries. The cause of death agreement between PMCT and the forensic autopsy was perfect (100%) for blunt force head injury and fatal physical abuse and very good (91%) for gunshot injuries. There was zero concordance for determining a cause of death for five natural deaths. The forensic autopsy could not determine the cause of death in three cases; and PMCT showed perfect agreement for the same three cases. There were a number of significant injuries demonstrated with PMCT across all five anatomical regions. The results further showed there were a number of significant injuries and certain measurements performed during the forensic autopsy, which are currently not possible with PMCT. The next chapter will discuss the implications of the findings of this study and the relevance it has for forensic pathology and post-mortem forensic imaging practice.

CHAPTER SEVEN

DISCUSSION

7.1 CHAPTER INTRODUCTION

This chapter presents a discussion of the results of this study and the implications thereof. The first section of this chapter is aligned with the four objectives of the research study, which were to establish (i) the degree of concordance between PMCT and the forensic autopsy in terms of the spectrum and anatomical location of injury types diagnosed amongst subjects; (ii) The discordance between PMCT and the forensic autopsy for injury categories diagnosed; (iii) whether PMCT can accurately establish the cause of death in abused children; and (iv) whether the findings of this study support the notion that selected forensic cases can undergo PMCT in the absence of the forensic autopsy.

The chapter continues by providing arguments why the forensic autopsy could not be considered the gold standard for injury types indentified, successes of the study; study limitations identified; and recommendations for future similar post-mortem imaging studies. The chapter ends with an overview of the contribution of the study to the body of knowledge; the role of PMCT imaging in cases of child abuse; the author's reflections on the future of forensic imaging in South Africa and the implications thereof for health care; and a conclusion.

A forensic autopsy comprises a comprehensive, external physical inspection of a body, as well as internal exploration of organs via dissection within the cranial, thoracic, abdominal and pelvic cavities and, where appropriate, the extremities (Ayoub & Chow, 2008; Ruder et al., 2011). One of the main purposes of forensic autopsies is to determine the cause of death (and, in trauma victims, to describe the causal mechanism of trauma), as well as to document comprehensively the injuries sustained for presentation as evidence in a court of law (Dirnhofer et al., 2006; Urbanik et al., 2009; O'Donnell, 2010). Diagnostic assessments made during forensic autopsies are further supported by supplementary examinations such as histology, toxicology, DNA analysis, pharmacology, virology, microbiology, LODOX® (O'Donnell & Woodford, 2008) and in rare cases, skeletal surveys.

Considering that forensic autopsies enable a comprehensive assessment (i.e., a physical external and internal inspection) of a deceased body, a complete assessment of injuries related to child

abuse can be made. Cross-sectional post-mortem imaging, too, enables a whole-body examination of the deceased. One fundamental analogy that can be drawn between the forensic autopsy and whole body PMCT imaging of the deceased is that both examinations enable a full inspection of the body to document the inflicted injuries (or disease processes) and to establish the cause and manner of death. It is therefore essential that, if PMCT is to replace the forensic autopsy for certain cases, the same diagnostic standards are maintained with cross-sectional post-mortem imaging. The results described in Chapter Five have shown that both examinations have drawbacks which inhibit the identification of certain injury types. This is often influenced by the anatomical location thereof. It is a well-established fact (and the results of this study have shown) that PMCT is not able to demonstrate all injuries with the same degree of accuracy as with the forensic autopsy. Conversely, not all injuries are identified during the forensic autopsy. This study therefore explored the strengths and weaknesses of both examinations. This chapter will provide a detailed overview of these strengths and weaknesses, and their unique diagnostic aptitude and dissimilarities.

7.2 CASE HISTORIES OF SUBJECTS ENROLLED

Thirty subjects, aged between one day and 17 years, underwent a whole body PMCT examination prior to undergoing a mandatory forensic autopsy following death with unnatural or suspicious causes. The WHO's definition of child abuse was adopted for this study: all forms of physical and emotional ill-treatment or neglect, that result in actual or potential harm to the child's health, development or dignity. The five subtypes of child abuse are: physical abuse; sexual abuse; neglect and negligent treatment; emotional abuse; and exploitation (WHO, 2014). The definition applied was broad to cater for overt and covert forms of abuse. The justification for enrolment of all 30 subjects was that they either had a case history of having succumbed to suspected physical child abuse, neglect or negligent treatment, or sudden unexplained deaths.

Of the 30 subjects enrolled, 25 had succumbed to either physical abuse or assault, supervisory neglect, or negligent treatment. Eleven of these 25 subjects had died as a result of gunshot injuries, whilst four had succumbed as a result of a pedestrian RTAs (Speelman et al., 2022). All four children who had died in pedestrian RTAs were nine years old or younger and the circumstances of their death met the study's definition of supervisory neglect. Three subjects had died as a result of concealment of birth: they were abandoned shortly after birth, and so met the

study's definition of having suffered negligent treatment. Two subjects had died because of repetitive physical abuse (Speelman et al., 2022). One subject died as a result of asphyxiation after reportedly being strangled by their mother shortly after birth; another died due to suspected suffocation by the mother and the body was subsequently hidden in a cupboard for three days. One had died due to blunt force head injuries caused by being hit on the head with a golf club in a case of domestic violence. Another one had died after being struck on the head with a brick (Speelman et al., 2022). One had died due to hyperthermia after being locked in the boot of an abandoned car. Five subjects in this study had succumbed due to natural disease. These five cases were all enrolled due to findings at the scenes of death which in each case justified a sudden or unexplained death.

The section that follows discusses the reasoning behind why the forensic autopsy was considered an imperfect reference standard, thereafter the interpretation of the spectrum of injuries identified with both examinations across all subjects ensue.

7.3 THE FORENSIC AUTOPSY AS AN IMPERFECT REFERENCE STANDARD

The study set out to evaluate the strengths and weaknesses of PMCT, compared to the forensic autopsy, for injury diagnosis. The forensic autopsy could not be used as the gold standard against which to measure the performance of PMCT as, per a study by Jackowski, (2013) some injuries were also missed by the forensic autopsy in this study. Instead, similar to a study by Adelman et al. (2018), both examinations were used in comparison to each other as the reference standard. When comparing an index examination (e.g., PMCT) against an imperfect reference standard (in this case, the forensic autopsy), calculating sensitivity and specificity of such an index examination is described by Trikalinos and Balion (2012) as naïvely biased. Instead, both examinations must be treated as two separate measurement methods (or examinations, in this instance) (Trikalinos & Balion, 2012). If not treated as two separate measurement methods, all findings made with PMCT that are not observed with the forensic autopsy must be considered as false positives, as argued by Jackowski, (2013) which would be wrong in a study such as this. The results of this study were thus analysed with the understanding that all findings diagnosed with PMCT indeed existed and disregarded any false positives in this regard. This is largely because the forensic autopsy could not serve as a true gold standard (Graziani et al., 2018). It is acknowledged that some injuries diagnosed with PMCT might also be false positives, but arguably such cases would

be few and will thus not affect the overall results of the study. The design of the study also did not make provision for cross-checking of all diagnoses made to assess any false positives diagnosed by both examinations.

However, percent agreement was calculated to show the concordance between PMCT and the forensic autopsy for diagnosis of injury types (Le Blanc-Louvry et al., 2013). This concordance showed certain trends which could be compared with those of other studies. Percent agreement is a widely accepted form of statistical analysis in forensic diagnostic imaging accuracy studies and has been used by various experts (Leth & Ibsen, 2009; Scholing et al., 2009; Kasahara et al., 2012; Le Blanc-Louvry et al., 2013; Leth, Struckmann & Lauritsen, 2013; Krentz et al., 2016). The Cohen Kappa degree of concordance (with a 95% confidence interval) was also calculated to measure interrater reliability (variability) for cause of death attribution, as assigned by the forensic autopsy and PMCT.

7.4 SPECTRUM OF INJURIES DIAGNOSED WITH THE FORENSIC AUTOPSY AND PMCT

The first major objective of this study was to compare the degree of concordance of injuries diagnosed with PMCT to those of the forensic autopsy. A wide spectrum of injuries as well as incidental findings were identified with both the forensic autopsy and PMCT. For ease of reference, all injuries sustained were divided into six groups: five anatomical regions (namely, head and neck; thorax; abdomen and pelvis; spinal column and spinal cord; and extremities); and one miscellaneous group. The latter group was created as a few injuries could not be listed under a specific anatomical region. A combined total of 82 injury types were identified with the forensic autopsy and PMCT. With the forensic autopsy, a total of 348 findings were identified (mostly injuries) compared with a total of 241 diagnosed with PMCT. This implies that PMCT had a 69% agreement with the forensic autopsy. Overall, 438 findings were diagnosed with both the forensic autopsy and PMCT combined. This figure includes injuries not identified by the other examination. A total of 197 and 89 discrepant findings were noted for PMCT and the forensic autopsy respectively (Addendum B1).

When considering the combined number of injuries identified with PMCT, more injuries were identified with the forensic autopsy in five of the six groups, which included the head and neck, thorax, abdomen and pelvis, and the miscellaneous group. The only anatomical location where

more injuries were diagnosed with PMCT compared to the forensic autopsy was within the spinal column. The latter finding could be because the forensic pathologists did not suspect spinal fractures, as the spinal column was not always dissected in all forensic cases. This could explain the underreporting. The cross-sectional, multi-planar capabilities of PMCT enhance the diagnosis of spinal fractures and this could explain its higher sensitivity within this anatomical region.

For the forensic autopsy, the highest number of injuries were identified within the thorax, mostly affecting the lungs, heart and pleural cavities. Seven of the 11 gunshot victims sustained injuries to the thorax. This observation could explain the high number of injuries recorded in the thorax, given the considerable damage gunshot injuries can cause to organ systems. The second highest number of injuries was recorded in the head and neck. A considerable number of injuries sustained involved the brain, skull, face and neck. Nine subjects sustained injuries to the head and neck region: six subjects sustained blunt force head injuries; and three subjects sustained gunshot head injuries and one subject a gunshot injury to the neck only. The other anatomical regions sustained significantly fewer injuries compared to the head and thorax.

A pure look at the global number of injuries identified by the forensic autopsy and PMCT across the six groups does not adequately reflect the performance of these two examinations for identifying individual injury types. Both examinations had shortfalls which will be discussed in detail in the following sections.

7.4.1 Head and neck injuries

Traumatic head injuries are a common finding in forensic pathology and have a high morbidity and mortality (Jacobsen & Lynnerup, 2010). In forensic pathology, head injury assessment includes analysis of external lesions of the scalp, the cranium, intracranial lesions, and facial fractures. The majority of head injuries seen were the result of direct blunt force injury to the head, while a smaller number were the result of gunshot injuries.

In this study, the forensic autopsy diagnosed more brain contusions and lacerations. This finding is consistent with that of Yen et al. (2007), Le Blanc-Louvry et al. (2013) and Maklouf et al. (2013), but inconsistent with that of Jacobsen and Lynnerup (2010). In the latter study, more brain contusions and lacerations were diagnosed with PMCT than with the forensic autopsy. More cases of brain compression or swelling were also diagnosed with PMCT than with the forensic autopsy.

This finding is inconsistent with that of Yen and colleagues who showed that the forensic autopsy was able to identify significantly more cases of brain compression and swelling of the cerebellar tonsils and increased brain pressure (Yen et al., 2007).

Superficial or deep brain parenchymal injuries, such as contusions or lacerations, are not always discernible on PMCT imaging. One significant advantage that forensic autopsy holds over PMCT is that a visual macroscopic and microscopic assessment of the brain surface and brain parenchyma is possible, which may explain the forensic autopsy competitive edge in this regard (Adelman et al., 2018). PMCT imaging is unable to demonstrate surface anatomy of the brain in the same manner (orientation) and level of detail as is possible with the naked eye. For example, the natural 3D full colour display of the surface of the brain is not possible with this imaging modality (Murken et al., 2012).

PMCT generally has a good diagnostic yield for the diagnosis of intracranial haemorrhages. In this study, however, the forensic autopsy diagnosed more SDHs and SAHs compared to PMCT. This finding is similar to that of other studies (see Yen et al., 2007; Daly et al., 2013; Le Blanc-Louvry, 2013; Mishra et al., 2018); and PMCT has been shown to be less sensitive in demonstrating SDHs smaller than 3 mm (Yen et al., 2007). All five SDHs missed in the present study were described by the forensic pathologists as smear SDHs and were invisible on PMCT. This could explain PMCT's poor performance in this regard. Conversely, Jacobsen and Lynnerup (2010) showed substantial agreement between the forensic autopsy and PMCT for the diagnosis of SDH, which is contrary to the findings of the above five studies and the present study. The dimensions (i.e., size) of the SDHs diagnosed in the study of Jacobsen and Lynnerup (2010) were not stated and the reasons for their substantial agreement could not be established.

With PMCT more intraventricular haemorrhages were diagnosed compared with the forensic autopsy. This finding is consistent with that of Daly et al. (2013); whilst, in their study comprising five subjects, Yen and colleagues found perfect agreement between the forensic autopsy and PMCT (Yen et al., 2007). The poor performance of the forensic autopsy in the diagnoses of intraventricular haemorrhages could be because the integrity of the ventricular system is often disturbed after opening of the meninges (especially in a badly injured brain) (Daly et al., 2013). In PMCT, the ventricular system remains largely intact during PMCT image acquisition and could explain the higher sensitivity to diagnosis of this injury type.

Brain oedema may present radiographically in various ways: as bilateral or unilateral effacement of sulci and gyri; obliteration or effacement of the lateral ventricles; and, in severe cases, it may cause tonsillar herniation (Yen et al., 2007). With the forensic autopsy more brain oedema was diagnosed compared to PMCT. This finding is consistent with that of Yen et al. (2007).

In the present study, pneumocephali were evident in the majority of subjects with open skull fractures and these were all identified on PMCT. Not surprisingly, no pneumocephali were diagnosed during the forensic autopsies. This finding is in keeping with studies by Daly et al. (2013), Le Blanc-Louvry (2013) and Maklouf et al. (2013). The forensic autopsy does not routinely conduct examinations to establish the presence of pneumocephalus. If pneumocephalus is suspected, underwater confirmation is required with the use of an aspirometer which allows assessment of the amount and composition of the gas (Gebhart et al., 2012).

More skull and facial fractures were diagnosed with PMCT than with the forensic autopsy. Five of the skull fractures missed during the forensic autopsy involved both walls, the roof, and the floor of the orbits of some subjects. The orbital cavity for these subjects was not opened during the forensic autopsy and could explain the underreporting. Non-displaced skull fractures are less likely to be explored during autopsy and may be an additional reason for the underreporting (Mishra et al., 2018). The findings of the present study are consistent with those of Mishra et al. (2018). Other studies however showed that with the forensic autopsy more skull fractures were diagnosed compared to PMCT (Poulsen & Simonsen, 2007; Yen et al., 2007; Leth & Ibsen, 2009; Le Blanc-Louvry et al., 2013). These findings suggest that PMCT has mixed results for the diagnosis of skull fractures. The present study identified a range of skull fractures which enabled a good comparison between the forensic autopsy and PMCT for diagnosis of this injury type. Clival fractures are commonly the result of blunt head trauma. The mortality rate following clival fractures is high due to brainstem trauma or vertebro-basilar occlusion (Menkü et al., 2004; Winkler-Schwartz et al., 2015). In this study, a rare fracture dislocation of the clivus was diagnosed with PMCT, but not with the forensic autopsy, underscoring this imaging modality's ability to delineate rare and deeply located base of skull fractures.

None of the seven facial fractures diagnosed with PMCT were diagnosed with the forensic autopsy, confirming the advantage PMCT holds over the forensic autopsy in this regard. Other studies have shown consistently similar results (Yen et al., 2007; Leth & Ibsen, 2009; Le Blanc-

Louvry et al, 2013; Krentz et al., 2016; Mishra et al., 2018). This is not a surprising result as, for cosmetic and ethical reasons, the face is rarely opened during the forensic autopsy (Thali et al., 2003a; Yen et al., 2007).

Extracranial injuries were not well seen during PMCT imaging. Two cases involving haemorrhages surrounding the optic nerve sheaths, as well as two lacerations of the parotid glands, were not diagnosed with PMCT. The parotid gland lacerations were the result of gunshot injuries to the neck. No other similar studies were found where injuries to the optic nerve sheaths or parotid glands were recorded, so no direct comparisons could be made with existing literature.

Subscalpular haemorrhages may involve several layers of soft tissue that covers the cranium. Haemorrhages in these layers are difficult to discern with PMCT. Consistent with studies by Leth and Ibsen (2009) and Mishra et al. (2018), the forensic autopsy diagnosed more scalp injuries compared to PMCT. Bruises and scalp lacerations involving the skin are currently not identifiable on PMCT. Soft tissue injuries of the scalp are much better observed with the naked eye, which could explain the higher sensitivity of the forensic autopsy in this regard (Leth & Ibsen, 2009). Moreover, the soft tissue resolution of scalp injuries currently possible with PMCT does not equate to the level of detail obtainable with a visual physical inspection during forensic autopsies (Leth & Ibsen, 2009). The forensic autopsy identified two more subgaleal haemorrhages in the present study compared with PMCT, underscoring PMCT's inferiority for the diagnosis of extracranial soft tissue injuries. PMCT lacks the natural full colour, 3D and macroscopical analysis of tissue that is possible with forensic autopsies (Murken et al., 2012), which could explain the poor performance of this imaging modality in this regard. The identification of subgaleal and subscalpular haemorrhages is a shortcoming of PMCT which will remain for the foreseeable future unless algorithms are developed to display soft tissue in greater detail, and preferably in 3D.

Oral and pharyngeal injuries are not readily discernible on PMCT: none of the injuries of the pharynx, tongue, and tonsil identified with the forensic autopsy were diagnosed with PMCT. This shortcoming can be explained in the same way as for scalp injuries: unless significant injuries are present, PMCT is generally not able to demonstrate soft tissue injuries of mucous membranes and oral structures, such as the tonsils.

With the forensic autopsy four lacerations involving the carotid and internal jugular veins, were diagnosed and not identified with PMCT. Graziani and colleagues showed that with the autopsy significantly more neck haemorrhages were diagnosed compared to PMCT (Graziani et al., 2018).

7.4.2 Thoracic injuries

In the present study, a wide range of thoracic injuries identified were caused by blunt force and gunshot injuries. The identification of lung injuries has significance for any forensic autopsy (Germerott et al., 2010). Lung injuries in this study involved lung perforation or lung damage, such as a permanent cavity of any lobe following a GSW, or localised lung contusion. Parenchymal lung injuries such as lung contusions are not clearly discernible with PMCT. Lung haemorrhages are common findings in penetrating gunshot injuries. In the present study significantly more parenchymal lung injuries, as well as lung parenchymal haemorrhages were diagnosed with the forensic autopsy, compared to PMCT. This finding is consistent with that of Le Blanc-Louvry et al. (2013), Adelman et al. (2018) and Mishra et al. (2018). Even though other PMCT studies have shown promising results for the diagnosis of certain parenchymal lung haemorrhages, dedicated multiphase PMCTA was shown to be poor for the diagnosis of parenchymal lesions. This is due to poor contrast media perfusion to inner organs, resulting in lower contrast resolution in the deceased (Chevallier et al., 2013). The poor diagnosis of lung haemorrhages by PMCT will thus remain a shortcoming for this modality, even with contrast enhancement.

There are many factors that inhibit the diagnosis of lung injuries on PMCT. Post-mortem diagnosis of pulmonary injury and disease is complicated since post-mortem congestion and livor mortis interfere with lung assessment (Sieswerda-Hoogendoorn et al., 2014). Blood sedimentation, which occurs shortly after death (also known as hypostasis), and other conditions, such as lung congestion and lung oedema, can often be mistaken for consolidation (pneumonia) (Dirnhofer et al., 2006; Poulsen & Simonsen, 2007; Sieswerda-Hoogendoorn et al., 2014). There are therefore limits to the lung injuries that can be identified with PMCT, as post-mortem lung alterations can be overshadowed by interval-dependent overlap of blood sedimentation, also known as inner livores (Germerott et al., 2010). Post-mortem lung ventilation, which is not yet common practice in forensic centres, is said to improve the diagnosis of lung injuries and other abnormalities (Sieswerda-Hoogendoorn et al., 2014; Westphal et al., 2014).

In the present study, there was good agreement between the forensic autopsy and PMCT for the diagnosis of lung collapse. This finding is inconsistent with that of Adelman et al. (2018) who showed that PMCT identified more lung collapses compared to the autopsy. Their study had more cases (n = 23) compared to the present study; and the forensic autopsy did not identify 13 cases compared to the five not diagnosed with PMCT. The very good agreement found with the present study could be the result of the expertise of the forensic pathologists and reviewers, or the small number of cases involved, so larger studies could show different results. With the forensic autopsy more lung congestions were diagnosed as compared to PMCT. No other publications could be found that referred to lung congestion, so no comparison could be drawn.

Petechial haemorrhages are common findings in forensic pathology. Petechial haemorrhages of soft tissue surfaces can be caused by a variety of conditions and can be found in traumatic and natural causes of death (Maxeiner & Jekat, 2010). In this study, no petechial haemorrhages could be identified by PMCT as they are virtually impossible to diagnose with this modality (Thomsen et al., 2009). This is due to PMCT's inability to demonstrate soft tissue in colour, and with the same level of detail and resolution possible during visible inspection with the forensic autopsy. This is therefore another example where PMCT will have poor performance for the foreseeable future, as these common forensic autopsy findings are currently not discernible with PMCT.

During a traumatic event, aspiration of blood or gastric content can compromise respiration and can be potentially fatal. Aspirations are often a consequence of severe trauma to the lung and mediastinal structures. Similarly, neurological trauma may also cause aspiration of blood and gastric content (Zech et al., 2016). Detecting signs of aspiration during a forensic examination is of vital importance, as it may show whether an injury occurred pre- or post-mortem, and whether such fatal injury was the major cause of death (Scaparra et al., 2016). With the forensic autopsy more cases of aspiration (n = 11) were diagnosed compared to PMCT (n = 1). Findings of the present study are congruent with those of Krentz et al. (2016) and Adelman et al. (2018) but contrary to those of Filograna et al. (2011) and Scaparra et al. (2016). In the latter two studies, there was good agreement between PMCT and the autopsy for the diagnosis of aspiration. However, these two studies were done retrospectively and prospectively, focusing solely on radiological signs of aspiration, which could explain the high level of agreement between the forensic autopsy and PMCT in their studies. Conversely, one explanation for the low detection

rate of aspiration in the present study could be that aspiration was not actively sought by the reviewers, given the fact that full body sequences had to be analysed.

A surprising finding in the present study, given that this abnormality is usually well seen during clinical CT, was that, with the forensic autopsy, three more cases of lung atelectasis were diagnosed compared with PMCT. This finding is inconsistent with that of Aghayev and colleagues who demonstrated good agreement between the forensic autopsy and PMCT (Aghayev et al., 2008). Atelectasis is better identified following contrast media enhancement, as collapsed pulmonary tissue enhances intensely (Christe et al., 2010). It is anticipated that, once PMCTA applications are widely applied in forensic pathology, the level of agreement of PMCT in this regard will improve.

Overall, with PMCT more traumatic injuries involving the pleural cavity were diagnosed compared to the forensic autopsy. There was very good agreement between the forensic autopsy and PMCT for the diagnosis of haemothoraces. This finding is inconsistent with that of Daly et al. (2013) and Mishra et al. (2018). In the present study, more pneumothoraces were diagnosed with PMCT compared to the forensic autopsy. This finding is consistent with other studies (see Daly et al., 2013; Le Blanc-Louvry et al., 2013; Maklouf et al., 2013; Mishra et al., 2018). Similar to the findings of Hoey et al. (2007), the forensic autopsy in the present study missed one tension-pneumothorax. The diagnosis of pneumothoraces requires a specialised underwater dissection technique which was not performed amongst subject in this study and can explain the underreporting. Most of the subjects with pneumothoraces had severe injuries to the thorax, so the assumption is that these pneumothoraces were not tested for, as such a finding might be considered secondary to establish the cause of death in a subject with severe injuries to the thorax.

CT scanning is known for demonstrating pleural effusions with excellent sensitivity. These are hardly missed using CT imaging (Halvorsen et al., 1986; Moy et al., 2013). There was moderate agreement between the forensic autopsy and PMCT for the diagnosis of pleural effusions. This finding is consistent with studies by Le Blanc-Louvry et al. (2013), but inconsistent with that of Westphal et al. (2014) and Adelman et al. (2018). Due to the small number of pleural effusions identified within the present study, it is difficult to comment on PMCT's performance in this regard. Small pleural effusions may also, at times, be considered of little forensic significance during forensic autopsies, and can thus go unreported (Daly et al., 2013). This could perhaps explain the lower number identified with the forensic autopsy in the present study. Considering that Le Blanc-

Louvry et al. (2013) had significantly more cases than in the present study (an average of 73 pleural effusions were identified with PMCT, compared to 55 at autopsy), it is fair to assume that their study provides a much better indication of PMCT performance when compared to the forensic autopsy for the identification of pleural effusions.

Subpleural blebs are lung cysts located within the subpleural lung or within the pleura itself; they are usually ≤ 2 cm in diameter (Amjadi et al., 2007). The forensic autopsy identified two more subpleural blebs, compared with PMCT. No other comparable studies could be found, so no comparison could be made with existing literature. The small number of cases identified in this study also inhibits judgement as to which of the two examinations are better for this diagnosis.

7.4.3 Heart and mediastinum injuries

Cardiac injuries following gunshot injuries or RTAs can have fatal consequences for victims. In the present study, PMCT identified fewer cardiac injuries compared to the forensic autopsy. For example, PMCT was less sensitive for the identification of focal haemorrhage of the atria and ventricular walls, and sub-epicardial petechial haemorrhages. In addition, focal haemorrhages of the cardiac musculature and surrounding haemopericardia were not well seen with PMCT. PMCT further did not demonstrate any of the five heart lacerations diagnosed with the forensic autopsy, all the result of gunshot injuries to the thorax. Similarly, two cases of heart valve perforation following a gunshot injury were not identified with PMCT. These findings are consistent with those of other studies (see Levy et al., 2006; Aghayev et al., 2008; Krentz et al., 2016; Adelman et al., 2018) and confirm PMCT's overall poor diagnostic yield for penetrating and haemorrhagic injuries involving the heart.

The poor performance of PMCT to depict cardiac injuries can be ascribed to the poor resolution of cardiac structures, collapsed chambers, and the inherent lack of contrast media enhancement in the absence of PMCTA (Proisy et al., 2013). Even though PMCT can reliably demonstrate pericardial effusion, identifying the exact vascular injury site is generally difficult, unless autopsy is performed (Shiotani et al., 2008). Air embolism can be fatal and PMCT enables exquisite delineation of cardiac gas collections. In the present study, an air embolism was successfully identified in the right ventricle with PMCT, in the case of a gunshot injury to the thorax. Diagnosis of air embolism at autopsy requires a special technique, such as puncturing of the heart under

water. This technique is only done where a history of fatal air embolism is suspected and would not be searched for following a lethal GSW. This could explain why this was not diagnosed at the forensic autopsy (Martin, 2020). However, PMCT will negate the performance of these specialised techniques in cases where fatal air embolism is the suspected cause of death.

Haemorrhage of structures within the mediastinum can be subtle and difficult to identify with PMCT. Mediastinal haemorrhages were only diagnosed with the forensic autopsy. This finding is in keeping with that of Aghayev et al. (2008). A systematic review, in which PMCT findings were compared with those of the autopsy, showed that PMCT was inferior to the autopsy for the identification of cardiac and mediastinal injuries in 10 studies (Jalalzadeh et al., 2015). The findings of the present study are therefore congruent with the findings of this systematic review. In the present study, more heart displacements were identified with PMCT compared to the forensic autopsy, a finding consistent with that of Aghayev et al. (2008). During autopsy, identification of heart and mediastinal displacement (also known as mediastinal shift), especially when caused by tension pneumothorax, remains a challenge (Thomsen et al., 2009; Jalalzadeh et al., 2015). Evidence of mediastinal shift is often lost during a forensic autopsy once the chest cavity is opened (Cha et al., 2010). The only mediastinal shift diagnosed with the forensic autopsy in the present study was diagnosed with the aid of the LODOX® system.

7.4.4 Thoracic cage injuries

The presence of rib fractures in children is considered a hallmark of child abuse (Van Rijn & Sieswerda-Hoogendoorn et al., 2012b). The number of rib fractures present, and the absence or presence of healing, has medico-legal significance (Hong et al., 2011). The identification of rib fractures in the context of fatal child abuse thus has critical relevance for any forensic examination. There was near perfect agreement between the forensic autopsy and PMCT for the diagnosis of rib fractures. Other studies by Le Blanc-Louvry et al. (2013), Adelman et al. (2018) and Leth and Ibsen (2009) have shown that the forensic autopsy identified more rib fractures compared with PMCT. Shelmerdine and colleagues (2018) have shown that CT provides a higher diagnostic yield for rib fracture identification and anatomical localisation compared to projection radiography. This finding was supported by a systematic review and meta-analysis (Alzahrani, et al., 2021). CT should be considered as an adjunct examination given that 3D reconstructions with curved reformation can be performed which improved rib fracture detection (Shelmerdine, et al., 2018).

Incomplete or undisplaced rib fractures, or those without callus formation, can be difficult to diagnose with PMCT (Poulsen & Simonsen, 2007; Leth & Ibsen, 2009; Hong et al., 2011). Even HRCT may fail to demonstrate re-attached fracture edges (Schulze et al., 2013). This phenomenon may explain the lower diagnostic yield of PMCT for the identification of rib fractures.

Very few post-mortem publications exist in which comparisons were drawn between the autopsy and PMCT for the identification of sternal fractures. Sternal fractures are unusual in children and are highly suggestive of physical abuse[9] (Jacobi et al., 2010; Paddock et al., 2017). Sternal fractures are also associated with high energy trauma (Restrepo et al., 2009). All sternal fractures in the present study were the result of gunshot wounds to the thorax. In this study, there was moderate agreement between the forensic autopsy and PMCT for the identification of sternal fractures. This finding is in keeping with Adelman et al. (2018) who found no particular advantage of one examination over the other. The number of sternal fractures in the present study was small. Considering that Adelman et al. (2018) had a much larger sample (n = 29), it is safe to assume that both examinations have a moderate sensitivity for the identification of sternal fractures given their larger sample size.

7.4.5 Diaphragmatic injuries

Diaphragmatic injuries in paediatric populations are rare (Kerr & Maconochie, 2008). In the present study, PMCT was unable to identify diaphragmatic contusions diagnosed at the forensic autopsy. This finding is in keeping with that of other studies (see Aghayev et al., 2008; Maklouf et al., 2013; Adelman et al., 2018). Contrary to these findings, other studies have shown good agreement between the forensic autopsy and PMCT for the identification of diaphragmatic injuries (see Daly et al., 2013; Sifaoui et al., 2017). These findings suggest that PMCT generally has mixed results for the identification of diaphragmatic injuries. Injuries of the diaphragm are usually not well seen in clinical practice. Diaphragmatic lacerations or other injuries may even be missed by thin CT slice imaging during image acquisition due to the complex shape of the thin diaphragmatic

[9] Physical abuse in this chapter will imply physical abuse caused by blunt force trauma and will exclude other forms of abuse caused by sharp force injuries, chemicals, burns, and neglect, amongst others.

musculature, its horizontal orientation, and poor contrast resolution (Kerr & Maconochie, 2008; Adelman et al., 2018). This phenomenon may explain the poor diagnostic yield of PMCT in this regard. Tears of the diaphragm are often discovered following secondary signs such as herniation of the abdominal viscera into the thoracic cavity (Adelman et al., 2018).

7.4.6 Abdominal and pelvic injuries

With the forensic autopsy significantly more solid organ injuries of the abdomen were diagnosed compared to PMCT. For example, a total of 14 solid organ injuries were diagnosed with the forensic autopsy; only two of these were diagnosed with PMCT (viz a single renal injury and one laceration of the liver). The findings of this study are consistent with those of other studies (Daly et al., 2013; Le Blanc-Louvry et al., 2013; Mishra et al., 2018). In this study, the intra-abdominal injuries not discernible with PMCT included two spleen lacerations, soft tissue haemorrhages of the pancreas, peri-adrenal soft tissue and adrenal medulla. Unlike in clinical practice, the diagnosis of liver, spleen and pancreatic injuries in forensic imaging is compromised due to the lack of contrast enhancement (Makhouf et al., 2013). This poor diagnostic yield is further complicated by inherent poor contrast resolution, and lack of visceral fat in children. In adults, the presence of visceral fat enables organ differentiation (Dedouit et al., 2011).

PMCT did not diagnose any of the eight hollow organ injuries identified with the forensic autopsy. With PMCT more pneumoperitoneums were diagnosed compared to the forensic autopsy. For example, three were diagnosed with PMCT compared to none with the forensic autopsies. This finding is in keeping with that of Mishra et al. (2018). The presence of a pneumoperitoneum always suggests a hollow organ perforation, but, unlike with the forensic autopsy, localising the exact site of organ perforation is difficult with PMCT (Dedouit et al., 2011; Kasahara et al., 2012; Maklouf et al., 2013; Levy et al., 2016). This will remain a shortcoming for PMCT in the interim.

In this study, there was perfect agreement between the forensic autopsy and PMCT for the diagnosis of haemoperitoneum. This finding is consistent with that of Hoey et al. (2007). Even though PMCT is able to identify the location of haemoperitoneum, measuring the volume of blood is not possible due to the diverse anatomical organs and intricate muscle and mesenteric planes. Unlike diagnosis with the forensic autopsy, PMCT failed to demonstrate one laceration of the abdominal aorta, the only injured major blood vessel within the abdomen. Another study also

showed that PMCT missed a considerable number of 18 aortic ruptures (Leth et al., 2013). Unlike with the forensic autopsy, the exact location of aortic lacerations is generally not easily discernible with unenhanced PMCT, and so these are often only suspected when secondary signs, such as free fluid in the abdomen, are present (Daly et al., 2013; Leth et al., 2013).

Overall, the number of pelvic fractures in this study was small. There was moderate agreement between the forensic autopsy and PMCT for diagnosis of pelvic injuries. Fractures missed by the forensic autopsy in the present study included a fracture of the symphysis pubis, acetabulum and one involving the sacro-iliac joint. An injury missed by PMCT included one hip dislocation. This hip dislocation was diagnosed using LODOX® but was not visible on the PMCT images and presumably could have been reduced inadvertently prior to the PMCT imaging. Leth and Ibsen (2009) argue that some pelvic fractures are not easily accessible for inspection during autopsy. Further, some pelvic injuries are difficult to assess during the forensic autopsy (Jalalzadeh et al., 2015). This is mostly because pelvic dissections are challenging, and non-displaced pelvic fractures require the bony pelvis to be exposed directly (Adelman et al, 2018). Pelvic fractures are rare in children who are victims of blunt trauma (Ortega et al., 2014). Similarly, scientific publications on post-mortem imaging of this injury type are scarce, making it difficult to assess the sensitivity of the forensic autopsy and PMCT in this regard.

The findings of the present study for pelvic injury diagnosis are consistent with studies by Daly et al. (2013), Adelman et al. (2018) and Mishra et al. (2018), but inconsistent with those of Poulsen and Simonsen (2007), Sochor et al. (2008) and Le Blanc-Louvry et al. (2013). Two other studies have shown that the forensic autopsy can miss between five and 30 pelvic fractures (Chavellier et al., 2013; Adelman et al., 2018). The number of pelvic injuries in the present study was too small to draw any meaningful conclusions. Considering that the number of pelvic fractures identified with PMCT in the study by Adelman and colleagues were high (n = 30), compared to the autopsy, these findings may suggest that PMCT performed better to the forensic autopsy for the identification of pelvic fractures. These mixed findings described suggest that both the forensic autopsy and PMCT might, on occasion, fail to identify some pelvic fractures. Physical abuse often results in superficial injuries to the skin and genitalia. Three superficial injuries to the genitals of a physically abused infant were diagnosed during the forensic autopsy but, for obvious reasons, were not seen with PMCT.

7.4.7 Spinal column and spinal cord injuries

Spinal injuries have forensic significance in the trauma setting, as these may indicate the degree and severity of the assault. Spinal injuries, even if isolated, can result in fatal complications such as spinal shock and paralysis of breathing muscles, often resulting in death (Makino et al., 2014). Since cervical spine injuries often contribute to the cause of death, so the identification of such injuries is critical in forensic examinations (Uhrenholt & Boel, 2010). PMCT was able to demonstrate injuries to the spinal column with exquisite detail. The destruction of the 'calcium rich' bony spinal column is easily discernible on PMCT, better than with any other diagnostic imaging modality. In the present study, there was moderate agreement between the forensic autopsy and PMCT for spinal fracture diagnosis. Adelman and colleagues showed slight agreement between the forensic autopsy and PMCT for spinal fracture diagnosis. In their study, the forensic autopsy and PMCT missed seven and eight spinal fractures respectively (Adelman et al., 2018).

One dislocation of the atlanto-occipital joint was missed during PMCT in the present study. However, on review of the PMCT images by the author, this joint appeared undisplaced and this could account for this dislocation being missed. An atlanto-occipital dislocation was also missed by PMCT in a study conducted by Uhrenholt and Boel (2010). The general ability of PMCT to diagnose atlanto-occipital dislocations cannot be judged on the basis of one missed case, as in the present study and that of Uhrenholt and Boel (2010). The reliability of PMCT in identifying this injury type requires further validation with larger study populations. Missing such a significant injury during post-mortem imaging, when conducted solely in the absence of a forensic autopsy, poses detrimental consequences for the medico-legal investigation (Uhrenholt & Boel, 2010).

In this study, more thoracic vertebrae were found to be fractured compared to other regions of the spine. The higher number of thoracic vertebral fractures corresponded directly with the higher number of thoracic injuries diagnosed overall within this study. All spinal fractures in this study were the result of gunshot injuries.

Spinal cord injuries may result in severe morbidity and increased mortality for affected individuals. PMCT has been shown to have poor sensitivity for the identification of spinal cord injuries identified during the forensic autopsy. Compared to MRI, PMCT imaging of the spinal cord lacks contrast resolution, resulting in poor delineation thereof (Makino et al., 2014). In the present study, the forensic autopsy identified three spinal cord transections, compared to only one identified with

PMCT. The spinal cord transection diagnosed with PMCT was the result of a fatal gunshot wound to the neck. In this case, identification of the spinal cord transection with PMCT was enhanced by an accumulation of air separating the brain from the spinal cord at the level of transection. See Figure 6.20 in Chapter Six. Findings of the present study are comparable with those of studies by Sochor et al. (2008) and Kasahara et al. (2012), in which PMCT failed to demonstrate three spinal cord transections and nine spinal cord injuries, respectively.

Makino and colleagues have shown that the majority of significant spinal cord injuries identified with the forensic autopsy, such as transections, or severe spinal deformity, tiny spinal cord haemorrhages and contusions, had normal PMCT findings, including no bony abnormalities of the spinal column (Makino et al., 2014). The ability of PMCT to demonstrate spinal cord injuries will remain poor in the foreseeable future. Prospects of imaging the spinal column and cord using new advances, such as dual-energy CT which can acquire images with two energy levels, may improve visualisation of minute spinal structures (Uhrenholt & Boel, 2010). However, the widespread application of dual-energy CT imaging in forensic medical centres has not yet commenced. In the present study, PMCT was also not able to identify associated injuries diagnosed with the forensic autopsy, such as haemorrhage staining which suggested a spinal cord injury caused by a corresponding lumbar vertebral fracture.

7.4.8 Extremity fractures

Extremity fractures are common findings in physical abuse cases, gunshot injuries, as well as RTAs. PMCT readily demonstrates disruption of the bony cortex and joint spaces, as well as the presence of bony fragments. Most extremity fractures diagnosed in the present study involved the upper extremity. There was almost perfect agreement between the forensic autopsy and PMCT for identification of extremity fractures. This finding is consistent with studies by Poulsen and Simonsen (2007), but inconsistent with those of Le Blanc-Louvry and Daly et al. (2013) and Adelman et al. (2018) where PMCT identified more extremity fractures compared to the forensic autopsy. Where the forensic autopsy does not record extremity fractures, it could be because these fractures were not explored during the examination. This occurs when there is no clinical indication of a fracture present prior to the forensic autopsy (Martin, 2020). Adelman and colleagues have shown that distal extremity fractures are often missed during autopsy. However, the authors did not explain the reasons why these distal extremity fractures were often missed in

their study (Adelman et al., 2018). The extremity fractures missed by PMCT within the present study included two metacarpal fractures, one radial and one ulna fracture. These fractures were diagnosed by the forensic pathologist with the aid of a skeletal survey conducted prior to the forensic autopsy. These fractures, upon retrospective review by the author, appeared not displaced, without any callus formation, and could explain why they were not identified with PMCT.

PMCT was useful for identification of extremity fractures caused by physical abuse. Forensically significant findings that suggested fatal physical abuse identified with PMCT in one subject included fractures in different stages of healing, as well as a CML. In the same subject, the presence of callus formation accompanied by acute fractures of the distal humerus and bilateral tibia confirmed the diagnosis of repetitive physical abuse, with the forensic autopsy. Based on the findings of this study, PMCT can serve as a useful adjunct screening modality to employ before the forensic autopsy to indicate which area to dissect during the forensic autopsy.

Only two scapular fractures were identified with the forensic autopsy and PMCT in the present study. The number of scapular fractures in the present study was too small to draw any meaningful conclusion as to the diagnostic concordance of either of the two examinations. A larger study has shown that with PMCT more scapular fractures were diagnosed compared to the autopsy (Adelman et al., 2108). Given the larger sample size in their study, their findings provide a better assessment of the sensitivity of two examinations for the identification of scapular fractures.

7.4.9 Soft tissue oedema

A multitude of factors can cause generalised soft tissue oedema. It occurs when excessive fluid accumulates in either intracellular or extracellular (interstitial spaces). Interstitial oedema in the trauma setting is usually caused by damage to the endothelium of vessels, resulting in leaking of fluid into intercellular spaces (Scallan et al., 2010). Discussion of these factors falls outside the scope of this thesis. In the present study, a small number of subjects presented with soft tissue oedema of the limbs following trauma. Generalised soft tissue oedema was better identified with the forensic autopsy, compared with PMCT. No other studies were found that draw a comparison between the forensic autopsy and PMCT for the identification of soft tissue limb oedema. It was therefore not possible to place the findings of the present study within the context of other studies.

Similarly, the small number of soft tissue oedema identified in the present study negated any meaningful conclusion of these findings.

7.4.10 Retained bullets

South Africa has a high burden of fatal gunshot injuries (Martin et al., 2010). Due to the high number of gunshot fatalities, retrieval of bullets for ballistic testing forms an essential part of forensic pathology. Gunshot injuries always cause underlying damage to soft tissue, deeper organs, or vasculature (Katz et al., 2013). For all gunshot-related injuries, PMCT enables the assessment of bullet trajectories through the body, as well as the destructive effects of bullets on the organs and anatomical structures affected (Filograna et al., 2010; Norberti et al., 2019). Assessment of gunshot-related deaths requires a thorough crime scene analysis, understanding of wound morphology, chemical analysis of gunshot residue, analysis of entrance wounds and exit wounds, the location of bullet tracks, the directionality of bullets, the subsequent injuries, as well as cause of death (Andenmatten et al., 2008). Various injuries were caused amongst victims who sustained fatal gunshot injuries. These injuries were discussed under the relevant injury type identified per anatomical region.

In the present study, there was a perfect concordance between the forensic autopsy and PMCT for the localisation of retained bullets. This finding is in keeping with that of Andenmatten and colleagues who showed that PMCT matched autopsy findings in terms of the number of retained bullets (Andenmatten et al., 2008). The high radio-density of bullets and small pieces of shrapnel render the anatomical location of these foreign bodies easily discernible on PMCT imaging (Adelman et al., 2018). The retrieval of bullets is important. It assists in determining the type of weapon used, the unique rifling characteristics of the weapon used, and the firing range. Chemical detection of gunshot powder, and its distribution is also a critical component of gunshot deaths analysis and assist with determining the firing range, even though this analysis does not fall within the domain of forensic imaging (Andenmatten et al., 2008).

7.5 INJURY CATEGORIES DISCREPANCY FOR THE FORENSIC AUTOPSY AND PMCT

The second major objective of this study was to determine the discordance between the forensic autopsy and PMCT for injury categories not diagnosed. As highlighted in the previous section, both the forensic autopsy and PMCT missed a range of injuries across the different anatomical regions. Adelman and colleagues argued that it is important to analyse data in imaging studies (such as this one) from different angles to get a better understanding of the true discrepancies (Adelman et al., 2018). The section that follows describes the injury categories in which the discordance was evident between the forensic autopsy and PMCT. These injury categories were obtained after related injury types were grouped together and analysed (see Addendum B2). This discordance analysis provides a holistic assessment of similar injuries grouped together, compared to individual injury types. It can be argued that this holistic assessment provides a more accurate reflection of the concordance/discordance of these two examinations, rather than individual injury type assessment based on anatomical region.

The injury categories were created through combining the different injury types, based on their imaging characteristics. This categorisation was based on many previous, similar post-mortem diagnostic accuracy studies conducted by experts in the field, such as Le Blanc Louvry et al. (2013); Leth et al. (2013); Krentz et al. (2016); Adelman et al. (2018); and Ampanozi et al. (2020). For this study, a total of 11 categories were identified, incorporating the full spectrum of injuries which were highlighted in sections 7.4.1 – 7.4.8.

7.5.1 Intracorporeal gas collections

After death, gas can accumulate in various structures of the body. This gas can be a result of a vascular embolism, putrefaction, or penetrating injuries, and is a common finding with PMCT (Gebhart et al., 2012). Gas can enter the circulatory system as a result of trauma, during surgical or therapeutic intervention (e.g., conventional angiography), or through criminal intervention (Bajanowski et al., 1998). In forensic pathology, the detection of an air embolism is essential for determining the cause of death; and establishing the correct diagnosis is important for civil lawsuits and criminal cases (Ali et al., 2016). Putrefactive gas occurs as a result of decomposition of soft tissue, whilst a gas embolism may be a vital consequence following trauma, such as open wounds,

decompression accidents in divers, or intensive care procedures like artificial respiration or resuscitation (Gebhart et al., 2012).

In the present study, significantly more gas collections were diagnosed with PMCT compared to the forensic autopsy. Except for one tension pneumothorax, a total of 34 gas collections, all identified with PMCT were not diagnosed with the forensic autopsy. This finding is in keeping with that of Adelman et al. (2018). This was the category in which the forensic autopsy had the highest discrepancy with PMCT. Efforts to detect gas at forensic autopsies are not routinely made and require constant practice and education (Scholing et al., 2009). Dissection of the affected organ under water for collection and analysis of such air is a time-consuming process. Even if tissues, or organs such as the heart, are submerged under water, the presence of gas can be missed (Jalalzadeh et al., 2015). Aspiration of gas is usually performed with an aspirometer which allows an analysis of the amount and composition of the gas (Bajanowski et al., 1998; Gebhart et al., 2012). Differentiation between putrefactive and traumatic gas collections with PMCT remains challenging but can be solved by adequate knowledge of circumstances of a case (Gebhart et al., 2012).

Subcutaneous (surgical) emphysema is often a sign of underlying soft tissue trauma and is a common finding in trauma-related deaths (Gebhart et al., 2012; Katz et al, 2013). Subcutaneous emphysema is readily discernible with PMCT imaging. In the present study, a total of 23 counts of subcutaneous emphysema were identified, none of which was diagnosed with the forensic autopsy. The findings of the present study are consistent with those of Mishra et al. (2018) and confirm that PMCT generally identifies more gas in anatomical structures. Even though surgical emphysema is a non-significant finding relevant to the cause of death, the presence thereof, and consideration of the mechanism of death, may help corroborate and establish the cause of death (Mishra et al., 2018).

PMCT has thus a great advantage over the forensic autopsy as the detection of gas is diagnosed effortlessly compared to the labour-intensive processes during forensic autopsies (Gebhart et al., 2012). Considering that gas accumulations in different body structures are a common finding in penetrating trauma or the result of putrefaction, PMCT ability to detect gaseous collections with ease implies that this imaging modality will continue to play a significant role in the forensic assessment of gaseous collections in the deceased.

7.5.2 Haemorrhagic injuries

Trauma is a significant cause of death and disability worldwide. It is estimated that about 40% of deaths are the result of haemorrhages (Curry et al., 2011). Haemorrhagic injuries are often a consequence of organ parenchymal trauma involving macroscopic and microscopic vasculature and many body parts can be affected. In the present study, the forensic autopsy diagnosed more haemorrhagic injuries compared to PMCT. Overall, a total of 40 haemorrhagic injuries identified in different anatomical locations with the forensic autopsy were not diagnosed with PMCT. Even though haemorrhages are often reported in forensic radiology literature, not many studies have compared the performance of the forensic autopsy and PMCT for this injury category which negated a direct comparison with existing literature. One study has shown that, with PMCT, soft tissue haemorrhages were missed in strangled victims (Kempster et al., 2009).

The reason for PMCT's poor performance in this regard is its inability to illustrate organ parenchyma, and subsequent small vascular and parenchymal injuries, especially if there are few surrounding soft tissue haemorrhages (Ross et al., 2010; Palmiere et al., 2013). Even post contrast media administration, enhancement of organ parenchyma is not adequate to detect organ parenchymal lesions (Chevallier et al., 2013; Grabherr et al., 2017). The identification of subtle haemorrhagic injuries will remain a challenge for PMCT in the foreseeable future.

Despite the forensic autopsy's superiority in detecting haemorrhages, the following eight haemorrhagic injuries were missed in this study: six cerebral intraventricular haemorrhages and two intracerebral parenchymal haemorrhages. The two latter intracerebral haemorrhages not diagnosed during the forensic autopsy included two focal haemorrhages in two different subjects. In these two cases, parts of the brain were badly damaged (shattered). In the context of a badly damaged brain, these intracerebral haemorrhages could have been considered insignificant during the forensic autopsy and could explain the underreporting.

7.5.3 Large blood vessel injuries

Blood vessel injuries, such as lacerations of the aorta, are common findings in trauma-related deaths (Sochor et al., 2008). Large blood vessel injuries have clinical significance for forensic autopsy examinations, as these injuries often lead to sudden death following a traumatic event

(Jalalzadeh et al., 2015). Establishing the anatomical location of a fatal haemorrhage forms the primary focus of many forensic investigations, especially where the cause of death is suspected to be fatal haemorrhage (Palmiere et al., 2014). It is thus important during post-mortem imaging to demonstrate the anatomical location and sources of bleeding with anatomical accuracy and certainty. In the present study, the forensic autopsy detected nine large blood vessel injuries not seen with PMCT. All blood vessel injuries in the present study were the result of gunshot injuries. The findings of this study are consistent with those of other studies (see Chavellier et al., 2013; Le Blanc-Louvry et al., 2013; Grabherr et al., 2018). Other similar studies have shown that aortic ruptures are often missed with PMCT, even though with varying frequency (Hoey et al., 2007; Sochor et al., 2008; Leth & Ibsen, 2009). The low sensitivity of PMCT for the detection for large blood vessel injuries, such as in the aorta and IVC, can have detrimental outcomes for any forensic examinations. The poor performance of PMCT in diagnosing blood vessel rupture could be due to the lack of contrast media administration which is common in clinical practice. Collapsed blood vessels are a common post-mortem finding, hampering diagnosis of vessel pathology (Aghayev et al., 2006; Ampanozi et al., 2015; Grabherr et al., 2017). The sensitivity of PMCT to diagnose large blood vessel laceration or ruptures will improve when PMCTA becomes routine practice in forensic examinations.

7.5.4 Fluid collections

Aspirated fluid in the trachea and main bronchi was poorly seen with PMCT in this study: only one of the 11 diagnosed with the forensic autopsy was seen with PMCT. Three cases of ascites and three pleural effusions were not diagnosed with the forensic autopsy. This finding is inconsistent with that of Adelman and colleagues who showed a substantial agreement between the forensic autopsy and PMCT for the identification of pleural fluid (Adelman et al., 2018). Both the forensic autopsy and PMCT has excellent sensitivity for the detection of pleural fluid with volumes larger than 500 ml. However, PMCT was shown to be more sensitive for detection of volumes of pleural fluid less than 150 ml (Adelman et al., 2018). A possible explanation for this finding could be that these small collections are often thought to be non-significant at autopsy, and hence the underreporting. The relative ease with which ascites can be identified with PMCT is thought to be due to the fluid constituency thereof, which can easily be established using Hounsfield units (Sutton, 1998; Leth, 2011).

7.5.5 Hollow organs

Non accidental abdominal injuries commonly affect hollow organs such as the duodenum and stomach (McNaughton, 1997). Hollow organs can be ruptured by a blow or kick to the abdomen (Dubowitz & Bennett, 2007). In the present study, the forensic autopsy identified nine hollow organ injuries not diagnosed with PMCT. This finding underscore PMCT's poor sensitivity for the diagnosis of hollow organ injuries. Other studies have shown similar results (Le Blanc-Louvry, et al., 2013; Mishra et al., 2018). By contrast, Makhlouf and colleagues showed that PMCT and the forensic autopsy identified the same number of hollow organ injuries (Makhlouf et al., 2013). Another study showed that the forensic autopsy did not diagnose 10 hollow organ injuries which were identified with PMCT (Adelman et al., 2018). As far as could be ascertained, this is the only study where hollow organ injuries identified with PMCT were not diagnosed during the forensic autopsy. The failure of PMCTs to demonstrate contusions of hollow organs is due to the inherently poor resolution of the viscera of the gastro-intestinal tract obtained during imaging. PMCT lacks the natural full colour, 3D macroscopical analysis of tissue possible with the forensic autopsy (Murken et al., 2012; Westphal et al., 2012). PMCT is, however, consistently able to show hollow organ distension, especially where this is the result of an injury (Adelman et al., 2018).

7.5.6 Skeletal injuries

Skeletal injuries are important indicators of trauma mechanism and frequency (Leth, 2011). Skeletal injuries in children are unique and a child's skeleton differs biochemically and physiologically from that of an adult, resulting in different mechanisms and injury patterns (Pärtan et al., 2003; Fayad, Corl & Fishman, 2009). Paediatric skeletal injuries can therefore be complex to identify, considering the various physiological developmental stages, giving rise to epiphyseal plates which often simulate fractures.

In the present study, both the forensic autopsy and PMCT did not diagnose all skeletal fractures. With the forensic autopsy, however, substantially more skeletal fractures were not identified compared to PMCT. This represents the category in which the forensic autopsy had the second highest discrepant findings compared with PMCT. A total of 33 skeletal fractures were not identified with the forensic autopsy, compared to eight skeletal fractures with PMCT. This finding also underscores the benefit of having analysed injury categories rather than individual injury

types only, giving a more holistic overview of the performance of each examination. The findings of this study are in keeping with those of many other studies conducted amongst adult populations (Sochor et al., 2008; Daly et al., 2013; Le Blanc-Louvry et al., 2013; Leth and Thomsen, 2013; Krentz et al., 2016; Adelman et al., 2018; Mishra et al., 2018). Findings of a systematic review have shown that in six of eight studies reviewed, PMCT identified more skeletal injuries compared to the autopsy (Jalalzadeh et al., 2015). The findings of the present study are thus congruent with those of this systematic review.

The forensic autopsy only employs imaging technologies that display fracture patterns in 2D with the use of LODOX® and skeletal surveys. The 3D demonstration of complex fracture patterns possible with PMCT provides a competitive edge that is not possible with the forensic autopsy (Michaud et al., 2019). This functionality will remain an advantage which PMCT will hold over conventional forensic imaging methods.

7.5.7 Muscle injuries

In the present study, the forensic autopsy identified more muscle injuries. Not many publications could be found that compare the forensic autopsy to PMCT for the diagnosis of muscles injuries. In the present study, a total of nine muscle injuries were not identified with PMCT. This finding is in keeping with that of Kasahara et al. (2012). One study has shown that, with PMCT, seven temporal muscle haemorrhages were missed out of a total of 20 identified with the forensic autopsy (Yen et al., 2007). Another study has shown that, with PMCT, one intramuscular haemorrhage of the temporalis muscle, a subcutaneous haemorrhage of the deltoid muscle, and of the gluteus maximus muscle, were not diagnosed with PMCT (Cha et al., 2010). Depending on the degree of injury, muscle injuries can be readily identified on PMCT. Considering that a number of gunshot injuries occurred amongst 11 subjects in the present study, it can be argued that these muscular injuries were not actively searched for during PMCT, and thus not documented by the reviewers. Further larger studies are required to confirm the concordance of PMCT in the diagnosis of muscle injuries.

7.5.8 Soft tissue injuries

Soft tissue injuries are, after skeletal injuries, the second most common finding in physically abused children (Dubowitz & Bennett, 2007). Assessment and documentation of soft tissue injuries in suspected fatal child abuse is critical for any forensic examination. In the trauma setting, soft tissues injuries are a common consequence of sharp and blunt force injuries. Overall, a total of 24 soft tissue injuries were not diagnosed with PMCT. This finding is congruent with that of Sochor et al. (2008), Schnider et al. (2009), Thomsen et al. (2009), Chavellier et al. (2013), Daly et al. (2013), Adelman et al. (2018) and Grabherr et al. (2018). The findings of the present study thus underscore PMCT's poor performance in detecting superficial and deeply located soft tissue injuries. A recent systematic review confirmed that PMCT has limited resolution for the diagnosis of soft tissue injuries (Blokker et al., 2016). There is thus overwhelming evidence that PMCT is less sensitive for the detection of internal soft tissue injuries and this remains one major limitations for this imaging modality (Bolliger et al., 2008; Grabherr et al., 2016).

7.5.9 Solid organ injuries

In the trauma setting, solid organ injuries are common findings. PMCT identified significantly fewer solid organ injuries compared to the forensic autopsy. This is the category in which PMCT had the highest discrepant findings with the forensic autopsy. Overall, a total of 88 solid organ injuries were not diagnosed with PMCT. As alluded to before, this finding is another example of the benefit of having analysed injury categories rather than individual injury types only, giving a more holistic overview of each examination's performance. The findings of the present study are in keeping with those of Chavellier et al. (2013) and Krentz et al. (2016). A systematic review has shown that, in eight studies reviewed, the forensic autopsy detected more liver, splenic and renal injuries, compared with PMCT. Small superficial liver, spleen and renal lacerations are particularly difficult to diagnose with PMCT (Jalalzadeh et al., 2015). PMCT weakness for the identification of solid organ injuries will, as for soft tissue injuries, remain a shortcoming in the foreseeable future (Bolliger et al., 2008; Shiotani et al., 2008; Grabherr et al., 2016). This shortcoming may pose detrimental consequences for medico-legal investigations.

7.6 UNDER WHAT CIRCUMSTANCES CAN PMCT ACCURATELY ESTABLISH THE CAUSE OF DEATH?

The third objective set out to explore under what circumstances PMCT can accurately establish the cause of death. The forensic autopsy identified 11 different causes of death amongst the 30 subjects. The majority had died as a result of unnatural causes, and these were recorded as follows: fatal gunshot injuries (n = 11); blunt force head injuries (n = 6); asphyxia (n = 1); hyperthermia (n = 1); fatal physical abuse (n = 1); severe abdominal and pelvic injuries (caused by fatal physical abuse) (n = 1); and haemorrhage from an unclamped umbilical cord (n = 1). The following causes of death were assigned by the forensic autopsy to five subjects who had succumbed due to natural diseases: pneumonia (n = 3); gastro-enteritis (n = 1); and mucolipidosis (n = 1). The forensic autopsy could not assign a cause of death in three cases (Speelman et al., 2022). Two of the three cases involved concealment of birth; and, in the remaining case, the new-born was allegedly smothered by his mother, but this could not be proven at autopsy (see Addendum B3).

The Cohen Kappa statistic was used to calculate the strength of the interrater reliability for the cause of death ratings between the forensic autopsy and both reviewers (i.e., both reviewers individually) for all subjects. The Cohen Kappa statistic for the cause of death rating between the forensic autopsy and reviewer 1 was k = 0,624 (95% Confidence interval: 0.45 – 0.80; p = 0.00) and reviewer 2 was k = 0,582 (95% Confidence interval 0.41 – 0.76, p = 0.00) respectively. The Cohen Kappa statistic suggested an overall substantial and moderate level of agreement with the forensic autopsy for Reviewers 1 and 2 respectively (Speelman et al., 2022). Leth and colleagues in a similar study, reported a Cohen Kappa value of k = 0,64, which is almost comparable to that for reviewer 1 (Leth, Struckmann & Lauritsen, 2013). The two reviewers in this study had a near perfect interrater reliability as Cohen kappa statistic was k = 0.905 (95% Confidence interval 0.78 – 1.00, p = 0.00) (Speelman et al., 2022). Unlike percentage agreement the Cohen Kappa statistic is a very good instrument to measure interrater reliability as it caters for chance agreement between raters (McHugh, M. 2012).

Using the percent agreement, the overall mean percent agreement for PMCT compared to the forensic autopsy for all 30 cause of death ratings was 69% (70% and 67% for Reviewers 1 and 2 respectively) (Speelman et al., 2022). PMCT's accuracy to assign a cause of death in similar studies in children ranges between 18% – 67% (Sieswerda-Hoogendoorn et al., 2014; Arthurs et

al., 2016; Van Rijn et al., 2017; Shelmerdine et al., 2019). The findings of the present study compared slightly better to these studies, falling just outside the upper range (Speelman et al., 2022). The mean cause of death agreement of PMCT (i.e., for both reviewers combined) for all unnatural deaths in this study was 80% (82% and 77% for Reviewers 1 and 2 respectively), which, according to the percent agreement table, was very good. The percent agreement was even higher for traumatic deaths at 88% (Speelman et al., 2022). See Tables 6.1 and 7.1 for a summary of these findings.

Table 7.1 Percent agreement between forensic autopsy and PMCT for three death categories

Cause of death category: Forensic Autopsy	**n**	**PMCT average % agreement**	**Reviewer 1 % agreement (n)**	**Reviewer 2 % agreement (n)**
Unnatural	22	80%	82% (18)	77% (17)
Natural	5	0%	0% (0)	0% (0)
Unknown: • Suspected suffocation (1) • Concealment of birth (2)	3	100%	100% (3)	100% (3)
Total	30	69%	70% (21/30)	67% (20/30)

When analysing the different cause of death scoring separately for the respective cause of death categories, the findings showed that there was perfect agreement between the forensic autopsy and PMCT for the cause of death rating for blunt force head injuries. For this category, the cause of death was correctly assigned with PMCT for six cases. In a similar study, Mishra and colleagues found a good agreement for the same cause of death category (Mishra et al., 2018). However, their sample included a larger sample of 21 subjects who had died as a result of head injuries. The findings of the present study for this category must be interpreted with caution, given the small sample size. Another study has shown that, with PMCT, the cause of death agreement for head injuries was correctly assigned in 79% of cases (Yen et al., 2007). These three findings therefore suggest that PMCT generally has a high agreement for deaths caused by head injuries.

In the present study, the average cause of death was correctly assigned with PMCT in 100% of gunshot injuries, which suggests perfect agreement with the forensic autopsy. Andenmatten et al. (2008) found a 77% agreement between the forensic autopsy and PMCT for the cause of death for gunshot injuries. The findings of the present study are thus better to that of Andenmatten and colleagues. However, the number of gunshot victims in the present study was small. Larger

studies amongst victims with gunshot injuries should be conducted to confirm this finding. The cause of death for one subject who sustained fatal physical abuse was correctly assigned with the forensic autopsy and both reviewers due to the classic skeletal fractures indicating repetitive physical abuse.

There was no agreement between the forensic autopsy and PMCT in the case of the five subjects who had succumbed due to natural disease. PMCT was unable to assign a cause of death in these five natural deaths consisting of three cases of pneumonia, one gastroenteritis and one mucolipidosis. No radiological signs of pneumonia or gastro-enteritis were evident on PMCT imaging (Speelman et al., 2022). PMCT analysis of lung parenchyma can be obscured by post-mortem oedema resulting from fluid leaking into the alveolar space. Post-mortem lung congestion and lung oedema can often be mistaken for lung consolidation impeding the diagnosis of pneumonia (Dirnhofer et al., 2006; Poulsen & Simonsen, 2007; Proisy et al., 2013; Sieswerda-Hoogendoorn et al., 2014). The subject diagnosed with mucolipidosis presented with a spontaneous bruise on the leg, considered to be a consequence of the liver not producing blood clotting factors further exacerbated by the co-existence of bone marrow lymphohistiocytosis resulting in low platelet production. No abnormal findings were diagnosed for this subject on post-mortem skeletal survey or PMCT (Speelman et al., 2022). Other studies have shown that PMCT has varied results for establishing the cause of death for natural disease: results can range between 10% and 83% (Weustink et al., 2009; Kasahara et al., 2012; Noda et al., 2013; Proisy et al., 2013).

Despite the availability of supplementary examinations, a cause of death could not be determined with the forensic autopsy in three children, consisting of two concealments of birth and one suspected suffocation (Speelman et al., 2022). No cause of death could be assigned at forensic autopsy for these cases, because no clear external or internal signs of injuries resulting in ultimate death could be found. Similarly, PMCT could not identify a cause of death for these three cases. One large study showed that no cause of death could be established by either the forensic autopsy or PMCT in 14% of cases (Leth & Thomsen, 2013). The remaining unnatural deaths in which no cause of death could be determined with PMCT in this study included a case of haemorrhage from an unclamped umbilical cord, asphyxiation and hyperthermia.

An incorrect cause of death was assigned with PMCT in one case. (Subject 16, Addendum B3). According to the scene findings this subject was found lying supine in an informal settlement with unknown details surrounding his death and a single gunshot wound (Speelman et al., 2022). The cause of death for this subject was assigned by the forensic autopsy as gunshot injury to the chest. Reviewers 1 and 2 assigned the cause of death as tension haemo-pneumothorax and fatal stab wound respectively. On PMCT, no penetrating trauma or bullet trajectory was evident even though a right sided tension haemopneumothorax, corresponding subcutaneous emphysema and a small left sided pneumothorax was identified (Speelman et al., 2022).

Table 7.2 Unknown causes of death assigned with the forensic autopsy and Reviewers 1 and 2

Subject no.	Initial manner of death	Cause of death assigned with FA	Unknown cause of death: Reviewer 1	Unknown cause of death: Reviewer 2
1	SUDI	Pneumonia	Unknown	Unknown
2	SUDI	Pneumonia	Unknown	Unknown
3	SUDI	Gastroenteritis	Unknown	Unknown
4	Concealment of birth	Unknown	Unknown	Unknown
5	SUDI	Pneumonia	Unknown	Unknown
6	Concealment of birth	Haemorrhage from unclamped cord	Unknown	Unknown
8	Concealment of birth	Unknown	Haemorrhage from unclamped cord	Unknown
11	SUDI	Severe abdominal and pelvic injuries	Severe abdominal and pelvic injuries	Unknown
12	Gunshot wound	Gunshot injuries	Gunshot injuries	Unknown
18	Suffocation	Unknown	Unknown	Unknown
20	Asphyxia – smothering	Asphyxia	Unknown	Unknown
22	SUDI	Hyperthermia	Unknown	Unknown
24	SUDI	Mucolipidosis	Unknown	Unknown

FA = Forensic autopsy

The present study had a large variation in the cases enrolled, despite an attempt to narrow the sample population to suspected fatal child abuse. The injuries that subjects presented with were diverse and were found across multiple organ systems. This heterogeneity impacted on the number of cases presenting with similar causes of death (Speelman et al., 2022). This problem was also identified by other authors such as Ampanozi et al. (2017). Since there were many factors that led to variation in the cause of death ratings with PMCT, future studies are recommended that

will focus on a case mix with more or less similar causes of death, for example, skeletal injuries only in NAI, in order to narrow the focus and PMCT's reliability for determining a cause of death.

7.7 CAN CERTAIN CASES UNDERGO PMCT IN THE ABSENCE OF THE FORENSIC AUTOPSY?

The fourth objective of this study was to establish whether certain cases can be selected to undergo PMCT, without the need of a forensic autopsy. A high-level overview of this study demonstrated that the forensic autopsy was a more comprehensive examination, having diagnosed more injuries overall compared to PMCT. Even though this study had a small sample size, the large number of injuries sustained enabled the author to ascertain whether certain cases can undergo PMCT in the absence of a forensic autopsy. As alluded to before, some injuries were not diagnosed by the forensic autopsy or PMCT. The next section will highlight certain advantages not alluded to previously which the forensic autopsy holds over PMCT. The next section will thus describe those procedures conducted during a forensic autopsy which are not possible with PMCT. Based on the findings of the present study, the discussion that follows will thus be used to support or refute the argument as to whether PMCT can replace the forensic autopsy under certain conditions. The discussion that follows is based on procedures which were mostly conducted during the forensic autopsy within this study.

7.7.1 Organ pallor

Organ pallor (and subendocardial haemorrhages) is a common but critical forensic finding which suggests exsanguination, or hypovolemic shock, following significant blood loss during a critical or fatal injury (Andermatten et al., 2008). Due to the lack of visual cues, PMCT is unable to demonstrate organ pallor (Andermatten et al., 2008). Among the 30 subjects, the forensic autopsy identified a total of 81 organs presenting with pallor. These organs often included the lungs, heart, liver, kidneys, pancreas and spleen. This finding is in keeping with that of Thomsen et al. (2009). The inability of PMCT to demonstrate a significant finding such as organ pallor might have detrimental consequences for a criminal investigation (Thomsen et al., 2009). This shortcoming will thus remain a drawback for this imaging modality until algorithms are developed that can demonstrate organ colour, or the effect of diminished organ perfusion.

7.7.2 Measurement of free fluid

Fluid can accumulate in the pleural cavity as either an exudate or transudate and is usually associated with surrounding pathology (Tomcsányi et al., 2004). The presence of pericardial fluid in the pericardial cavity is a sign of significant injury to the heart musculature, or the surrounding pericardial layers. During forensic autopsies, the volume of free blood, or fluid, within cavities such as the pleural, pericardial, and abdominal cavity, can easily be measured. This is done to assess the volume of blood loss prior to death, or to determine the presence of other pathological fluids such as pleural effusions or ascites. In the present study, 10 ml of pleural fluid were measured in the pleural cavity in one subject during the forensic autopsy. In addition, between 100 and 1,500 ml of blood were measured as either haemothoraces in the pleural cavities, or free fluid within the thorax, whilst 60 ml of blood were measured within the pericardial cavity in one subject. Between 50 and 150 ml of free blood were measured within the peritoneal cavity during the forensic autopsies (refer to Addendum B5). Fluid within the pleural, pericardial and peritoneal cavity (ascites or blood) cannot be routinely measured during a PMCT examination. Recent studies have shown that PMCT enables the measurement of fluid in some abnormal locations (Leth & Ibsen, 2009). However, this is an activity not routinely performed in clinical practice and requires a certain level of expertise.

Another assessment routinely performed during the forensic autopsy is content analysis of fluid within the stomach. The presence and constituency of stomach content is often assessed to determine the substance consumed before death, which is often used in criminal investigations to ascertain the estimated time of death (Kaul et al., 2017). Such fluid can also be retained for toxicological analysis.

7.7.3 Skin injuries and other findings

Skin injuries can present in the form of abrasions, scabs, scars or bite marks. These skin injuries can be a sign of physical abuse and may, in some cases, be the only external sign of child abuse (Legano et al., 2009; Van Rijn & Sieswerda-Hoogendoorn, 2012a). In the present study, one physically abused subject presented with multiple scabs, scars and bite marks on his skin. The bite marks on the skin, which were not detectable with PMCT, were reported by a forensic odontologist as having been inflicted by an adult (Speelman et al., 2022). However, some injuries

to the skin, subcutaneous layers and subcutaneous tissue are sometime visible on PMCT images and are usually directly related to the clinical history or mode of injury (Katz et al., 2013).

Another important documentation that takes place during the forensic autopsy is the establishing of skin signs, such as ligature marks, following suicide or homicide. Ligature marks can be caused by ligature strangulation or hanging (Gascho et al., 2019). These ligature marks are of forensic significance as they can indicate the type of material used to cause the inflicted suicide or homicide and determine associated skin damage. These ligature marks, as for other skin signs, are not currently detectable with PMCT.

Even though 3D reconstruction of the skin is currently possible with PMCT, this functionality has limitations as it cannot depict small abrasions (Grabherr et al., 2017). However, Urbanova and colleagues reported that dermatological signs such as skin colouring due to livor mortis, strangulation ligature marks, moles and tattoos were well recognised in 3D models acquired with surface photogrammetry (Urbanová et al., 2015). This is a functionality that will need further validation in a range of clinical or forensic scenarios. In addition, photogrammetry with cross-sectional imaging capabilities is currently not common practice in forensic centres.

Another important assessment made during forensic autopsies is the distribution of hypostasis, which depends on the position of the body after death. Post-mortem staining is usually pronounced on dependent areas such as the back of the head, shoulders, thighs and calves if the subject died in the supine position. This assessment is used to determine the position of the body at the time of death and, in some cases, may give significant clues as to the manner of death (Vij, 2011). These findings were routinely recorded during the forensic autopsies and analysed in the present study. This kind of assessment is, for the same reasons mentioned previously, not possible with PMCT, even though a physical assessment of the body preceding a PMCT examination, will be possible.

In the present study, the documentation of tattoos, piercings, and signs such as circumcision, are often used in forensic pathology, especially for identification of unidentified persons. The recording of such unique identifiable signs is currently not possible with PMCT.

7.7.4 Mucosal assessment

Abdominal injuries caused by NAI may cause contusion, laceration and rupture of solid organs such as the liver, spleen, pancreas and kidneys, or of hollow organs such as the small and large bowel (Ng et al., 1997). In such cases the mucosa of the gastro-intestinal tract is often injured. In addition, the mucosa of the rectum may also be injured following sexual abuse (Pollanen et al., 2002). PMCT is poor in delineating mucosal injuries of the gastro-intestinal tract and genital tract. In the present study, discoloration of the mucosa of the stomach and bladder wall which was recorded during the forensic autopsies was not seen with PMCT. Similarly, PMCT is unable to demonstrate mucosal haemorrhage or necrosis evident during any forensic autopsy (Kasahara et al., 2012). This will remain a shortcoming for PMCT for the foreseeable future.

7.7.5 Establishing entrance and exit wounds

Entrance and exit wound assessments during forensic autopsies are based on forensic classification of morphological and biophysical changes in the victim's clothing and skin, bone and other affected organs (Oehmichen et al., 2003). During the forensic autopsies in this study, all gunshot injuries were meticulously and scientifically documented. The size of gunshot entrance and exit wounds was carefully measured in millimetres and each wound was described by the forensic pathologists based on its anatomical appearance (for example, whether round, spherical or slit-like; and whether any abrasions, searing of the skin, soot, or staining were present). Further, the anatomical location of all entrance and exit wounds is recorded in relation to the midline and the distance from the heel of the victim. None of these activities are possible with PMCT. Not all entrance and exit wounds in the present study could be determined with PMCT.

Forensic pathologists also need to consider the cause and manner of injury, entry and exit characteristics, distance and direction of the fire, as well as the vitality of the wound. These are important considerations for criminal investigations (Shrestha et al., 2020). Even though the directionality of bullets was discernible with PMCT in this study for some cases, it was not possible for all gunshot injuries. During forensic autopsies, determining the directionality of gunshot injuries for some cases is possible with the use of probes (Butler et al., 2016).

Preliminary studies have shown that PMCT may play a role in determining the direction of firing, as well as firing distance, in gunshot injuries (Thali et al., 2003b; Elkhateeb et al., 2018).

Furthermore, in PMCT images, Thali and colleagues were able to show gunshot residue visible under the skin of subjects who had sustained gunshot injuries (Thali et al., 2003b). Where assessment of the skin is impossible due to a badly decomposed body, PMCT can play a role in the assessment of entrance and exit wounds (Andenmatten et al., 2008) because bullet tracks in the body may still be visible with PMCT, even if the skin is badly damaged.

7.7.6 Histological assessment

Histology forms an essential part of any forensic examination. It is done to confirm, refute or complete macroscopic autopsy findings. Autopsy with histology is considered the ultimate standard for conducting a detailed forensic assessment of the cause and manner of death (Maeda, 2012). Histology advances the assessment of pathological conditions and vitality of lesions (Delabarde et al., 2017). One major drawback of PMCT is that histopathological and microbiological assessment of body tissue is not possible (Rüegger et al., 2014). Even though histology plays a confirmatory role, it has been shown to provide new information in up to 25% of cases undergoing forensic autopsies; and it altered the cause of death in about 13% of cases (De la Grandmaison et al., 2010; Leth & Thomsen, 2013).

In the present study, histology was critical in confirming a diagnosis of mucolipidosis in a neglected 10-month-old male infant. This subject did not meet his developmental milestones and presented with subcutaneous haemorrhage of the left femoral area. The physical examination did not reveal any signs of injuries and the cause of death was determined by histology. The present study also showed that, during a forensic autopsy, a range of special dissection techniques can be conducted (such as a bloodless field layered dissection of the neck area, which showed an injury to the brachiocephalic artery and vein) and often soft tissue haemorrhage and contusions are observed, techniques not possible with PMCT. Histological assessment of tissue during forensic autopsies often shows haemorrhage within parenchyma, which aids diagnosis. These functionalities are not possible with PMCT.

7.7.7 Estimation of foetal age

Three neonates enrolled in this study had been abandoned shortly after birth. The perinatal examination requires of the forensic pathologist to establish gestational age, record the body

weight, and conduct external body measurements (Cohen & Scheimberg, 2018). The following measurements are usually recorded to determine gestational age in foetuses or neonates: head circumference, abdominal circumference, crown heel length, crown rump length, chest circumference, abdominal circumference, right calf circumference, left calf circumference, right foot length, left foot length, and whether or not any features of prematurity were evident. These measurements in millimetres are measured against gestational-related normal values, usually customised against maternal ethnicity and specific country (Cohen & Scheimberg, 2018). In the present study, PMCT could be used to measure foot length of foetuses and neonates using certain reference standards. However, measurement of head circumference, abdominal circumference and crown rump length, crown heel length, chest circumference and calf circumference, are currently not possible with PMCT.

7.7.8 Establishing organ weight

Organ weight is routinely determined during a forensic autopsy. The purpose of weighing organs is to determine deviations from the normal reference range. Where present, these deviations may provide additional evidence in supporting an abnormal morphological finding. Autopsy parameter standards are regarded as reference ranges, not normal ranges. This means that measurements made during the autopsy are compared to these reference ranges, which are not considered absolute normal ranges (Bartosch et al., 2019). Organs weights for infants and neonates, below and above the 5th and 95th percentile respectively, may suggest underlying pathology (Pryce et al., 2014).

Organ weights enable the assessment of organ-specific diagnosis, such as congestion, organo-megaly, oedema of the lungs or brain, or fatal haemorrhages resulting in organ pallor (Jackowski et al., 2006). In the present study, organs such as brain, lungs, heart, liver, spleen, kidneys, and liver of most subjects, were weighed. Abnormal organ weights found during forensic autopsies may guide further sampling of tissue for further investigation (Pryce et al., 2014). Organ weighing is not routinely possible with PMCT, so abnormal organ weights might go unnoticed should PMCT be used to replace the forensic autopsy in selected cases.

A preliminary study has shown promising results for weight assessment of the liver and spleen (Jackowski et al., 2006). However, this activity requires dedicated software and a certain level of PMCT expertise. Organ weight assessment with PMCT is also complicated by the presence of

intrahepatic air, histology done prior to organ weighing during normal forensic autopsy, or emptying of the gall bladder prior to liver weighing, which may alter the weight of the liver (Jackowski et al., 2006). Further validation of PMCT for weighing organs is required to compensate for these discrepancies. Organ weighing in routine post-mortem imaging is thus not a simple activity and will remain a shortcoming for PMCT.

Table 7.3 provides a summary of the above discussions as well as the clinical interpretation, clinical significance as well as the importance of such findings in the fatal abuse setting. The totals in this table include the observations made for some of the 30 subjects, within the study, whilst Addendum B6 contains only the observations for subjects who sustained blunt force head injuries, gunshot injuries as well as physical abuse.

Table 7.3 Special procedures/assessments performed during the forensic autopsy

Assessments	Sub-categories	Number of cases detected at FA	Number of cases detected on PMCT	What is the clinical interpretation/clinic significance?	Important to find in the setting of fatal abuse
Organ pallor		81	0	Suggest hypovolemic shock or exsanguination	Yes
Free fluid volume measurement		20	0	Suggest volume of blood loss/ Identify type of free fluid present as an exudate/transudate	Yes No
Fluid content analysis		6	0	Can identify type of fluid/food ingested. For example: bile or blood in stomach following trauma. Digested food particles can be used to estimate time of death. Blood in airways: may show aspiration following severe trauma.	Yes No Yes
Skin injuries and other findings	Skin/scalp abrasions/ Bruises Scars Graze wounds (bullet scraping) Tattoos or piercings Mongolian spots Eczema	55 11 42 4 5 2 1	0 0 0 0 0 0 0	May suggest physical abuse (if not caused by trauma). May suggest physical abuse (if not caused by trauma). May suggest physical abuse (if not caused by trauma). May assist in determining number of bullets fired at victim in presence of other gunshot wounds. Assist with identification of unidentified persons Suggest congenital abnormality Suggest skin disease	Yes Yes Yes Yes No No No
Mucosal assessment	Lingual frenulum Gastrointestinal tract Bladder	3 6 3	0 0 0	May indicate physical assault to mouth. Injury may suggest physical trauma to affected anatomical structure. Injury may suggest physical trauma to bladder	Yes Yes Yes
Gunshot wounds	Entrance wounds Exit wounds	24 14	9 0	May show anatomical location of gunshot wound Exit wounds assist with differentiating between perforating and penetrating gunshot wounds.	Yes Yes
Histological assessment		9	0	Provides additional information to macroscopic assessment.	Not applicable
Estimation of foetal/neonatal age		7	4	Assist with age determination of abandoned neonates	Yes
Establishing organ weight		220		Determine deviation from normal reference ranges	Yes

FA = Forensic autopsy

7.8 PMCT AS A SUPPLEMENTARY EXAMINATION TO THE FORENSIC AUTOPSY

If PMCT is to replace the forensic autopsy, it needs to record the same level of detail and accuracy as that of the forensic autopsy. In this study, there were a few discrepant findings where PMCT was not able to identify some important injuries which were highlighted extensively in this chapter. Pursuant to this, the preceding discussion showed that there are many other techniques conducted during a forensic autopsy that forensic pathologists employ to document injuries and the manner and cause of death. If PMCT is to replace the forensic autopsy, many of these techniques will not be possible to perform, possibly with detrimental consequences for the post-mortem examinations. Based on the above arguments, particularly with respect to the discrepant findings shown with PMCT in this study, and the inability to conduct certain clinical and physical assessments, it is the author's view that PMCT cannot yet replace the forensic autopsy.

However, PMCT contributes significantly to the number of injuries identified overall. The results of this study showed that, with PMCT, a number of injuries not routinely diagnosed with the forensic autopsy can be identified. Additional injuries were also identified by other researchers such as Scholing et al. (2009) and Krentz et al. (2016). The author agrees that PMCT can therefore serve as a supplementary examination to the forensic autopsy. This is a view shared by many other authors such as Aghayev et al., 2008, Sochor et al., 2008, and Jalalzadeh et al., 2015. Using PMCT as a supplementary examination to the forensic autopsy will enable the diagnosis of additional injuries or incidental findings not routinely diagnosed. Grabherr and colleagues are correct in arguing that a single examination may not always be sufficient to assess a wide spectrum of injuries and that the best results are obtained by combining post-mortem imaging such as by PMCT, with the forensic autopsy (Grabherr et al., 2016). This study has shown that there are areas where PMCT findings are concordant with the forensic autopsy. For example, in a subject who sustained one gunshot wound to the head, PMCT may demonstrate gross injuries. The forensic pathologists can in such a scenario, elect to conduct a limited, extensive, or no forensic autopsy at all, if appeased with the PMCT findings. In a busy forensic setting such as the SRFPS where annually more than 4000 unnatural deaths are examined, PMCT may potentially alleviate the workload of forensic pathologists (Speelman et al., 2022). Even though PMCT can illustrate traumatic injuries well, its role should preferably not be to determine a cause of death. For example, in subjects with multiple gunshot injuries it

is not always possible for the radiologist to determine which injury resulted in the ultimate cause of death of the subject (Speelman et al., 2022). A case in point: Subject 13 presented with gunshot wounds to the head, neck and thorax. Based on PMCT appearances, any of the three gunshot wounds could have resulted in the subject's ultimate death. Establishing a cause of death should remain the purview of the forensic pathologist who ordinarily consider a range of factors before deriving at a cause of death. One of those factors will be incorporating the findings of PMCT as identified by experienced radiologists (Speelman et al., 2022). Combining PMCT with the forensic autopsy may result in a much more robust forensic examination, increasing the likelihood that a larger spectrum of injuries will be identified. This, arguably, will enhance forensic examinations in the sense that the examination will be more comprehensive, and the outcome improved, especially in criminal investigations.

7.9 STUDY'S SUCCESS

This study was successful in many ways. The children enrolled presented with various forms of blunt and sharp trauma, resulting in a wide spectrum of injuries and their associated PMCT image appearances. The wide spectrum of injuries diagnosed, involving many organ-systems, provided an opportunity to compare and draw valid conclusions about PMCT performance against the forensic autopsy in children.

Post-mortem imaging studies involving children only were limited (Aalders et al., 2017). As far as could be determined, at the time of writing this thesis only seven studies have been conducted in which PMCT findings of only children were compared with those of the forensic autopsy (Noda et al., 2013; Proisy et al., 2013, Sieswerda-Hoogendoorn et al., 2014; Arthurs et al., 2016; Krentz et al., 2016; Van Rijn et al., 2017, Shelmerdine et al., 2019). Four of these seven studies were conducted on children who had succumbed due to natural disease, whilst the remaining three studies included children who had died of both natural and unnatural causes. In the present study, the majority of children succumbed as a result of unnatural or violent deaths. This, therefore, makes this the only study to date where the majority of children demised as a result of unnatural causes.

The forensic autopsy identified 11 different causes of death for the 30 subjects. Even though the number of case-counts per cause of death category was not extensive, it enabled the

researcher to draw valid conclusions about PMCT's ability to assign the cause of death for all eleven categories.

The time delay between the time of death and acquisition of the PMCT imaging can significantly affect the diagnostic quality of PMCT images and hence inhibit radiological interpretation thereof. Putrefaction and hypostasis may set in between four and six hours after death (Mishra et al., 2018). For comparative diagnostic accuracy forensic imaging studies as described in this thesis, it is essential that PMCT images are acquired soon after death to minimise the effect of putrefaction on the human body and thus image quality. The majority of subjects in this study were scanned within two days after admission to the mortuary, which resulted in the majority of PMCT images being of diagnostic quality, ensuring minimal interference with the radiological interpretation of the PMCT images.

All bodies were scanned on the same CT scanner, ensuring consistency in the scanning protocols and hardware used for image acquisition. Only two diagnostic radiographers were responsible for the image acquisition, lending further consistency to imaging protocols applied. All PMCT studies were reviewed independently by two paediatric radiologists. The radiologists were blinded to the forensic autopsy findings during PMCT image interpretation. Due to this being a research study, the radiology reports were not made available to the forensic pathologists at any stage during the study period. The forensic pathologists were therefore blinded to the PMCT findings. The use of a modified consensus reading, enabled the researcher not to overestimate the agreement of PMCT for diagnosis of different injury types and for determining the cause of death. This enabled some simulation of clinical practice, where radiologists with different levels of experience, including those undergoing training, are expected to interpret CT examinations and provide provisional or final radiology reports for cases interpreted.

7.10 PMCT IMAGING PROTOCOL OPTIMISATION

PMCT protocol optimisation is an important aspect to follow when conducting post-mortem examinations. Shelmerdine and colleagues (2019) developed a consensus based PMCT imaging protocol for children. Even though this imaging protocol was published one year after data collection for this study was concluded, it was pleasing to note that eight of the 13 PMCT

parameters used for this study, aligned to the ESPR-ISFRI PMCT imaging protocol parameters listed in Table 3.14 in Chapter 3. The five parameters not used as per the ESPR-SFRI PMCT imaging protocol, in the actual study included pitch, mAs, FOV, slice thickness and image reconstruction. These five PMCT parameters used in the actual study, were those recommended by the vendor and were thought not to have influenced dose or image quality significantly during image acquisition.

In order to fully comprehend how PMCT examinations can be optimised, users should have a solid understanding of the various parameters involved in image formation as well as the physical properties of a CT scanner and how these intertwine with dose and image composition. CT users should therefore have a good understanding of the various techniques available to optimise PMCT protocols and thereby reducing dose and improving image quality as explained in Section 3.8 of Chapter 3. It is thus recommended that these ESPR-ISFRI PMCT guidelines be used for all future post-mortem imaging studies involving children. One major advantage of using these guidelines, as advocated by the authors of this protocol, is that application thereof will enhance uniformity as well as improve image quality especially when prospective multi-centres review and or research studies are to be undertaken (Shelmerdine et al., 2019).

7.11 LIMITATIONS OF THE STUDY

Several limitations were evident during the execution of the research study. Unlike in clinical practice, subjects were scanned fully clothed, with their arms next to their bodies. At times, this resulted in imaging artefacts. Similarly, retained bullets also caused some streak artefacts which compromised image quality at the level of the bullet, and might have compromised diagnosis of additional injuries in some cases. However, the effect of these streak artefacts for majority of the 11 subjects was negligible.

Radiology reporting occurred in isolation, with only the clinical history taken into consideration (Speelman et al., 2022). This silo method of image analysis does not mirror CT imaging in clinical practice, where the results of other studies or examinations may be taken into consideration, or where discussion between radiologist and pathologists [or referring clinician] sometimes occurs (Arthurs et al., 2016). The reviewers did not have access to any further scene findings such as photographs, witness reports, clinical notes for those deceased subjects

admitted via a hospital, results of other clinical examinations such as pre-mortem CT, pre-mortem MRI, other imaging studies or laboratory findings (Speelman et al., 2022). For example, in infants the Road to Health Chart was used by local health facilities to record their immunisation status and developmental milestones. The latter was used by forensic pathologists to assess the clinical history and status of affected infants. The radiology reviewers did not have access to such important medical information. It is hoped that this cooperation will prevail in forensic practice when PMCT imaging is to become routine practice.

The forensic autopsies were conducted by different forensic pathologists. The diagnostic accuracy of the forensic autopsy reports might have been influenced by this, since the forensic autopsy is an observer-dependent procedure (Yen et al., 2007). Similar to the limitation identified by other experts, the careful selection of cases in the present study could have resulted in selection bias; and might have led to an overestimation of the usefulness of PMCT in routine forensic pathology (Thomsen et al., 2009; Van Rijn et al., 2017). However, due to the limited funding available for this research study, the researcher had to apply care when enrolling subjects to exclude cases that might not have contributed to the aim of the study.

The relatively small sample size of the study and small number of injuries identified per category, negated statistical significance testing of the results. As stated in Section 4.6, Chapter Four, because data were collected prospectively, the sample size of 30 facilitated completion of the research study within the time constraints imposed for completion of this doctoral degree.

Similar to limitations experienced by others, the sensitivity and specificity of PMCT, compared to the forensic autopsy, could not be calculated, as the autopsy also could not identify all injuries, rendering it not a true gold standard against which to measure PMCT's performance (Roberts et al., 2012; Le Blanc-Louvry et al., 2013). The author did not assess any false positives or false negatives for any of the two examinations, as this was not feasible due to logistical complexities. In Section 7.3 above, it was alluded to that due to the design of the study, the author was unable to assess any false positives or false negatives for either the forensic autopsy or PMCT. The logistical complexities were due to the fact that the author had no other way of determining that what the forensic pathologists reported as an injury, or observation was indeed true for all such reported cases. Conversely, all PMCT imaging findings reported by the reviewers could not be independently verified within the body of subjects due to the design of the study.

The cases enrolled, did not fully represent the total case mix of children managed at the forensic facility for suspected fatal child abuse. For example, there were no cases as a result of hanging, deliberate poisoning, fatal stabbings, fatal burns, or other supervisory neglect such as drowning, physical neglect such as starvation, fatal burns, and fatal sexual abuse, which suggests that the study findings might have further overestimated the performance of PMCT in reference to a broader spectrum of fatal child abuse cases.

Use of different terminology by the forensic pathologists and radiologists complicated the recording of some injuries. For example, the radiologists would describe fluid in the pericardial cavity as ‘pericardial haemorrhage’, whilst the forensic pathologists would describe this as ‘pericardial effusion’. This hampered harmonisation of the terminology during data collection, and subsequent analysis in a small number of injury types. There was even intra-disciplinary variation in the use of terminology which complicated interpretation, such as the use of ‘pleural effusion’, and ‘haemothorax’ for blood within the pleural cavity. The Hounsfield units do allow discrimination between fluid and blood on PMCT images where blood has an average reading of 20, cerebro-spinal fluid 15, and water 0 (Bushong, 2013).

On occasion, thin slice image acquisition was not used where required, which might have compromised image resolution and diagnosis of subtle fractures, as minute fractures require thinner slices to enable high resolution images.

7.12 RECOMMENDATIONS

The following are recommendations which future researchers should consider when conducting similar studies:

- Utilise a larger sample size.
- Enrol cases with more or less the same manner of death or suspected cause of death.
- Standardisation of pathological/injury terminology for recording of injuries by pathologists and radiologists to harmonise data recording and analysis (Speelman et al., 2022).
- Compare the sensitivity and specificity of PMCT with that of the forensic autopsy for diagnosis of muscle injuries.

- There is a need for further education and training of radiographers with respect to optimisation of PMCT examinations (as covered under Section 3.8 in Chapter Three) as well as the medico-legal aspects related to post-mortem cross-sectional imaging.

7.13 STUDY'S CONTRIBUTION TO THE BODY OF KNOWLEDGE

This study has made several contributions to the body of knowledge. Overall, the findings highlighted the benefits PMCT can bring to forensic applications in children. The study has shown that PMCT was able to successfully identify a wide spectrum of injury types in children.

The forensic autopsy compared to PMCT, diagnosed more of the following injury categories: haemorrhagic, hollow organ, large blood vessel, muscle, soft tissue, solid organ injuries and fluid collections. PMCT identified more gas collections and skeletal injuries.

There was a good degree of concordance between the forensic autopsy and PMCT for diagnosis of the following injury types: SAH, intracerebral haemorrhages, diastasis of skull bones, lung collapse, haemothoraces, rib fractures, haemoperitoneum, and some upper and lower extremity fractures. With the forensic autopsy more brain contusions, brain lacerations, SDH's, blood and gastric content aspirations, lung haemorrhages, lung parenchymal injuries, cardiac and abdominal organ injuries, as well as large blood vessel perforations were diagnosed compared to PMCT. Contrary, with PMCT more facial bone fractures, some skull fractures e.g., orbital, intraventricular haemorrhages, brain compression/swelling, pneumocephalus, pneumothoraces (albeit that this was the result of forensic autopsy protocols and case management, rather than inherent weaknesses of the procedures), and some spinal fractures were diagnosed compared to the forensic autopsy.

As with other studies, this study has shown that PMCT provides additional information about injuries or trauma not available at the time of death or during physical inspection, or even during the autopsy (Urbanik et al., 2009; Jackowski, 2013; Noda et al., 2013). PMCT was also able to determine the extent of inflicted injury for two cases of fatal physical abuse. In one subject (Subject 11), no significant external injuries were evident. PMCT showed fractures of the left 8–10 dorsal ribs, and a fracture of the superior ramus of the pubis. The ribs fractured were

undisplaced on PMCT and were not noted with the forensic autopsy. In this subject, a fracture of the superior ramus was diagnosed with both the forensic autopsy and PMCT.

In this study, PMCT has been shown to provide valuable insight into incidental congenital and anatomical variants, as well as evidence of medical mishaps. PMCT demonstrated the location of medical devices such as catheters, endotracheal tubes and foreign bodies. For example, PMCT demonstrated three incorrectly positioned endotracheal tubes located in the right main bronchus, none of which were recorded with the forensic autopsy. The incorrect placement of the ET tube has forensic significance as it suggests that intubation was not done correctly. The consequence of an incorrectly placed ET tube invariably leads to compromised mechanical ventilation as it implies that the majority of the air was pumped only into the right lung with subsequent compromised aeration to the left lung which can result in ipsilateral lung collapse. This is one example where forensic pathologists can play a role in the education of health care professionals by reporting such medical errors to the responsible clinical managers. Incidental findings such as these have particular relevance where medical mishaps are to be investigated or corrected.

For various reasons, paediatric post-mortem imaging is different to adult post-mortem imaging. Paediatric imaging has different disease aetiology, pathology, and radiographic appearances, and requires imaging techniques with a specific skill set to maximize its yield and clinical benefit (Arthurs et al., 2015). For example, PMCT in neonates and children requires a high skill set in image interpretation due to the complexity of their anatomy, physiology and wide spectrum of diseases. A case in point is that PMCT imaging of the abdomen is sometimes complicated by a lack of fat and generally poor contrast resolution of CT images (Olsen & Gunny, 2006). Fractures are sometimes difficult to identify in children, especially if epiphyseal plates are present. With the correct level of radiological expertise, valuable contributions can be made in a difficult field such as paediatric imaging which, at times, may generate images with very confounding appearances, often a consequence of the stage of the physiological development and age of the child. Reviewers 1 and 2 both had 20 yand 14 years of experience respectively in reporting PMCT examinations. Classic skeletal manifestations of physical abuse, such as the CML, or fractures at different stages of healing, were eloquently demonstrated with PMCT.

The findings of this study did not support the notion that PMCT can replace the forensic autopsy, but rather that this imaging modality should serve as an adjunct examination to forensic autopsies in children whose demise was due to suspected abuse, irrespective of the manner of death (Speelman et al., 2022). PMCT must therefore be routinely employed as a supplementary examination in the investigation of these cases.

The entrance criteria for this study being solely for children who had demised as a result of suspected abuse and sudden unexplained deaths, made this an original study, particularly in the South African context. To the author's knowledge, this is the first study of this kind ever to be performed in Africa, making this study unique to the continent. The support provided by the two international paediatric radiology experts is evidence of the kind of international collaboration possible for a study of this kind. Minimal infrastructure or logistical arrangements were required for the PMCT image interpretation, making such a study replicable for poorly resourced institutions. The researcher also developed extensive transdisciplinary knowledge, which facilitated his professional development. This is a potential benefit that researchers wishing to conduct similar studies are set to gain.

Even though this was a small study, it may serve as a reference for other researchers wishing to perform similar post-mortem imaging studies in Africa. Furthermore, it is in the interests of health care delivery, and the growth of both the radiology and radiography professions, that research studies such as this are conducted in South Africa. Adelman and colleagues are correct when arguing that the strengths and weaknesses of comparative post-mortem forensic imaging versus forensic autopsy studies are multifactorial (Adelman et al., 2018). These include intrinsic factors such as organ or tissue density, size and location of injuries, extrinsic factors such as PMCT protocols applied, resources available, and the expertise of PMCT operators and imaging reviewers (Scholing et al., 2009; Adelman et al., 2018). These factors could be the cause of the large variation notable in findings of similar diagnostic imaging accuracy studies. This study was not much different in the sense that various factors impacted on the ultimate results, as highlighted in this chapter. However, all factors considered, this study still made a valuable contribution to the intellectual debate, knowledge building and advanced current thinking related to cross-sectional post-mortem forensic imaging in children. As noted in this thesis, this study had some common trends with similar studies in adult populations.

7.14 PMCT IMAGING FOR CHILD ABUSE

Violence against children is unacceptable, never justified, and always preventable. Violence exists in every country in the world and cuts across culture, class, education, income and ethnic origin (Pinheiro, 2006). The high burden of serious and long-term consequences of child abuse, often fatal (as in the present study), necessitates increased investment in preventative and therapeutic strategies from early childhood (Gilbert et al., 2009). South Africa has a high burden of child abuse. Furthermore, South Africa has committed to being a Pathfinder Country in which global leadership will be displayed in the elimination of violence against children. It is imperative that policy makers and service providers be pro-active in eliminating violence against children (Artz et al., 2018). It is the responsibility of all health care professionals involved in the management of children to play an active role in the prevention and detection of child abuse. Where abuse is evident, effective documentation and safeguarding of evidence must be upheld to promote the administration of justice, ultimately for the benefit of the child and other children.

Paediatric death investigations are essential to confirm, or rule out, child abuse, especially where there are suspicious circumstances surrounding death (Ruder, 2015). As evident in this study, diagnostic imaging has been shown to play an important role in the diagnosis of child abuse, whether in live or deceased children as advocated by the AAP (AAP, 2009b). The major advantage of diagnostic imaging is that it provides objective, repeatable evidence of existing skeletal, head and thoraco-abdominal injuries (Jain, 2015). This study has also shown how PMCT was able to identify the extent of injuries as a result of fatal physical abuse, as well as other forms of child abuse such as neglect or physical violence.

Thus far, PMCT, as a diagnostic imaging modality, has remained an autopsy adjunct examination which facilitates holistic forensic examinations of the body (Persson et al., 2008). PMCT will play a strong supportive role in documenting the nature and extent of injuries in abused children (Speelman et al., 2022). The role of PMCT in forensic sciences will grow as the benefits of this imaging modality are realised, especially in South Africa. This study has shown that many injuries that would have potentially gone unnoticed during the forensic autopsy can now be documented as part of post-mortem cross-sectional imaging. PMCT thus enables a comprehensive forensic assessment of injuries, pathological diseases, congenital abnormalities and medical mishaps. Considering that child abuse will continue to be a health burden and form a huge part of the workload of forensic institutes, it is prudent that the role of

PMCT is expanded for diagnosis of this social anomaly. In the interests of a fatally abused child, the sole purpose of forensic pathology must be to establish the evidence in a meticulous way. Forensic autopsy supported by PMCT imaging will go a long way in documenting the extent of fatal child abuse related injuries, arguably ensuring justice for the victim of the injustice committed.

7.15 AUTHOR'S REFLECTION ON THE FUTURE OF POST-MORTEM FORENSIC IMAGING IN SOUTH AFRICA AND THE IMPLICATIONS THEREOF FOR HEALTH CARE MANAGEMENT

There is currently a lack of cross-sectional forensic imaging expertise in SA. There is thus a dire need for the development of forensic radiologic, and radiographic expertise, in cross-sectional forensic imaging. It is imperative that all professions, namely, forensic pathology, radiology and radiography, make a concerted effort to promote the use of PMCT imaging for all forensic autopsies. This will forefront the standard of care in South Africa, as is the case at the Virtopsy Centre in Zurich, the Victorian Institute of Forensic Medicine in Melbourne, Australia, and the Forensic Institute at the University of Bern, Switzerland.

There will thus be a need for the forensic pathology, radiology and radiography professions to share interdisciplinary knowledge, and to improve scientific research in forensic imaging and practice (Thali et al., 2003b; Brogdon, 2011). There will have to be some expansion of the scopes of radiology, radiography and forensic pathology. The imaging appearance of PMCT due to putrefaction can be complex and require extensive knowledge and understanding of these processes. Forensic pathologists will have to understand CT technology and PMCT imaging appearances; whilst radiologists will have to become familiar with certain forensic pathology techniques, and forensically important findings, such as the impact of hypostasis (blood sedimentation), also known as livor mortis, putrefaction, and many other normal post-mortem findings seen on PMCT. Radiographers will inter alia, have to be sensitised about maintaining the authenticity of and ensuring continuity of evidence. Based on the limited PMCT forensic imaging currently conducted in South Africa, there may be a need for radiographers to undergo dedicated forensic imaging courses, as the scanning of deceased bodies differs significantly to that of imaging in live subjects.

Collaboration amongst these three professions may be an ideal opportunity for critically needed skills development, but also for growth, specialisation and further education and training of forensic pathologists, radiologists and radiographers. This integration will arguably lead to benefits for all three professions. In the absence of a forensic radiology sub-speciality, the interpretation of PMCT should be conducted by a multi-disciplinary team consisting of an experienced radiologist interpreting the images, the forensic pathologists conducting the forensic autopsy and a forensic radiographer to acquire the PMCT examinations (Krentz et al., 2016). Forensic radiographers are already an integral part of the forensic examinations in a few forensic centres (Chevallier et al., 2013; Ebert at al., 2016). The practice of forensic pathology will be boosted significantly by such transdisciplinary collaboration and the additional benefits that cross-sectional imaging holds as described in this thesis.

The gradual introduction of PMCT and PMMRI as cross-sectional forensic imaging modalities should be given due consideration within forensic institutes in South Africa and even in Africa as a whole. Whilst PMCT, in the author's view, is not able to replace the forensic autopsy, this modality will in the near future, form an indispensable supplementary examination to the forensic autopsy, as outlined by the findings of this study. Even though activities related to policy formulation did not form part of this study, there is a need for ringfencing dedicated funding to support the installation and roll out of PMCT and PMMRI in forensic institutions in South Africa. The results have shown that the implementation of routine PMCT services for fatally abused children will be justified. PMCT will bring significant benefits to forensic pathology, as highlighted in this chapter. The benefits and opportunities that PMCT provides for other disciplines within forensic pathology, such as anthropology, odontology, or forensic ballistic research amongst others, in South Africa, are endless.

7.16 CHAPTER SUMMARY

One of the main objectives of the proposed research study was to assess the degree of concordance between the forensic autopsy and PMCT in diagnosing injuries in fatally abused children. The researcher postulated that fatally abused children will have many intracerebral injuries, such as SDH, SAH, or EDH and other associated skeletal and soft tissue injuries. Many of these injuries, are diagnosed with relative ease using CT**,** lending an opportunity to establish

whether PMCT, has a higher concordance with the forensic autopsy in this group compared to non-abused children. It was further postulated that the findings within this group of child deaths might yield a higher sensitivity for PMCT compared to the autopsy, which might inform whether or not this imaging modality is able to replace the forensic autopsy for some specified clinical conditions. These were untested assumptions which were analysed after data collection. The rationale was to limit the range of injuries sustained to a narrow group caused by fatal abuse. It was anticipated that this narrow application (i.e limited type of injuries) would allow a careful and narrowed comparison of the degree of concordance between PMCT and the autopsy results. However, this was found not to be the case, as injuries differed extensively amongst the subjects.

Considering that both examinations had shortcomings, the findings of this study supported the notion that a combined use of the forensic autopsy and PMCT increases the number of significant injuries that can be diagnosed and indirectly enhances determining the cause of death (Sochor et al., 2008; Chevallier et al., 2013; Krentz et al., 2016). The combined use of PMCT with the forensic autopsy in child abuse provide a comprehensive forensic autopsy which will assist the administration of justice. The role of PMCT will continually grow as PMCT techniques and forensic radiology expertise are improved in South Africa. As far as could be ascertained, the Salt River Forensic Pathology Service serving as the one research site was the first forensic institution in South Africa to conduct PMCT on deceased children. The Salt River Forensic Pathology Service has, following the initiation of this study, implemented a policy that where indicated, all children with suspicious circumstances of death, now undergo PMCT imaging at a dedicated children's hospital in Cape Town South Africa. The potential benefits this imaging modality holds for forensic pathology in South Africa will continue to evolve as more deceased children undergo PMCT.

REFERENCE LIST

Aalders, M., Adolphi, N., Daly, B., Davis, G., De Boer, H., Decker, S., Dempers, J., Ford, J., Gerrard, C., Hatch, G., Hofman, P., Lino, M., Jacobsen, C., Klein, W., Kubat, B., Leth, P., Mazuchowski, E., Nolte, K., O'Donnell, C., Thali, M., Van Rijn, R. & Wozniak, K. 2017. Research in forensic radiology and imaging: Identifying the most important issues. *Journal of Forensic Radiology and Imaging*. 8:1–8. DOI: 10.1016/j.jofri.2017.01.004

AAP (American Academy of Pediatrics). 2001. Shaken Baby Syndrome: Rotational cranial injuries - Technical report. *Pediatrics*. 108:206–210. DOI: 10.1542/peds.108.1.206

AAP (American Academy of Pediatrics). 2009a. Diagnostic imaging of child abuse. *Pediatrics*. 123:1430–1435. DOI: 10.1542/peds.2009-0558

AAP (American Academy of Pediatrics). 2009b. Abusive head trauma in infants and children. *Pediatrics*. 123:1409–1411. DOI: 10.1542/peds.2009-0408

Ablin, D., Greenspan, A. & Reinhart, M. 1992. Pelvic injuries in child abuse. *Pediatric Radiology*. 22:454–457. DOI: 10.1007/bf02013511

Ablin, D., Greenspan, A., Reinhart, M. & Grix, A. 1990. Differentiation of child abuse from osteogenesis imperefecta. *American Journal of Roentgenology*. 154:1047–1048. DOI: 10.2214/ajr.154.5.2108539

Abrahams, N., Mathews, S., Lombard, C., Martin, L., & Jewkes, R. 2017. Sexual homicides in South Africa: A national cross-sectional epidemiological study of adult women and children. *PLoS One.* 12(10):e0186432. DOI: 10.1371/journal.pone.0186432

Abrahams, N., Mathews, S., Martin, L., Lombard, C., Nannan, N. & Jewkes, R. 2016. Gender differences in homicide of neonates, infants and children under 5 years in South Africa: Results from the cross-sectional 2009 National Child Homicide Study. *PLoS Med.* 13(4):e1002003. DOI: 10.1371/journal.pmed.1002003

Adams, V.I. 2008. Autopsy protocol. In: *Guidelines for reports by autopsy pathologists*. New York: Humana Press. 1–40.

Adamsbaum, C., Mejean, N., Merzoug, V., & Rey-Salmon, C. 2010. How to explore and report children with suspected non-accidental trauma. *Pediatric Radiology*. 40:932–938. DOI: 10.1007/s00247-010-1591-0

Adelman, A., Vasserman, M., Graziani, G., Kugel, C., Meir, K., Bdolah-Abram, T. & Krispin, A. 2018. Post-mortem computed tomography compared to medico-legal autopsy – pathologies in the torso and limbs. *Journal of Forensic Radiology and Imaging*. 12:43–49. DOI: 10.1016/j.jofri.2017.12.002

Aggarwal, B., Aggarwal, A., Gothi, R., Doda, S. & Aggarwal, S. 2002. Clinical applications of multi-detector row (multi-slice) CT. *Indian Journal of Radiology and Imaging*. 12(4):473–482.

Aghayev, E., Christe, A., Sonnenschein, M., Yen, K., Jackowski, C., Thali, M., Dirnhofer, R. & Vock, P. 2008. Postmortem imaging of blunt chest trauma using CT and MRI. *Journal of Thoracic Imaging*. 23:20–27. DOI: 10.1097/rti.0b013e31815c85d6

Aghayev, E., Sonnenschein, M., Jackowski, C., Thali, M., Buck, U., Yen, K., Bolliger, S., Dirnhofer, R. & Vock, P. 2006. Postmortem radiology of fatal hemorrhage: Measurement of cross-sectional areas of major blood vessels and volumes of aorta and spleen on MDCT and volumes of heart chambers on MRI. *American Journal of Roentgenology.* 187:209–215. DOI: 10.2214/AJR.05.0222

Ali, Z., Bolster, F., Goldberg, E., Fowler, D. & Li, L. 2016. Systemic air embolism complicating upper gastrointestinal endoscopy: A case report with post-mortem CT scan findings and review of the literature. *Forensic Sciences Research*. 1(1):52–57.

Alzahrani, N., Jeanes, A., Paddock, M., Shuweidhi, F. & Offiah, A. 2021. The diagnostic performance of chest computed tomography in the detection of rib fractures in children investigated for suspected physical abuse: a systematic review and meta-analysis. *European Radiology*, 31, 7088 – 7097. DOI: 10.1007/s00330-021-07775-3

American College of Radiology. 2020. *ACR-SPR Practice parameter for the performance and interpretation of skeletal surveys in children*. 1–9. Accessed at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/Skeletal-Survey.pdf [2020, 16 February].

Amjadi, K., Alvarez, G., Vanderhelst, E., Velkeniers, B., Lam, M. & Noppen, M. 2007. The prevalence of blebs or bullae among young healthy adults. *Chest*. 132:1140–1145. DOI: 10.1378/chest.07-002913:284–292. DOI: 10.1007/s12024-017-9878-1

Ampanozi, G., Flach., P., Fornaro, J., Ross, S., Schweitzer, W., Thali, M. & Ruder, T. 2015. Systematic analysis of the radiographic findings of aortic dissections on unenhanced postmortem computed tomography. *Forensic Science, Medicine and Pathology*. 11:162–167. DOI: 10.1007/s12024-015-9654-z

Ampanozi, G., Halbeer, D., Ebert, L., Thali, M. & Held, U. 2020. Postmortem imaging findings and cause of death determination compared with autopsy: A systematic review of diagnostic accuracy and meta-analysis. *International Journal of Legal Medicine*. 134:321–337. DOI: 10.1007/s00414-019-02140-y

Ampanozi, G., Thali, Y., Schweitzer, W., Hatch, G., Ebert, L., Thali, M. & Ruder, T. 2017. Accuracy of non-contrast PMCT for determining cause of death. *Forensic Science, Medicine and Pathology*. 13:284-292 DOI: 10.1007/s12024-017-9878-1

Andenmatten, M., Thali, M., Kneubuehl, B., Oesterhelweg, L., Ross, S., Spendlove, D. & Bolliger, S. 2008. Gunshot injuries detected by post-mortem multislice Computed Tomography (MSCT): A feasibility study. *Legal Medicine*. 10:287–292. DOI: 10.1016/j.legalmed.2008.03.005

Andronicus, M., Oates, R., Peat, J., Spalding, S. & Martin, H.1998. Non-accidental burns in children. *Burns*. 24:552–558. DOI: 10.1016/S0305-4179(98)00062-X

Anilkumar, A., Fender, L., Broderick, N., Somers, J. & Halliday, K. 2006. The role of follow-up chest radiograph in suspected non-accidental injury. *Pediatric Radiology*. 36:216–218. DOI:10.1007/s00247-005-0054-5

Arlotti, S., Forbes, B., Dias, M. & Bonsall, D. 2007. Unilateral retinal hemorrhages in shaken baby syndrome. *Journal of the American Association for Pediatric Ophthalmology and Strabismus*. 11:175–178. DOI: 10.1016/j.jaapos.2006.09.023

Arthurs, O., Guy, A., Thayyil, S., Wade, A., Jones, R., Norman, W., Scott, R., Robertson, N., Jacques, T., Chong, W., Gunny, R., Saunders, D., Olsen, O., Owens, C., Offiah, A., Chitty, L., Taylor, A. & Sebire, N. 2016. Comparison of diagnostic performance for perinatal and paediatric

post-mortem imaging: CT versus MRI. *European Radiology*. 26:2327–2336. DOI: 10.1007/s00330-015-4057-9

Arthurs, O, Hutchinson, J. & Sebire, N. 2017. Current issues in postmortem imaging of perinatal and forensic childhood deaths. *Forensic Science, Medicine and Pathology*. 13:58–66. DOI: 10.1007%2Fs12024-016-9821-x

Arthurs, O., Van Rijn, R., Taylor, A. & Sebire, N. 2015. Paediatric and perinatal postmortem imaging: The need for a subspecialty approach. *Pediatric Radiology*. 45:483–490. DOI: 10.1007/s00247-014-3132-8

Arthurs, O., van Rijn, R. & Sebire, N. 2014. Current status of paediatric post-mortem imaging: an ESPR questionnaire-based survey. *Pediatric Radiology*. 44: 244- 251. DOI: 10.1007/s00247-013-2827-6

Artz, L., Ward, C., Leoschut, L., Kassanjee, R. & Burton, P. 2018. The prevalence of child sexual abuse in South Africa: The Optimus Study South Africa. *South African Medical Journal*. 108(10):791–792. DOI:10.7196/SAMJ.2018.v108i10.13533

Atwal, G., Rutty, G., Carter, N. & Green, M. 1998. Bruising in non-accidental head injured children: A retrospective study of the prevalence, distribution and pathological associations in 24 cases. *Forensic Science International*. 96:215–230. DOI: 10.1016/s0379-0738(98)00126-1

Ayoub, T. & Chow, J. 2008. The conventional autopsy in modern medicine. *Journal of the Royal Society of Medicine*. 101:177–181. DOI: 10.1258%2Fjrsm.2008.070479

Baerg, J., Thirumoorthi, A., Vannix, R., Taha, A., Young, A. & Zouros, A. 2017. Cervical spine imaging for young children with inflicted trauma: Expanding the injury pattern. *Journal of Pediatric Surgery*. 52:816–821. DOI: 10.1016/j.jpedsurg.2017.01.049

Baglivo, M., Winklhofer, S., Hatch, G., Ampanozi, G., Thali, M. & Ruder, T. 2013. The rise of forensic and post-mortem radiology – Analysis of the literature between the year 2000 and 2011. *Journal of Forensic Radiology and Imaging*. 1:3–9. DOI: 10.1016/j.jofri.2012.10.003

Bajanowski, T., West, A. & Brinkmann, B. 1998. Proof of fatal air embolism. *International Journal of Legal Medicine*. 111:208–211. DOI: 10.1007/s004140050153

Baker, A., Craig, B. & Lonergan, G. 2003. Homicidal commotion cordis: The final blow in a battered infant. *Child abuse and neglect*. 27:125–130. DOI: 10.1016/s0145-2134(02)00511-2

Bandyopadhyay, S. & Yen, K. 2002. Non-accidental fractures in child maltreatment syndrome. *Clinical Pediatric Emergency Medicine.* 3:145–152. DOI: 10.1053/cpem.2002.126755

Bankier, A., Levine, D., Halpern, E. & Kressel, H. 2010. Consensus interpretation in imaging research: Is there a better way? *Radiology*. 257:14–17. DOI: 10.1148/radiol.10100252

Barber, I., Perez-Rossello, J., Wilson, C., Silvera, M. & Kleinman, P. 2013. Prevalence and relevance of pediatric spinal fractures in suspected child abuse. *Pediatric Radiology*. 43:1507–1515. DOI: 10.1007/s00247-013-2726-x

Barnes, P., Norton, C., Kemp, A. & Sibert, J. 2005. Abdominal injury due to child abuse. *The Lancet*. 366:234–235. DOI: 10.1016/s0140-6736(05)66913-9

Barret, J. & Keat, N. 2004. Artifacts in CT: Recognition and avoidance. *Radiographics*. 24, 1679 – 1691. DOI: 10.1148/rg.246045065

Bartosch, C., Vilar, I., Rodrigues, M., Costa, L., Botelho, N. & Brandäo, O. 2019. Fetal autopsy parameters standards: Biometry, organ weights, and long bone lengths. *Virchows Archives*. 475: 499–511. DOI: 10.1007/s00428-019-02639-0

Baz, B. & Wang, N. 2012. Physical abuse of children: Identification evaluation and management. *Primary Care Reports*, Vol. 18(7):81–95. http://web.b.ebscohost.com.libproxy.cput.ac.za/ehost/pdfviewer/pdfviewer?vid=1&sid=b545b31c-0771-4f5e-a5d0-c9a1804479d4%40sessionmgr102 [2021, 9 March].

Bechtel, K., Stoessel, K., Leventhal, J., Ogle, E, Teague, B., Lavietes, S., Banyas, B., Allen, K., Dziura, J. & Duncan, C. 2004. Characteristics that distinguish accidental from abusive injury in hospitalized young children with head trauma. *Pediatrics*. 114:165–168. DOI: 10.1542/peds.114.1.165

Beck, J. 2014. Can cross sectional imaging contribute to the investigation of unexplained child deaths? A literature review. *Radiography*. 20:206–210. DOI: 10.1016/j.radi.2013.12.004

Bedford, P. 2012. Routine CT scan combined with preliminary examination as a new method in determining the need for autopsy. *Forensic Science, Medicine and Pathology.* 8:390–394. DOI: 10.1007/s12024-012-9349-7

Bell, N. 2008. Ethics in child research: Rights, reason and responsibilities. *Children's Geographies*. 6:7–20. DOI: 10.1080/14733280701791827

Bertulli, C. & Cochat, P. 2017. Munchausen syndrome by proxy and pediatric nephrology. *Nephrologie & Therapeutique*. 13:482–484. DOI: 10.1016/j.nephro.2016.12.006

Betts, T., Ahmed, S., Maguire, S. & Watts, P. 2017. Characteristics of non-vitreoretinal ocular injury in child maltreatment: A systematic review. *Eye*. 31:1146–1154. DOI: 10.1038/eye.2017.25

Bilo, R., Robben, S. & Van Rijn, R. 2011. *Forensic aspects of paediatric fractures. Differentiating accidental trauma from child abuse.* Heidelberg, Germany: Springer. DOI: 10.1007/978-3-540-78716-7

Blokker, B., Wagensveld, I., Weustink, A., Oosterhuis, J. & Hunink, M. 2016. Non-invasive or minimally invasive autopsy compared to conventional autopsy of suspected natural deaths in adults: A systematic review. *European Radiology*. 26:1159–1179. DOI: 10.1007%2Fs00330-015-3908-8

Blumenthal, I. 2002. Shaken baby syndrome. *Postgraduate Medical Journal*. 78:732–735. DOI: 10.1136/pmj.78.926.732

Boal, D. 2008. Child abuse. In *Caffey's Pediatric Diagnostic Imaging*. 11th ed. Slovis, Ed., T, Adler, B., Bloom, D., Bulas, D., Coley, B., Donaldson, J., Faerber, E., Frush, D., Schulman, M. & Strouse, P., Assoc. eds. Philadelphia, PA: Mosby Elsevier.

Boleken, M., Cevik, M., Yagiz, B., Ter, M., Dorterler, M. & Aksoy, T. 2013. The characteristics and outcomes of penetrating thoracic and abdominal trauma among children. *Pediatric Surgery International*. 29:795–800. DOI: 10.1007/s00383-013-3339-z

Bolliger, S., Thali, M., Ross, S., Buck, U., Naether, S. & Vock, P. 2008. Virtual autopsy using imaging: Bridging radiologic and forensic sciences. A review of the Virtopsy and similar projects. *Forensic Medicine*. 18:273–282. DOI: 10.1007/s00330-007-0737-4

Bowling, A. 2010. *Research methods in health: Investigating health and health services*. 3rd ed. Maidenhead, UK: McGraw Hill Open University Press. 202

Brennan, L., Rubin, D., Christian, C., Duhaime, A., Mirchandani, H. & Rorke-Adams, L. 2009. Neck injuries in young pediatric homicide victims. *Journal of Neurosurgery*. 3:232–239. DOI: 10.3171/2008.11.PEDS0835

Brogdon, B. 2011. Child abuse. In *Brogdon's Forensic Radiology.* M. Thali, M. Viner, M. & B. Brogdon (Eds). Boca Raton, FL: CRC Press. xiii, 255 - 278

Brogdon, B. & Lichtenstein, J. 2011. Forensic radiology in historical perspective. In *Brogdon's Forensic Radiology.* M. Thali, M. Viner & B. Brogdon (Eds). Boca Raton: CRC Press. 9 - 24

Bryce, C. 2013. The impact of advances in post-mortem imaging on forensic practice. *Journal of Forensic Science & Criminology.* 1(1):1–2. DOI: 10.15744/2348-9804.1.e103

Bushong, S. 2013. *Radiological Science for Technologists: Physics, Biology and Protection*. 10th ed. St Louis, MO: Elsevier Mosby.438 - 451

Butler, B., Fries, C., Panock, J., Jorden, M. & Melinek, J. 2016. Catching a bullet: Gunshot wound trajectory analysis used to establish body position. *Academic Forensic Pathology*. 6:739–745. DOI: 10.23907%2F2016.070

Cadzow, S. & Armstrong, K., 2000. Rib fractures in infants: Red alert! The clinical features, investigations and child protection outcomes. *Journal of Pediatrics and Child Health*. 36(4):322–326. DOI: 10.1046/j.1440-1754.2000.00515.x

Caffey, J. 1946. Multiple fractures in the long bones of infants suffering from chronic subdural hematoma. *The American Journal of Roentgenology and Radium Therapy*. 56(2):163–173.

Caffey, J. 1972. On the theory and practice of shaking infants. *American Journal of Diseases of Children*. 124(2):161–169.

Caffey, J. 1974. The shaken infant syndrome: Manual shaking by the extremities withs whiplash-induced intracranial and intraocular bleedings, linked with residual permanent brain damage and mental retardation. *Pediatrics*. 54:396–403.

Campbell, M.J. & Machin, D. 2002. *Medical statistics*. 3rd ed. Chichester, England: John Wiley & Sons Limited. 75

Campbell, N., Collville, J., Van der Heyde, Y. & Van As, A. 2013. Firearm injuries to children in Cape Town, South Africa: Impact of the 2004 Firearms Control Act. *The South African Journal of Surgery*. 52(3):92–96. DOI: 10.7196/SAJS.1220

Carrol, R. & Wood, J. 2012. Sudden unexpected infant death: A compassionate forensic approach to care. *Clinical Pediatric Emergency Medicine*. 13(3):239–248. DOI: 10.1016/j.cpem.2012.06.011

Carty, H. 1993. Case report: Child abuse-necklace calcification – a sign of strangulation. *The British Journal of Radiology*. 66:1186–1188.

Carty, H. 1995. The radiological features of child abuse. *Current Pediatrics*. 5(4):230 – 235.

Carty, H. 1997. Non-accidental injury: a review of the literature. *European Radiology*. 7:1365–1376.

Cattaneo, C., Marinelli, E., Di Giancamillo, A., Di Giancamillo, M., Travetti, O., Vigano, l., Poppa, P., Porta, D., Gentilomo, A. & Grandi, M. 2006. Sensitivity of autopsy and radiological examination in detecting bone fractures in an animal model: Implications for the assessment of fatal child physical abuse. *Forensic Science International*.164:131–137. DOI: 10.1016/j.forsciint.2005.12.016

Centers for Disease Control and Prevention. 2020. *Preventing abusive head trauma*. Accessed at: https://www.cdc.gov/violenceprevention/childabuseandneglect/Abusive-Head-Trauma.html [2020, 21 November].

Centre for Crime Prevention and Justice. 2012. Desktop study on violence against children in South Africa. Accessed at: http://www.cjcp.org.za/uploads/2/7/8/4/27845461/unicef_vac_study_final_april2012.pdf [2019, 4 March].

Cha, J., Kim, D., Paik, S., Park, J., Park, S., Lee, H., Hong, H., Choi, D., Yang, K., Chung, N., Lee, B. & Seo, J. 2010. Utility of Postmortem autopsy via whole-body imaging: Initial

observations comparing MDCT and 3.0T MRI findings with autopsy results. *Korean Journal of Radiology.* 11(4):395–406. DOI: 10.3348/kjr.2010.11.4.395

Chadwick, D., Chin, S., Salerno, C., Landsverk, J. & Kitchen, L. 1991. Deaths from falls in children: How far is fatal? *The Journal of Trauma.* 31(10):1353–1355. DOI: 10.1016/0736-4679(92)90300-I

Chapman, S. 2004. Non accidental injury. *Imaging*. 16(2):161–173. DOI: 10.1259/imaging/63188608

Chapman, S. 2008. Non-accidental injury. In *Imaging in pediatric skeletal trauma*. K. Johnson, & E. Bache, Eds. Birmingham, United Kingdom: Springer. 159 -173

Charlier, P., Carlier, R., Roffi, F., Ezra, J., Chaillot, P., Duchat, F., Hyunh-Charlier, I. & Lorin De La Grandmaison, G. 2012. Postmortem abdominal CT: Assessing normal cadaveric modifications and pathological processes. *European Journal of Radiology.* 81:639–647. DOI: 10.1016/j.ejrad.2011.01.054

Chester, D., Jose, R., Aldlyami, E., King, H. & Moiemen, N. 2006. Non-accidental burns in children – are we neglecting neglect. *Burns*. 32:222–228. DOI: 10.1016/j.burns.2005.08.018

Chevallier, C., Doenz, F., Vaucher, P., Palmiere, C., Dominguez, F, A., Binaghi, S., Mangin, P. & Grabherr, S. 2013. Postmortem computed tomography angiography versus conventional autopsy: Advantages and inconveniences of each method. *International Journal of Legal Medicine*. 127:981–989. DOI: 10.1007/s00414-012-0814-3

Choudhary, A., Ishak, R., Zacharia, T. & Dias, M. 2014. Imaging of spinal injury in abusive head trauma. A retrospective study. *Pediatric Radiology*. 44:1130–1140. DOI: 10.1007/s00247-014-2959-3

Christe, A., Flach, P., Ross, S., Spendlove, D., Bolliger, S., Vock, P. & Thali, M. 2010. Clinical radiology and postmortem imaging (Virtopsy) are not the same: Specific and unspecific post-mortem signs. *Legal Medicine*. 12:215–222. DOI 10.1016/j.legalmed.2010.05.005

Christian, C. & States, L. 2017. Medical Mimics of child abuse. *American Journal of Roentgenology*. 208:982–990. DOI:10.2214/AJR.16.17450

Christianson, O., Winslow, J., Frush, D. & Samei, E. 2015. Automated technique to measure noise on clinical CT examinations. *American Journal of Roentgenology*. 205,W93 – W99. DOI: 10.2214/AJR.14.13613

Christine, C., Francesco, D., Paul, V., Cristian, P., Alejandro, D., Stefano, B., Patrice, M. & Solke, G. 2013. Postmortem computed tomography angiography vs. conventional autopsy: advantages and inconveniences of each method. *Internal Journal of Legal Medicine*. Vol. 127, 981 – 989, DOI 10.1007/s00414-012-0814-3

Cirielli, V., Cima, L., Bortolotti, F., Narayanasamy, M., Scarpelli, M., Danzi, O., Brunelli, M., Eccher, A., Vanzo, F., Ambrosetti, M., El-Dalati, G., Vanezis, P., De Leo, D. & Tagliaro, F. 2018. Virtual autopsy as a screening test before traditional autopsy: The Verona experience on 25 cases. *Journal of Pathology Informatics*. 9:28. DOI: 10.4103/jpi.jpi_23_18

City of Cape Town. 2021. Health Districts. Accessed at: http://resource.capetown.gov.za/documentcentre/Documents/Maps%20and%20statistics/CCT-HealthSubdistricts.pdf [2021, 1 February]

Cohen, M. & Scheimberg, I. 2018. Forensic aspects of perinatal deaths. *Academic Forensic Pathology*. 8(3):452–491. DOI: 10.1177/1925362118797725

College of Radiographers. 2005. The Child and the Law: The roles and responsibilities of the radiographer. Accessed at: https://www.sor.org/learning/document-library/child-law-roles-responsibilities-radiographer [2018, 21 October].

Cordner, S., Burke, M., Dodd, M., Lynch, M., Ranson, D. & Robertson, S. 2001. Issues in child homicides: 11 cases. *Legal Medicine*. 3:95–103. DOI: 10.1016/s1344-6223(01)00016-5

Curry, N., Hopewell, S., Dorée, C., Hyde, C., Brohi, K. & Stanworth, S. 2011. The acute management of trauma hemorrhage: A systematic review of randomized controlled trials. *Critical Care*. 15:R92. DOI: 10.1186/cc10096

Daly, B., Abboud, S., Ali, Z., Sliker, C. & Fowler, D. 2013. Comparison of whole-body postmortem 3D CT and autopsy evaluation in accidental blunt force traumatic death using the abbreviated injury scale classification. *Forensic Science International*. 225:20–26. DOI: 10.1016/j.forsciint.2012.08.006

Darling, S., Done, S., Friedman, S. & Feldman, K. 2014. Frequency of intrathoracic injuries in children younger than 3 years with rib fractures. *Pediatric Radiology*. 44:1230–1236. DOI: 10.1007/s00247-014-2988-y

David, T. 1999. Shaken baby syndrome: Non-accidental head injury in infancy. *Journal of the Royal Society of Medicine*. 92:556–561.

Dawes, A., Bray, R. & Van der Merwe, A. 2007. Monitoring child well-being. A South African rights-based approach. Accessed at: https://www.hsrcpress.ac.za/books/monitoring-child-well-being [2019, 17 October].

Day, F., Clegg, S., McPhillips, M. & Mok, J. 2006. A retrospective case series of skeletal surveys in children with suspected non-accidental injury. *Journal of Clinical Forensic Medicine*. 13:55–59. DOI: 10.1016/j.jcfm.2005.08.001

De Clercq, E., Badarau, D., Ruhe, K. & Wangmo, T. 2014. Body matters: rethinking the ethical acceptability of non-beneficial clinical research with children. *Medicine, Health Care and Philosophy*. DOI: 10.1007/s11019-014-9616-3

De la Grandmaison, G., Charlier, P. & Durigon, M. 2010. Usefulness of systematic histological examination in routine forensic autopsy. *Journal of Forensic Sciences*. 55:85–88. DOI: 10.1111/j.1556-4029.2009.01240.x

De Lange, C., Vege, A. & Stake, G. 2007. Radiography after unexpected death in infants and children compared to autopsy. *Pediatric Radiology*. 37:159–165. DOI: 10.1007/s00247-006-0364-2

Debelle, G. 2012. Interpreting physical signs of child maltreatment: 'Grey cases' and what is 'reasonably possible'. *Paediatrics and Child Health*. 12(11):470–475. DOI: 10.1016/j.paed.2012.08.001

Dedouit, F., Mallinger, B., Guilbeau-Frugier, C., Rougé, Rousseau, H. & Telmon, N. 2011. Lethal visceral traumatic injuries secondary to child abuse: A case of practical application of autopsy, radiological and microscopic studies. *Forensic Science International*. 206:e62–e66. DOI: 10.1016/j.forsciint.2010.08.027

Delabarde, T., Cannet, C., Raul, J., Géraut, A., Taccoen, M. & Ludes, B. 2017. Bone and soft tissue histology: A new approach to determine characteristics of offending instrument in sharp force injuries. *International Journal of Legal Medicine*. 131:1313–1323. DOI: 10.1007/s00414-017-1613-7

Deltoff, M. 1994. Non-accidental pediatric trauma: Radiographic findings in the abused child. *Journal of the Canadian Chiropractic Association*. 38(2):98–105.

Di Pietro, M., Cassady, C., Kleinman, P., Applegate, K., Wood, B., Zerin, J., Mercado-Deane, M., Seibert, J. & Stolic, A. 2009. Diagnostic imaging of child abuse. *Pediatrics*. 123(5):1430–1435. DOI: doi:10.1542/peds.2009-0558

Dirnhofer, R., Jackowski, C., Vock, P., Potter, K, & Thali, M. 2006. Virtopsy: Minimally invasive imaging guided virtual autopsy. *Radiographics*. 26(5):1305–1333. DOI: 10.1148/rg.265065001

Doberentz, E., Madea, B. & Müller, A. 2014. Coronal clefts in infants – rare differential diagnosis of traumatic injuries of vertebral bodies in battered children. *Legal Medicine*. 16:333–336. DOI: 10.1016/j.legalmed.2014.06.011

Donnelly, L., Emery, K., Brody, A., Laor, T., Gylys-Morin, V., Anton, C., Thomas, S. & Frusg, D. 2001. Minimizing radiation dose for pediatric body applications of single-detector helical CT: Strategies at a large children's hospital. *American Journal of Roentgenology.* 176, 303 – 306. DOI: 10.2214/ajr.176.2.1760303

Dubowitz, H. & Bennett, S. 2007. Physical abuse and neglect of children. *Lancet*. 369:1891–1899. DOI: 10.1016/S0140-6736(07)60856-3

Dudley, M. & Garg, M. 2014. Fatal child abuse presenting with multiple vertebral and vascular trauma. *Journal of Forensic Sciences*. 59(2):386–389. DOI: 10.1111/1556-4029.12326

Duhaime, A., Gennarelli, T., Thibault, L., Bruce, D., Margulies, S. & Wiser, R. 1987. The shaken baby syndrome. A clinical, pathological, and biomechanical study. *Journal of Neurosurgery*. 66:409–415.

Du Toit-Prinsloo, L. & Saayman G. 2012. Performance of autopsies in South Africa: Selected legal and ethical perspectives. *Continuing Medical Education*. 30:53–55. Accessed at: http://www.cmej.org.za/index.php/cmej/article/view/2326/2188>. [2021, 10 March].

Dwek, J. 2011. The radiographic approach to child abuse. *Clinical Orthopaedics and Related Research*. 469:776–789. DOI: 10.1007/s11999-010-1414-5

Ebert, L., Flach, P., Schweitzer, W., Leipner, A., Kottner, S., Gascho., D., Thali, M. & Breitbeck, R. 2016. Forensic 3D surface documentation at the Institute of Forensic Medicine in Zurich – Workflow and communication pipeline. *Journal of Forensic Radiology and Imaging*. 5:1–7. DOI: 10.1016/j.jofri.2015.11.007

Elkhateeb, S., Mohammed, E., Meleka, H. & Ismail, A. 2018. Postmortem computed tomography and autopsy for detection of lesions and causes of death in gunshot injury cases: A comparative study. *Egyptian Journal of Forensic Sciences.* 8:50. DOI: 10.1186/s41935-018-0078-2

Ellis, P. 1997. The pathology of fatal child abuse. *Pathology*. 29(2):113–121.

Erfurt, C., Hahn, G., Roesner, D. & Schmidt, U. 2010. Pediatric radiological diagnostic procedures in cases of suspected child abuse. *Forensic Science, Medicine and Pathology*: 7:65–74. DOI: 10.1007/s12024-010-9148-y

Fanconi, M. & Lips, U. 2010. Shaken baby syndrome in Switzerland: Results of a prospective follow-up study, 2002–2007. *European Journal of Pediatrics*. 169:1023–1028. DOI: 10.1007/s00431-010-1175-x

Fayad, L., Corl, F. & Fishman, E. 2009. Pediatric skeletal trauma: Use of multiplanar reformatted and three-dimensional 64 row multidetector CT in the emergency department. *Radiographics*. 29(1):135–150. DOI: 10.1148/rg.291085505

Feldman, W., Weinberger, E., Milstein, J. & Fligner, C. 1997. Cervical spine MRI in abused infants. *Child Abuse and Neglect*. 21(2):199–205.

Fernando, S., Obaldo, R., Walsh, I. & Lowe, L. 2008. Neuroimaging of nonaccidental head trauma: pitfalls and controversies. *Pediatric Radiology*. 38:827–838. DOI: 10.1007/s00247-007-0729-1

Filograna, L., Ross, S., Bolliger, S., Germerott, T., Preiss, U., Flach, P. & Thali, M. 2011. Blood aspiration as a vital sign detected by Postmortem Computed Tomography Imaging, *Journal of Forensic Sciences*. 56. DOI: 10.1111/j.1556-4029.2011.01704.x

Filograna, L., Tartaglione, T., Filograna, E., Cittadini, F., Oliva, A. & Pascali, V. 2010. Computed Tomography (CT) virtual autopsy and classical autopsy discrepancies: Radiologist's error or a demonstration of post-mortem multi-detector computed tomography (MDCT) limitation? *Forensic Science International*. 195:e13–e17. DOI: 10.1016/j.forsciint.2009.11.001

Flach, P., Gascho, D., Schweitzer, W., Ruder, T., Berger, N., Ross, S., Thali, M. & Ampanozi, G. 2014b. Imaging in forensic radiology: An illustrated guide for post-mortem computed tomography technique and protocols. *Forensic Science, Medicine and Pathology.* 10: 583-606. DOI: 10.1007/s12024-014-9555-6

Flach, P., Thali, M. & Germerott, T. 2014a. Times have changed! Forensic Radiology – a new challenge for Radiology and Forensic Pathology. *American Journal of Roentgenology*. 202: W325–334. DOI: 10.2214/AJR.12.10283

Fligner, C. & Dighe, M. 2011. Fetal and perinatal death investigation: Redefining the autopsy and the role of radiologic imaging. *Ultrasound Clinics*. 6:105–117. DOI: 10.1016/j.cult.2011.01.003

Gabos, P., Tuten, R., Leet, A. & Stanton, R. 1998. Fracture-dislocation of the lumbar spine in an abused child. *Pediatrics*. 101. DOI: 10.1542/peds.101.3.473

Garstang, J., Ellis, C. & Sidebotham, P. 2015. An evidence-based guide to the investigation of sudden unexpected death in infancy. *Forensic Science, Medicine and Pathology*. 11(3):345–257. DOI: 10.1007/s12024-015-9680-x

Gascho, D., Heimer, J., Tappero, C. & Schaerli, S. 2019. Relevant findings on postmortem CT and postmortem MRI in hanging, ligature strangulation and manual strangulation and their

additional value compared to autopsy – a systematic review. *Forensic Science, Medicine and Pathology*.15:84 – 92. DOI: 10.1007/s12024-018-0070-z

Gebhart, F., Brogdon, B., Zech, W., Thali, M & Germerott, T. 2012. Gas at postmortem computed tomography – an evaluation of 73 non-putrefied trauma and non-trauma cases. *Forensic Science International*. 222:162–169. DOI: 10.1016/j.forsciint.2012.05.020

Germerott, T., Preiss, U., Ebert, L., Ruder, T., Ross, S., Flach, P., Ampanozi, G., Filograna, L. & Thali, M. 2010. A new approach in virtopsy: Postmortem ventilation in multi-slice computed tomography. *Legal Medicine*. 12:276–279. DOI: 10.1016/j.legalmed.2010.07.001

Gilbert, R., Spatz Widom, C., Browne, K., Fergusson, D., Webb, E. & Janson, S. 2009. Child maltreatment 1 Burden and consequences of child maltreatment in high-income countries. *The Lancet*. 373:68–81. DOI: 10.1016/S0140-6736(08)61706-7

Gill, P. & Falder, S. 2017, Early management of paediatric burn injuries. *Paediatrics and Child Health*. 27(9):406–414. DOI: 10.1016/j.paed.2017.03.011

Glaser, D. 2005. Child maltreatment. *Psychiatry*. 4(7):53–57. DOI: 10.1383/psyt.2005.4.7.53

Glemser, P., Pfleiderer, Heger, A., Tremper, J., Krauskopf, Schlemmer, H., Yen, K. & Simons, D. 2017. New bone post-processing tools in forensic imaging: A multi-reader feasibility study to evaluate detection and diagnostic accuracy in rib fracture assessment. *Internal Journal of Legal Medicine*. 131:489–496. DOI: 10.1007/s00414-016-1412-6

Goldwater, P. 2017. Infection, the neglected paradigm in SIDS research. *Archives of Disease in Childhood*. 102(8):767–772. DOI: 10.1136/archdischild-2016-312327

Gorincour, G., Sarda-Quarello, L., Laurent, P., Brough, A. & Rutty. 2015. The future of pediatric and perinatal post-mortem imaging. *Pediatric Radiology*. 45:509–516. DOI: 10.1007/s00247-014-3266-8

Goske, M., Applegate, K., Bulas, D., Butler, P., Callahan, M., Coley, B., Don, S., Frush, D., Hernanz-Schulman, M., Kaste, S., Morrison, G., Sidhu, M., Strauss, K. & Treves, S. 2011. Image Gently: progress and challenges in CT education and advocacy. *Pediatric Radiology.* 41, Supplement 2, S461 – S466. DOI 10.1007/s00247-011-2133-0

Grabherr, S., Baumann, P., Minoiu, C., Fahrni, S. & Mangin, P. 2016. Post-mortem imaging in forensic investigations: current utility, limitations, and ongoing developments. *Research and Reports in Forensic Medical Science*. 6:25–37. DOI: 10.2147/RRFMS.S93974

Grabherr, S., Doenz, F., Steger, B., Dirnhofer, R., Dominguez, A., Sollberger, B., Gygax, E., Rizzo, E., Chevallier, C., Meuli, R. & Mangin, P. 2011. Multi-phase post-mortem CT angiography: Development of a standardized protocol. *International Journal of Legal Medicine*. 125:791–802. DOI: 10.1007/s00414-010-0526-5

Grabherr, S., Egger, C., Vilarino, R., Campana, L., Jotteradn, M. & Dedouit, F. 2017. Modern post-mortem imaging: an update on recent developments. *Forensic Sciences Research.* 2(2): 52–64. DOI: 10.1080/20961790.2017.1330738

Grabherr, S., Grimm, J., Dominguez, A., Vanhaebost, J. & Mangin, P. 2014. Advances in post-mortem CT-angiography. *British Journal of Radiology*. 87:20130488. DOI: 10.1259/bjr.20130488

Grabherr, S., Heinemann, A., Vogel, H., Rutty, G., Morgan, B., Woźniak, K., Dedouit, F., Fischer, F., Lochner, S., Wittig, H., Guglielmi, G., Eplinius, F., Michaud, K., Palmiere, C., Chevallier, C., Mangin, P. & Grimm, J. 2018. Postmortem CT Angiography compared with autopsy. A forensic multicenter study. *Radiology*. 288(1):270–276. DOI: 10.1148/radiol.2018170559

Graziani, G., Tal, S., Adelman, A., Kugel, C., Bdolah-Abraham, T. & Krispin, A. 2018. Usefulness of unenhanced postmortem computed tomography- Findings in postmortem non-contrast computed tomography of the head, neck and spine compared to traditional medicolegal autopsy. *Journal of Forensic and Legal Medicine*. 55:105–111. DOI: 10.1016/j.jflm.2018.02.022

Greeley, C. 2015. Abusive head trauma: A review of the evidence base. *American Journal of Roentgenology*. 204:967–973. DOI: 10.2214/AJR.14.14191

Green, H. 1980. Child abuse presenting as chylothorax. *Pediatrics*. 66(4):620–621.

Gregory, T. 1999. Skin lesions that mimic child abuse. Patient Care, 15 May 1999, p. 169. *Gale Academic Onefile*. Accessed at:

https://link.gale.com/apps/doc/A54693924/AONE?u=capetech&sid=AONE&xid=d1b06fbe [2019, 17 September].

Guleserian, K., Gilchrist, B., Luks, F, Wesselhoeft, C. & DeLuca, F. 1996. Child abuse as a cause of traumatic chylothorax. *Journal of Pediatric Surgery*. 31(12):1696–1697.

Gun Free South Africa. 2017. Firearms control briefing. Protecting children from armed violence. Accessed at: https://www.saferspaces.org.za/uploads/files/Gun_Free_South_Africa_two.pdf [2021, 5 January].

Guthkelch, A. 1971. Infantile subdural haematoma and its relationship to whiplash injuries. *British Medical Journal*. 2:430–431.

Haakma, W., Rohde, M., Uhrenholt, L., Pedersen, M. & Boel, L. 2017. Identification of discrete vascular lesions in the extremities using post-mortem computed tomography angiography – Case reports. *Journal of Forensic Radiology and Imaging*. 9:47–50. DOI: 10.1016/j.jofri.2017.04.001

Halvorsen, R., Fedyshin, P., Korobkin, M. Foster, W. & Thompson. 1986. Ascites or pleural effusion? CT differentiation: Four useful criteria. *Radiographics*. 6(1):135–149.

Harper, N., Feldman, K., Sugar, N., Anderst, J. & Linberg, D. 2014. Additional injuries in young infants with concern for abuse and apparently isolated bruises. *The Journal of Pediatrics*. 165(2):383–388. DOI: 10.1016/j.jpeds.2014.04.004

Haynes, R., Frelinger, A., Giles, E., Goldstein, R., Tran, H., Kozakewich, H., Haas, E, Gerrits, A., Mena, O., Trachtenberg, F., Paterson, D., Berry, G., Adeli, K., Kinney, H. & Michelson, A. 2017. High serum serotonin in sudden infant death syndrome. *Proceedings of the National Academy of Sciences*. 114(29):7695–7700. DOI: 10.1073/pnas.1617374114

Heinemann, A., Vogel, H., Heller, M., Tzikas, A. & Püschel, K. 2015. Investigation of medical intervention with fatal outcome: the impact of post-mortem CT and CT Angiography. *La Radiologia Medica*. 120(9):835–845. DOI: 10.1007/s11547-015-0574-5

Herr, S. 2011. Abdominal and chest injuries in abused children. In *Child abuse and neglect. Diagnosis, treatment and evidence*. C. Jenny, Ed. St Louis, MO: Elsevier Saunders. 326–331.

Higginbotham-Jones, J. & Ward, A. 2014. Forensic radiology: The role of cross-sectional imaging and virtual post-mortem examinations. *Radiography*. 20:87–90. DOI: 10.1016/j.radi.2013.10.003

Hill, P., Pickford, M. & Parkhouse. 1997. Phytophotodermatitis mimicking child abuse. *Journal of the Royal Society of Medicine*. 90:560–561.

Hilmes, M., Hernanz-Schulman, M., Greeley, C., Piercey, L., Yu, C. & Kan, J. 2011. CT identification of abdominal injuries in abused pre-school-age children. *Pediatric Radiology.* 41:643–651. DOI: 10.1007/s00247-010-1899-9

Hinchliffe, S., Godfrey, H. & Hind, C. 1994. Attitudes of junior medical staff to requesting permission for autopsy. *Postgrad Medical Journal*. 70:292–294.

Hines, E. 2016. Child abuse by poisoning. *Clinical Pediatric Emergency Medicine*. 17:296–301. DOI: 10.1016/j.cpem.2016.10.003

Hobbs, C. & Wynne, J. 1990. The sexually abused battered child. *Archives of Disease in Childhood*. 65:423–427.

Hodgman, E., Pastorek, R., Saeman, M., Cripps, M., Bernstein, I., Wolf, S., Kowalske, K., Arnoldo, B. & Phelan, H. 2016. The Parkland Burn Center experience with 297 cases of child abuse from 1974 to 2010. *Burns*. 42:1121–1127. DOI: 10.1016/j.burns.2016.02.013

Hoey, B., Cipolla, J., Grossman, M., McQuay, N., Shukla, P., Stawicki, S., Stehly, C. & Hoff, W. 2007. Postmortem Computed Tomography, “CATopsy”, predicts cause of death in trauma patients. *The Journal of Trauma, Injury, Infection and Critical Care*. 63:979–986. DOI: 10.1097/TA.0b013e318154011f

Home Office, The Forensic Science Regulator, Department of Justice and the Royal College of Pathologists (2012) Code of practice and performance standards for forensic pathology in England, Wales and Northern Ireland. https://www.rcpath.org/uploads/assets/5617496b-cd1a-4ce3-9ec8eabfb0db8f3a/Code- of-practice-and-performance-standards-for-forensic-pathology-in-England-Wales-and-Northern-Ireland.pdf. Accessed 27 December 2021.

Hong, T., Reyes, J., Moineddin, R., Chiasson, D., Berdon, W. & Babyn, P. 2011. Value of postmortem thoracic CT over radiography in imaging of pediatric rib fractures. *Pediatric Radiology*. 41:736–748. DOI: 10.1007/s00247-010-1953-7

Hoskote, A., Martin, K., Hormbrey, P., Burns, P. & Burns, E. 2003. Fractures in infants: One in four is non-accidental. *Child Abuse Review.* 12:384–391. DOI: 10.1002/car.806

HPCSA (Health Professions Council of South Africa). 2016.Guidelines for good practice: General ethical guidelines for health researchers. Booklet 13. Accessed at: https://www.hpcsa.co.za/Uploads/editor/UserFiles/downloads/conduct_ethics/Booklet%2013.pdf [2019, 10 September].

Hsieh, K., Zimmerman, R., Kao, H. & Chen, C. 2015. Revisiting neuroimaging of abusive head trauma in infants and young children. *American Journal of Roentgenology*. 204:944–952. DOI:10.2214/AJR.14.13228

Ichikawa, Y., Sato, A., Sato, K., Nakamura, K., Kitagawa, N., Tanoue, K. & Shiro, H. 2015. Chylothorax associated with child abuse. *Pediatrics International*. Doi:10.1111/ped.12707.

Image Gently (2021). The Alliance. Accessed at: https://www.imagegently.org/About-Us/The-Alliance [2021, 03 October].

Image Wisely (2021). About us. Accessed at: https://www.imagewisely.org/About-Us [2021, 03 October].

Iwase, H., Yajima, D., Hayakawa, M., Yamamoto, S., Motani, H., Sakuma, A., Kasahara, S. & Ito, H. 2010. Evaluation of Computed Tomography as a screening test for death inquest. *Journal of Forensic Sciences* 55(6):1509–1515. DOI: 10.1111/j.1556-4029.2010.01465.x

Jackowski, C. 2013. Editorial: Special issue on postmortem imaging 2013. *Forensic Science International*. 225:1–2. DOI: 10.1016/j.forsciint.2013.01.029

Jackowski, C., Thali, M., Buck, U., Aghayev, E., Sonnenschein, M., Yen, K., Dirnhofer, R. & Vock, P. 2006. Noninvasive estimation of organ weights by postmortem Magnetic Resonance Imaging and Multislice Computed tomography. *Investigative Radiology*. 41(7):572–578. DOI: 10.1097/01.rli.0000221323.38443.8d

Jacobi, G., Dettmeyer, R., Banaschak, S., Brosig, B. & Herrmnann, B. 2010. Child abuse and neglect: diagnosis and management. *Deutsches Ärzteblatt International.* 107(13):231–240. DOI: 10.3238/arztebl.2010.0231

Jacobsen, C. & Lynnerup, N. 2010. Craniocerebral trauma – Congruence between post-mortem computed tomography diagnoses and autopsy results. *Forensic Science International*. 194:9–14. DOI: 10.1016/j.forsciint.2009.10.001

Jahn, W. 2011. The 4 basic ethical principles that apply to forensic activities are respect for autonomy, beneficence, non-maleficence, and justice. *Journal of Chiropractic Medicine*. 10:225–226. DOI: 10.1016/j.jcm.2011.08.004

Jain, N. 2015. The role of diagnostic imaging in the evaluation of child abuse. *BC Medical Journal*. 57(8):336–340.

Jalalzadeh, H., Giannakopoulosm G., Berger, F., Fronczek, J., van de Goot, F., Reijnders, U. & Zuidema, W. 2015. Post-mortem imaging compared with autopsy in trauma victims – A systematic review. *Forensic Science International*. 257:29–48. DOI: 10.1016/j.forsciint.2015.07.026

Jeffery, A. 2010. The role of Computed Tomography in adult post-mortem examinations: An overview. *Diagnostic Histopathology*. 16(12):546–551. DOI: 10.1016/j.mpdhp.2010.08.017

Johnson, K., Chapman, S. & Hall, C. 2004. Skeletal injuries associated with sexual abuse. *Pediatric Radiology*. 34:620–623. DOI: 10.1007/s00247-004-1216-6

Kabbani, A. & Gaillard, F. 2020. Inca bone. *Radiopaedia*. Accessed at: https://radiopaedia.org/articles/inca-bone on [2020, 6 January].

Kaczor, K., Pierce, M., Makoroff, K. & Corey, T. 2006. Bruising and physical child abuse. *Clinical Pediatric Emergency Medicine*. 7(3):153–160. DOI: 10.1016/j.cpem.2006.06.007

Karibe, H., Kameyama, M., Hayashi, T., Narisawa, A. & Tominaga, T. 2016. Acute subdural hematoma in infants with abusive head trauma: A literature review. *Neurologia Medico-chirurgica*. 56:264–273. DOI: 10.2176/nmc.ra.2015-0308

Karmazyn, B., Lewis, M., Jennings, S., Hibbard, R. & Hicks, R., 2011. The prevalence of uncommon fractures on skeletal surveys performed to evaluate for suspected abuse in 930 children. Should practice guidelines change? *American Journal of Roentgenology*. 197:W159–W163. DOI: 10.2214/AJR.10.5733

Kasahara, S., Makino, Y., Hayahawa, M., Yajima, D., Ito, H. & Iawaso, H. 2012. Diagnosable and Non-diagnosable causes of death by post-mortem computed tomography: A review of 339 cases. *Legal Medicine*. 14:239–245. DOI: 10.1016/j.legalmed.2012.03.007

Katz, D., Ganson, G., Klein, M. & Mazzie, J. 2013. CT of the skin and subcutaneous tissues. *Emergency Radiology.* 20:57–68. DOI: 10.1007/s10140-012-1077-5

Kaul, M., Kumar, K., Kaul, A., Chanana, A. & Kumar, A. 2017. Digestive status of stomach contents – An indicator of time since death. *IOSR Journal of Dental and Medical Sciences*. 16(10):26–35. DOI: 10.9790/0853-1610102635

Kaza, R., Platt, J., Goodsitt, M., Al-Hawary, M., Maturen, K., Wasnik, A. & Pandya, A. 2014. Emerging techniques for dose optimization in abdominal CT. *Radiographics*. 34, 4 – 17. DOI: 10.1148/rg.341135038

Kemp, A. 2008. Fractures in physical child abuse. *Paediatrics and Child Health*. Vol. 18, Issue 12, 550 – 553. DOI: 10.1016/J.PAED.2008.09.001

Kemp, A., Butler, A., Morris, S., Mann, M., Kemp, K., Rolfe, K., Sibert, J. & Maguire, S. 2006. Which radiological examinations should be performed to identify fractures in suspected child abuse. *Clinical Radiology*. 61:723–736.

Kemp, A., Dunstan, F., Harrison, S., Morris, S., Mann, M., Rolfe, K., Datta, S., Thomas, D., Sibert, J. & Maguire, S. 2008. Patterns of skeletal fractures in child abuse: Systematic review. *British Medical Journal.* 337:1 – 8. DOI: 10.1136/bmj.a1518

Kemp, A., Joshi, A., Mann, M., Tempest, V., Liu, A., Holden, S. & Maguire, S. 2010. What are the clinical and radiological characteristics of spinal injuries from physical abuse: A systematic review. *Archive of Disease in Childhood*. 95:355–360. DOI: 10.1136/adc.2009.169110

Kemp, A., Maguire, S., Nuttal, D., Collins, P. & Dunstan, F. 2014. Bruising in children who are assessed for suspected physical abuse. *Archive of Disease in Childhood*. 99:108–113. DOI: 10.1136/archdischild-2013-304339

Kempe, C., Silverman, F., Steele, B., Droegemueller, W. & Silver, H. 1962. The battered child syndrome. *Journal of the American Medical Association*. 181:17–24.

Kempter, M., Ross, S., Spendlove, D., Flach, P., Preiss, U., Thali, M. & Bolliger, S. 2009. Post-mortem imaging of laryngohyoid fractures in strangulation incidents: First results. *Legal Medicine*. 11:267–271. DOI:10.1016/j.legalmed.2009.07.005

Kerr, M. & Maconochie, I. 2008. Paediatric chest trauma (part 2) – Hidden injuries. *Trauma*, 10, 195 – 210. DOI: 10.1177/1460408608096289

Khumalo-Mugabi, L., Moffatt, S., Bekker, W., Smith, M., Bruce, J., Laing, G. Manchev, V., Kong, V. & Clarke, D. 2020. Penetrating trauma in children and adolescents in Pietermaritzburg. *South African Journal of Surgery*. 58(1):33–36. DOI: 10.17159/2078-5151/2020/v58n1a3017

Kirchoff, S., Scaparra, E., Grimm, J., Scherr, M., Graw, M., Reiser, M. & Peschel, O. 2016. Postmortem computed tomography (PMCT) and autopsy in deadly gunshot wounds – a comparative study. *International Journal of Legal Medicine*. 130:819–826. DOI: 10.1007/s00414-015-1225-z

Kleinman, P. 1990a. Diagnostic imaging in infant abuse. *American Journal of Roentgenology*. 155:703–712.

Kleinman, P. 1990b. Differentiation of child abuse and osteogenesis imperfecta: Medical and Legal Implications. *American Journal of Radiology*. 154:1047–1048.

Kleinman, P. 2008. Problems in the diagnosis of metaphyseal fractures. *Pediatric Radiology*. 38:388–394. DOI: 10.1007/s00247-008-0845-6

Kleinman, P., Kleinman, P. & Savageau, J. 2004. Suspected infant abuse: Radiographic skeletal survey practices in pediatric health care facilities. *Radiology*. 233:477–485. DOI: 10.1148/radiol.2332031640

Kleinman, P., Marks, S., Richmond, J. & Blackbourne, B. 1995. Inflicted skeletal injury: A postmortem radiologic-histopathologic study in 31 infants. *American Journal of Roentgenology*. 165(3):647–650.

Kleinman, P., Morris, N., Makris, J., Moles, R. & Kleinman, P. 2013. Yield of radiographic skeletal surveys for detection of hand, foot, and spine fractures in suspected child abuse. *American Journal of Roentgenology*. Vol. 200, 641 – 644. DOI: 10.2214/AJR.12.8878

Klevens, J. & Leeb, R. 2010. Child maltreatment fatalities in children under 5: Findings from the National Violence Death Reporting System. *Child abuse and Neglect*. 34:262–266. DOI: 10.1016/j.chiabu.2009.07.005

Knight, B. 1986. The history of child abuse. *Forensic Science International*. 30:135–141.

Kos, L. & Shwayder, T. 2006. Cutaneous manifestations of child abuse. *Pediatric Dermatology*. 23(4):311–320. DOI: 10.1111/j.1525-1470.2006.00266.x

Koumellis, P., McConachie, N. & Jaspan, T. 2009 Spinal subdural haematomas in children with non-accidental head injury. *Archive of Disease in Childhood*. 94:216–219. DOI 10.1136/adc.2008.141671

Kraft, J. 2011. Imaging of non-accidental injury. *Orthopaedics and Trauma*. 25:109–118. DOI: 10.1016/j.mporth.2011.01.008

Krentz, B., Alamo, L., Grimm, J., Dedouit, F., Bruguier, C., Chevallier, C., Egger, C., Da Silva, L. & Grabherr, S. 2016. Performance of post-mortem CT compared to autopsy in children. *International Journal of Legal Medicine*. 130:1089–1099. DOI: 10.1007/s00414-016-1370-z

Krugman, S., Lantz, P., Sinal, S., De Jongh, A. & Coffman, K. 2007. Forced suffocation of infants with baby wipes: A previously undescribed from of child abuse. *Child Abuse and Neglect*. 31:615–621. DOI: 10.1016/j.chiabu.2006.12.012

Labbé, J. 2005. Ambroise Tardieu: The man and his work on child maltreatment a century before Kempe. *Child Abuse and Neglect*. 29:311–324. DOI: 10.1016/j.chiabu.2005.03.002

Laczniak, A., Sato, Y. & Nashelsky, M. 2011. Postmortem gastric perforation (gastromalacia) mimicking abusive injury in sudden unexplained infant death. *Pediatric Radiology*. 41:1595–1597. DOI: 10.1007/s00247-011-2061-z

LaMorte, W. 2020. Central Limit Theorem. The role of probability. Boston University School of Public Health. Accessed at: https://sphweb.bumc.bu.edu/otlt/MPH-Modules/BS/BS704_Probability/BS704_Probability12.html [2020, 28 December].

Landis, R. & Koch, G. 1977. The measurement of observer agreement for categorical data. *Biometrics*. 33(1):159–174.

Lawrence, R. 2004. Understanding fatal assault if children: A typology and explanatory theory. *Children and Youth Services Review*. 26:837–852. DOI: 10.1016/j.childyouth.2004.02.024

Lazoritz, S., Baldwin, S. & Kini, N. 1997. The whiplash shaken infant syndrome: Has Caffey's syndrome changed or have we changed his syndrome? *Child Abuse and Neglect*. 21(10):1009–1014.

Leach, C., Blair, P., Fleming, P., Smith, I., Platt, M., Berry, P., Golding, J. & Confidential Enquiry into Stillbirths and Deaths (CESDI) SUDI Research Group. 1999. Epidemiology of SIDS and explained sudden infant deaths. *Paediatrics*. 104(4). Accessed at: https://pediatrics.aappublications.org/content/pediatrics/104/4/e43.full.pdf [2019, 19 May].

Le Blanc-Louvry, I., Thureau, S., Duval, C., Papin-Lefebvre, F., Thiebot, J., Dacher, J., Gricourt, C. Touré, E. & Proust, B. 2013. Post-mortem computed tomography compared to forensic autopsy findings: A French experience. *European Radiology*. 23:1829–1835. DOI: 10.1007/s00330-013-2779-0

Lee, S., Davis, S., Doremus, B., Kouk, S. & Stetson, W. 2016. Interobserver agreement in the classification of partial-thickness rotator cuff tears using the Snyder Classification System. The Orthopaedic Journal of Sports Medicine. 4:1- 5 DOI: 10.1177/2325967116667058.

Legano, L., McHugh, M. & Palusci, V. 2009. Child abuse and neglect. *Current Problems in Pediatric and Adolescent Health Care*. 39(2):31–54. DOI: 10.1016/j.cppeds.2008.11.001

Le Roux-Kemp, A. & Burger, E. 2014. Shaken baby syndrome: A South African medico-legal perspective. *Potchefstroom Electronic Law Journal*. 17:1286–1316.

Leth, P. 2011. CT scanning in forensic medicine. Accessed at: https://www.researchgate.net/publication/221917517_CT-scanning_in_Forensic_Medicine [2020, 5 March].

Leth, P. & Ibsen, M. 2009. Abbreviated injury scale scoring in traffic fatalities: Comparison of Computerized Tomography and autopsy. *The Journal of Trauma, Injury, Infection and Critical Care* 68:1413–1416. DOI: 10.1097/TA.0b013e3181b251b8

Leth, P., Struckmann, H. & Lauritsen, J. 2013. Interobserver agreement of the injury diagnoses obtained by post-mortem computed tomography of traffic fatality victims and a comparison with autopsy results. *Forensic Science International*. 225:15–29. DOI: 10.1016/j.forsciint.2012.03.028

Leth, P. & Thomsen, J. 2013. Experience with post-mortem computed tomography in Southern Denmark 2006–2011. *Journal of Forensic Radiology and Imaging*. 1:161–166. DOI: 10.1016/j.jofri.2013.07.006

Levin, A., Luyet, F. & Knox, B. 2016. Ophthalmologic concerns in abusive head trauma. *Journal of Family Violence*. 31:797–804. DOI: 10.1007/s10896-016-9840-0

Levy, A., Abbott, R., Mallak, C., Getz, J., Harcke, H., Champion, H. & Pearse, L. 2006. Virtual autopsy: Preliminary experience in high-velocity gunshot wound victim. *Radiology*. 240(2):522–528. DOI: 10.1148/radiol.2402050972

Lindberg, D. 2012. Abusive abdominal trauma – an update for the pediatric emergency medicine physician. *Abusive Abdominal Trauma*. 13(3):187–193. DOI: 10.1016/j.cpem.2012.06.008

Lonergan, G., Baker, A., Morey, M. & Boos, S. 2003. From the Archives of the AFIP. Child abuse: Radiologic-pathologic correlation. *Radiographics*. 23:811–845. DOI: 10.1148/rg.234035030

Lowen, D. & Reece, R. 2008. *Visual diagnosis of child abuse on CDRom*. 3rd ed. [CD Rom]. Elk Grove Village, IL: American Academy of Pediatrics.

Madu, S., Idemudia, S. & Jegede, A. 2002. Perceived parental disorders as risk factors for child sexual and physical and emotional abuse among high school students in the Mpumulanga province, South Africa. *Journal for the Social Sciences*. 6(2):103–112.

Maeda, H. 2012. Histology in forensic practice. *Forensic Science Medicine and Pathology*. 8:62–63. DOI: 10.1007/s12024-011-9256-3

Maguire, S. 2010. Which injuries may indicate child abuse? *Archives of Disease in Childhood*. Education and practice edition. 95:170–177. DOI: 10.1136/adc.2009.170431

Maguire, S., Hunter, B., Hunter, L., Sibert, J., Mann, M. & Kemp, A., 2007. Diagnosing abuse: a systematic review of torn frenulum and other intra-oral injuries. *Archive of Disease in Childhood*. 92:1113–1117 DOI: 10.1136/adc.2006.113001

Maguire, S., Moynihan, S., Mann, M., Potokar, T. & Kemp, A. 2008. A systematic review of the features that indicate intentional scalds in children. *Burns*. 34:1072–1081. DOI: 10.1016/j.burns.2008.02.011

Maguire, S, Okolie, C. & Kemp, A. 2014. Burns as a consequence of child maltreatment. *Paediatrics and Child Health*. 24(112):557–561. DOI: 10.1016/j.paed.2014.07.014

Maguire, S., Upadhyaya, M., Evans, A., Mann, M., Haroon, M., Tempest, V., Lumb, R. & Kemp, A. 2013. A systematic review of abusive visceral injuries in childhood – their range and recognition. *Child Abuse and Neglect*. 37:430–445. DOI: 10.1016/j.chiabu.2012.10.009

Makhlouf, F., Scolan, V., Ferretti, G., Stahl, C. & Paysant, F. 2013. Gunshot fatalities: Correlation between post-mortem multi-slice computed tomography and autopsy findings: A 30-months retrospective study. *Legal Medicine*. 15:145–148. DOI: 10.1016/j.legalmed.2012.11.002

Makino, Y., Yokota, H., Hayakawa, M., Yajima, D., Inokuchi, G., Nakatani, E. & Iwase, H. 2014. Spinal cord injuries with normal postmortem CT findings: A pitfall of virtual autopsy for detecting traumatic death. *American Journal of Roentgenology*. 203:240–244. DOI:10.2214/AJR.13.11775

Maldjian, P. & Goldman, A. 2012. Reducing radiation dose in body CT: A primer on dose metrics and key CT technical parameters. *American Journal of Roentgenology*. 200, 741 – 747. DOI: 10.2214/AJR.12.9768

Malik, A. & Faerber, E. 2018. Pediatric abdominal and pelvic imaging in non-accidental trauma. *Applied Radiology.* Accessed at: https://www.appliedradiology.com/communities/Pediatric-Imaging/pediatric-abdominal-and-pelvic-imaging-in-non-accidental-trauma [2018, 24 December].

Marcos, L. & Kahler, R. 2015. Phytophotodermatitis. *International Journal of Infectious Diseases*. 38:7–8. DOI: 10.1016/j.ijid.2015.07.004

Martin, C., Thiart, G., McCollum, G., Roche, S. & Maqungo, S. 2010. The burden of gunshot injuries on orthopaedic healthcare resources in South Africa. *South African Medical Journal*. 107(7):626–630. DOI: 10.7196/SAMJ.2017.v107i7.12257

Mathews, S., Abrahams, N., Jewkes, R., Martin, L. & Lombard, C. 2013a. The epidemiology of child homicides in South Africa. *Bulletin of the World Health Organisation*. 91:562–568. DOI: 10.2471/BLT.12.117036

Mathews, S., Abrahams, N. & Martin, L. 2013b. Child death reviews in the context of child abuse fatalities – learning from International Practice (Briefing Paper). Children's Institute, University of Cape Town. Accessed at: http://www.ci.uct.ac.za/child-murder/briefs/child-death-review-in-the-context-of-child-abuse-fatalities-learning-from-international-practice [2019, 5 October].

Mathews, S. & Martin, L. 2016. Developing an understanding of fatal child abuse and neglect: Results from the South African child death review pilot study. *South African Medical Journal*. 106(12):1160–1163. DOI: 10.7196/SAMJ.2016.v106.i12.12130

Mathews, B., Bromfield, L., Walsh, K., Cheng, Q. & Norman, R. 2017. Reports of sexually abuse of boys and girls: Longitudinal trend over a 20-year period in Victoria, Australia. *Child Abuse and Neglect*, Vol. 66, 9 – 22. DOI: 10.1016/j.chiabu.2017.01.025

Matschke, J., Herrmann, B., Sperhake, J., Körber, F., Bajanowski, T. & Glatzel, M. 2009. Shaken baby syndrome: A common variant of non-accidental head injury in infants. *Deutsches Arzteblatt International*. 106:211–217. DOI: 10.3238/arztebl.2009.0211

Matzopoulos, R.G., Bloch, K., Lloyd, S., Berens, C., Bowman, B., Myers, J. & Thompson, M. 2020. Urban upgrading and levels of interpersonal violence in Cape Town, South Africa: The violence prevention through urban upgrading programme. *Social Science & Medicine*. 255. DOI: 10.1016/j.socscimed.2020.112978

Matzopoulos, R.G., Prinsloo, M., Pillay-van Wyk, V., Gwebushe, N., Mathews, S., Martin, L., Laubscher, R., Abrahams, N., Msemburi, W., Lombard, C. & Bradshaw, D. 2015. Injury related mortality in South Africa: A retrospective descriptive study of postmortem investigations. *Bulletin of the World Health Organisation*. 93:303–313. DOI: 10.2471/BLT.14.145771

Matzopoulos, R.G., Thompson, M.L. & Myers, J.E. 2014. Firearm and non-firearm homicide in 5 South African cities: a retrospective population-based study. *American Journal of Public Health*. 104:455–460. DOI: 10.2105/AJPH.2013.310650

Maxeiner, H. & Jekat, R. 2010. Resuscitation and conjunctival petechial hemorrhages. *Journal of Forensic and Legal Medicine*. 17:87–91. DOI: 10.1016/j.jflm.2009.09.010

McDonald, K. 2007. Child abuse: Approach and management. *American Family Physician*. 75:221–228.

McGrath, T., McInnes, M., Langer, F., Hong, J., Korevaar, D. & Bossuyt, P. 2017. Treatment of multiple test readers in diagnostic accuracy systematic reviews-meta-analyses of imaging studies. *European Journal of Radiology*. 93:59–64. DOI: 10.1016/j.ejrad.2017.05.032

McHugh, M. 2012. Interrater reliability. *Biochemia Medica*. 22 (3): 276 – 282.
DOI: 10.11613/BM.2012.031

McKinney, A., Thompson, L., Truwit, C., Velders, S., Karagulle, A. & Kiragu, A. 2008. Unilateral hypoxic-ischemic injury in young children from abusive head trauma, lacking craniocervical vascular dissection or cord injury. *Pediatric Radiology*.38:164–174.
DOI: 10.1007/s00247-007-0673-0

McNaughton, J. 1997. Portable guides to investigating child abuse: An overview. United States Department of Justice. Accessed at: https://www.ncjrs.gov/pdffiles/portgde.pdf [2020, 9 July].

McNulty, J., Burke, N., Pelletier, N., Grgurich, T., Lombardo, R., Hennessy, W. & Conlogue, G. 2014. The impact of analogue and digital radiography for the identification of occult post-mortem rib fractures in neonates: A porcine model. *Journal of Forensic Radiology and Imaging*. 2:20–24. DOI: 10.1016/j.jofri.2013.09.001

Menkü, A., Koç, R. Tucer, B., Durak, A & Akdemir, H. 2004. Clivus fractures: Clinical presentations and courses. *Neurosurgical review*. 27(3):194–198. DOI: 10.1007/s10143-004-0320-2

Metz, J., Schwartz, K., Feldman, K. & Lindberg, D. 2014. Non-cutaneous conditions clinicians might mistake for abuse. *Archives of Disease in Childhood*. 99:817–823. DOI: 10.1136/archdischild-2013-304701

Michaud, K., Genet, P., Sabatasso, S. & Grabherr, S. 2019. Postmortem imaging as a complementary tool for the investigation of cardiac death. *Forensic Sciences Research*. 4(3):211–222. DOI: 10.1080/20961790.2019.1630944

Milat, G., Kugener, B., Chevalier, P., Chahine, M., Huang, H., Malicier, D., Rodriguez-Lafrasse, C. & Rousson, R. 2009. Contribution of long-QT syndrome genetic variants in Sudden Infant Death Syndrome. *Pediatric Cardiology*. 30:502–509. DOI: 10.1007/s00246-009-9417-2

Mishra, B., Joshi, M., Lalwani, S., Kumar, A., Kumar. A., Kumar, S., Gupta, A., Sagar, S., Singhal, M., Panda, A. & Rattan, A., 2018. A comparative analysis of the findings of postmortem Computed tomography scan and traditional autopsy in traumatic deaths: Is technology mutually complementing or exclusive? *Archives of Trauma Research*. 7(1):24–29. DOI: 10.4103/atr.atr_55_17

Mohanty, M., Singh, B., Arun, M., Menezes, R. & Palimar, V. 2011. Autopsy: The changing trends. *International Journal of Medical Toxicology and Forensic Medicine*. 1(1):17–23.

Mok, J. 2008. Non-accidental injury in children – An update. *Injury*. Vol. 39, 978 – 985. DOI: 10.1016/j.injury.2008.04.002

Moy, M., Levsky, J., Berko, N., Godelman, A., Jain, V. & Haramati, L. 2013. A new simple method for establishing pleural effusion size on CT scans. *Chest*. 143:1054–1059. DOI: 10.1378/chest.12-1292

Murken, D., Ding, M., Branstetter, B. & Nichols, L. 2012. Autopsy as quality control measure for Radiology and vice versa. *American Journal of Roentgenology*. 199:394–401. DOI: 10.2214/AJR.11.8386

Nadarasa, J., Deck, C., Meyer, F, Willinger, R. & Raul, J. 2014. Update on injury mechanism in abusive head trauma – shaken baby syndrome. *Pediatric Radiology*, Vol. 44, S565-S570. DOI 10.1007/s00247-014-3168-9

Nagayama, Y., Oda, S., Nakaura, T., Tsuji, A., Urata, J., Furusawa, M., Utsunomiya, D., Funama, Y., Kidoh, M. & Yamashita, Y. 2018. Radiation dose reduction at pediatric CT: use of low tube voltage and iterative reconstruction. *Radiographics*. 38, 1421 – 1440. DOI 10.1148/rg.2018180041

Naidoo, S. 2000. A profile of the oro-facial injuries in child physical abuse at a children's hospital. *Child Abuse and Neglect*. 24:521–534. DOI: 10.1016/S0145-2134(00)00114-9

Narain, A. & Goldstein, M. 2016. Skeletal manifestation of child maltreatment. *Clinical Pediatric Emergency Medicine*. 17(4):274–283. DOI: 10.1016/j.cpem.2016.09.004

National Association of Medical Examiners (2005) Forensic Autopsy Performance Standards. https://www.thename.org/assets/docs/2016%20NAME%20Forensic%20Autopsy%20Standards%209-25-2020.pdf. Accessed 27 December 2021.

National Forensic Pathology Service Committee. 2011. National Code of Guidelines for Forensic Pathology Practice in South Africa. Academic and Professional Advisory Committee Workgroup Edition 14–18 November 2011. Unpublished Code of Guidelines.

Newton, D., Coffin, C., Clark, E. & Lowichik, A. 2004. How pediatric autopsy yields valuable information in a vertically integrated health care system. *Archives of Pathology and Laboratory Medicine*. 128(11):1239–1246. DOI: 10.1043/1543-2165(2004)128<1239:HTPAYV>2.0.CO;2

Ng, C. & Hall, C. 1998. Costochondral junction fractures and intra-abdominal trauma in non-accidental injury (child abuse). *Pediatric Radiology*. 28(9):671–676. DOI: 10.1007/s002470050436

Ng, C., Hall, C. & Shaw, D. 1997. The range of visceral manifestations of non-accidental injury. *Archives of Disease in Childhood*. 77:167–174. DOI: 10.1136/adc.77.2.167

Noda, Y., Yoshimura, K., Tsuji, S., Ohashi, A., Kawasaki, H., Kaneko, K., Ikeda, S., Kurokawa, H. & Tanigawa, N. 2013. Postmortem Computed Tomography imaging in the investigation of nontraumatic death in infants and children. *Biomedical Research International*. 2013. DOI: 10.1155/2013/327903

Nor, F. & Zainun, K. 2016. Non accidental injury in children in Kuala Lumpur: An urban perspective. *Egyptian Journal of Forensic Sciences.* 6:553–557. DOI: 10.1016/j.ejfs.2016.11.005

Norberti, N., Tonelli, P., Giaconi, C., Nardi, C., Focardi, M., Nesi, G., Miele, V. & Colagrande, S. 2019. State of the art in post-mortem computed tomography: A review of current literature. Virchows Archives. 475:139–150. DOI: 10.1007/s00428-019-02562-4

O'Donnell, C. 2010. An image of sudden death: Utility of routine post-mortem computed tomography scanning in medico-legal autopsy practice. *Diagnostic Histopathology*. 16:552–555. DOI: 10.1016/j.mpdhp.2010.08.010

O'Donnell, C. & Woodford, N. 2008. Post-mortem radiology – a new sub-speciality? *Clinical Radiology*. 63:1189–1194. DOI: 10.1016/j.crad.2008.05.008

Obuchowski, N. 2004. How many observers are needed in clinical studies of medical imaging. *American Journal of Roentgenology*. 182:867–869. DOI: 10.2214/ajr.182.4.1820867

Oehmichen, M., Gehl, H., Petersen, D., Höche, W., Gerling, I. & König, H. 2003. Forensic pathological aspects of postmortem imaging of gunshot injury to the head: Documentation and biometric data. *Acta Neuropathology*. 106:570–580. DOI: 10.1007/s00401-003-0683-4

Offiah, A. 2012. Radiological features of child maltreatment. *Paediatrics and Child Health*. 22(11):483–489. DOI: 10.1016/J.PAED.2012.06.007

Offiah, A. & Hall, C. 2009. *Radiological atlas of child abuse*. Oxford: Radcliffe Publishing. 17 - 117

Offiah, A., Van Rijn, R., Perez-Rosello, J. & Kleinman, P. 2009. Skeletal imaging of child abuse (non-accidental injury). *Pediatric Radiology*. 39:461–470. DOI: 10.1007/s00247-009-1157-1

Olsen, Ø. & Gunny, R. 2006. Is there a role for CT in the neonate? *European Journal of Radiology*. 60:233–242. DOI: 10.1016/j.ejrad.2006.07.015

Ortega, H., Reid., S., Vander Velden, H., Truong, W., Laine, J., Weber, L. & Engels. J. 2014. Patterns of injury and management of children with pelvic fractures at a non-trauma center. *The Journal of Emergency Medicine*. 4:140–146. DOI: 10.1016/j.jemermed.2014.04.036

Otwombe, K., Dietrich, J., Sikkema, K., Coetzee, J., Hopkins, K., Laher, F. & Gray, G. 2015. Exposure to and experiences of violence among adolescents in lower socio-economic groups in Johannesburg, South Africa. *BMC Public Health*. 15:450. DOI: 10.1186/s12889-015-1780-8

Oyake, Y., Aoki, T., Shiotani, S., Kohno, M., Ohashi, N., Akutsu, H. & Yamazaki, K. 2006. Postmortemn computed tomography for detecting cause of deaths in infants and children: retrospective review of cases. *Radiation Medicine*. 24:493–502. DOI: 10.1007/s11604-006-0061-y

Paddock, M., Spriff, A. & Offiah, A. 2017. Imaging and reporting considerations for suspected physical abuse (non-accidental injury) in infants and young children. Part 1: initial considerations and appendicular skeleton. *Clinical Radiology*. 72:179–188. DOI: 10.1016/j.crad.2016.11.016

Palmiere, C., Grabherr, S. & Augsburger, M. 2014. Postmortem computed tomography angiography, contrast medium administration and toxicological analyses in urine. *Legal Medicine*. 17:157–162. DOI: 10.1016/j.legalmed.2014.12.005

Palmiere, C., Lobrinus, J., Mangin, P. & Grabherr, S. 2013. Detection of coronary thrombosis after multi-phase postmortem CT-angiography. *Legal Medicine*. 15:12–18. DOI: 10.1016/j.legalmed.2012.08.005

Parakh, A., Kortesniemi, M. & Schindera, S. 2016. CT Radiation dose management: A comprehensive optimization process for improving patient safety. *Radiology*. 280, 663 – 673. DOI: 10.1148/radiol.2016151173

Parks, S., Annest, J., Hill, H. & Karch, D. 2012. Pediatric abusive head trauma: Recommended definitions for public health surveillance and research. Atlanta (GA): Centers for Disease Control and Prevention. Accessed at: https://www.cdc.gov/violenceprevention/pdf/pedheadtrauma-a.pdf [2019, 3 September].

Pärtan, G., Pamberger, P., Blab, E. & Hruby. 2003. Common tasks and problems in paediatric trauma radiology. *European Journal of Radiology*. 48:103–124. DOI: 10.1016/S0720-048X(03)00199-2

Paterson, D.S. 2013. Serotonin gene variants are unlikely to play a significant role in the pathogenesis of sudden infant death syndrome. *Respiratory Physiology & Neurobiology.* 189:301–314. DOI: 10.1016/j.resp.2013.07.001

Paul, A. & Adamo, M. 2014. Non-accidental trauma in pediatric patients: A review of epidemiology, pathophysiology, diagnosis and treatment. *Translational Pediatrics.* 3(3):195–207. DOI: DOI: 10.3978/j.issn.2224-4336.2014.06.01

Pawlik, M., Kemp, A., Maguire, S., Nuttal, D., Feldman, K.W. & Lindberg, D.M. 2016. Children with burns referred for child abuse evaluation: Burn characteristics and co-existent injuries. *Child Abuse and Neglect*. 55:52–61. DOI: 10.1016/j.chiabu.2016.03.006

Persson, A., Jackowski, C. Engström, E. & Zachrisson, H. 2008. Advances of dual source, dual energy imaging in postmortem CT. *European Journal of Radiology*. 68:446–455. DOI: 10.1016/j.ejrad.2008.05.008

Pierce, M. & Bertocci, G. 2006. Fractures resulting from inflicted trauma: Assessing injury and history compatibility. *Clinical Pediatric Emergency Medicine*. 7:143–148. DOI: 10.1016/j.cpem.2006.06.005

Pinheiro, P. 2006. World report on violence against children. Geneva, United Nations. Accessed at: https://digitallibrary.un.org/record/587334?ln=en [2021, 5 March].

Pollanen, M., Smith, C., Chiasson, D., Cairns, J. & Young, J. 2002. Fatal child abuse maltreatment syndrome. A retrospective study in Ontario, Canada, 1990–1995. *Forensic Science International*. 126:101–104. DOI: 10.1016/s0379-0738(02)00008-7

Pomara, C., Fineschi, V., Scalzo, G. & Guglielmi, G. 2009. Virtopsy versus digital autopsy: Virtual autopsy. *La Radiologia Medica*.114:1367–1382. DOI: 10.1007/s11547-009-0435-1

Poulsen, K. & Simonsen, J. 2007. Computed Tomography as routine in connection with medico-legal autopsies. *Forensic Science International*. 171:190–197. DOI: 10.1016/j.forsciint.2006.05.041

Power, S., Moloney, F., Twomey, M., James, K., O'Connor, O. & Maher, M. 2016. Computed Tomography and patient risk: Facts, perceptions and uncertainties. *World Journal of Radiology*. 8(12):902–915. DOI: 10.4329/wjr.v8.i12.902

Prasad, T. & Tully, J. 2017. Late onset congenital dermal melanocytosis – 'Mongolian blue spots' confused as child abuse" Are there more lessons to be learnt? *Journal of Paediatrics and Child Health.* DOI 10.1111/jpc.13608

Pretorius, K. & Van Nierkerk, A. 2014. Childhood psychosocial development and fatal injuries in Gauteng, South Africa. *Child: Care, Health and Development*. 41(1):35–44. DOI: 10.1111/cch.12140

Proisy, M., Marchand, A., Loget, P., Bouvet, R., Roussey, M., Pelé, F., Rozel, C., Treguier, C., Darnault, P. & Bruneau, B. 2013. Whole-body post-mortem computed tomography compared with autopsy in the investigation of unexpected death in infants and children. *European Radiology*. 23:1711–1719. DOI: 10.1007/s00330-012-2738-1

Pryce, J., Bamber, A., Ashworth, M., Kiho, L., Malone, M. & Sebire, N. 2014. Reference ranges for organ weights of infants at autopsy: results of >1000 consecutive cases from a single centre. *BMC Clinical Pathology*. 14:18. DOI: 10.1186/1472-6890-14-18

Rainio, J., Lalu, K., Ranta, H., Takamaa, K. & Penttilä. 2001. Practical and legal aspects of forensic autopsy expert team operations. *Legal Medicine*. 3:220–232. DOI: 10.1016/S1344-6223(01)00041-4

Raissaki, M., Veyrac, C., Blondiaux, E. & Hadjigeorgi, C. 2011. Abdominal imaging in child abuse. *Pediatric Radiology*. 41:4–16. DOI: 10.1007/s00247-010-1882-5

Rajiah, P., Guild, J., Browning, T., Venkataraman, V. & Abbara, S. 2020. A comprehensive CT radiation dose reduction and protocol standardization program in a complex, tertiary hospital system. Current problems in Diagnostic Radiology. 49, 340 – 346. DOI https://doi.org/10.1067/j.cpradiol.2020.04.007

Rao, P. & Carty, H. 1999. Non-accidental injury: Review of the Radiology. *Clinical Radiology.* 54:11–24.

Reid, A., Hendricks, M., Groenewald, P. & Bradshaw, D. 2016. Where do children die and what are the causes? Under-5 deaths in the Metro West geographical service area of the Western Cape, South Africa, 2011. *South African Medical Journal*. 106(4):359–364. DOI: 10.7196/SAMJ.2016.v106i4.10521

Reinhorn, M, Kaufman, H., Hirsch, E. & Millham, F. 1996. Penetrating thoracic trauma in a pediatric population. *Annals of Thoracic Surgeons*. 61:1501–1505.

Restrepo, C., Martinez, S., Lemos, D., Washington, L., McAdams, H., Vargas, D., Lemos, J., Carrillo, J. & Diethelm, L. 2009. Imaging appearances of the sternum and sternoclavicular joints. *Radiographics*. 29(3):839–859. DOI: 10.1148/rg.293055136

Richter, L., Mathews, S., Kagura, J. & Nonterah, E. 2018. A longitudinal perspective on violence in the lives of South African children from the birth to twenty plus cohort study in Johannesburg-Soweto. *South African Medical Journal*. 108(3):181–186. DOI: 10.7196/SAMJ.2018.v108i3.12661

Roberts, I., Benamore, R., Benbow, E., Lee, S., Harris, J., Jackson, A., Mallet, S., Patankar, T., Peebles, C., Roobottom, C. & Traill, Z. 2012. Post-mortem imaging as an alternative to autopsy in the diagnosis of adult deaths: A validation study. *The Lancet*. 379:136–142. DOI: 10.1016/S0140-6736(11)61483-9

Rooks, V., Sisler, C. & Burton, B. 1998. Cervical spine injury in child abuse: report of two cases. *Pediatric Radiology*, Vol. 28, 193 – 195.

Ross, A. & Juarez, C. 2014. A brief history of fatal child maltreatment and neglect. *Forensic Science Medicine and Pathology*. 10:413–422. DOI: 10.1007/s12024-014-9531-1

Ross, R., Cosima, S., Flach, P., Oesterhelweg, L., Thali, M. & Bolliger, S. 2010. Multi-slice computed tomography (MSCT) of mountaineering casualties in the Swiss Alps – advantages and limitations. *Legal Medicine*. 12:271–275. DOI: 10.1016/j.legalmed.2010.06.002

Ross, S., Bolliger, S., Ampanozi, G., Oesterhelweg, L., Thali, M. & Flach, P. 2014. Postmortem CT Angiography: Capabilities and limitations in traumatic and natural causes of death. *Radiographics*. 34:830–846. DOI: 10.1148/rg.343115169

Royal College of Paediatrics and Child Health, 2016a. Child protection evidence systematic review on bruising. Accessed at: https://www.rcpch.ac.uk/resources/child-protection-evidence-bruising [2018, 23 September].

Royal College of Paediatrics and Child Health. 2016b. Child protection evidence systematic review on Spinal injuries. Accessed at: https://www.rcpch.ac.uk/resources/child-protection-evidence-spinal-injuries [2019, 13 January].

Ruder, T. 2015. What are the greatest challenges or barriers to applying post-mortem imaging in pediatric radiology? *Pediatric Radiology*. 45:480. DOI: 10.1007/s00247-014-3152-4

Ruder, T., Hatch, G., Thali, M. & Fischer, N. 2011. One small scan for radiology, one giant leap for forensic medicine – Post-mortem imaging replaces forensic autopsy in a case of traumatic aortic laceration. *Legal Medicine*. 13:41–43. DOI: 10.1016/j.legalmed.2010.10.003

Rüegger, C., Bartsch, C., Martinez, R., Ross, S., Bolliger, S., Koller, B., Held, L., Bruder, E., Bode, P., Caduff, R., Frey, B., Schäffer, L. & Bucher, H. 2014. Minimally invasive, imaging guided virtual autopsy compared to conventional autopsy in foetal, newborn and infant cases: Study protocol for the paediatric virtual autopsy trial. *BMC Pediatrics*. 14:15. DOI: 10.1186/1471-2431-14-15

Runyan, D., Wattam, C., Ikeda, R., Hassan, F., Ramiro, L. in Krug, E, Dahlberg, L., Mercy, J., Zwi, A. & Lozano, Eds. 2002. *World report on violence and health*. Geneva, World Health Organisation. Accessed at:

https://www.who.int/violence_injury_prevention/violence/world_report/en/summary_en.pdf [2021, 11 March]

Rutty, G. 2007. Are autopsies necessary? The role of computed tomography as a possible alternative to invasive autopsies. *Rechtsmedizin*. 17:21–28. DOI: 10.1007/s00194-006-0408-9

Rydberg, J., Buckwalter, K., Caldemeyer, K., Phillips, M., Conces, D., Aisen, A., Persohn, S., & Kopecky, K. 2000. Multisection CT: Scanning techniques and clinical applications. *Radiographics* 20:1787–1806. DOI: 10.1148/radiographics.20.6.g00nv071787

Saayman, G., 2001. Physical abuse in children (Non-accidental injury syndrome). *South African Family Practice*. 45(1):26.

SAMRC (South African Medical Research Council). 2002. *Guidelines on Ethics for Medical Research: Use of Biohazards and Radiation.* Booklet 4. Parow, Cape Town: SAMRC. Accessed at: https://www.samrc.ac.za/sites/default/files/attachments/2018-06-27/ResponsibleConductResearchGuidelines.pdf [2021, 11 March]

Scallan J., Huxley, V. & Korthuis, R. 2010. Capillary fluid exchange: Regulation, functions, and pathology. San Rafael, CA: Morgan & Claypool Life Sciences. DOI: 10.4199/c00006ed1v01y201002isp003

Scaparra, E., Kirchoff, C., Reiser, M. & Kirchoff, S. 2016. Detection of blood aspiration in deadly head gunshots comparing post-mortem computed tomography (PMCT) and autopsy. *European Journal of Medical Research*. 21:43. DOI: 10.1186/s40001-016-0237-6

Schnider, J., Thali, M., Ross, S., Oesterhelweg, L. Spendlove, D. & Bolliger, S. 2009. Injuries due to sharp trauma detected by post-mortem multislice computed tomography (MSCT): A feasibility study. *Legal Medicine*. 11:4–9. DOI: 10.1016/j.legalmed.2008.07.001

Scholing, M., Saltzherr, T., Fung Kon Jin, P., Ponsen, K., Reitsma, J., Lameris, J. & Goslings, J. 2009. The value of post-mortem computed tomography as an alternative for autopsy in trauma victims: A systematic review. *European Radiology*. 19:2333–2341. DOI: 10.1007/s00330-009-1440-4

Schulze, C., Hoppe, H., Schweitzer, W., Schwendener, N., Grabherr, S. & Jackowski, C. 2013. Rib fractures at post-mortem computed tomography (PMCT) validated against the autopsy. *Forensic Science International*. 233:90–98. DOI: 10.1016/j.forsciint.2013.08.025

Schweitzer, W., Thali, M., Breitbeck, R. & Ampanozi, G. 2014. Virtopsy. Accessed at: https://www.swisswuff.ch/wordpress/virtopsycommentary2014.pdf [2021, 5 March].

Scolaro, J., Chao, T. & Zamorano, D. 2016. The Morel-Lavallée lesion: Diagnosis and management. *Journal of the American Academy of Orthopaedic Surgeons*.10:667–672. DOI: 10.5435/JAAOS-D-15-00181

Sedlak, A., Schultz, D., Wells, S., Lyons, P., Doueck, H. & Gragg, F. 2006. Child protection and justice systems processing of serious child abuse and neglect cases. *Child Abuse and Neglect*. 30:657–677. DOI: 10.1016/j.chiabu.2005.11.010

Shelmerdine, S., Gerrard, C., Rao, P., Lynch, M., Kroll, J., Martin, D., Miller, E., Filograna, L., Martinez, R., Ukpo, O., Daly, B., Hyodoh, H., Johnson, K., Watt, A., Taranath, A., Brown, S., Perry, D., Boel, L., Borowska-Solynynko, A., van Rijn, R., Klein, W., Whitby, E. & Arthurs, O. 2019. Joint European Society of Paediatric Radiology (ESPR) and International Society for Forensic Radiology and Imaging (ISFRI) guidelines: paediatric postmortem computed tomography imaging protocol. *Pediatric Radiology*. 49: 694 – 701. DOI: 10.1007/s00247-018-04340-x

Shelmerdine, S., Davendralingam, N., Palm, L., Minden, T., Cary, N., Sebire, N. & Arthurs, O. 2019. Diagnostic accuracy of postmortem CT of children: A retrospective single-center study. *American Journal of Roentgenology*. 212:1335 – 1347. DOI: 10.2214/AJR.18.20534

Shelmerdine, S., Langan, D., Hutchinson, J., Hickson, M., Pawley, K., Suich, J., Palm, L., Sebire, N., Wade, A. & Arthurs, O. 2018. Chest radiographs versus CT for the detection of rib fractures in children (DRIFT): a diagnostic accuracy observational study. *Lancet Child Adolescent Health*, 2, 802-811. DOI: 10.1016/S2352-4642(18)30274-8

Shenoi, R., Camp, E., Rubalcava, D. & Cruz, A. 2017. Characteristics and outcomes of acute pediatric blunt torso trauma based on injury intent. *American Journal of Emergency Medicine*. 35:1791–1797. DOI: 10.1016/J.ajem.2017.05.053

Sheridan, M. 2003. The deceit continues: An updated literature review of Munchausen Syndrome by proxy. *Child Abuse and Neglect*. 27:431–451. DOI: 10.1016/S0145-2134(03)00030-9

Sheybani, E., Gonzalez-Araiza, G., Kousari, Y., Hulett, R. & Menias, C. 2014. Pediatric nonaccidental abdominal trauma: What the radiologist should know. *Radiographics*. 34:139–153. DOI: 10.1148/rg.341135013

Shiotani, S., Shiigai, M., Ueno, Y., Sakamoto, N., Atake, S., Kohno, M., Suzuki, M., Kimura, H., Kikuchi, K. & Hayakawa, H. 2008. Postmortem computed tomography findings as evidence of traffic accident-related fatal injury. *Radiation Medicine*. 26:253–260. DOI: 10.1007/s11604-007-0223-6

Shrestha, R., Kanchan, T. & Krishan, K. 2020. Gunshot Wounds Forensic Pathology. [Updated 2020 Apr 15]. In StatPearls, Treasure Island (FL): StatPearls Publishing; 2020. Accessed at: https://www.ncbi.nlm.nih.gov/books/NBK556119/ [2020, 10 August].

Shur, N. & Carey, J. 2015. Genetic differentials of child abuse: Is your case rare or real? *American Journal of Medical Genetics*, Part C, Seminars in Medical Genetics 169C: 281 – 288. DOI: 10.1002/ajmg.c.31464

Sieswerda-Hoogendoorn, T., Boos, S., Spivack, B., Bilo, R. & Van Rijn, R. 2012a. Educational paper. Abusive head trauma Part I. Clinical aspects. *European Journal of Pediatrics*: 171:415–423. DOI: 10.1007/s00431-011-1598-z

Sieswerda-Hoogendoorn, T., Boos, S., Spivack, B., Bilo, R. & Van Rijn, R. 2012b. Educational paper. Abusive head trauma Part II. Radiological aspects. *European Journal of Pediatrics*. 171:415–423. DOI: 10.1007/s00431-011-1611-6

Sieswerda-Hoogendoorn, T., Soerdjbalie-Maikoe, V., De Bakker, H. & Van Rijn, R. 2014. Postmortem CT compared to autopsy in children: Concordance in a forensic setting. *International Journal of Legal Medicine.* 128:957–965. DOI: 10.1007/s00414-014-0964-6

Sieswerda-Hoogendoorn, T. & Van Rijn, R. 2010. Current techniques in postmortem imaging with specific attention to paediatric applications. *Paediatric Radiology*. 40:141–152. DOI: 10.1007/s00247-009-1486-0

Sifaoui, I., Nedelcu, C., Beltran, G., Dupont, V., Lebigot, J., Gaudin, A., Zins, C., Maillard, C. & Aubé, C. 2017. Evaluation of unenhanced post-mortem computed tomography to detect chest injuries in violent death. *Diagnostic and Interventional Imaging*. 98:393–400. DOI: 10.1016/j.diii.2016.08.019

Sinard, J. 2001. Factors affecting autopsy rates, autopsy requests rates and autopsy findings at a large academic medical center. *Experimental and Molecular Pathology*. 70:333–343. DOI: 10.1006/exmp.2001.2371

Sink, E, Hyman, J., Matheny, T., Georgopoulos, G. & Kleinman, P. 2011. Child abuse. *Clinical Orthopaedics and Related Research*. 469:790–797. DOI: 10.1007/s11999-010-1610-3

Snow, B., Salcedo, E., Galante, J. & Greenholz, S. 2015. Traumatic tension chylothorax in a child: A case report. *Journal of Pediatric Surgery Case Reports*. 3:163–165. DOI: 10.1016/j.epsc.2015.02.010

Sochor, M., Trowbridge, M., Boscak, A., Maino, J. & Maio, R. 2008. Postmortem Computed Tomography as an adjunct to autopsy for analysing fatal motor vehicle crash injuries: Results of a pilot study. *The Journal of Trauma, Injury, infection and Critical Care*. 65(3):659–665. DOI: 10.1097/TA.0b013e3181238d66

South Africa. 1959. *Inquest Act 58 of 1959*. Pretoria: Government Printer. Accessed at: https://www.gov.za/documents/inquests-act-3-jul-1959-0000# [2020, 8 February].

South Africa. 1983. *The Human Tissue Act*, *No. 65 of 1983*. Pretoria: Government Printer.

South Africa. 2003a. *National Health Act 61 of 2003*. (Published under Government Notice No. R.869). Accessed at: https://www.gov.za/documents/national-health-act [2020, 9 November].

South Africa. 2003b. National Health Act 61 of 2003. Regulations; Rendering of Forensic Pathology Services. *Government Gazette.* No. 30075, 23 March 2018. (Published under Government Notice No R.359). Accessed at: https://www.gov.za/documents/national-health-act [2020, 9 November].

South Africa. 2005. *Children's Act 38 of 2005*. Accessed at: https://www.gov.za/sites/default/files/gcis_document/201409/a38-053.pdf [2014, 9 June].

South Africa. 2007. *Criminal Law (Sexual Offences and Related Matters) Amendment Act 32 of 2007*. Pretoria: Government Printer. Accessed at: https://www.justice.gov.za/legislation/acts/2007-032.pdf [2019, 10 October].

South Africa. Department of Health. 2015. *Ethics in Health Research, Principles, Processes and structures*. Accessed at: http://nhrec.health.gov.za/index.php/grids-preview [2021, 5 March].

South Africa. Department of Health. 2020. Forensic Pathology Service. Provincial Department of Health, Western Cape Government. Accessed at: https://www.westerncape.gov.za/dept/health/documents/public_info/A/20262 [2020, 29 October].

South Africa. Department of Statistics. 2021. City of Cape Town. Accessed at: http://www.statssa.gov.za/?page_id=993&id=city-of-cape-town-municipality [2021, 1 February].

South African Police Service. 2020. *The Forensic Science Laboratory*. Accessed at: https://www.saps.gov.za/faqdetail.php?fid=6 [2020, 7 November].

Speelman, A.C., Engel-Hills, P.C., Martin, L.J., van Rijn, R.R. & Offiah, A.C. 2022. Postmortem computed tomography plus forensic autopsy for determining the cause of death in child fatalities. *Pediatric Radiology*, DOI: 10.1007/s00247-022-05406-7

Speight, N. 2006. Child abuse. *Current Paediatrics*. 16:100–105. DOI: 10.1016/j.cupe.2005.12.008

Srinivas, S. & Moss, C. 2018. Skin lesions simulating child abuse. *Indian Journal of Paediatric Dermatology*. 19(3):187–193. DOI: 10.4103/ijpd.IJPD_56_18

Starling, S., Heller, R. & Jenny, C. 2002. Pelvic fractures in infants as a sign of physical abuse. *Child Abuse and Neglect*. 26:475–480. DOI: 10.1016/S0145-2134(02)00323-X

Steyn, M. 2011. Case report. Forensic anthropological assessment in a suspected case of child abuse from South Africa. *Forensic Science International*. 208:6–9. DOI: 10.1016/j.forsciint.2011.01.023

Strauss, K., Goske, M., Kaste, S., Bulas, D., Frush, D., Butler, P., Morrison, G., Callahan, M., & Applegate, K. 2010. Image Gently: Ten steps you can take to optimize image quality and lower CT dose for pediatric patients. *American Journal of Radiology.* 194, 868 – 873. DOI:10.2214/AJR.09.4091

Sunderland, R. 2002. Child abuse: Recognising the injuries. *Trauma*. 4:11–16. DOI: 10.1191/1460408602ta223oa

Sutton, D. 1998. *Textbook of radiology and imaging*. 7th ed., Vol. 1, Edinburgh: Churchill Livingstone.

Swerdlin, A., Berkowitz, C. & Craft, N. 2007. Cutaneous signs of child abuse. *Journal of the American Academy of Dermatology*. 57(3):371–392. DOI: 10.1016/j.jaad.2007.06.001

Talvik, I., Metsvaht, T., Leito, K., Põder, H., Kool, P., Väli, M., Lintrop, M., Kolk, A. & Talvik, T. 2006. Inflicted traumatic brain injury (ITBI) or shaken baby syndrome (SBS) in Estonia. *Acta Paediatrica*. 95:799–84. DOI: 10.1080/08035250500464923

Tfelt-Hansen, J., Winkel, B., Grunnet, M. & Jespersen, T. 2011. Cardiac channelopathies and sudden infant death syndrome. *Cardiology*. 119:21–33. DOI: 10.1159/000329047

Thali, M., Ross, S., Oesterhelweg, Grabherr, S., Buck, U., Naether, S., Jackowski, C., Bolliger, S., Vock., P., Christe, A. & Dirnhofer, R. 2007. Virtopsy. Working on the future of forensic medicine. *Rechtsmedizin*, 17: 7 – 12. DOI 10.1007/s00194-006-0419-6.

Thali, M., Yen, K., Schweitzer, W., Vock, P., Boesch, C, Ozdoba, C., Schroth, G., Ith, M., Sonnenschein, M., Doernhoefer, T., Scheurer, E., Plattner, T. & Dirnhofer, R. 2003a. Virtopsy, a new imaging horizon in forensic pathology: Virtual autopsy by post-mortem Multislice Computed Tomography (MSCT) and Magnetic Resonance Imaging (MRI) – a feasibility study. *Journal of Forensic Sciences*. 48(2):1–18. DOI: 10.1520/JFS2002166

Thali, M., Yen, K., Vock, P., Ozdoba, C., Kneubuehl, B., Sonnenschein, M. & Dirnhofer, R. 2003b. Image guided virtual autopsy findings of gunshot victims performed with multi-slice computed tomography (MSCT) and magnetic resonance imaging (MRI), and subsequent correlation between radiology and autopsy findings. *Forensic Science International*. 138:8–16. DOI: 10.1016/S0379-0738(03)00225-1

The Medical Imaging Technology Association. 2020. About DICOM: Overview. Accessed at: https://www.dicomstandard.org/about-home [2020, 29 December].

The Society for Pediatric Radiology and National Association of Medical Examiners. 2004. Postmortem radiography in the evaluation of unexpected death in children less than 2 years of age whose death is suspicious for fatal abuse. *Pediatric Radiology*. 34(8):675–677. DOI: 10.1007/s00247-004-1235-3

Thomsen, A., Jurik, A., Uhrenholt, L. & Vesterby, A. 2009. An alternative approach to Computerised Tomography (CT) in forensic pathology. *Forensic Science International*. 183:87–90. DOI: 10.1016/j.forsciint.2008.10.019

Thomsen, T., Elle, B. & Thomsen, J. 1997. Postmortem radiological examinations in infants: Evidence of child abuse. *Forensic Science International*. 90:223–230. DOI: 10.1016/S0379-0738(97)00166-7

Tomcsányi, J., Nagy, E., Somlói, M., Moldvay, J., Bezzegh, A., Bózsik, B. & Strausz. 2004. NT-brain natriuretic peptide levels in pleural fluid distinguish between pleural transudates and exudates. *The European Journal of Heart Failure*. 6:753–756. DOI: 10.1016/j.ejheart.2003.11.017

Trikalinos, T. & Balion, C. 2012. Options for summarizing medical tests performance in the absence of a “gold standard”. In *Methods Guide for Medical Test Reviews*. AHRQ Publication No. 12- EC017. Rockville, MD: Agency for Healthcare Research and Quality. [2012, June 5]. Accessed at: https://www.ncbi.nlm.nih.gov/books/NBK98232/pdf/Bookshelf_NBK98232.pdf.

Troiano, M. 2011. Child abuse. Risks, consequences and interventions. *Nursing Clinics of North America*. 46:413–422.

Uhrenholt, L. & Boel, L. 2010. Contributions from forensic imaging to the investigation of upper cervical fractures. *Journal of Forensic Sciences*. 55:1598–1602. DOI: 10.1111/j.1556-4029.2010.01527.x

UNODC (United Nations Office on Drugs and Crime). 2021. Victims of intentional homicide, 1990–2018. Accessed at: https://dataunodc.un.org/content/data/homicide/homicide-rate [2021, 8 September].

UNSCEAR, (United Nations Scientific Committee on the Effects of Atomic Radiation). 2013: access at: https://www.unscear.org/docs/reports/2013/13-85418_Report_2013_Annex_A.pdf [2021, 19 September].

Urbanik, A., Chrzan, R., Woźniak, K. & Moskata, A. 2009. Post-mortem CT examination – own experiences. *Polish Journal of Radiology*. 74(4):55–63.

Urbanová, P., Hejna, P. & Jurda, M., 2015. Testing photogrammetry-based techniques for three-dimensional surface documentation in forensic pathology. *Forensic Science International*, Vol. 250, 77 – 86. DOI: 10.1016/j.forsciint.2015.03.005

Usui, A., Kawasumi, Y., Hosokai, Y., Hayashizaki, Y., Saito, H. & Funayama, M. 2013. Postmortem radiography of gastromalacia: Case reports. *Japan Journal of Radiology*. 31:637–641. DOI: 10.1007/s11604-013-0229-1

Van Rijn, R. 2009. How should we image skeletal injuries in child abuse? *Pediatric Radiology*. 39. Supplement 2:S226–229. DOI: 10.1007/s00247-008-1109-1

Van Rijn, R., Beek, E., Van De Putte, E., Teeuw, A., Nikkels, P., Duijst, W., Nievelstein, R., o.b.o the Dutch NODO group. 2017. The value of postmortem computed tomography in paediatric natural cause of death: A Dutch observational study. *Pediatric Radiology*. 47:1514–1522. DOI: 10.1007/s00247-017-3911-0

Van Rijn, R. & Leth, P. 2017. Targeted coronary post-mortem CT angiography straight to the heart. *The Lancet*. 390:100–101. DOI: 10.1016/S0140-6736(17)31260-6

Van Rijn, R. & Sieswerda-Hoogendoorn, T. 2012. Educational paper. Imaging child abuse, the bare bones. *European Journal of Pediatrics*. 171:215–224. DOI 10.1007/s00431-011-1499-1

Velhamos, G., Jindal, A., Chan, L., Murray, J., Vassiliu, P., Berne, T., Asensio, J. & Demetriades, D. 2001. “Insignificant” mechanism of injury: Not to be taken lightly. *Journal of the American College of Surgeons*. 192:147–152. DOI: 10.1016/S1072-7515(00)00790-0

Vij, K. 2011. *Textbook of forensic medicine and toxicology*. 5th ed. New Delhi: Elsevier. 82. 177

Wadhera, R., Kalra, V., Gulati, S. & Ghai, A. 2013. Child abuse: Multiple foreign bodies in gastrointestinal tract. *International Journal of Pediatric Otorhinolaryngology*. 77:287–289. DOI: 10.1016/j.ijporl.2012.10.022

Wardinsky, T. 1995. Genetic and congenital defect conditions that mimic child abuse. *The Journal of Family Practice*. 14(4):377–383.

Weber, M., Ashworth, M., Risdon, R., Hartley, J., Malone, M. & Sebire, N. 2008. The role of post-mortem investigations in determining the cause of sudden unexpected death in infancy. *Archives of Disease in Childhood*. 93(12):1048–1053. DOI: 10.1136/adc.2007.136739

Weber, M. & Sebire, N. 2009. Postmortem investigation of sudden unexpected death in infancy: current issues and autopsy protocol. *Diagnostic Histopathology*. 15(11):510–523. DOI: 10.1016/j.mpdhp.2009.08.003

Welch, G. & Bonner, B. 2013. Fatal child neglect: Characteristics, causation and strategies for prevention. *Child Abuse and Neglect*. 37:745–752. DOI: 10.1016/j.chiabu.2013.05.008

Westphal, S., Apitzsch, J., Penzkofer, T., Kuhl, C., Mahnken, A. & Knüchel, R. 2014. Contrast-enhanced postmortem computed tomography in clinical pathology: Enhanced value of 20 clinical autopsies. *Human Pathology.* 45:1813–1823. DOI: 10.1016/j.humpath.2014.05.007

Westphal, S., Apitzsch, J., Penzkofer, T., Mahnken, A. & Knüchel, R. 2012. Virtual CT autopsy in clinical pathology: Feasibility in clinical autopsies. *Virchows Archiv*. 461:211–219. DOI: 10.1007/s00428-012-1257-4

Weustink, A., Hunink, M., van Dijke, C., Renken, N., Krestin, G. & Oosterhuis, J. 2009. Minimally invasive autopsy: An alternative to conventional autopsy. *Radiology*, Vol. 250, 897 – 904. DOI: 10.1148/radiol.2503080421

WHO (World Health Organisation). 2002. *World report on violence and health*. Geneva. Switzerland. Accessed at: https://www.who.int/violence_injury_prevention/violence/world_report/en/summary_en.pdf [2021, 3 February].

WHO (World Health Organisation). 2011. International statistical classification of diseases and related health problems, 10th rev., Vol. 3; Alphabetical index, 5th ed. Accessed at: www.who.int/classifications/icd/icdonlineversions/en/ on [2018, 5 February].

WHO (World Health Organisation). 2014. *Health Topics: Child Maltreatment*. Accessed at: http://www.who.int/topics/child_abuse/en/ [2014, 8 June].

WHO (World Health Organisation). 2019. *Child Maltreatment Infographics*. Accessed at: https://www.who.int/violence_injury_prevention/violence/child/Child_maltreatment_infographic_EN.pdf?ua=1 [2019, 5 October].

Wikimedia Commons. 2021. Map of South Africa with Cape Town highlighted. Accessed at: https://commons.wikimedia.org/wiki/File:Map_of_South_Africa_with_Cape_Town_highlighted_(2011).svg [2021, 1 February].

Winkler-Schwartz, A., Correa, J. & Marcoux, J. 2015. Clival fractures in a Level 1 trauma center. *Journal of Neurosurgery*. 122:227–235. DOI: 10.3171/2014.9.JNS14245

WMA (World Medical Association). 2013. Declaration of Helsinki, Ethical Principles for medical research involving human subjects. Accessed at: http://www.wma.net/en/30publications/10policies/b3/index.html.pdf?print-media-type&footer-right=[page]/[toPage] [2014, 4 June].

Woo Goo, H. 2012. CT Radiation dose optimization and estimation: an update for radiologists. *Korean Journal of Radiology.* 13, (1), 1 – 11. DOI: 10.3348/kjr.2012.13.1.1

World Health Organisation and International Society for Prevention of Child Abuse and Neglect (ISPCAN). 2006. *Preventing Child Maltreatment: A guide to taking action and generating evidence*. Accessed at: https://www.who.int/violence_injury_prevention/publications/violence/child_maltreatment/en/ [2019, 6 March].

Woźniak, K., Moskala, A. & Rzepecka-Woźniak, E. 2015. Imaging for homicide investigations. *La Radiologia Medica*. 129:846–855. DOI: 10.1007/s11547-015-0529-x

Wygnanski-Jaffe, T., Levin, A., Shafiq, A., Smith, C., Enzenauer, R., Elder, J., Morin, F., Stephens, D. & Atenafu, E. 2006. Postmortem orbital findings in Shaken baby Syndrome. *American Journal of Ophthalmology*. 142(2):233–240. DOI: 10.1016/j.ajo.2006.03.038

Yates, G. & Bass, C. 2017. The perpetrators of medical child abuse (Munchausen Syndrome by Proxy) – a systematic review of 796 cases. *Child Abuse and Neglect*. 72:45–53. DOI: 10.1016/j.chiabu.2017.07.008

Yen, K., Lövblad, K., Scheurer, E., Ozdoba, C., Thali, M., Aghayev, E., Jackowski, C., Anon, J., Frickey, N., Zwygart, K., Weis, J. & Dirnhofer, R. 2007. Post-mortem forensic neuroimaging: Correlation of MSCT and MRI findings with autopsy results. *Forensic Science International*. 173:21–35. DOI: 10.1016/j.forsciint.2007.01.027

Yu, D., Ngo, T. & Goldstein. 2016. Child abuse – a review of inflicted intraoral, esophageal and abdominal visceral injuries. *Clinical Pediatric Emergency Medicine*. 17:284–295. DOI: 10.1016/j.cpem.2016.09.005

Zarb, F., Rainford, L. & McEntee, M. 2010. Image quality assessment tools for optimization of CT images. *Radiography.* 16, 147 – 153. DOI 10.1016/j.radi.2009.10.002

Zech., W., Jackowski, C., Schwendener, N., Brencicova, E., Schuster, F. & Lombardo, P. 2016. Postmortem CT versus forensic autopsy: Frequent discrepancies of tracheobronchial content findings. *International Journal of Legal Medicine*. 130:1919–198. DOI: 10.1007/s00414-015-1264-5

Zhou, Y., Nute, J., Scott II, A. & Lee, C. 2017. Consistent low-contrast detectability for variable patient sizes and corresponding dose in abdominal CT. *Medical Physics.* 44, (3), 861 – 872. DOI: https://doi.org/10.1002/mp.12085

Zolotor, A. & Shanagan, M. 2010. Epidemiology of physical abuse: In *Child abuse and neglect: Diagnosis, treatment and evidence*. C. Jenny, Ed. St Louis, MO: Elsevier, p10 – 15.

ADDENDA

ADDENDUM A1: LIST OF FORENSIC AND CHILD ABUSE JOURNALS CONSULTED ABOUT TOPIC

1 Aggression and Violent Behaviour
2 American Journal of Forensic Medicine and Pathology
3 Anil Aggrawal's Internet Journal of Forensic Medicine and Toxicology
4 Encyclopaedia of Forensic and Legal Medicine
5 Forensic Imaging (Previously Journal of Forensic Radiology and Imaging)
6 Forensic Magazine
7 Forensic Science Medicine and Pathology
8 Forensic Science International
9 Indian Journal of Forensic Odontology
10 International Journal of Forensic Mental Health
11 International Journal of Legal Medicine
12 International Journal of Law and Psychiatry
13 International Journal of Medical Toxicology and Forensic Medicine
14 International Journal of Medical Toxicology and Legal Medicine
15 Internet Journal of Forensic Science
16 Journal of Clinical Forensic Medicine
17 Journal of Clinical Pathology and Forensic Medicine
18 Journal of Forensic & Legal Medicine
19 Journal of Forensic Biomechanics
20 Journal of Forensic Dental Sciences
21 Journal of Forensic Identification
22 Journal of Forensic Nursing (Wiley)
23 Journal of Forensic Odonto-Stomatology
24 Journal of Forensic Psychiatry
25 Journal of Forensic Psychiatry and Psychology
26 Journal of Forensic Sciences
27 Journal of Indian Academy of Forensic Medicine
28 Journal of Legal Medicine
29 Journal of Punjab Academy of Forensic Medicine & Toxicology
30 Legal Medicine
31 National Forensic Journal
32 Open Access Journal of Forensic Psychology
33 Romanian Journal of Legal Medicine
34 Science and Justice
35 The American Journal of Forensic Medicine and Pathology
36 Research and Reports in Forensic Medical Science
37 Sri Lanka Journal of Forensic Medicine, Science & Law
38 Z Zagadnień Nauk Sądowych = Problems of Forensic Sciences

ADDENDUM A2: SAMPLE RADIOLOGY REPORT

RADIOLOGY REPORT: CASE 007

POSTMORTEM CT FOR THE ASSESSMENT OF FATAL CHILD ABUSE

SUBJECT STUDY CODE: 007	**PMCT CODE: WC/[redacted]/2016**
SEX: Male	**AGE: 16 years**

FORENSIC PATHOLOGY OFFICERS REPORT/ SCENE FINDINGS:

Adult male received at [redacted] brought in Dead on arrival. He was allegedly involved in a gang related shooting linked with WC/1[redacted]/16 (removed at primary scene). The deceased sustained multiple Gun Shots Wounds.

RADIOLOGY REPORT:

For research purpose only

Head and Neck:
Normal soft tissue of the skull.
Normal skull shape.
No fractures.
Normal post-mortem density of the cerebellum. Fourth ventricle normally positioned and non dilated.
Reduced grey-white matter differentiation of the cerebrum, in keeping with the post-mortal status.
Normal size and aspect of the ventricles.
Normal size and aspect of the subarachnoid space.
No mid-line shift.
No intracranial haemorrhage.
Normal soft tissue of the neck on the left side.
Subcutaneous air in the soft tissue of the neck on the right side.
Normal segmentation of the cervical spine. No fractures or dislocation.
No air in the intracranial vessels.
Irregular dental placement of the molars in the maxilla.

Chest:
The entry and exit wounds are not marked.
Three metal artefacts, given the clinical history and shape of the objects, in keeping with bullets are identified.
Located at the posterior side of the right shoulder just subcutaneously positioned. There seems to be a fracture of the right scapula. There certainly are minor avulsion fragments at the posterior side of the right glenoid indicating a richochet trauma. There is a bullet trajectory through the 3rd and 4th vertebral body, given the expulsion of bone fragments on the right side the trajectory must have been left to right. On the coronal reconstruction also a lateral fracture of the left 4th rib is visible. Here also the fragments are on the left side of the fracture.

1. Located just dorso-cranial to the second right rib well within the soft tissue outside the chest cavity. There are dorso-lateral communitive fractures of the second and third right rib. On the coronal reconstruction there is an oblique bullet trajectory through the thoracic vertebral bodies (6-9). At the level of the 8th rib bone fragments have protruded into the spinal column. Given the expulsion of bone fragments at the cranial right side of the vertebral bodies the bullet must have been travelling from the left to the right in an upward trajectory. The 11th anterior rib

on the left side also shows a fracture, no clear fragments are seen. A soft tissue trajectory is seen at the level of the lower kidney pole in the left flank.

2. Dorsal of the dorsal side of the 9th right rib a third bullet is seen. The neck of the 9th right rib shows fragmentation. This is at the same level as the oblique bullet trajectory through the thoracic spine.

Subcutaneous emphysema along the left side of the chest.
Bilateral collapse of the lungs. The right lung shows a linear opacification (IM 112/280) which can be in keeping with a bullet trajectory.
Bilateral haemopneumothorax.
A bone fragment of unknown origin is seen in the left thoracic cavity (IM 142/280).
Normal position of the heart and great vessels.
Several calcified lesions in the mediastinum, most likely in keeping with tuberculosis.
Mild amount of air in the heart and great vessels, in keeping with post-mortem status.

Abdomen:
Normal segmentation of the lumbar/sacral spine. No fractures or dislocation.
Normal position and aspect of the liver. Air in the portal veins.
Normal position and aspect of the kidneys.
Normal position and aspect of the spleen.
Normal aspect of the bladder.
Pneumoperitoneum.
No free abdominal fluid.

Upper extremities:
Normal aspect of the humerus, ulna, and radius.
A linear soft tissue lesion is seen in the left shoulder (Coronal IM 42/91). Otherwise normal soft tissue aspect.

Lower extremities:
Normal aspect of the femur, fibula, and tibia.
Normal soft tissue aspect.

Conclusion:

The post-mortem total body CT in this 16-year old boy shows:

1. Presence of three bullets with two relatively clear bullet trajectories (see description above). A third trajectory is less clear and cannot be described with certainty.
2. A linear soft tissue lesion is seen in the left shoulder, in keeping with penetrating trauma.
3. Bilateral haemopneumothorax.
4. Pneumoperitoneum.

CAUSE OF DEATH (COD)	Penetrating trauma leading to bilateral haemopneumothorax and pneumoperitoneum (Fatal gunshot injuries)

Name of Radiologist: **Date:**

ADDENDUM A3: STANDARD OPERATING PROCEDURES: FORENSIC PATHOLOGY SERVICES

NATIONAL FORENSIC PATHOLOGY SERVICE COMMITTEE

1 Scene of death:

1.1 The Chain of Custody of the body starts at the scene of death – the South African Police (SAP) 180 form must be completed by the South African Police Service (SAPS) and handed to the authorised person*.

1.2 The FPS forensic pathology officer responsible for collecting the body will complete the FPS Death Scene Form at the scene of death and take digital photographs where possible.

2 Admission to designated facility

2.1 On admission of the body, the body is registered in the FPS Case Register and the FPS Case File is opened with a unique identifying alphanumeric number from the FPS Case Register.

2.2 Each body submitted is assigned a unique identifying alphanumeric number, whereby the facility as well as the body is identified e.g. the first case *(0001)* of the year 2007 *(2007)* at the Salt River Mortuary *(designated facility number 11)* in the Western Cape *(WC)* would be: *WC/11/0001/2007*. This unique identifying alphanumeric is used on each FPS form or register related to that case.

2.3 This register is updated at every step of the process, including but not limited to identification of body, completion of postmortem examination and release of the body.

2.4 The FPS Case File shall include, but is not limited to:

2.4.1 The incident log form of the case

2.4.2 SAP 180 (“Police Report Accompanying Body to Mortuary”) completed by the SAPS officer at the scene. At any scene of death, the South African Police Service will designate a member who will provide the Forensic Pathology Service member(s) with all relevant information known at the time regarding the circumstances of the death;

2.4.3 A death scene report compiled by the FPS forensic pathology officer of the designated facility who collected the body, including noting of the valuables, clothing and effects accompanying the body

2.4.4 All ‘chain of custody/evidence statements’

2.4.5 Medical/Clinical Case History

2.4.6 All other documents relating to the case is placed in the FPS Case File.

2.5 If the death appears to be due to unnatural causes, especially if there is a possibility that criminal proceedings may follow, the authorised person should perform a complete forensic autopsy. It is advised that this procedure should be followed in all cases of doubt.

2.6 The pathologist will ensure that the appropriate documentation is on hand and has

been completed, prior to commencement of the postmortem examination, e.g. Form SAP 180, the relevant clinical medical records which may include a Form GW7/24.

3 **The forensic autopsy:**

A complete forensic autopsy consists of:

3.1 A full external examination of the body including the mass and height of the body, a description of the clothing and any other accompanying items;

3.2 Recording of all identifying features;

3.3 All injuries should be noted on a sketch of the body;

3.4 The opening of all the major body cavities and the inspection of all the internal organs in situ;

3.5 All abnormal collections of fluid in the body should be accurately measured;

3.6 The removal of all the internal organs and their individual dissection and examination;

3.7 The mass of all organs which appear to be abnormal in size should be determined and noted;

3.8 All abnormal changes present should be fully examined and accurately and fully noted;

3.9 All special dissection techniques performed should be noted with the results thereof.

3.10 The judicious selection and collection of such specimens as may be deemed necessary for special laboratory investigation.

3.11 Photographs may be taken of the body and of injuries present at the time of the post-mortem examination.

3.12 At the end of the examination the pathologist will ensure that the dissected organs and tissues, except those retained for special investigations, are returned to the body.

4 The pathologist will complete a post-mortem examination report in all cases irrespective of the cause of death and a copy of this report is kept on file.

5 The body may not be released before or until the forensic pathologist is satisfied that a complete investigation has been done and that all examinations, including specimen collections, have been adequately performed; and that the scientific identification is complete (National Forensic Pathology Service Committee, 2011)

ADDENDUM A4: BLANK FORENSIC PATHOLOGY REPORT

DIRECTORATE: Forensic Pathology Services
REFERENCE: FORM FPS 007 WC11/00/2019 /
ENQUIRIES: 021-4066412

REPUBLIC OF SOUTH AFRICA

DEPARTMENT OF HEALTH- PROVINCE OF WESTERN CAPE

AFFIDAVIT IN TERMS OF SECTION 212(4), ACT 51/1977

REPORT ON A MEDICO-LEGAL POSTMORTEM EXAMINATION

WESTERN CAPE PM WC11/000/2019

SAPS CAS NO: 000/000/2019

To the Magistrate of **Cape Town,**

I, ……., state under oath that I declare that the following statement is true to the best of my knowledge and belief, and that I made this statement knowing that if it is tendered in evidence that I will be liable to prosecution if I willfully state in it anything that I know to be false, or which I do not believe to be true.

I am a medical practitioner registered with the **Health Professions Council of South Africa)** [registration number:……]. I am employed by the **Department of Health - Province of Western Cape** as a Specialist.

That at the Forensic Pathology Laboratory, 38 Durham Avenue, Salt River,

on: ……at……., employing my skill in Anatomy, Pathology, Medicine and Clinical Toxicology**,** I examined the body of :. ……

This body was identified to me by: Forensic Officer …… of **Department of Health, Forensic Laboratory, 38 Durham Avenue, Salt River, 7925.**

as being that of : ……**[PM WC11/000/2019]**

whose reputed age was: ±…….years

that the deceased was certified as dead on: 6 January 2019.

a) as informed on ……. at …….. (Time of death was not established as body was refrigerated prior to examination).

b) ……..days prior to my examination.

THE CHIEF POSTMORTEM FINDINGS MADE BY ME ON THIS BODY WERE:

1. ……

SCHEDULE OF OBSERVATIONS

GENERAL

1. **HEIGHT:** …… **WEIGHT:** ……
   PHYSIQUE: …… **NUTRITION:**……

2. **SPECIAL IDENTIFYING FEATURES:** The body was that of an …… with a plastic tag secured around the ……. wrist and …… ankle bearing the number **WC11/000/2019**.

3. **SECONDARY POSTMORTEM CHANGES:** Refrigerated. Remnants of rigor mortis were still present.

4. **EXTERNAL APPEARANCE OF BODY AND CONDITION OF LIMBS:**

(A) Clothing:

(B) The following fresh injuries were seen on the body: [See Annexure A]

(C) The following signs of Medical Intervention were seen on the body:

(D) Old healed scars:

HEAD AND NECK

5. SKULL:

6. INTRACRANIAL CONTENTS: BRAIN MASS: …….g.

7. ORBITAL, NASAL AND AURAL CAVITIES:

8. MOUTH, TONGUE AND PHARYNX:

9. NECK STRUCTURES:

CHEST

10. THORACIC CAGE AND DIAPHRAGM:

11. MEDIASTINUM AND OESOPHAGUS:

12. TRACHEA AND BRONCHI:

13. PLEURA AND LUNGS: RIGHT MASS: …..**g LEFT MASS: ……g**
Both lungs:

14. HEART AND PERICARDIUM: HEART MASS: ……**g**.

15. LARGE BLOOD VESSELS:

ABDOMEN

16. PERITONEAL CAVITY:
17. STOMACH AND CONTENTS:

18. INTESTINES AND MESENTERY:

19. LIVER, GALLBLADDER AND BILIARY PASSAGES: LIVER MASS: ……..g
20. PANCREAS:

21. SPLEEN: SPLEEN MASS: ……g.

22. ADRENALS:

23. KIDNEYS AND URETERS: RIGHT MASS: ……g LEFT MASS: …….g

Both kidneys:

24. URINARY BLADDER AND URETHRA:

25. PELVIC WALLS:

26. GENITAL ORGANS:

SPINE

27. SPINAL COLUMN:

28. SPINAL CORD:

29. SPECIMENS RETAINED:
(a) Nature of specimen/s
(b) Nature of investigation required
(c) Disposal of specimen/s

	(a)	(b)	(c)
1.	Femoral blood [Seal No's:	Alcohol	Forensic officer
2.			

30. ADDITIONAL OBSERVATIONS:

1) **History of ……. as per LAB 27 notes.**

2) **A diagram in this report is submitted as Annexure A.**

3) **A BI 1663 was filled in, ……**

CAUSE OF DEATH:

As a result of my observations, I concluded that the cause/causes of death was/were:

……

I certify that the deponent has acknowledged that he knows and understands the contents of this declaration, that he has no objection to taking the prescribed oath and considers it to be binding on his conscience, that he swore that the contents of the above declaration are the truth, the whole truth and nothing but the truth and that this declaration was sworn to before me, and the deponent's signature was placed thereon in my presence at

Dated at Cape Town,

on this ……. day of …….. 2019

SIGNATURE: ……

QUALIFICATIONS:……..

DESIGNATION: e.g. Specialist in Forensic Medicine

ADDRESS AND TELEPHONE NUMBER:

…….

I certify that the deponent has acknowledged that he knows and understands the contents of this declaration, that he has no objection to taking the prescribed oath and considers it to be binding on his conscience, that he swore that the contents of the above declaration are the truth, the whole truth and nothing but the truth and that this declaration was sworn to before me, and the deponent's signature was placed thereon in my presence at

Thus signed and sworn to before me at: CAPE TOWN

on this ……. day of …….

_____
COMMISSIONER OF OATHS, R.S.A.

Full Name:
Address:
Rank:

TRANSCRIBER'S CERTIFICATE

I, THE UNDERSIGNED, DO HEREBY CERTIFY AND DECLARE THAT THE AFOREGOING IS A TRUE AND CORRECT TRANSCRIPTION OF THE FINDINGS RECORDED BY …… IN THE EXAMINATION OF THE ABOVE POSTMORTEM.

PERFORMED BY :
TYPED ON :
DESIGNATION :

THE HANDWRITTEN FORM WAS HANDED TO ME BY: ……..

_____

DEPARTMENT OF FORENSIC MEDICINE

ADDENDUM A5: FINDINGS RECORDED ON SOME FORENSIC PATHOLOGY REPORTS

This list provides an overview of typical content covered within a paediatric forensic pathology report. This report could vary depending on the case history and only serves as an example.

Admission number of deceased e.g.

WC/….01/2017

- The pathologist will comment on the following aspects as per the respective headings:
- All external findings are referred to with the body in the standard anatomical position.

THE CHIEF FINDINGS MADE BY HIM/HER ON THIS BODY:

SCHEDULE OF OBSERVATIONS

GENERAL

The pathologist will record:

- Height of deceased in cm or metres
- Mass: in grams or kg
- Physique: whether appropriate for age

For neonates and infants:

- Nutrition: whether good for age (neonates and infants only)
- Head circumference:
- Foot length of neonate indicating gestation in weeks.
- In some cases the pathologist may also review the clinic card (Road to Health chart) of infants and neonates and may comment on:
    - whether immunization status is up to date
    - and infants general growth over time.

The following measurements may be recorded of foetuses or neonates:

- Head circumference: in mm
- Abdominal circumference: in mm
- Crown heel length: in mm
- Crown: rump length: in mm
- Head circumference: in mm
- Chest circumference: in mm
- Abdominal circumference: in mm
- Right calf circumference: in mm
- Left calf circumference: in mm
- Right foot length: in mm
- Left foot length: in mm

SPECIAL IDENTIFYING FEATURES:

The pathologist may describe:

- Condition of the skin or other identification features such as a Mongolian spot or birth marks present.
- Describe colour and texture of hair
- Record WC number on identity tag to confirm the identity of the body.
- Any tattoos if present
- Any piercings if present
- Dentition: whether own or artificial

FOR FOETUSES AUTOPSIED WHERE THE PLACENTA STILL ATTACHED

The pathologist may describe:

- The length and diameter of the placenta in millimetres.
- Length of the cord measured in millimetres.
- Whether the membranes are clear and complete.
- Whether cord is inserted eccentrically 2 cm from the periphery.
- Whether cotyledons were complete.
- Whether any retroplacental haemorrhage or any other abnormality is present.
- Based on the pathologist observation, which object was used to cut the cord (sharp or blunt)
- Whether the blood supply to placenta (e.g. two arteries and one vein) were visible on cross section.

SECONDARY POSTMORTEM CHANGES

The pathologist may describe whether:

- The body has been refrigerated.
- Rigor mortis is present or not and the status thereof (e.g. mild moderate or intense)
- Post-mortem lividity is moderate, red, posterior and fixed
- Blanching on fingertip pressure was present or not
- There was contact pallor over the shoulder blades, buttocks and calves
- Early or late decomposition of the body was evident
- Any bloating or colour changes of the body was present.
- Hypostasis was present on the posterior aspect of the body.
- The body was well preserved or decomposed.

EXTERNAL APPEARANCE OF THE BODY AND CONDITION OF LIMBS:

The pathologist may describe whether:

- The body was received clothed or not e.g:
- The deceased was wearing clothes, the colour and design and general condition thereof
- The clothes were blood stained.
- Presence of foreign material such as sand or stones on clothing.
- Presence of other bodily fluid such as vomit or mucus.

- For gunshot victims whether there are defects present in the clothing and whether such defects correspond with wounds on the body.
- Old burn marks are present when evident
- The general hygiene of the deceased whether clean or neglected.
- Any injuries are present, and if so, whether caused by blunt or sharp objects.
- Any notable appearances of the face or body where evident.
- Any notable abnormalities of the eyes were observed.
- Any external injuries to the body was evident.
- Fresh and old injuries (scab and contusions) were evident.
- Any fingernail cyanosis was present

In addition to the above: For foetuses or neonates:

The pathologist may describe whether:

- Any features of prematurity were evident or not
- Any evidence of jaundice, oedema or clubbing present.
- Any signs of a simian crease were apparent.
- Any dysmorphic features suggestive of congenital diseases were noted.
- There was nappy rash present.
- Any erupting teeth were evident

For external gunshot wounds:

- All injuries are documented in detail e.g.
    - Gunshot injuries are measured in millimetres.
    - The anatomical location of gunshot wounds is described to its relative distance from the midline and the heel.
    - Gunshot wounds are also described whether round, spherical or slit like and whether any abrasions were present.
    - Whether searing of the skin, soot staining was present.

SIGNS OF ANY MEDICAL INTERVENTION:

The pathologist may describe:

- Whether a nasogastric tube was present and its anatomical placement
- The location of electrocardiogram stickers if present
- Location of an endotracheal tube
- The anatomical location of an intercostal drain if present.
- Nasal prong oxygen if present
- Anatomical location of an intravenous drip and the fluid attached to it.
- Whether cutaneous puncture marks were present and whether these were consistent with attempts at drip insertion
- Location of plaster with cotton wool and the presumed purpose of that.
- Whether an intra-osseous needle was present or not.

HEAD AND NECK

SCALP AND SKULL

The pathologist may describe:

- The conditions and status of the skull bones and fontanelles.
- Whether the skull bones and fontanelles are appropriate for the age of neonate/infant.
- Whether any subcutaneous haemorrhage or caput/cephalohematoma was present over the vertex.
- Whether any fractures of the mandible or maxilla or zygoma was present.
- The diameter of skull fractures and whether inward bevelling was noted
- The anatomical location of skull fractures (if present).

INTRACRIANAL CONTENTS:

The pathologist may describe whether:

- The cerebellum, cerebrum and brain stem had a normal appearance.
- The falx cerebri and the tentorium cerebelli were intact.
- The meninges were normal.
- The lateral ventricles were patent or effaced.
- The dural sinuses contained any thrombi.
- Any intracerebral, subdural, subarachnoid or intraventricular haemorrhages were evident around or within the brain.
- Any contusions or herniations of the meninges were present.
- Any hygroma was present in subdural cavity
- The convolutions and sulci were flat or effaced (indicating raised intracranial pressure or brain oedema)
- Any macroscopic infarcts were present.
- The pituitary gland was normal
- The vessels comprising the Circle of Willis were normal.
- The entire brain will be placed in formalin for examination after fixation.
- The physical structure of the brain e.g. whether very soft and had any signs of prematurity.
- Sectioning of any parts of the brain may be done to assess for underlying pathology.
- The brain weight in grams is within normal range (reference is always made to normal organ weight)

ORBITAL AURAL AND NASAL CAVITIES

The pathologist may describe:

- The condition of the eyes and eye lids
- The condition of the orbital and nasal cavities.
- Whether any of these cavities were opened or not during autopsy.
- The anatomical location of the ears and whether the ears were set low, rotated and whether the cartilage was normal.
- Whether nostrils were patent
- The nose was upturned or not.
- Whether there were epicanthi folds underneath eyes
- Whether the cartilage of the septum of the nose was normal or injured
- Whether the tympanic membrane was normal or injured

- Whether the pupils were dilated and centrally situated (dilated pupils are a sign of raised intracranial pressure).

MOUTH, TONGUE AND PHARYNX:

The pathologist may describe:

- The condition and physical appearances of the mouth, tongue and pharynx.
- Whether the frenulum was intact (in children a ruptured frenulum used to be highly suggestive of physical abuse).
- Whether tonsils were normal or not.
- Whether philtrum was well defined.
- Any evidence of cleft lip or palate or not.
- Any injury to buccal cavity.
- Whether there is any evidence of micrognathia or microstomia.
- Whether tongue was congested or shows signs of haemorrhagic areas.

NECK STRUCTURES:

The pathologist may describe:

- Whether a bloodless field layered dissection of the neck was done to assess underlying anatomy for injury or disease.
- Whether any congenital or anatomically abnormalities were present.
- Whether any contusions, lacerations and haemorrhages were noted.
- Conditions of the carotid arteries and internal jugular veins and whether these were healthy and intact.
- Whether lymph nodes were normal or pathological

Thyroid

The pathologist may describe:

- Whether the thyroid cartilage was normal or not

Hyoid

The pathologist may describe:

- Whether this bone was intact on palpation. (A fractured hyoid bone is highly suggestive of strangulation).

Larynx (laryngeal cartilage);

The pathologist may describe:

- Whether normal or any pathology such as inflammation is present.
- Whether the larynx showed any sign of obstruction.
- Whether there was swelling of the vocal cords present.

CHEST:

THORACIC CAGE AND DIAPHRAGM

The pathologist may describe:

- The general condition of the thoracic cage.
- Whether any free fluid was present in the thoracic cavity.
- The status of the ribs, clavicles and sternum i.e. whether intact or fractured.
- Whether any blood, free fluid or pus was located within the pleural cavities.

MEDIASTINUM AND OESOPHAGUS

The pathologist may describe:

- The anatomical appearance of the thymus
- Whether the thymus was normal or not
- Whether oesophagus (mucosa) was normal or not.
- The applicable organ weight in grams.

TRACHEA AND BRONCHI:

The pathologist may describe:

- The anatomical appearance of the airways e.g. whether any foreign substance was present or not.
- Whether the airway mucosa was normal or not.
- Whether there was froth in the lumen of the entire trachea or bronchi
- Whether any foreign matter such as food or blood were in the trachea (suggesting aspiration).

PLEURA AND LUNGS

The pathologist may describe:

- The general anatomical appearance of the lungs.
- Whether the pleural space was clear of abnormal fluid and blood
- Any aspirate/aspiration was present in the lungs.
- Presence of any subpleural petechial haemorrhages,
- Contusion of any section of the lungs.
- The condition of the intrapulmonary blood vessels (normal or not)
- Whether pleural adhesions were present between any of the lobes.
- Whether visible intrapulmonary airways were clear.
- Where clinically indicated, perform a test for pneumothorax.
- For neonates, a hydrostatic test may be performed to assess whether the baby breathed before passing away.
- On further examination the pathologist may want to assess whether the thoracic pluck was buoyant in water for each lung.
- Whether any congestion, parenchymal resorptive atelectasis was present or not.
- The colour of the lung tissue and whether they felt spongy.
- Whether lung oedema was present.

- Whether there was pathology such as pneumonia or tuberculosis present.
- Whether hilar lymph nodes were normal or not.
- Whether any emboli were present in the vessels of the lungs.
- Whether anthracosis was present (for smokers).
- Cut section may be performed to assess whether underlying tissue were collapsed and or pale.
- The position of an endotracheal tube (if present) and whether lumen was patent and whether well positioned.
- The weight of right lung and left lung measured in grams (reference is always made to normal organ weight singular or combined organ weight)

HEART AND PERICARDIUM

The pathologist may describe:

- The condition of the heart chambers, muscles walls and valves.
- Whether the heart valves appear morphologically normal and whether any fibrosis, vegetations or calcifications were present.
- Whether the pericardial sac was intact and condition of pericardial fluid i.e. whether clear or blood stained.
- Measure the volume of pericardial fluid in millilitres.
- Whether coronary ostia and arteries followed a normal anatomical distribution and were patent.
- Whether any atrial ventricular septal defects were present.
- Whether the endocardium and myocardial thickness were within normal limits.
- Whether any subendocardial haemorrhage present in the posterior wall of the left ventricle of the heart.
- Whether the endocardium showed any evidence of fibrosis.
- Whether there was thrombus present in the heart.
- The histological appearance of cut sections of heart muscle
- Weight of the heart measured in grams (reference is always made to normal organ weight)

Neonates only:

The pathologist may describe whether:

- Foramen ovale was patent
- Ductus arteriosus was patent

Large blood vessels:

The pathologist may describe:

- Whether the aorta, SVC and IVC was normal
- Whether coarctation of the aorta was evident or not.
- Whether the renal arteries were patent and had any significant atherosclerosis.
- Whether pulmonary arteries were normal or had any thrombo-emboli.
- The presence of any injuries such as tears in the aorta, SVC and IVC.
- Whether fatty streaking was visible in any of the major vessels indicating atheromatous disease.

ABDOMEN

Peritoneal cavity:

The pathologist may describe:

- The general condition thereof and
- Whether any inflammation, free fluid (ascites) or adhesions were present.
- Whether there was contusion of the abdominal wall evident
- Whether any purulent exudate was evident in the peritoneal cavity.

Stomach and contents

The pathologist may describe:

- Whether the mucosa and rugae were normal
- Whether the stomach contained any fluid or food and if so, describe the constituency thereof.
- Whether there was any mucosal ulceration or erosion present.
- Any signs of gastritis.
- Any signs of contusions, haemorrhage of any part of the stomach and anatomical location thereof.

Intestines and mesentery

The pathologist may describe:

- Whether normal or abnormal or any signs of congenital abnormalities were present (neonates only).
- Whether the small bowel, the large bowel, and the mesentery were normal.
- Presence and condition of the appendix.
- Whether the mesenteric lymph nodes appeared normal.
- Whether any rotational abnormalities of the bowel were evident.
- Whether the bowel loops were adherent to each other.
- Whether the serosa of the bowel was adherent to the peritoneum of the anterior abdominal wall.

Liver, gallbladder and biliary passages:

The pathologist may describe:

- Whether the diaphragm was adherent to the capsule of the liver.
- Any pathology was evident within the liver.
- Whether the liver was enlarged or not.
- The overall colour of the liver on surface inspection as well as cut section.
- Whether the liver floats in formalin (where required).
- The anatomical appearance and shape of the liver including the capsule on surface inspection.
- Whether the surface of the liver was smooth and had sharp edges.
- Whether the biliary tract was unobstructed and free from disease.
- Whether the gallbladder contained clear bile and whether any gall stones were present.
- Whether bile could be expressed into the duodenum.
- Whether any injuries such as laceration of the liver was present
- Whether any masses or cysts were present.
- Histological appearance of cut sections of liver

- The ductus venosus is normal (neonates only)
- The weight of the liver measured in grams (reference is always made to normal organ weight)

Pancreas:

The pathologist may describe:

- The anatomical appearance of the pancreas on surface inspection
- Whether the pancreas had a normal colour on surface inspection and morphology was firm.
- Histological appearance of cut sections of pancreas
- Weight of the pancreas measured in grams (reference is always made to normal organ weight)

Spleen

The pathologist may describe:

- The anatomical appearance and size and shape of the spleen including whether the capsule was normal.
- Whether the capsule was translucent and tightly applied.
- Parenchyma of spleen was pale or of normal colour.
- Histological appearance of spleen on cut sections
- Weight of the spleen measured in grams (reference is always made to normal organ weight)

Adrenals:

The pathologist may describe:

- Whether the anatomical appearance, size and shape of the adrenals were normal.
- Whether any atrophy was present.
- No acute or old haemorrhage was present.
- Histological appearance of adrenals on cut section.
- Weight of the adrenals measured in grams (reference is always made to normal organ weight singular or combined organ weight)

Kidneys and ureters:

The pathologist may describe:

- Whether the anatomical appearance of the kidneys was normal.
- Whether the cortical medullary demarcation was normal.
- Condition and status of the kidney capsules and whether it stripped with ease.
- The status of the cortical surfaces.
- Whether the subcapsular surface of the kidneys appeared smooth.
- Whether the renal pelvis and the ureters were normal.
- Whether any masses or stones were present in the kidneys or not.
- Histological appearance of the kidneys on cut section.
- Status and anatomical appearance of the ureters.
- Whether the capsule strips easily and normal foetal lobulation is present (for neonates).

- Weights of the left and right kidney measured in grams (reference is always made to normal organ weight singular or combined organ weight)

Urinary bladder and urethra:

The pathologist may describe:

- Whether the anatomical appearance of the bladder was within normal limits.
- Whether the bladder mucosa showed normal trabeculation.
- Whether any urine was present as well as the constituency thereof.
- Whether the relations at the bladder trigone were normal.
- Condition of the anatomical appearance and mucosa of the urethra was normal.
- Whether any contusions into the soft tissue surrounding the bladder wall was present or not.
- Whether any discoloration of bladder wall was evident.
- The bladder muscle was intact.

Pelvic walls

The pathologist may describe:

- Whether any palpable fractures, dislocations or diastasis were present in any part of the pelvis.

External genital organs

The pathologist may describe:

- The general condition of the penis, scrotum and testes (for males)
- Whether the penis was uncircumcised or not.
- Whether the foreskin appears intact and normal.
- Whether the testes were palpable in the scrotum (for cases where not removed)
- Whether testes were removed for cut section and histological appearance thereof.
- The condition of the vagina, labia and cervix (for females).
- Whether the perianal skin and anal orifice were normal.
- Any visible scars, recent injuries, warts or discharge were evident to suggest recent sexual penetration (sexual abuse cases).

Internal genital organs

The pathologist may describe whether:

- Prostate and urethra was normal (for males)
- The uterus and ovaries were normal (for females)
- The spermatic cord showed any signs of injury such as fresh haemorrhage.
- Ovaries were removed for cut section and histological appearance thereof.
- The rectum appeared normal.
- Female genitalia were intact.
- The fallopian tubes and ovaries were intact and normal.

SPINE

Spinal column:

The pathologist may describe:

- The general anatomical appearance of the spine and intervertebral discs.
- Whether any injuries or fractures were present in any of the vertebrae.
- Whether any dislocations were present in any of the intervertebral joints.
- Whether any associated haemorrhage of the psoas muscles was evident bilaterally.
- Any evidence of spina bifida.

Spinal cord

The pathologist may describe:

- If exposed, the condition of the entire spinal cord.
- Whether any transection or haemorrhage was present.

MUSCLES:

If exposed, the pathologist may describe:

- Whether the muscles were pale or injured.
- Whether any haemorrhage, contusion or laceration of muscle tissue was evident.

RADIOGRAPHIC APPEARANCE OF FULL BODY LODOX SCAN

The pathologist may describe whether:

- Any bony fractures, dislocations or diastasis of any bones or joints were present or not.
- The general conditions of the lung fields are normal.
- The general appearance of the abdominal cavity and abdominal organs appeared normal.
- Any air was present in the pleural cavity, peritoneal cavity, cranium or blood vessels.
- Any opacification was present in the lungs
- Any hepato- or splenomegaly was evident
- The general condition of skeleton was normal

SKELETAL SURVEYS:

- The pathologist may also request skeletal surveys for children suspected of physical abuse. Such examinations are usually conducted at the Red Cross Children Memorial Hospital.
- A consultant paediatrics radiologist will review such cases and provide a written radiology report.

ADDITIONAL REPORTS

The pathologist may include reports from other experts such as:

- Radiology reports on recent and previous skeletal surveys reported on by consultant radiologists.
- Or an odontologist to assess for any injuries to the oral cavities or bite marks in some physical abuse cases.

ADDITIONAL OBSERVATIONS

The pathologist may, where indicated:

- Include a diagram detailing the injuries which are usually appended to the forensic pathology report.
- Refer to photographs taken by the Local Criminal Records Centre of the SAPS.
- Describe whether the investigating officer was present at the time of autopsy.
- Describe whether a forensic pathology officer assisted with the post-mortem examination by preparing and positioning the body for external examination and or performing prosection and evisceration of the organ blocks which are always done under the pathologist's direct supervision.
- Confirm that a death notice was completed using a notice death form and record the serial number thereof.
- Confirm that the forensic pathology report was compiled by him/herself and transcribed by him/herself from contemporaneous handwritten notes and that these were digitally dictated (recorded) directly into digital form with MS Word on the day of the post-mortem examination.

SPECIMENS RETAINED

The pathologist may, where indicated:

- List which organs were taken for histological examination.
- Describe whether tissue sections (including vitreous humour) were retained for histological examination.
- Describe whether a swab of the lungs was retained for microbiology which usually get sent to a dedicated microbiology lab.
- Describe whether lung sections and a heart sections were retained which usually get sent to a dedicated virology laboratory.
- Describe whether blood for drug screen was retained which usually get sent to a dedicated pharmacology laboratory.

When drawing blood for alcohol content the following process is followed:

- Blood for alcoholic content determination may be withdrawn from the femoral vessels under anti-septic condition.
- Such blood is withdrawn with a syringe and transferred to a test tube which had been removed from a polystyrene box with a dedicated seal no using the abbreviation PMK plus reference number (e.g. PMK1654738). (This is a fictitious number.)
- Both the test tube and the polystyrene box get marked with the same identification number (WC admission number) as the subject e.g. WC/11/3237/2016.
- After placing the test tube back into the polystyrene box with its label, this will be handed to a Forensic Officer for resealing with seal no 281039.

For retained bullet fragments:

- For subjects who suffered gunshot injuries, spent bullets will be recovered from the body and gets placed in separate test tubes. Such bullet fragments will be placed in an evidence bag with a seal number PA36574302940 (This is a fictitious number).

- The anatomical site where each bullet was recovered are recorded for each one removed.
- These bullets are then placed in an evidence bag with a seal number PA50946279044 (This is a fictitious number).

For concealment of birth: DNA are taken as follows:

- A blood specimen may be retained for DNA analysis which will be placed into one sterile Whatman FTA microcard. The Whatman FTA microcard will be marked using the neonate's admission number e.g. WC/11/1234/2017, and the area from which the neonate came, and dated. The card is then placed and sealed by the pathologists in an evidence bag marked with a reference number PA56473829201 (fictitious number) which then gets handed to a dedicated Forensic Officer for processing.

Sexual assault examination kit:

For suspected sexual assault victims, the following is done:

- Specimen from the glans penis, anus, external anal area, and nails may be retained and are placed onto sterile swabs removed from a paediatric sexual assault examination KIT (D7) with reference number: 14D6AB8732 (Fictitious number). The above gets sealed by the pathologist and are labelled with the child's admission number and gets dated e.g. 2017-06-14 which then gets placed into an evidence collection bag with reference number PAD 601234567 (fictitious number).

PEOPLE PRESENT DURING AUTOPSY:

Where required, the pathologist will record the names and job titles of people present during the autopsy. These persons may include:

- An additional forensic pathologist
- An odontologist
- Forensic Officer who serves as prosector
- Police officer of the SAPS Local Criminal Records Centre who took photographs of the deceased in the presence of the pathologist
- Any investigative detective and the police branch from which he/she may originate.

HISTOLOGY REPORT

The pathologist may describe:

- That the specimens were submitted to an examination requiring skill in histopathology, a branch of pathology and the following results were obtained:

THE HISTOLOGICAL REPORT:

The histological report may describe:

- Evidence of trauma to the anatomical parts removed e.g optic nerve sheath haemorrhage.
- Evidence of old and recent injury to the rib end.

- Whether any generalised chronic infection was present
- Whether striking global macro-and micro-vesicular steatosis with lipid within vacuolated bile duct epithelium.
- Whether tuberculosis in the hilar lymph nodes.
- The type of virus causing disease e.g acute cytomegalovirus pancreatitis
- Whether any lymphohistiocytosis was present in the bone marrow

REPORT BY ORAL PATHOLOGIST AND CONSULTANT FORENSIC ODONTOLOGIST

- In some cases, the services of oral pathologists and forensic odontologist may also be enlisted.
- Findings that may be made by such experts might be as follows:
    - Describe the shape and form of lesions on the face or mouth.
    - Whether such observed lesions fit the pattern of child abuse.
    - The presence of other lesions on the body and whether such could be bite marks.

Conclusion of pathology report:

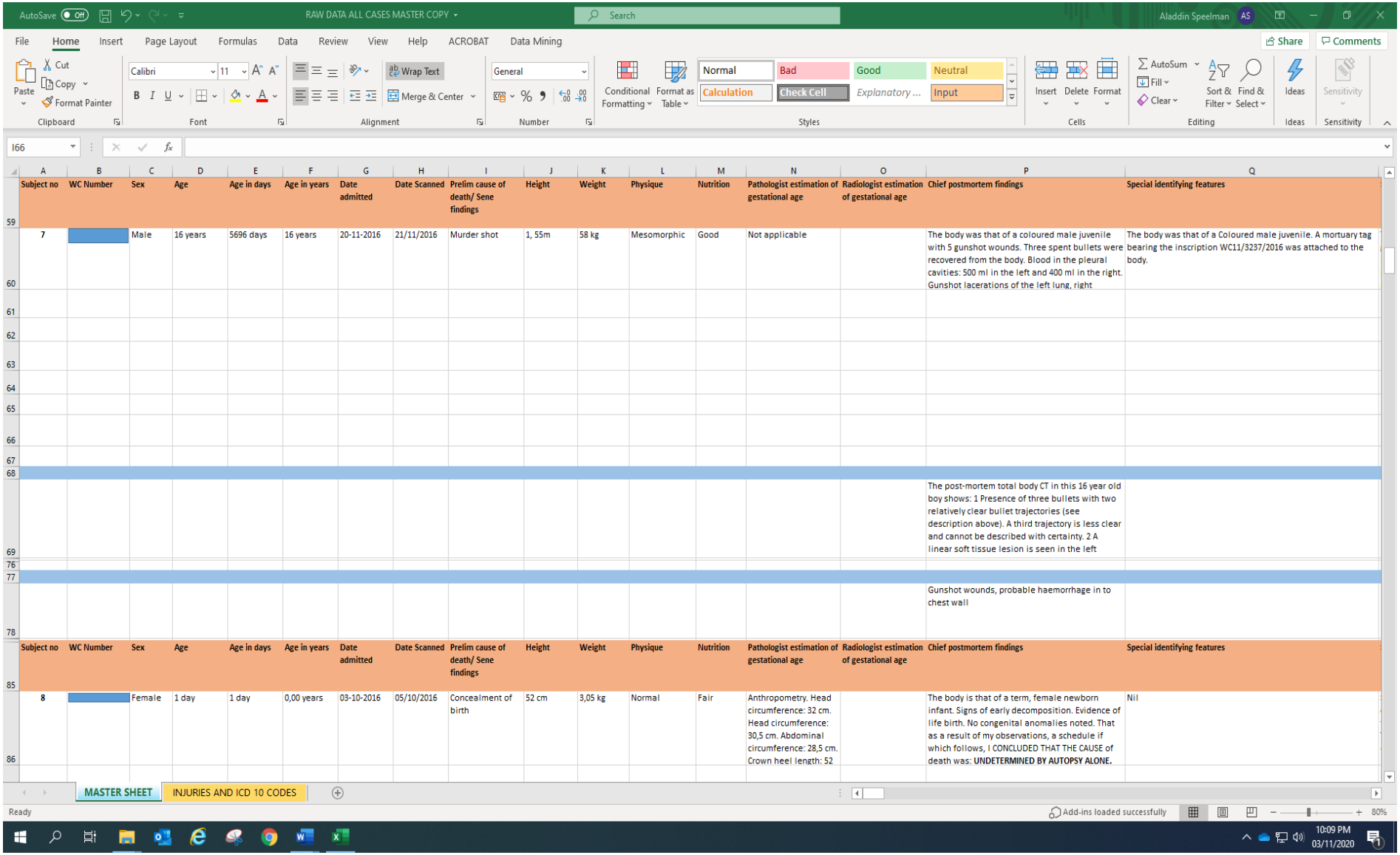
The pathologists will indicate that:

- The report was compiled and transcribed by him/herself.

Organ reference ranges relevant for this study were taken from the following sources:

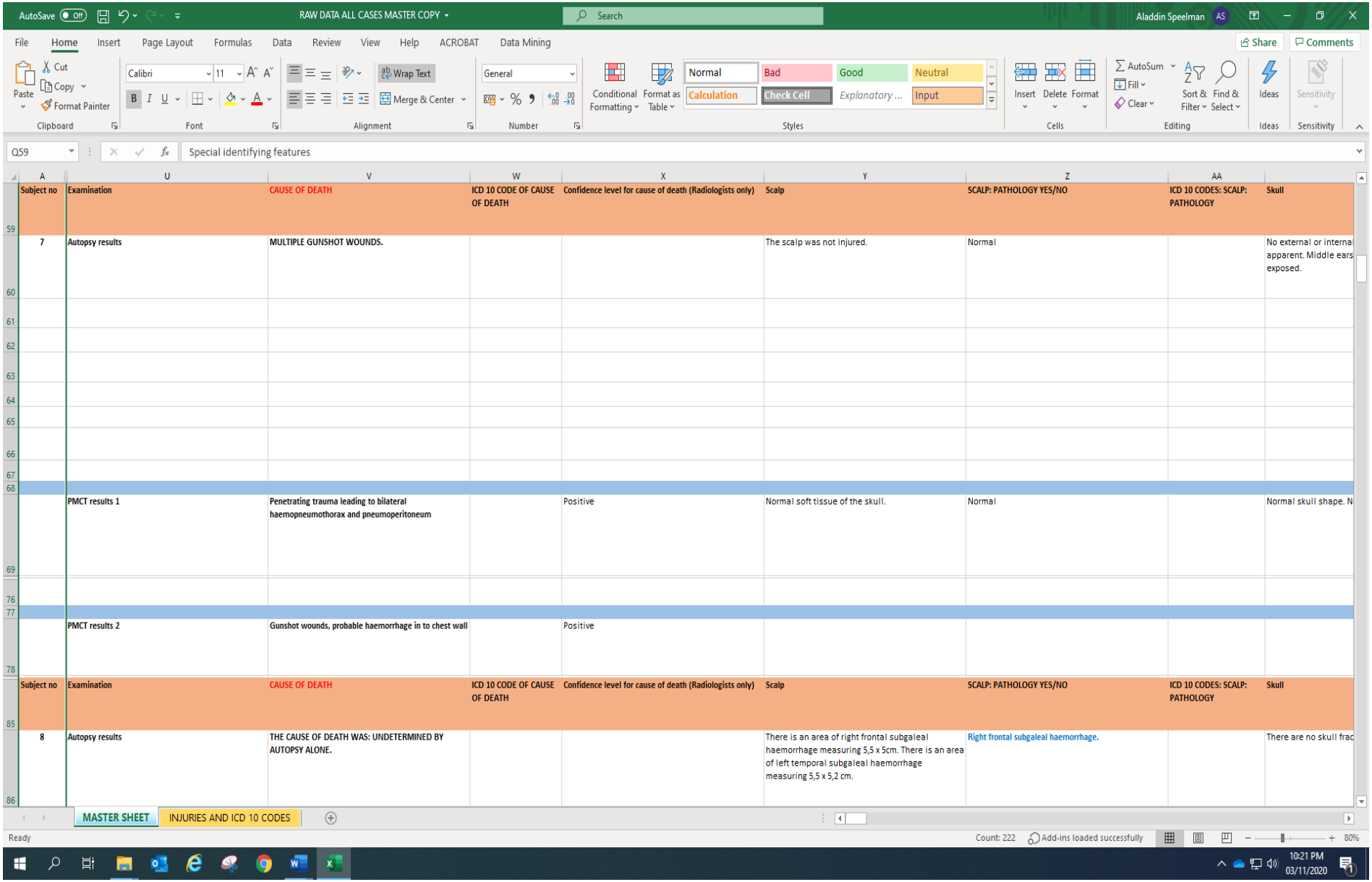
- The Forensic ABC in Medical Practice by TG Schwar, JD Loubser and JA Olivier, 1998. HAUM Educational Publishers, Pretoria
- Knight's Forensic Pathology, 3rd edition by B Knight and P. Saukko, Oxford University Press 2004.
- Peddle, L. and Kirk, G.M. (2017). Post-mortem organ weights at a South African Mortuary. American Journal of Forensic Medicine and Pathology. Volume 38(4), pp.277 – 282.
- Modified data from the Women and Infants Hospital, Providence R. From Jones KL, Harrison JW, Smith DW. J Pediatrics 1978: 92: 787.
- Molina DK, DiMaio, VJ, Normal organ weights in men. Part II- the brain, lungs liver, spleen and kidneys. Am J Forensic Med Pathol. 2012, 33(4): 368 – 372.
- Molina DK, DiMaio, VJ, Normal organ weights in women. Part II- the brain, lungs liver, spleen and kidneys. Am J Forensic Med Pathol. 2015, 36(3): 182 – 187.
- Molina DK, DiMaio, VJ, Normal organ weights in women. Part I- the heart. Am J Forensic Med Pathol. 2015, 36(3): 176 – 181.

ADDENDUM A6: SAMPLE OF MASTER DATA SHEET (PART 1)



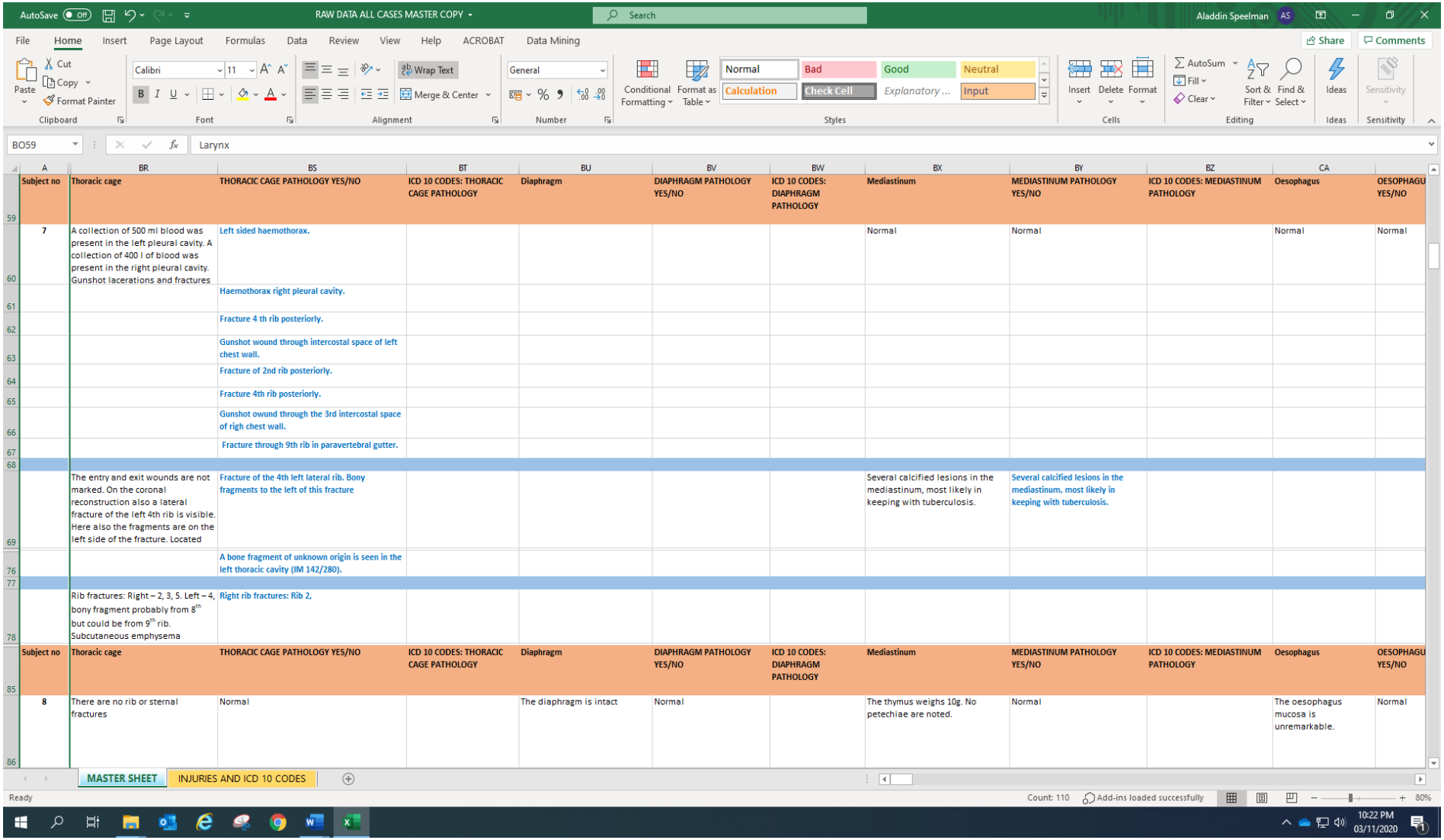
Subject no	WC Number	Sex	Age	Age in days	Age in years	Date admitted	Date Scanned	Prelim cause of death/ Sene findings	Height	Weight	Physique	Nutrition	Pathologist estimation of gestational age	Radiologist estimation of gestational age	Chief postmortem findings	Special identifying features
7	[redacted]	Male	16 years	5696 days	16 years	20-11-2016	21/11/2016	Murder shot	1, 55m	58 kg	Mesomorphic	Good	Not applicable		The body was that of a coloured male juvenile with 5 gunshot wounds. Three spent bullets were recovered from the body. Blood in the pleural cavities: 500 ml in the left and 400 ml in the right. Gunshot lacerations of the left lung, right	The body was that of a Coloured male juvenile. A mortuary tag bearing the inscription WC11/3237/2016 was attached to the body.
															The post-mortem total body CT in this 16 year old boy shows: 1 Presence of three bullets with two relatively clear bullet trajectories (see description above). A third trajectory is less clear and cannot be described with certainty. 2 A linear soft tissue lesion is seen in the left	
															Gunshot wounds, probable haemorrhage in to chest wall	
Subject no	WC Number	Sex	Age	Age in days	Age in years	Date admitted	Date Scanned	Prelim cause of death/ Sene findings	Height	Weight	Physique	Nutrition	Pathologist estimation of gestational age	Radiologist estimation of gestational age	Chief postmortem findings	Special identifying features
8	[redacted]	Female	1 day	1 day	0,00 years	03-10-2016	05/10/2016	Concealment of birth	52 cm	3,05 kg	Normal	Fair	Anthropometry. Head circumference: 32 cm. Head circumference: 30,5 cm. Abdominal circumference: 28,5 cm. Crown heel length: 52		The body is that of a term, female newborn infant. Signs of early decomposition. Evidence of life birth. No congenital anomalies noted. That as a result of my observations, a schedule if which follows, I CONCLUDED THAT THE CAUSE of death was: **UNDETERMINED BY AUTOPSY ALONE.**	Nil

ADDENDUM A6: SAMPLE OF MASTER DATA SHEET (PART 2)



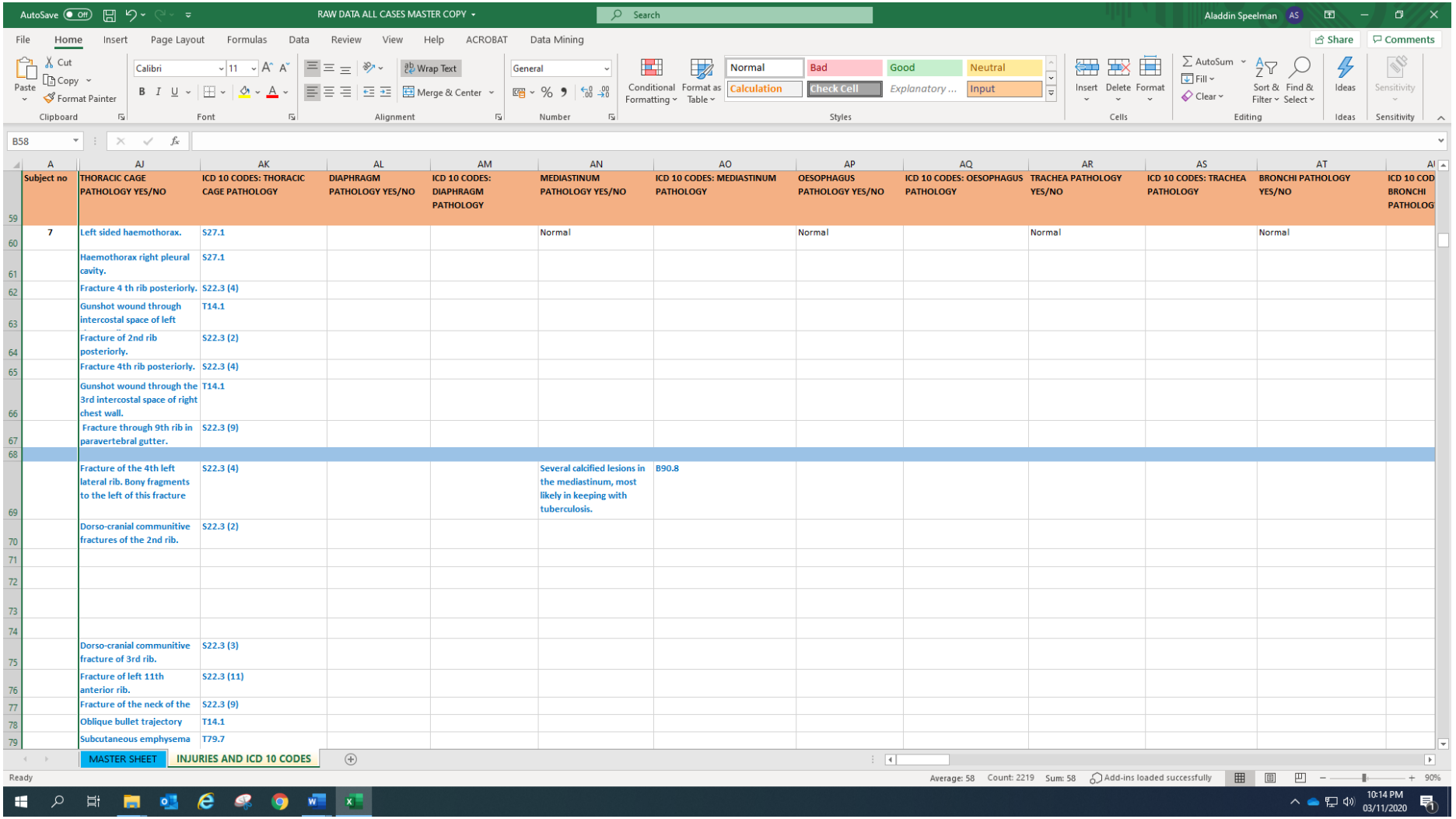
	A	U	V	W	X	Y	Z	AA	
59	Subject no	Examination	CAUSE OF DEATH	ICD 10 CODE OF CAUSE OF DEATH	Confidence level for cause of death (Radiologists only)	Scalp	SCALP: PATHOLOGY YES/NO	ICD 10 CODES: SCALP: PATHOLOGY	Skull
60	7	Autopsy results	MULTIPLE GUNSHOT WOUNDS.			The scalp was not injured.	Normal		No external or interna apparent. Middle ears exposed.
61									
62									
63									
64									
65									
66									
67									
68									
69		PMCT results 1	Penetrating trauma leading to bilateral haemopneumothorax and pneumoperitoneum		Positive	Normal soft tissue of the skull.	Normal		Normal skull shape. N
76									
77									
78		PMCT results 2	Gunshot wounds, probable haemorrhage in to chest wall		Positive				
85	Subject no	Examination	CAUSE OF DEATH	ICD 10 CODE OF CAUSE OF DEATH	Confidence level for cause of death (Radiologists only)	Scalp	SCALP: PATHOLOGY YES/NO	ICD 10 CODES: SCALP: PATHOLOGY	Skull
86	8	Autopsy results	THE CAUSE OF DEATH WAS: UNDETERMINED BY AUTOPSY ALONE.			There is an area of right frontal subgaleal haemorrhage measuring 5,5 x 5cm. There is an area of left temporal subgaleal haemorrhage measuring 5,5 x 5,2 cm.	Right frontal subgaleal haemorrhage.		There are no skull frac

ADDENDUM A6: SAMPLE OF MASTER DATA SHEET (PART 3)



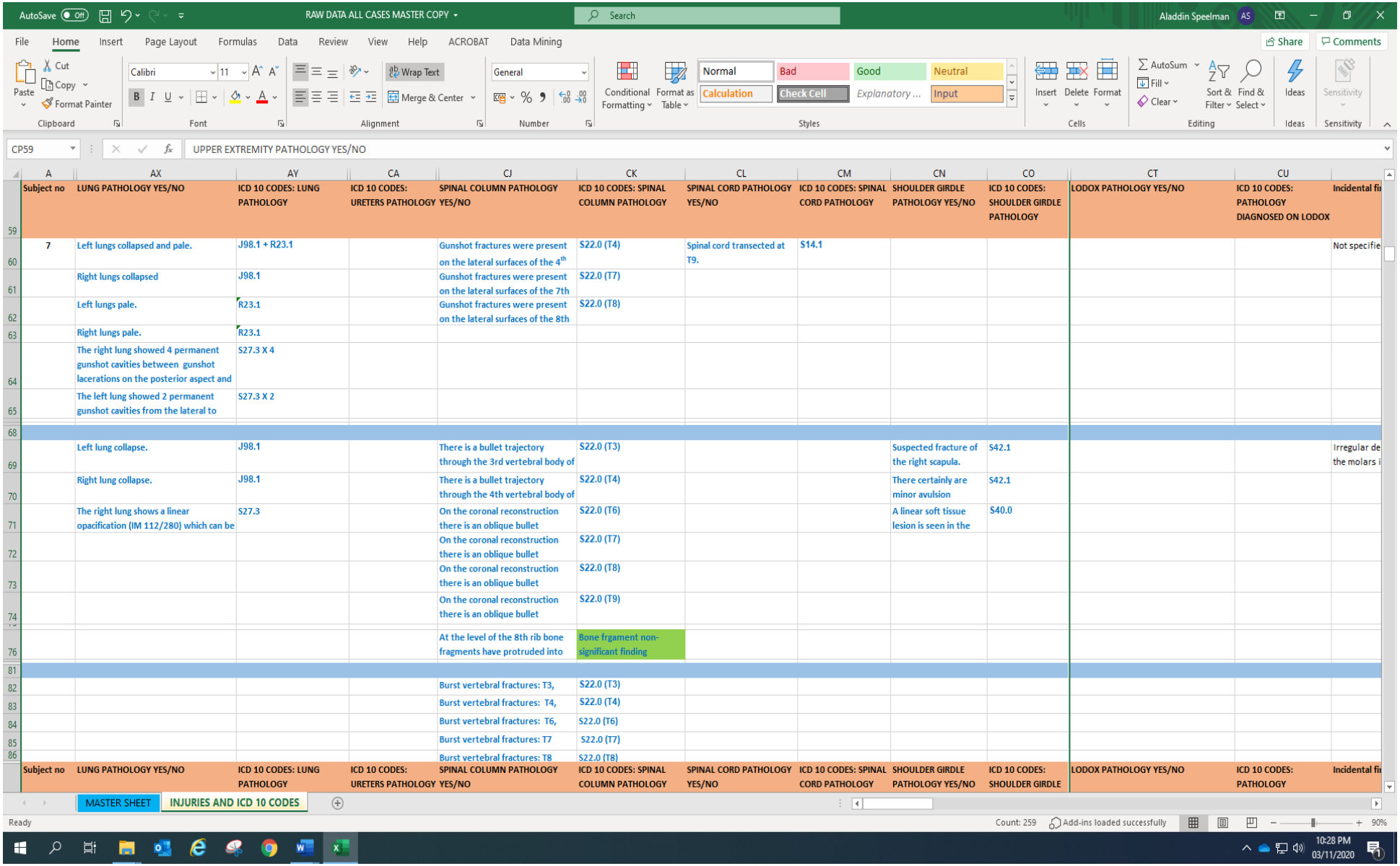
Subject no	Thoracic cage	THORACIC CAGE PATHOLOGY YES/NO	ICD 10 CODES: THORACIC CAGE PATHOLOGY	Diaphragm	DIAPHRAGM PATHOLOGY YES/NO	ICD 10 CODES: DIAPHRAGM PATHOLOGY	Mediastinum	MEDIASTINUM PATHOLOGY YES/NO	ICD 10 CODES: MEDIASTINUM PATHOLOGY	Oesophagus	OESOPHAGU YES/NO
7	A collection of 500 ml blood was present in the left pleural cavity. A collection of 400 l of blood was present in the right pleural cavity. Gunshot lacerations and fractures	Left sided haemothorax.					Normal	Normal		Normal	Normal
		Haemothorax right pleural cavity.									
		Fracture 4 th rib posteriorly.									
		Gunshot wound through intercostal space of left chest wall.									
		Fracture of 2nd rib posteriorly.									
		Fracture 4th rib posteriorly.									
		Gunshot owund through the 3rd intercostal space of righ chest wall.									
		Fracture through 9th rib in paravertebral gutter.									
	The entry and exit wounds are not marked. On the coronal reconstruction also a lateral fracture of the left 4th rib is visible. Here also the fragments are on the left side of the fracture. Located	Fracture of the 4th left lateral rib. Bony fragments to the left of this fracture					Several calcified lesions in the mediastinum, most likely in keeping with tuberculosis.	Several calcified lesions in the mediastinum, most likely in keeping with tuberculosis.			
		A bone fragment of unknown origin is seen in the left thoracic cavity (IM 142/280).									
	Rib fractures: Right – 2, 3, 5. Left – 4, bony fragment probably from 8th but could be from 9th rib. Subcutaneous emphysema	Right rib fractures: Rib 2,									
Subject no	Thoracic cage	THORACIC CAGE PATHOLOGY YES/NO	ICD 10 CODES: THORACIC CAGE PATHOLOGY	Diaphragm	DIAPHRAGM PATHOLOGY YES/NO	ICD 10 CODES: DIAPHRAGM PATHOLOGY	Mediastinum	MEDIASTINUM PATHOLOGY YES/NO	ICD 10 CODES: MEDIASTINUM PATHOLOGY	Oesophagus	OESOPHAGU YES/NO
8	There are no rib or sternal fractures	Normal		The diaphragm is intact	Normal		The thymus weighs 10g. No petechiae are noted.	Normal		The oesophagus mucosa is unremarkable.	Normal

ADDENDUM A7: SAMPLE OF DATA SHEET WITH ICD 10 CODES (PART 1)



Subject no	THORACIC CAGE PATHOLOGY YES/NO	ICD 10 CODES: THORACIC CAGE PATHOLOGY	DIAPHRAGM PATHOLOGY YES/NO	ICD 10 CODES: DIAPHRAGM PATHOLOGY	MEDIASTINUM PATHOLOGY YES/NO	ICD 10 CODES: MEDIASTINUM PATHOLOGY	OESOPHAGUS PATHOLOGY YES/NO	ICD 10 CODES: OESOPHAGUS PATHOLOGY	TRACHEA PATHOLOGY YES/NO	ICD 10 CODES: TRACHEA PATHOLOGY	BRONCHI PATHOLOGY YES/NO	ICD 10 COD BRONCHI PATHOLOG
7	Left sided haemothorax.	S27.1			Normal		Normal		Normal		Normal	
	Haemothorax right pleural cavity.	S27.1										
	Fracture 4 th rib posteriorly.	S22.3 (4)										
	Gunshot wound through intercostal space of left	T14.1										
	Fracture of 2nd rib posteriorly.	S22.3 (2)										
	Fracture 4th rib posteriorly.	S22.3 (4)										
	Gunshot wound through the 3rd intercostal space of right chest wall.	T14.1										
	Fracture through 9th rib in paravertebral gutter.	S22.3 (9)										
	Fracture of the 4th left lateral rib. Bony fragments to the left of this fracture	S22.3 (4)			Several calcified lesions in the mediastinum, most likely in keeping with tuberculosis.	B90.8						
	Dorso-cranial communitive fractures of the 2nd rib.	S22.3 (2)										
	Dorso-cranial communitive fracture of 3rd rib.	S22.3 (3)										
	Fracture of left 11th anterior rib.	S22.3 (11)										
	Fracture of the neck of the	S22.3 (9)										
	Oblique bullet trajectory	T14.1										
	Subcutaneous emphysema	T79.7										

ADDENDUM A7: SAMPLE OF DATA SHEET WITH ICD 10 CODES (PART 2)



Subject no	LUNG PATHOLOGY YES/NO	ICD 10 CODES: LUNG PATHOLOGY	ICD 10 CODES: URETERS PATHOLOGY	SPINAL COLUMN PATHOLOGY YES/NO	ICD 10 CODES: SPINAL COLUMN PATHOLOGY	SPINAL CORD PATHOLOGY YES/NO	ICD 10 CODES: SPINAL CORD PATHOLOGY	SHOULDER GIRDLE PATHOLOGY YES/NO	ICD 10 CODES: SHOULDER GIRDLE PATHOLOGY	LODOX PATHOLOGY YES/NO	ICD 10 CODES: PATHOLOGY DIAGNOSED ON LODOX	Incidental fi
7	Left lungs collapsed and pale.	J98.1 + R23.1		Gunshot fractures were present on the lateral surfaces of the 4th	S22.0 (T4)	Spinal cord transected at T9.	S14.1					Not specifie
	Right lungs collapsed	J98.1		Gunshot fractures were present on the lateral surfaces of the 7th	S22.0 (T7)							
	Left lungs pale.	R23.1		Gunshot fractures were present on the lateral surfaces of the 8th	S22.0 (T8)							
	Right lungs pale.	R23.1										
	The right lung showed 4 permanent gunshot cavities between gunshot lacerations on the posterior aspect and	S27.3 X 4										
	The left lung showed 2 permanent gunshot cavities from the lateral to	S27.3 X 2										
	Left lung collapse.	J98.1		There is a bullet trajectory through the 3rd vertebral body of	S22.0 (T3)			Suspected fracture of the right scapula.	S42.1			Irregular de the molars i
	Right lung collapse.	J98.1		There is a bullet trajectory through the 4th vertebral body of	S22.0 (T4)			There certainly are minor avulsion	S42.1			
	The right lung shows a linear opacification (IM 112/280) which can be	S27.3		On the coronal reconstruction there is an oblique bullet	S22.0 (T6)			A linear soft tissue lesion is seen in the	S40.0			
				On the coronal reconstruction there is an oblique bullet	S22.0 (T7)							
				On the coronal reconstruction there is an oblique bullet	S22.0 (T8)							
				On the coronal reconstruction there is an oblique bullet	S22.0 (T9)							
				At the level of the 8th rib bone fragments have protruded into	Bone frgament non-significant finding							
				Burst vertebral fractures: T3,	S22.0 (T3)							
				Burst vertebral fractures: T4,	S22.0 (T4)							
				Burst vertebral fractures: T6,	S22.0 (T6)							
				Burst vertebral fractures: T7	S22.0 (T7)							
				Burst vertebral fractures: T8	S22.0 (T8)							
Subject no	LUNG PATHOLOGY YES/NO	ICD 10 CODES: LUNG PATHOLOGY	ICD 10 CODES: URETERS PATHOLOGY	SPINAL COLUMN PATHOLOGY YES/NO	ICD 10 CODES: SPINAL COLUMN PATHOLOGY	SPINAL CORD PATHOLOGY YES/NO	ICD 10 CODES: SPINAL CORD PATHOLOGY	SHOULDER GIRDLE PATHOLOGY YES/NO	ICD 10 CODES: SHOULDER GIRDLE	LODOX PATHOLOGY YES/NO	ICD 10 CODES: PATHOLOGY	Incidental fi

ADDENDUM A8: ICD 10 CODES FOR INJURIES PER ANATOMICAL REGION

HEAD AND NECK	STATISTICAL CODE	ICD 10 CODE
Brain compression traumatic (diffuse)	**A1**	**S06.2**
Brain contusion (localised) (focal)	**A2**	**DS06.3**
Brain laceration (cortex or any part) (diffuse) (membrane) (focal)	**A3**	**ES06.3**
Brain oedema: traumatic	**A4**	**S06.1**
Diastasis: skull bones	**A5**	**M84.8**
Fracture: mandible	**A6**	**S02.6**
Fracture: maxilla	**A7**	**S02.4**
Fracture: nasal bone/septum	**A8**	**S02.2**
Fracture: orbit (including wall, floor & roof)	**A9**	**S02.8**
Fracture: skull (complex: parts not specified)	**A10**	**S02.9**
Fracture skull: depressed (any part)	**A11**	**S02.0**
Fracture: skull: base (involving clivus), temporal bone, occipital bone, petrous temporal bone, skull base area not specified.	**A12**	**S02.1**
Fracture: skull: frontal bone	**A13**	**BS02.0**
Fracture: skull: parietal bone	**A14**	**AS02.0**
Haemorrhage: scalp	**A15**	**R58**
Injury: pharynx (throat)	**A16**	**S10.1**
Injury: scalp	**A17**	**S00.0**
Injury: tongue	**A18**	**S09.9 (To)**
Injury: tonsils	**A19**	**S09.9 (T)**
Intracerebral haemorrhage (traumatic)	**A20**	**S06.3**
Intraventricular haemorrhage	**A21**	**I61.5**
Laceration: common carotid artery	**A22**	**S15.0**

Laceration: internal jugular vein	**A23**	**S15.3**
Open wounds of other parts of the head	**A24**	**S01.8**
Pneumocephalus	**A25**	**G93.8**
Subgaleal haemorrhage	**A26**	**P15.8**
Subarachnoid haemorrhage (traumatic)	**A27**	**S06.6**
Subdural haemorrhage (traumatic)	**A28**	**S06.5**
THORAX	**STATISTICAL CODE**	**ICD 10 CODE**
Aspiration of blood	**B1**	**W80**
Aspiration of gastric content/food	**B2**	**W79**
Displacement of heart (and great vessels)	**B3**	**I51.8**
Fracture: rib	**B4**	**S22.3**
Fracture: ribs (multiple)	**B5**	**S22.4**
Fracture: sternum	**B6**	**S22.2**
Haemothorax (traumatic)	**B7**	**S27.1**
Haemorrhage: heart (atrium) (Including atrium, endo- and epicardium)	**B8**	**S26.0**
Haemorrhage: lung (sub-pleural) (petechial)	**B9**	**R04.8**
Haemorrhage: mediastinum	**B10**	**R04.9**
Haemorrhage: thymus	**B11**	**E32.8**
Laceration: heart	**B12**	**S26**
Lung atelectasis	**B13**	**JJ98.1**
Lung collapse	**B14**	**J98.1**
Lung congestion	**B15**	**J81**
Lung consolidation	**B16**	**J98.9**
Lung injury	**B17**	**S27.3**
Perforation heart valves	**B18**	**HS26**
Pleural effusion	**B19**	**J90**

Pneumothorax (traumatic)	**B20**	**S27.0**
Subpleural bleb	**B21**	**J43.9**
ABDOMEN AND PELVIS	**STATISTICAL CODE**	**ICD 10 CODE**
Ascites	**C1**	**R18**
Contusion: diaphragm	**C2**	**S27.8**
Contusion: duodenum	**C3**	**S36.4**
Fracture: ischium	**C4**	**S32.8**
Fracture: symphysis pubis	**C5**	**S32.5**
Haemoperitoneum	**C6**	**FS36.8**
Injury: adrenal gland	**C7**	**S37.8**
Injury: kidney	**C8**	**S37.0**
Injury: pancreas	**C9**	**S36.2**
Injury: spleen	**C10**	**S36.0**
Injury: superficial (anus, penis)	**C11**	**S30.8**
Injury: stomach	**C12**	**S36.3**
Laceration: liver	**C13**	**S36.1**
Pneumoperitoneum (following injury of intra-abdominal organs)	**C14**	**GS36.8**
Umbilical hernia	**C15**	**K42.9**
SPINAL COLUMN	**STATISTICAL CODE**	**ICD 10 CODE**
Fracture: vertebra C1	**D1**	**S12.0**
Fracture: vertebra C2	**D2**	**S12.1**
Fracture vertebra (T1 – T12)	**D3**	**S22.0**
Fracture vertebra (L 1 – 5)	**D4**	**S32.0**
Spinal cord transection	**D5**	**S14.1**
UPPER EXTREMITY	**STATISTICAL CODE**	**ICD 10 CODE**

Fracture: humerus (including proximal and distal)	**E1**	**S42.2**
Fracture: metacarpal bone (second & third)	**E2**	**S62.3**
Fracture: radius (midshaft)	**E3**	**S52.3**
Fracture: scapula	**E4**	**S42.1**
Fracture: ulna	**E5**	**S52.2**
LOWER EXTREMITY	**STATISTICAL CODE**	**ICD 10 CODE**
Fracture: metatarsal bone (second & third)	**F1**	**S92.3**
Fracture: tibia (shaft)	**F2**	**S82.2**
OTHER	**STATISTICAL CODE**	**ICD 10 CODE**
Air embolism (air in blood vessel) (any site)	**G1**	**T79.0**
Atheroma (atherosclerosis) of aorta/blood vessels	**G2**	**I70**
Bullet retained: buttocks, C-spine, humerus, mandible, neck, shoulder, thorax	**G3**	**AA1**
Oedema: soft tissue	**G4**	**R60.0**
Enlarged lymph nodes (unspecified)	**G5**	**R59.9**
Haemorrhage: subcutaneous	**G6**	**R23.3**
Injury: aorta	**G7**	**S25.0**
Injury: muscle	**G8**	**T14.6**
Laceration: skin	**G9**	**T14.1**
Pallor (pale organs internal or external)	**G10**	**R23.1**
Subcutaneous emphysema/air	**G11**	**T79.7**

ADDENDUM A9: ETHICS APPROVAL: RESEARCH ETHICS COMMITTEE, FACULTY OF HEALTH AND WELLNESS SCIENCES, CAPE PENINSULA UNIVERSITY OF TECHNOLOGY

Cape Peninsula
University of Technology

HEALTH AND WELLNESS SCIENCES RESEARCH ETHICS COMMITTEE (HW-REC)
Registration Number NHREC: REC- 230408-014

P.O. Box 1906 • Bellville 7535 South Africa
Symphony Road Bellville 7535
•Tel: +27 21 959 6917 • Fax +27 21 953 8490
Email: lebenyat@cput.ac.za

06 October 2014
CPUT/HW-REC 2014/H12

Faculty of Health and Wellness Sciences – Nursing and Radiography Department

Dear Mr Speelman

YOUR APPLICATION TO THE HW-REC FOR ETHICAL CLEARANCE

At the meeting of the Health and Wellness Sciences-REC on 2 October 2014 approval was granted to Aladdin Speelman pending minor amendments that have now been received and reviewed. This approval is for research activities related to your DTech Radiography Technology at CPUT.

TITLE: Postmortem Computerized Tomography in the assessment of fatal child abuse.

SUPERVISOR: Prof. P. Engel-hills
CO-SUPERVISER: Prof. L Martin

Comment:
Approval will not extend beyond 07 October 2015. An extension should be applied for 6 weeks before this expiry date should data collection and use/analysis of data, information and/or samples for this study continue beyond this date.

The investigator(s) should understand the conditions under which they are authorized to carry out this study and they should be compliant to these conditions. **It is required that the investigator(s) complete an annual progress report that should be submitted to the HW-REC in December of that particular year, for the HW-REC to be kept informed of the progress and of any problems you may encounter.**

Kind Regards

MR. NAVINDHRA NAIDOO
CHAIRPERSON – ETHICS RESEARCH COMMITTEE
FACULTY OF HEALTH AND WELLNESS SCIENCES

ADDENDUM A10: ETHICS APPROVAL: HUMAN RESEARCH ETHICS COMMITTEE: FACULTY OF HEALTH SCIENCES, UNIVERSITY OF CAPE TOWN

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room E52-24 Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6338 • **Facsimile** [021] 406 6411
Email: sumayah.ariefdien@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

03 September 2015

HREC REF: 822/2014

Prof L Martin
Forensic Medicine
Entrance 3, Level 1
Falmouth Building
FHS

Dear Prof Martin

PROJECT TITLE: POSTMORTEM COMPUTERISED TOMOGRAPHY IN THE ASSESSMENT OF FATAL CHILD ABUSE (DOCTOR TECHNOLOGY-candidate-A Speelman)

Thank you for your response letter dated 02 September 2015, addressing the issues raised by the Human Research Ethics Committee (HREC).

It is a pleasure to inform you that the HREC has formally approved the above-mentioned study.

Approval is granted for one year until the 30th September 2016.

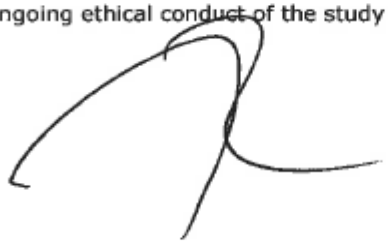
Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

We acknowledge that the following student:- Aladdin Speelman is also involved in this project.

Please quote the HREC reference no in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Yours sincerely



PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE
Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938

Hrec/ref:822/2014

ADDENDUM A11: SITE PERMISSION: HEALTH RESEARCH COMMITTEE, THE PROVINCIAL DEPARTMENT OF HEALTH, WESTERN CAPE GOVERNMENT

Western Cape Government
Health

STRATEGY & HEALTH SUPPORT
Health.Research@westerncape.gov.za
tel: +27 21 483 6857; fax: +27 21 483 9895
5th Floor, Norton Rose House, 8 Riebeek Street, Cape Town, 8001
www.capegateway.gov.za)

REFERENCE: WC_2015RP45_363
ENQUIRIES: Ms Charlene Roderick

Symphony Way
Bellville South Industrial
Cape Town
7535

For attention: **MR Aladdin Speelman**

Re: POSTMORTEM CT (PMCT) IN THE ASSESSMENT OF FATAL CHILD ABUSE.

Thank you for submitting your proposal to undertake the above-mentioned study. We are pleased to inform you that the department has granted you approval for your research.
Please contact the following people to assist you with any further enquiries in accessing the following sites:

Salt River Mortuary **S Fawcus** **Contact No: 021 659 5579**

Kindly ensure that the following are adhered to:

1. Arrangements can be made with managers, providing that normal activities at requested facilities are not interrupted.
2. Researchers, in accessing provincial health facilities, are expressing consent to provide the department with an electronic copy of the final feedback (annexure 9) within six months of completion of research. This can be submitted to the provincial Research Co-ordinator (Health.Research@westerncape.gov.za)

3. The reference number above should be quoted in all future correspondence.

Yours sincerely

AA HAWKRIDGE

DR A HAWKRIDGE
DIRECTOR: HEALTH IMPACT ASSESSMENT
DATE: 26/11/2015.
CC

ADDENDUM A12: SITE PERMISSION: NETCARE RESEARCH OPERATIONS COMMITTEE, NETCARE MANAGEMENT (PTY) LIMITED

Netcare Management (Pty) Limited

Tel: + 27 (0)11 301 0000
Fax: Corporate +27 (0)11 301 0499
76 Maude Street, Corner West Street, Sandton, South Africa
Private Bag X34, Benmore, 2010, South Africa

RESEARCH OPERATIONS COMMITTEE FINAL APPROVAL OF RESEARCH

Approval number: UNIV-2014-0051

Mr Aladdin Speelman

E mail: speelmana@cput.ac.za

Dear Mr Speelman

RE: POSTMORTEM COMPUTERISED TOMOGRAPHY IN THE ASSESSMENT OF FATAL CHILD ABUSE

The above-mentioned research was reviewed by the Research Operations Committee's delegated members and it is with pleasure that we inform you that your application to conduct this research at [redacted] has been approved, subject to the following:

i) Research may now commence with this FINAL APPROVAL from the Netcare Research Operations Committee.

ii) All information regarding Netcare will be treated as legally privileged and confidential.

iii) Netcare's name will not be mentioned without written consent from the Netcare Research Operations Committee.

iv) All legal requirements regarding patient / participant's rights and confidentiality will be complied with.

v) The research will be conducted in compliance with the GUIDELINES FOR GOOD PRACTICE IN THE CONDUCT OF CLINICAL TRIALS IN HUMAN PARTICIPANTS IN SOUTH AFRICA (2006)

vi) Netcare must be furnished with a STATUS REPORT on the progress of the study at least annually on 30th September irrespective of the date of approval from the Netcare Research Operations Committee as well as a FINAL REPORT with reference to intention to publish and probable journals for publication, on completion of the study.

vii) A copy of the research report will be provided to the Netcare Research Operations Committee once it is finally approved by the relevant primary party or tertiary

ADDENDUM B1: INJURY CATEGORY DISCORDANCE BETWEEN THE FORENSIC AUTOPSY AND PMCT

Injury categories	No. of injuries not diagnosed with forensic autopsies	No. of injuries not diagnosed with PMCT
1 Gas collections	33	0
2 Haemorrhagic injuries	8	40
3 Fluid collections	7	10
4 Hollow organ injury	0	9
5 Large blood vessel injuries	0	9
6 Muscle injuries	0	8
7 Skeletal injuries	33	8
8 Soft tissue injuries	1	24
9 Solid organ injuries	7	88
Total	**89**	**196**

ADDENDUM B2: INJURY TYPE DISCORDANCE BETWEEN THE FORENSIC AUTOPSY AND PMCT

(The totals for forensic autopsy were measure against the combined scores for Reviewers 1 and 2).

Injury categories	Injury type/abnormality	Number of discrepant findings: FA	Number of discrepant findings: PMCT
Gas collections	Pneumocephalus	13	-
	Pneumoperitoneum	3	-
	Pneumothorax	17	-
	Sub-totals	**33**	**-**
Large blood vessel injuries	Perforation: aorta	-	3
	Laceration: carotid artery	-	2
	Laceration: internal jugular vein	-	2
	Perforation superior pulmonary artery	-	1
	Perforation Superior Vena Cava	-	1
	Sub-totals	-	**9**
Haemorrhagic injuries	Haemorrhage: heart	-	6
	Haemorrhage: intraventricular (brain)	6	-
	Haemorrhage: intracerebral	2	-
	Haemorrhage: lung	-	13
	Haemorrhage: mediastinum	-	7
	Hemorrhage optic nerves sheath	-	2
	Haemorrhage: soft tissue	-	3
	Haemorrhage: subgaleal	-	2
	Haemorrhage: thymus	-	1
	SAH	-	1
	SDH	-	5
	Sub-totals	**8**	**40**
Fluid collections	Ascites	3	-
	Aspiration: blood		7
	Aspiration: gastric content		3
	Haemoperitoneum	-	-
	Haemothorax	1	-
	Pleural effusion	3	-
	Sub-totals	**7**	**10**
Hollow organ injuries	Injury bladder	-	3
	Injury: bronchus	-	1
	Contusion: duodenum	-	3
	Contusion stomach	-	2
	Sub-totals	**-**	**9**
Muscle injuries	Contusion: diaphragm	-	2
	Injury: various muscles	-	3
	Injury: tongue	-	3
	Sub-totals	**-**	**8**
Skeletal injuries	Diastasis skull bones	-	-

	Dislocation cervical vertebra 1	-	1
	Dislocation hip	-	1
	Fracture acetabulum	1	-
	Fracture: cervical vertebra 1	1	-
	Fracture: cervical vertebra 2	2	-
	Fracture: facial bones	7	-
	Fracture: fibula	-	-
	Fracture: humerus	1	-
	Fracture ilium (involving SI joint)	1	-
	Fracture: ischium	-	-
	Fracture: lumbar vertebrae	-	1
	Fracture: metacarpal bone	-	2
	Fracture: metatarsal bone	1	-
	Fracture: radius	-	1
	Fracture: rib	-	1
	Fracture: scapula	1	-
	Fracture: skull (including base)	12	-
	Fracture: sternum	1	-
	Fracture: symphysis pubis	1	-
	Fracture: thoracic vertebrae	4	-
	Fracture: tibia	-	-
	Fracture: ulna	-	1
	Sub-totals	**33**	**8**
Soft tissue injuries	Injury: pharynx	-	4
	Injury: scalp	-	12
	Injury: superficial soft tissue (genitals)	-	3
	Oedema: soft tissue (various)	-	5
	Wound: head	-	-
	Morel-Lavallée lesion	1	-
	Sub-totals	**1**	**24**
Solid organ injuries	Atelectasis: lung	-	3
	Bleb: Sub-pleural	-	2
	Brain compression	4	-
	Brain oedema	-	6
	Collapse: lung	-	1
	Congestion: lung	-	9
	Contusion: brain	-	8
	Heart displacement	3	-
	Heart valve perforation	-	2
	Injury: adrenal	-	3
	Injury: kidney	-	1
	Injury: lung	-	21
	Injury: pancreas	-	3
	Injury: parotids	-	2
	Injury: spleen	-	2
	Injury: tonsils	-	2
	Laceration: brain	-	9
	Laceration: heart	-	5
	Laceration: liver	-	3
	Laceration: skin	-	4
	Transection: spinal cord	-	2
	Sub-totals	**7**	**88**
	No of findings not diagnosed by each examination	**89**	**196**

ADDENDUM B3: CAUSE OF DEATH SCORED WITH THE FORENSIC AUTOPSY AND REVIEWERS 1 AND 2

Subject number*	Age	Sex	Initial manner of death	Cause of death: Forensic Autopsy	Cause of death: PMCT Reviewer 1	Cause of death: PMCT Reviewer 2
1	1 month	Male	SUDI	Pneumonia	Unknown	Unknown
2	5 months	Male	SUDI	Pneumonia	Unknown	Unknown
3	2 months	Male	SUDI	Gastro-enteritis	Unknown	Unknown
4	1 day	Female	Concealment of birth	Unknown	Unknown	Unknown
5	3 months	Male	SUDI	Pneumonia	Unknown	Unknown
6	1 day	Male	Concealment of birth	Haemorrhage from unclamped umbilical cord.	Unknown	Unknown
7	16 years	Male	Gunshot wound	Gunshot injuries: multiple	Gunshot injuries	Gunshot injuries
8	1 day	Female	Concealment of birth	Unknown	Unknown	Unknown
9	18 months	Male	RTA Pedestrian	Blunt force head injury	Blunt force head injury	Blunt force head injury
10	2 years	Female	RTA Pedestrian	Blunt force head and neck injury	Blunt force head injury	Blunt force head injury
11	3 years	Male	SUDI	Severe abdominal and pelvic injuries (physical abuse)	Blunt abdominal trauma	Unknown
12	14 years	Male	Gunshot wound	Gunshot injuries: chest and thigh	Gunshot injuries	Gunshot injuries
13	17 years	Male	Gunshot wound	Gunshot injuries: head and chest	Gunshot injuries	Gunshot injuries
14	18 months	Male	SUDI/Assault	Child abuse (physical)	Child abuse (physical)	Child abuse (physical)
15	17 years	Male	Gunshot wound	Gunshot injury: chest	Gunshot injury	Gunshot injury
16	17 years	Male	Gunshot wound	Gunshot injury: chest	Tension haemo-pneumothorax	Fatal stab wound
17	4 years	Female	Gunshot wound	Gunshot injury: head	Gunshot injury	Gunshot injury
18	3 days	Male	Suffocation	Unknown	Unknown	Unknown
19	7 years	Male	Gunshot wound	Gunshot injury: neck	Gunshot injury	Gunshot injury
20	1 day	Male	Strangled	Asphyxia- smothering.	Unknown	Unknown
21	6 years	Male	Homicide/Blunt Force	Blunt force head injury	Blunt force head injury	Blunt force head injury
22	1 year	Female	SUDI	Hyperthermia	Unknown	Unknown
23	9 years	Male	RTA Pedestrian	Multiple blunt force injuries to the head and body.	Blunt force head injury	Blunt force head injury
24	10 months	Male	SUDI	Mucolipidosis	Unknown	Unknown
25	5 years	Female	RTA Pedestrian	Blunt force head injury	Blunt force head injury	Blunt force head injury
26	16 years	Male	Gunshot wound	Gunshot injuries: thorax and leg	Gunshot injuries	Gunshot injuries
27	19 months	Male	Assault	Blunt force head injury	Blunt force head injury	Blunt force head injury
28	16 years	Male	Gunshot wound	Gunshot injury: abdomen	Gunshot injury	Gunshot injury
29	16 years	Male	Gunshot wound	Gunshot injuries: head and chest	Gunshot injuries	Gunshot injuries
30	16 years	Male	Gunshot wound	Gunshot injury: chest	Gunshot injury	Gunshot injury

*Subjects listed in chronological order of presentation/recruitment to the study/ Highlighted text display the unknown CoD. (Speelman et al., 2022).

ADDENDUM B4: SIGNIFICANT INJURIES SEEN DURING PMCT EXAMINATIONS

Anatomical region	Subject number	Blunt force head injury	Gunshot injuries	Physical Abuse
Head and neck: Skull fractures				
Orbits	9 (Orbital fracture: part unspecified) 10 (Roof, floor and orbit wall fractures) 25 (Orbit wall) 29 (Orbit wall)	X X X	 X	
Frontal bone fractures	21, 27 (unilateral) 9, 29 (bi-lateral)	X	X	
Parietal bone fractures	10: (bi-lateral) 17, 21, 25, 27: (unilateral)	X	X	
Skull base fracture (involving clivus)	10	X		
Depressed skull fracture	10	X		
Occipital bone fracture	10, 13, 14: (unilateral) 21: (bi-lateral)	X	X	X
Temporal bone fracture	13, 25 (unilateral)	X	X	
Diastatic fractures	9 (coronal suture and squamosal sutures) 27 (coronal suture)	X		
Soft tissue swelling on the vertex of the head	14 associated with subcutaneous hematomas.			X
Facial bone fractures. Maxilla fracture	 9	X		
Nasal bone fracture	10, 25	X		
Mandible fracture	10	X		
Intracranial Brain oedema/ raised intracranial pressure	 9, 10, 11, 13, 21, 27	X	X	X
Intraventricular haemorrhages	9, 10, 13, 21, 25	X	X	
SDH	25	X		
SAH	13, 17, 25, 27	X	X	
Intracerebral haemorrhages	10, 25, 27	X		
Pneumocephalus	9, 13, 15, 17	X	X	
Soft tissue swelling scalp	25	X		
Subgaleal haemorrhage	27	X		
Haemorrhage along the bullet trajectory.	17		X	
Location of entrance wounds: head	13, 17		X	
Retained bullets and fragments in the head	7, 13 (n = 3 each) 17, 29 (n = 2 each)		X	
Assessment of ricochet trauma, following gunshot	7, 13		X	

(Bullet ricochet of internal tabula of left temporal bone)				
Assessment of location of bony fragments: head	17		X	
Thorax Traumatic aspiration	26		X	
Pneumothorax	7, 10, 15, 16, 26, 29, 30 (bilateral) 12, (unilateral)	X	X	
Tension pneumothorax	13		X	
Haemothorax	7, 12, 15, 26, 29, 30 (bilateral) 13, 16 (unilateral)		X	
Pleural effusion	11, 25, 27 (bilateral)	X		X
Perforation of lungs.	13, 16, 26, 30		X	
Lung collapse	7, 12 (bilateral) 29, 30 (unilateral)		X	
Tunnelled lacerations of the lungs	7 (showing bullet tracks)		X	
Displacement of the heart and mediastinum	13, 15, 16, 29		X	
Rib fractures following gunshot injuries.	7 (4th rib, 2nd & 3rd, 5th rib, 9th, 11th rib) 13: (3rd rib) 15: 3rd rib) 26 (7th rib) 29 (8th rib)		X	
Rib fractures following physical abuse:	11 (left post ribs 8th, 9th, 10th) 14 (10th, 11th right, 10th left)			X
Air in the right ventricle, suggesting an air embolism	15		X	
Pneumomediastinum	15, 19		X	
Haemopericardium.	29, 30		X	
Sternum fracture	15, 19		X	
Calcified mediastinal lymph nodes	7		X	
Retained bullets and bullet fragments	13 (bullet fragments left lung) 15 (bullet: posterior to erector spina muscle)		X	
Assessment of entrance wounds: thorax	15		X	
Bullet tract through soft tissue surrounding ribs	12		X	
Directionality of the bullet: (e.g. left to the right and in an upward trajectory)	7, 26		X	
Abdomen and pelvis Free abdominal fluid	9	X		X
Haemo-peritoneum	28 (extension thereof into abdominal cavity)		X	
Pneumoperitoneum	26, 28		X	
Intra-abdominal haemorrhages	11, 28		X	X

Laceration of the liver (if not subtle)	11			X
Bullet trajectory in left lower kidney pole	7		X	
Fractures of the superior pubic ramus	11			X
Spinal column and spinal cord Cervical vertebra 1 fracture	19		X	
Cervical vertebra 2 fracture	13, 19		X	
Thoracic vertebrae fracture	7 (T6 – T9) 13 (T9)		X	
Bullet trajectory and direction through tissue	7 (T3 & 4) 13 (paravertebral) 29 (Paraspinal T9)		X	
Transection of the cervical myelum	13 (level of C1)		X	
Extremities Humerus fracture	26		X	
Healing fractures	14 (left proximal and distal humerus. (callus formation left proximal humerus),			X
Metaphyseal corner fractures	14 (left distal humerus)			X
Radial bone fracture	14, 29		X	X
Scapular fracture	7		X	
Fractures: glenoid fossa of scapula.	14		X	
Tibial fractures:	14 (left and right proximal tibia (callus formation present on right tibia)			X
Fibular fracture	14			X
Fracture 2nd metatarsal bone	25	X		
Entrance and exit gunshot injuries: extremities	29		X	
Oedema right upper femur	25	X		
Presence of bullet tract	26 dorsal side of upper leg, (directionality not discernible) 29 (forearm)		X	
Ricochet fracture to glenoid cavity of right scapula.	7		X	
Directionality of the bullet tract and its relation to the bony skeleton	29 (left forearm)		X	
Retained bullets in the soft tissue surrounding extremities.	12 (anterior to humeral head)		X	

ADDENDUM B5: SIGNIFICANT INJURIES NOT SEEN DURING PMCT EXAMINATIONS

Anatomical region	Subject number	Blunt force head injury	Gunshot injuries	Physical Abuse
Head and Neck Presence and anatomical location of scalp lacerations Subject 21, 25 (2 each for subject)	21, 25	X		
Scalp abrasions	9 (one only) 21 (4 abrasions) 25 (4 abrasions each)	X		
Scalp bruising	21 (right side)	X		
Subscalpular haemorrhage (especially if small)	10 (frontal region of head) 14 (vertex, occipital area and frontal area) 25 (extensive part of scalp)	X		X
Subgaleal haemorrhages	27 (anterior to coronal suture)	X		
Sub-periosteal blush haemorrhages of bones of the skull	14			X
Cortical contusion over any surface of the brain	10 (temporal & occipital lobes) 21 (right temporal and parietal lobes) 25 (cerebellum and right temporal lobe)	X		
Brain lacerations	9 (frontal and temporal lobes) 13 (left cerebellum, occipital & parietal lobe) 17 (occipital and frontal lobe)	X	X	
Laceration of the meninges (Dura mater)	27	X		
Extrusion of brain matter following cranial fractures	10 (extruded via auditory meatus) 27 (extruded through left scalp)	X		
Contusion, previous scarring and healing laceration of the tongue	14 (scarring and healing laceration) 25	X		X
Laceration of the frenulum	14			X
Soft tissue haemorrhages within neck muscles	13, 15, 21	X	X	
Contusions of the upper pharynx and tonsils.	14, 19		X	X
Haemorrhage: (Blood draining from the) mouth, ears or nose	17, 28, 29		X	
Smear of blood in mouth	12		X	
Thorax Contusions of any part of the lungs	10, 11, 12, 25, 29	X	X	X
Petechial hemorrhages (sub-pleural)	10	X		
Blood-stained pleural effusion	11			X
Petechial hemorrhages: (sub-endocardial)	25	X		

Haemorrhagic areas in lungs	11, 14			X
Aspiration	10, 11, 12, 16, 19, 21, 25, 28, 29, 30: (blood) 11 (bile) 25 (gastric contents)	X	X	X
Soft tissue haemorrhage: mediastinum	12		X	
Focal haemorrhages of the atria or ventricles	25	X		
Sub-epicardial petechial haemorrhages of atria and ventricles	19		X	
Sub-endocardial haemorrhages	14, 16		X	X
Haemorrhage of the parietal pericardium	14			X
Associated haemorrhage in soft tissue surrounding rib fractures (if subtle).	14			X
Abrasions: thorax	25	X		
Contusion of right hemi-diaphragm	11			X
Assessment of visual cues such as pallor of lungs and heart suggesting exsanguination or hypovolemic shock.	11 (heart pale) 12, 13, 14, 16, 19, 28 (lungs pale)		X	
Ability to measure volume of fluid in thoracic cavity.	7 (500 ml blood left lung) & (400 ml right lung) 11 (10 ml pleural fluid) 12 (700 ml of blood in right hemithorax) 13 (200 ml of blood in left pleural space) 15 (1300 ml of blood in right chest cavity) 16 (1100 ml of blood in right pleural cavity) 26 (150 ml of blood in right side of thorax) 26 (100 ml of blood in left side of thorax) 29 (1500 ml blood in the right thorax) 30 (700 ml of blood in right thorax) 30 (60 ml of blood in pericardium)		X	X
Abdomen and pelvis Contusion of the anterior abdominal wall	14			X
Contusion of hollow organs	11 (duodenal wall) 14 (duodenal-jejunal junction)			
Contusions of the stomach wall	11			X
Contusions of the right peri-renal soft tissue	11, 14			X
Contusion and bruising of the testis	11			X
Contusions of soft tissue surrounding the bladder wall	11			X
Spleen laceration	7, 10	X	X	
Peri-pancreatic haemorrhage (around tail) (if subtle)	10	X		
Peri-adrenal haemorrhages	14			X
Haemorrhage in the adrenal medulla (especially if subtle)	11			X
Smear haemorrhage liver	12		X	

Subcutaneous haemorrhage perineum Subject 11: Stretch from perineum to rectus abdominus muscle	11			X
Fresh haemorrhages of the spermatic cord	14			X
Swelling of scrotum and penis	11			X
Ability to measure volume of fresh blood in peritoneal cavity.	11 (150 ml of blood) 28 (50 ml frank blood) 29 (100 ml blood)		X	X
Assessment of visual cues due to exsanguination or hypovolemic shock.	7, 9, 11, 14, 15, 19, 26, 29 (liver pale) 12 (pancreas pale) 14, 19, 26, 29 (both kidneys pale) 19, 29 (spleen pale)		X	X
Extremities: Skin abrasions over the body	25: 4 in total	X		
Spine and spinal column: Transection of spinal cord	7 (transection at T9) 10 (medulla: atlanto-occipital joint) 14 (haemorrhage staining of spinal cord)	X	X	
				X
Significant skin injuries not seen with PMCT				
Fresh or healing bruises of any part of the body	11, 14			X
Skin abrasions	10	X		
Scabs where present	14, 16		X	X
Scars where present	16, 26, 28		X	
Hyper-pigmented scars, granulation tissue or depigmented healed brushed-type abrasions	11, 14			X
Circumferentially scarring around anus suggesting sexual abuse/assault with blunt object)	14			X
Bite marks on body	14 (obtained with assistance of forensic Odontologist)			X
Skin abrasions surrounding gunshot	13, 16, 26 (multiple)		X	
Scraping of the skin by bullet, showing directionality of bullets on external surface.	13 (directionality of bullet not certain) 28 (directionality of bullet not certain) 29 (3 scrape bullet wounds)		X	
Mongolian spot as a congenital variant	14			X
Tattoos or body piercings for identification purposes.	13 (Letters FBS tattooed on back of shoulder) 15 (Letters FIN below antecubital fossa) 29 (Numbers ‘26’ dorsum of left hand)		X	

Measurements conducted during forensic autopsy				
Measurement of entrance and exit wounds (not always possible for all wounds)	7 (5 entrance wounds) 12, 16, 26 (2 entrance wounds each) 15 17, 19, 28, 30 (1 entrance wound each) 12, 16, 19, 26, 28, 30 (1 exit wound each) 13 (3 entrance wounds) 13 (3 exit wounds) 13 (2 re-entrance wound of an exit wound) 29 (5 entrance wounds) 29 (5 exit wounds)		X	
Measurement of exact anatomical location of gunshot injuries from heel.	7, 12, 13, 15, 16, 17, 19, 26, 28, 29, 30		X	
Recovery of bullet fragments for ballistics testing	7 (3 bullets) 12, 15, 17, 26, 28, (1 bullet each) 13, 29 (2 bullets each)		X	

ADDENDUM B6: SUPPLEMENTARY EXAMINATIONS CONDUCTED AS PART OF THE FORENSIC AUTOPSIES

Subject number	Age	Lodox®	Histology	Toxicology	DNA	Pharmacology	Microbiology	Virology	Skeletal survey	Ballistics	Other
1	1 month	Yes	No	No	No	No	No	No	No	No	
2	5 months	Yes	No	No	No	No	No	No	No	No	
3	2 months	Yes	No	No	No	No	No	No	No	No	
4	1 day	Yes	No	No	No	No	No	No	No	No	
5	3 months	Yes	Yes	No	No	Yes	Yes	Yes	No	No	
6	1 day	Yes	Yes	Yes	No	No	No	No	No	No	
7	16 years	No	No	Yes	No	No	No	No	No	Yes[a]	
8	1 day	Yes	Yes	No	Yes	No	No	No	No	No	
9	18 months	No	No	No	No	No	No	No	No	No	
10	2 years	No	No	No	No	No	No	No	No	No	
11	3 years	Yes	No	No	No	No	No	No	No	No	
12	14 years	Yes	No	No	No	No	No	No	No	Yes[a,b]	Vitreous humour Sexual assault kit
13	17 years	Yes	No	Yes	No	No	No	No	No	Yes[a]	
14	18 months	Yes	Yes	No	No	Yes	No	No	Yes	No	Forensic Odontology
15	17 years	Yes	No	Yes	No	No	No	No	No	Yes[a]	
16	17 years	No	No	Yes	No	No	No	No	No	No	
17	4 years	No	No	No	No	No	No	No	No	Yes[a]	
18	3 days	Yes	Yes	No	Yes	No	No	No	No	No	
19	7 years	Yes	No	No	No	No	No	No	No	No	
20	1 day	Yes	Yes	No	Yes	Yes	Yes	No	No	No	Neuropathology
21	6 years	Yes	No	No	No	No	No	No	No	No	
22	1 year	Yes	Yes	Yes	Yes	No	No	No	No	No	
23	9 years	Yes	No	Yes	No	No	No	No	No	No	
24	10 months	Yes	Yes	No	No	No	No	No	Yes	No	
25	5 years	Yes	No	No	No	No	No	No	No	No	
26	16 years	No	No	Yes	No	No	No	No	No	Yes[a,b]	
27	19 months	Yes	Yes	No	No	No	No	No	No	No	
28	16 years	Yes	No	Yes	No	No	No	No	No	Yes[a,b]	
29	16 years	Yes	No	Yes	No	No	No	No	No	Yes[a,b]	
30	16 years	No	No	Yes	No	No	No	No	No	Yes[b]	
Total		**23**	**8**	**11**	**4**	**3**	**2**	**1**	**2**	**9**	

a: bullets retained for ballistic analysis; b: Clothing retained for ballistic analysis