FATAL NON-ACCIDENTAL INJURY IN SOUTH AFRICA: A GAUTENG HOSPITAL'S PERSPECTIVE ON THE INCIDENCE AND FRACTURE TYPES ON POST-MORTEM SKELETAL SURVEYS

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A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Medicine in Clinical Disciplines (Diagnostic Radiology)

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Johannesburg, September 2021

Submission format

This research report, for the purposes of Master of Medicine, Department of Diagnostic Radiology, has been drafted in the Submissible Format as per the University of the Witwatersrand guidelines.

The original research article is written in the manuscript style required by Clinical Radiology with the intention to publish.

Requirements outlined by Clinical Radiology for the original paper manuscript include:

- Word limit: 3500
- Structured abstract:
    - 250 words
    - Aim
    - Materials and methods
    - Results
    - Conclusion
- Manuscript Headings:
    - Introduction
    - Materials and methods
    - Results
    - Discussion
    - Acknowledgements
    - References
- References: 30 or less
- The article was written with British English spelling
- Referencing done in Vancouver style.

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I Robyn Meryl Wessels (Student number: 1829846) am a student registered for the degree of Master of Medicine in Diagnostic Radiology in the academic year 2021.

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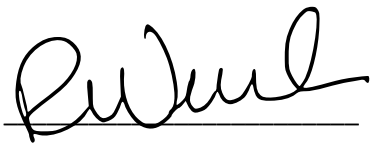
Signature:  Date: 04/09/2021

15 May 2021

The Postgraduate Office
Faculty of Medicine
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To Whom It May Concern:

Re: Dr Robyn Wessels' role as primary author for her MMed Diag. Rad. article

This is a joint declaration by all the authors that Dr Robyn Wessels is the primary author for this paper is based on her being an MMed student who was responsible for generating the entire manuscript for her project, summarising the statistical analysis findings, as well as performing and updating the literature review.
The co - authors (study supervisor) edited the manuscript.

Yours sincerely,

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Acknowledgements

I am indebted to my supervisor, colleagues, friends and family who all provided answers and support to my many questions and academic contemplations.

Introduction

The World Health Organization (WHO) defines child abuse and child maltreatment as "all forms of physical and/or emotional ill-treatment, sexual abuse, neglect or negligent treatment or commercial or other exploitation, resulting in actual or potential harm to the child's health, survival, development or dignity in the context of a relationship of responsibility, trust or power".(1) Child abuse or non-accidental injury (NAI) in its severest form is fatal.(2)

South Africa (SA) has been reported to have double the global average of child homicides.(3) Mathews et al concluded that the rate of child homicide was 5,5 per 100 000 in their study population of two South African provinces in 2009.(3) The homicide rate was higher in children under the age of 5 years.(3) The under 5 year age group has also been identified in various studies as the prime age group for NAI.(4-7) The rate of death as a result of child abuse and neglect was also highest in this age group with nearly half of all child homicide cases (44,5%) being attributed to child abuse or neglect.(3, 8)

Autopsy remains the main investigation in cases of suspicious child deaths with post-mortem skeletal surveys (PMSS) playing an adjunctive role.(9, 10) Skeletal surveys are the primary imaging modality to detect occult skeletal injuries in cases of suspected NAI in living and deceased patients.(11) Some studies have debated the need for routine PMSS, while others have highlighted their importance in detecting occult fractures.(12, 13) In South Africa, however, there is limited capacity for the performance of PMSS as it is a resource constrained environment in terms of the availability of imaging equipment, radiographers and radiologists with experience in post-mortem imaging.

The standard views required in PMSS are debated in the literature and varies depending on individual country or institutional regulations.(12, 14-16) In SA, the South African Society of Paediatric Imaging (SASPI) stipulates guidelines for live skeletal surveys (LSS). In our institution, modified skeletal survey guidelines from the Red Cross War Memorial Children's Hospital

(RCWMCH) in Cape Town, which are similar to the SASPI guidelines, are used for both living and deceased patients (Table 1).

The procedure of performing a PMSS is more cumbersome and time consuming than performing a LSS. The post-mortem condition of the patient (rigor mortis, decomposition, post autopsy changes) provides unique challenges in obtaining and maintaining the diagnostic quality of the PMSS images. Hughes-Roberts et al found a larger proportion of significant artefacts in the PMSS when compared to the LSS.(9) Despite these factors PMSS remains the current standard for occult fracture detection and fracture dating in suspected fatal cases of NAI in South Africa.(17)

The patterns of fractures associated with NAI in living patients have been published internationally.(15, 16, 18) In contradistinction, only a single South African study was published in 2007 detailing the fracture patterns sustained in living patients at the RCWMCH.(6) The fracture patterns in PMSS in South Africa have not been investigated to date.

The paucity of research on the fractures sustained in fatal NAI and the debate regarding the validity of the PMSS provided the motivation for our study framework in a South African tertiary hospital setting. The Charlotte Maxeke Johannesburg Academic Hospital (CMJAH) is a tertiary hospital with a 1088 bed capacity serving part of the catchment area for the Gauteng province, the most densely populated province in South Africa.

The aim and objectives of this study were therefore to determine the incidence and characteristics of the fractures in child fatalities suspected of having been subjected to NAI and to establish how many fractures occurred in high, moderate and low specificity locations for NAI, as per O'Çonnor et al.(19) The degree of concordance between two readers of varying reporting experience levels was also assessed.

Materials and Methods

A retrospective review of all the consecutive PMSS referred to CMJAH by the local forensic pathology services performed just over a 6-year period (1 January 2012 to 3 December 2018) was

conducted. The PMSS of all child fatalities with suspected NAI, those who were found to be deceased in suspicious or unknown circumstances or those who had died unexpectedly, were included in the study. The study included all children from the age of birth to adolescence. The WHO definition of adolescence, those aged between 10 - 19 years, was employed. Where the date of birth was not available, estimation of age was made using a bone age atlas.(20)

All cases on film (prior to April 2016) and those saved digitally onto the hospital's picture archiving and communication system (PACS) (after 1 April 2016) were assessed. The views were acquired according to the protocol in Table 1.

Each skeletal survey was read independently by a radiology registrar (year three of study) and a paediatric radiologist (four years of experience) blinded to all clinical details except sex and age. A standardised checklist for reporting was used by the readers for data collection, which assessed demographic details, technical aspects and skeletal survey findings.

Statistical analysis was done with STATA 15. The descriptive statistics: mean, median, standard deviation and inter-quartile rate were used to describe the continuous variables including age and the number of fractures per patient. Frequencies and proportions were used to describe the type of fractures and other categorical variables. Incidence rates were calculated for the number of fractures in the study population, first overall as well as by the type of fracture. Associations between categorical variables were tested using the Fisher's exact test. Cohen's Kappa was used to determine the concordance between readers. Tests were evaluated at a 5% level of significance.

Ethical approval was granted by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand (Clearance certificate number: M181112).

Results

Technical aspects

A total of 73 post-mortem skeletal surveys were analysed. With regards to the technical aspects assessed: 21/73 (28.8%) had adequate views, 52/73 (71.2%) surveys had inadequate views, with

39/52 (75%) of these due to incorrect positioning. Artefacts were found in 54/73 (74%) of the PMSS. The majority of the artefacts encountered were due to identification bands 34/54 (63%) and medical tubes and lines 11/54 (20.4%).

Demographics

No statistical significance in sex was found: 38/73 (52.1%) were male and 35/73 (47.9%) were female ($p > 0.05$). The mean age of the study population was 26 months (Standard Deviation (SD): 27 months). The age range was 0 months – 13 years. The median age of the study population was 14 months. The median age of those that sustained fractures was 24 months. 39/73 (53.4%) cases were under the age of 24 months.

Fracture characteristics

A total of 73 PMSS yielded fractures in 33/73 (45.2%). Overall, 115 fractures were sustained. The mean age of those who sustained at least one fracture was 28 months (SD: 21 months). A comparison between the cases that sustained fractures according to the different age groups is illustrated in Graph 1. There was no statistical significance when comparing the ages of those that sustained fractures to those that did not sustain any fractures ($p>0.05$).

When considering the sex and age comparatively, the mean age of those with at least one fracture in girls was 27 months (SD: 23 months) and in boys was 30 months (SD: 19 months). The mean number of fractures sustained per case was 115/33 (3.5). The mean number of fractures sustained when comparing girls to boys were as follows: boys 2.7 (SD 4.3) and girls 1.7 (SD 2.5).

The most common fracture locations per region were the chest 39/115 (33.9%), skull 20/115 (17.4%), upper limbs 31/115 (27%) and lower limbs 25/115 (21.7%). (Table 2)

The top five most common bones fractured were the ribs 37/115 (32.2%), parietal bone 13/115 (11.3%), ulna 13/115 (11.3%), femur 13/115 (11.3%) and radius 11/115 (9.6%) (Table 2). There

was no statistical significance in the numbers of the fractures between the top five most common bones fractured ($p>0.05$).

High specificity fractures accounted for 40/144 (27.7%) of fracture locations. Moderate specificity fractures accounted for 30/144 (20.8%) and low specificity fractures 74/144 (51.4%) of fracture locations (Table 3).

Fracture dating

With regards to fracture ages, 17/33 (51.5%) cases demonstrated acute fractures, 16/33 (48.5%) healing fractures and 5/33 (15.2%) chronic fractures.

Reader Agreement

When comparing agreement on the incidence of the top five bones fractured the reader agreement was as follows: ribs (Kappa value 0.7), parietal bone (Kappa value – 0.87), ulna (Kappa value - 0.85), femur (Kappa value - 0.87) and radius (Kappa value - 0.93).

With regards to the high, moderate and low specificity groups overall, the mean reader agreement was as follows, summarized in Table 3: high specificity group (Kappa value - 0.73), moderate specificity group (Kappa value - 0.9) and low specificity group (Kappa value - 0.8).

Discussion

Our study is the first to document the fracture types and characteristics in deceased children being investigated for suspected fatal NAI in a South African population.

The assessment of the adequacy of the PMSS identified a high number with inadequate views, with three quarters due to poor positioning. This is not an unusual finding in post-mortem imaging, as an audit of skeletal surveys in the United Kingdom (UK) 3 years after the British Society of Paediatric Radiology (BPSR) standards were published, revealed that only 15% included all views.(21) This reiterates the widespread challenges faced and the need for quality assurance when performing

PMSS.(9, 21) As these studies were conducted over a number of years with various radiographers and radiologists in attendance, all of who had varying levels of training, this may have accounted for the higher incidence of inadequate positioning. Currently in our department, PMSS and LSS are only performed during working hours by radiographers with the most experience in this type of imaging, where possible. Each skeletal survey is approved by a consultant radiologist. Due to the small number of paediatric radiologists in South Africa, and in our hospital specifically, not every skeletal survey can be reviewed by this type of specialist. It is imperative that there is adherence to, and consistency of the imaging generated according to the local protocol. This will facilitate obtaining PMSS of sufficient diagnostic quality to aid accurate interpretation by radiologists with varying levels of experience.(21-23) Additionally, a significant number of artefacts were recorded, however these are similar to that reported by Hughes et al.(9)

We compare the rest of our findings specifically to two key studies detailed in Table 4. We found no differences between the age or sex of those who sustained fractures and those without fractures. The mean age of our study population was younger compared to the van As et al study, however much younger children were reported by Hughes et al.(6, 9) We have established that there is a much higher yield for fractures on PMSS, almost four times than on LSS in the Cape Town population and five times more than on PMSS in the UK.(6, 9) This initial finding should be corroborated with future comparative studies on LSS and PMSS in South Africa. Despite the differences in these two countries findings, we concur that fatal NAI is more common in younger children and the injuries sustained tend to be more severe.(6, 9)

The characteristics of fractures in our study were concordant with the literature in that the most common regions fractured were the chest, skull and limbs.(4, 6, 7, 18, 24) Most articles were based on findings in LSS with a few on PMSS. We demonstrated similar findings to those of van As et al. in that high specificity fracture locations for NAI (metaphyseal corner fractures, scapula and sternal fractures) were rare in this series (Table 3).(14) Only rib fractures were more common in our series compared to van As et al, whereas skull fractures were in the majority in the latter.

This may show a possible difference in fracture patterns sustained per province in South Africa. The need for future local studies to establish the spectrum of fracture patterns in our population at multiple centres is emphasized.

In some studies the need for routine PMSS has been debated.(12) McGraw et al concluded that the addition of a PMSS added valuable additional information to the autopsy findings in cases of suspected fatal NAI. In his study about post-mortem radiography, 92% of the extremity fractures identified were metaphyseal corner fractures.(13) These types of fractures are highly specific for NAI and are often difficult to detect on routine autopsy.(10, 13) In our study, however we found fewer metaphyseal corner fractures compared to the studies performed by McGraw et al and Kleinman et al.(13, 25) More importantly, we found that overall there was a high incidence of limb fractures in our PMSS series. The majority of limb fractures would have otherwise been occult on autopsy, since these regions are not routinely dissected.(9, 10) This illustrates the utility of PMSS as a necessary adjunct in the evaluation of fatal NAI in identifying and documenting the extent of injuries for the ensuing medicolegal proceedings.

We assessed fracture dating which has not been investigated in our population previously. Our study focused on a broad fracture dating classification, i.e. acute, healing or chronic fractures as defined by Paddock et al.(15) Acute fractures made up over half of those who sustained fractures. This possibly indicates the severity of the injuries sustained and that a proportion of patients do not survive to recover from them. The overall number of fractures in multiple stages of healing could allude to the repeated abuse in these cases. Fracture dating in PMSS remains an important observation to make in suspected cases of NAI, as determining the chronicity of fractures contributes to the medico-legal case by providing evidence of previously sustained injury.(15, 16)

It is important to report on reader agreement to indicate if the assessment criteria are robust and valid in clinical practice. This has not been assessed in our setting before. Our study showed substantial to almost perfect agreement between our readers (Table 3). The substantial agreement was noted in the identification of high specificity fractures. This could be due to finite details being

overlooked by less experienced readers. This finding speaks to the challenges of offering these much-needed services in a country with a higher prevalence of NAI compared to worldwide with limited paediatric radiology expertise in PMSS. The need for dissemination of this training and expertise to general radiologists and radiology registrars should therefore be encouraged.

Limitations

The most notable limitation to our study is its retrospective nature which may have introduced bias. This study was conducted at a single centre. Furthermore, no comparison of PMSS to LSS, autopsy findings or the final medicolegal investigation outcome with confirmed cases of fatal child abuse was performed.

Conclusion and Recommendations

Our study analysed the first and largest number of post-mortem skeletal surveys in South Africa to date. We have shown that in cases of suspected NAI, the types of fractures found in PMSS were similar to those seen in LSS and predominantly occurred in those under 24 months of age, whereas some of the classically described high specificity fracture locations for NAI in the international literature, were rare. Future local studies are needed to investigate possible differences in the types of fractures sustained according to region.

PMSS in the South African setting is a valuable adjunct to autopsy in detecting occult fractures of the limbs, which formed a large portion of the fractures that would not have been discovered or routinely dissected on autopsy. We therefore recommend PMSS at least be performed in suspected fatal NAI cases in children up to 24 months of age.

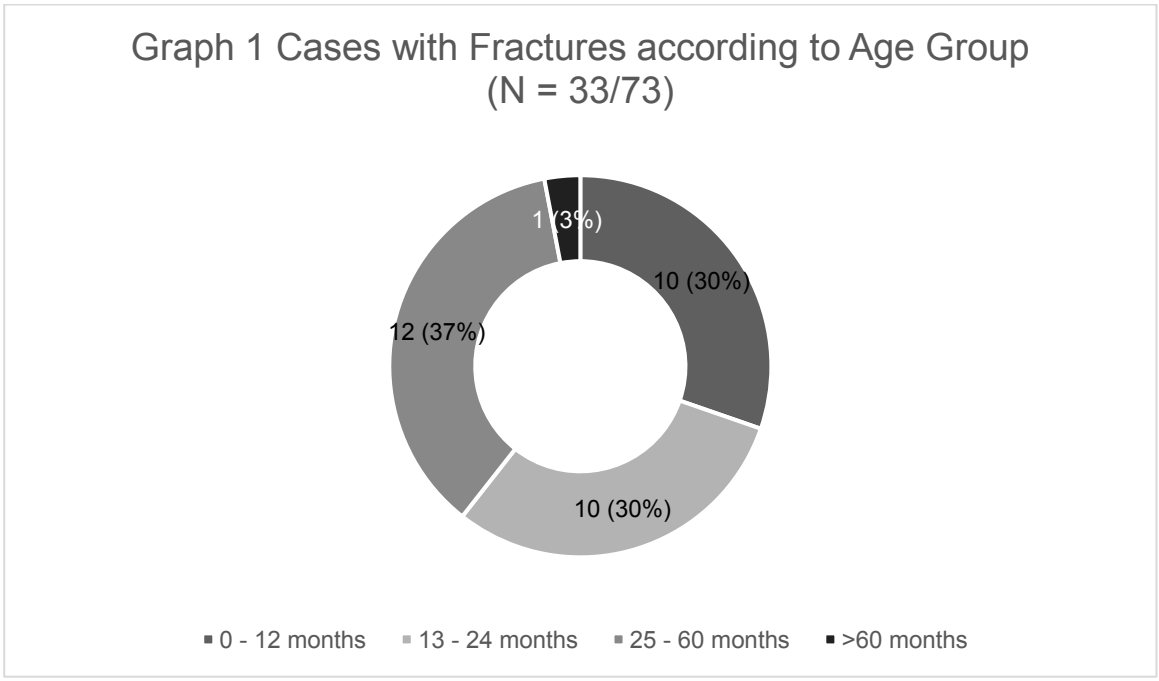
Standardised radiographic technique as per the local guidelines and quality assurance of PMSS is vital to obviate factors that affect interpretation. Furthermore, in our resource limited setting, the encouragement and continuous education and training of radiographers regarding imaging

technique, general radiologists and radiology registrars on interpreting PMSS remains key to improving the investigation of these cases.

Acknowledgments

The authors wish to acknowledge all the radiographers, registrars and radiologists in our department who make post-mortem imaging possible in a resource constrained environment.

Graphs


Graph 1 Cases with Fractures according to Age Group
(N = 33/73)
1 (3%)
10 (30%)
12 (37%)
10 (30%)
0 - 12 months
13 - 24 months
25 - 60 months
>60 months

Tables

Table 1 Skeletal Survey Views for Non-Accidental Injury (modified from RCWMCH guidelines)

Axial Skeleton		
Region	Views	Notes
Skull[1]	AP and Lateral	
Chest	AP, Bilateral oblique ribs	
Abdomen	AP	To demonstrate spine, pelvis, hips and lower ribs
Spine	Lateral	
Appendicular Skeleton		
Region	Views	Notes
Upper and lower limbs	AP	Centre on joints
Hands and feet	AP	
Knees, ankles, wrists and elbows	Lateral[2]	

[1]In LSS, a CT brain is performed, however we have modified this protocol for PMSS.

[2]These views are added at the discretion of the attending radiologist.

Table 2 Fractures according to region and site

Region	Site	Number (%)
Skull	Frontal bone	4 (3.5%)
	Parietal bone	13 (11.3%)
	Occipital bone	3 (2.6%)
Chest	Ribs	37 (32.2%)
	Clavicle	1 (0.9%)
	Scapula	1 (0.9%)
Upper limbs	Humerus	6 (5.2%)
	Radius	11 (9.6%)
	Ulna	13 (11.3%)
	Metacarpals	1 (0.9%)
Lower limbs	Femur	13 (11.3%)
	Tibia	8 (7%)
	Fibula	2 (1.7%)
	Metatarsals	2 (1.7%)
		Total: 115

Table 3 Specificity of fracture locations and reader agreement		
Specificity	Fracture/Location/Type	Number (%)
High	Classic metaphyseal lesions	2 (1.5%)
	Rib fractures (especially posteromedial)	37 (27.8%)
	Scapular fractures	1 (0.8%)
	Spinous process fractures	0
	Sternal fractures	0
		Total: 40
		Reader agreement: Kappa value – 0.73
Moderate	Multiple fractures (especially bilateral)	21 cases (15.8%)
	Fractures of different ages	5 cases (3.8%)
	Vertebral body fractures and subluxations	0
	Digital fractures	0
	Complex skull fractures	4 (3.0%)
		Total: 30
		Reader agreement: Kappa value – 0.9
Low	Subperiosteal new bone formation	25 (18.8%)
		1 (0.8%)
	Clavicular fractures	26 (19.5%)
	Long bone shaft fractures	11 (8.3%)
	Linear skull fractures	11 (14.8%)
		Total: 74
		Reader agreement: Kappa value – 0.8
		Grand Total: 144

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273 **Table 4 Comparison between this study's main findings and key studies**

Author, (year), region	Number of cases (mean age +/- SD)	Live Skeletal Survey results (LSS)	Post-Mortem Skeletal Survey results (PMSS)	Fracture Characteristics
				Anatomical Regions
Wessels, (2021), Johannesburg, SA	73 (28 +/- 21 months)	N/A	73 surveys 33 (45.2%) abnormal surveys	21 (21.8%) with multiple fractures 37/115 (32.2%) rib fractures 20/115 (17.4%) skull fractures 31/115 (27%) upper limb long bone fractures 25/115 (21.7%) lower limb long bone fractures
Hughes-Roberts, (2012), Cambridge, UK	195 (7.1 +/- 9.2 months)	67 surveys 16 (23.8%) abnormal surveys	128 surveys 11 (8.6%) abnormal surveys	LSS: 4 multiple fractures 6 skull fractures 9 long bone fractures PMSS: 5 multiple fractures 5 skull fractures 4 long bones fractures
Van As, (2007), Cape Town, SA	1037 (44.8 +/- 49.2 months)	121 surveys (11.7%) sustained fractures	N/A	21 (17.3%) with multiple fractures 57/149 (38.2%) skull fractures 29/149 (19.4%) upper limb long bone fractures 26/149 (17.4%) lower limb long bone fractures

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Annexures

1. Ethics certificate

Annexure 1: Ethics Certificate

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

R14/49 Dr Robyn Wessels

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M181112

NAME: (Principal Investigator)	Dr Robyn Wessels
DEPARTMENT:	Diagnostic Radiology Charlotte Maxeke Johannesburg Academic Hospital
PROJECT TITLE:	Fatal NAI: A Gauteng hospitals perspective on the incidence and fracture types
DATE CONSIDERED:	30/11/2018
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Halvani Moodley
APPROVED BY:	Dr. CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	03/12/2018

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on the Third Floor, Faculty of Health Sciences, Phillip Tobias Building, 29 Princess of Wales Terrace, Parktown, 2193, University of the Witwatersrand. I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. In this case, the study was initially reviewed in November and will therefore be due in the month of November each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES