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Viljoen, Ilana

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The Value of Comparative Radiographs in the Diagnosis of Extremity Fractures in Children by Doctors in the Emergency Department

Dr Ilana Viljoen

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 Diagnostic Radiology

Johannesburg, 2017

Declaration

I, Ilana Viljoen, declare that this research report is my own work. It is being submitted for the degree of MMed(RadD) at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

Dr Ilana Viljoen

On this 26th day of October 2017.

I dedicate this work to my family and loved ones who have supported me throughout my medical career and without whose love and patience none of this would be possible.

Publications and presentations

This research was presented at the SASPI (South African Society of Paediatric Imaging) congress in Stellenbosch on 5 November 2016.

The conference abstract has been published online in the South African Journal of Radiology on 26 July 2017.

Abstract

INTRODUCTION: The practice of routinely requesting radiographs of both limbs (injured and unaffected side) in a suspected extremity fracture in a child for comparison purposes, is widespread and accepted in Emergency Departments in South Africa, despite the fact that it has been discouraged in literature.

AIM: The aim of this study was to evaluate the ability of junior emergency department doctors to diagnose selected common paediatric extremity fractures without and with comparative views.

METHOD: Study participants evaluated a set of 30 paediatric extremity radiographs, first without comparison views and then 5 – 7 days later with comparison views. They indicated the presence or absence of a fracture and their level of confidence in making a diagnosis. The selected radiographs included normal films as well as subtle and obvious fractures at the following sites: Hand/wrist/forearm, elbow, and foot/ankle/lower leg.

RESULTS: The overall ability to detect paediatric extremity fractures (sensitivity) did not significantly improve with comparison views compared to without them (p=0.28). There was, however, a significant (7,8%) increase in detection rates of elbow fractures, when comparison radiographs were added (p=0.0068). A significant improvement in confidence levels (12%) was found amongst the participants with comparative views compared to without them (p- value=0.0001). The ability to detect normal paediatric extremity radiographs (specificity), improved by 15.3% with the addition of comparison views (p-value=<0.0001).

CONCLUSION: There is an overestimation of the value of comparison views in diagnosing paediatric extremity fractures. The findings of this study do not support the routine use of comparison views in the Emergency Department. Selective use is justified. Training of junior Emergency Medicine doctors to recognise paediatric fractures should be prioritised rather than relying on comparative radiographs.

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List of Abbreviations and Terminology

ANOVA = Analysis Of Variance

CR = Comparative radiographs

CS = Confidence score

EM = Emergency Medicine

ED = Emergency Department

MO = Medical Officer

Ottawa Ankle Rule = OAR

PI = Principle investigator

1. Introduction

1.1. Rationale

The conventional practice of routinely radiographing both limbs (the injured and corresponding unaffected limb) in a suspected extremity fracture in a child for comparison purposes is widespread in the emergency and other departments in South Africa. Despite the fact that this practice has been discouraged as early as 1980 (1), it is still requested and accepted as routine practice by most doctors, exposing these children to potentially unnecessary additional radiation.

The aim of this project was to ascertain whether adequate diagnostic accuracy could be achieved by routinely radiographing only the affected extremity in the Emergency Department (ED) setting. This largely depends on the diagnostic skills of Emergency Medicine (EM) personnel, especially after hours when, in most cases, no radiologist is available to report the radiographs and mostly junior doctors are responsible for making diagnoses (2, 3).

1.2. Background

The majority of radiographs in EDs are initially interpreted by the ED doctors themselves, as most South African government hospitals do not have after hours service for reporting of radiographs by a radiologist (2).

As early as 1978 it was recognised that the evaluation of skeletal injuries in children were challenging due to a number of reasons and the value of comparison radiographs (CR) came into question (4). Issues of medical costs, radiation exposure and medico-legal problems were considerations in clinical practice (4).

Two studies were done at that time to evaluate the value of comparison views in paediatric extremity fracture diagnosis. The first study, by DF Merten in 1978 assessed paediatric radiologists. The results indicated that routine use of CRs is not the predominant practice under paediatric radiologists and suggested a relatively low diagnostic yield (4). The

justifications provided by respondents for routine use of CRs were to identify normal variants, detect subtle fractures and to evaluate and compare soft tissue. On the other hand, support for their selective use only, was motivated by the unnecessary radiation, increased health care cost and the low yield rate (4).

A second, similar study, done in 1979 by McCauley et al., showed that the initial diagnoses of extremity fractures made by paediatric radiologists, were not altered by comparison views. This study also included residents in radiology (These trainees are called registrars in South Africa). Routine comparison views did increase the confidence the residents had in diagnosing fractures, but lack of comparison views did not lead to any missed fractures. It, in fact, resulted in over-diagnosing of fractures. The extremity comparison radiographs thus had more of a psychological benefit on less experienced doctors (5).

Based on these two studies (where radiologists were assessed), The American Academy of Paediatrics released a publication in 1980 (1), stating that the routine use of comparison radiographs of the unaffected extremity is not justified, and should be discontinued. A comparison radiograph might be requested after the attending doctor or radiologist has reviewed the radiograph of the affected limb. It was acknowledged that a subtle fracture might be overlooked even if comparison views are done (1). The academy did however concede that exceptions could be made in cases where there are no radiologists to review the radiographs at any stage, or if the child will not be able to be followed up if indicated (1).

Despite the above-mentioned guidelines, the value of routine CR in paediatric extremity fractures in various settings has been debated for years but no agreement exists. In a more recent (2004) publication in the Emergency Medicine Journal, Swischuck and Hernandez, stated that it is worthwhile to do CRs as it eliminates ambiguity and a definitive diagnosis can quickly be made. This is further justified by the authors' explanation that many fractures of extremities present only with pain and swelling, most likely representing subtle underlying fractures (6).

According to Merten (4) individual personal and practical considerations determine the use of CR. The most important factors are personal experience, training level, availability of radiology consultation and clinical demand (4).

1.3. Radiation exposure and the paediatric population

Balancing radiation exposure/protection and diagnostic quality is a pertinent issue in paediatric radiological imaging (7). In a review article pertaining to radiation risks of computed tomography (CT) scanning, it is stated that equivalent doses of radiation given to a child and an adult would result in a 10 times higher risk for neoplastic conversion in children (especially gonads, breast and thyroid tissue) (8). It is estimated that the average lifetime risk of a fatal radiation induced malignancy in adults is 1%/Sievert (Sievert = Unit of radiation absorption) where in children it is up to 10%/Sievert (Sv) (7). The risk is even higher in newborns, estimated at 15%/Sv in males and 30%/Sv in females (7). Compared to computed tomography (CT), radiation doses from conventional radiographs are relatively low, with effective doses of 0.1-1 μSv (7).

Although lower levels of radiation are required for the paediatric radiological imaging studies, this population is more sensitive to radiation exposure. This is partly due to their longer life expectancy (there is a relatively long latent period between radiation exposure and it's potential consequences). Secondly, growing children's organs are more sensitive to radiation exposure (9). It is thus of utmost importance to use radiological examinations carefully and consider radiation exposure when selecting imaging procedures (9).

Care can be taken to reduce radiation dose to paediatric patients from an imaging technique perspective. This can be achieved by optimizing exposure parameters for each individual child in terms of patient characteristics and clinical question. Suggested exposure settings by manufacturers are probably too high (7). Similarly the physicians have to consider radiation dose when requesting radiological imaging and be conscientious in selecting appropriate procedures for individual clinical conditions (9)

Generally physicians are not adequately educated regarding the risks of radiation to children. A Canadian study in 2014, assessing physicians' knowledge of radiation exposure and potential malignancy risks to children, found that only a third of paediatric emergency physicians could choose the correct estimated chance of potential cancer risk of a CT brain in a child (10).

Overall, medical personnel must make sure that the benefit of the imaging study justifies the risk of radiation exposure in each child (9). The 'Image Gently' campaign is a worldwide and national initiative to inform individual imaging protocols and advocates the ALARA (As Low As Reasonably Achievable) principle (11).

1.4. Epidemiology of paediatric extremity trauma

Children typically present with different mechanisms of injury and fracture types than adults and there is a distinct difference in the radiological appearance of fractures in children. Fracture types unique to children include torus/buckle fractures (axial compression fracture), greenstick fracture (where the mechanism is by bending) and epi-or metaphyseal injuries (growth plate injuries) (7). 6-30% of paediatric fractures involve the physis (growth plates) and growth disturbance/arrest is found in about 15% (12).

The anatomy of paediatric long bones is clearly unique and subsequently paediatric fractures are classified according to specific fracture patterns. The Salter Harris classification is most commonly used to describe epiphyseal injuries. This classification provides anatomical, radiological and prognostic information regarding epiphyseal injuries and fractures that influences the management. The Salter Harris classification provides prognostic information in terms of probability of growth disturbances (13).

A study in Canada in the 1970's on paediatric fractures found that fractures occur more in boys, the left side and in the upper extremities. The hand and forearm were the most common sites. The most commonly fractured bone was the radius. The epiphysis was involved in almost 14% of the fractures and 16.3% were torus fractures (14).

The above trend was confirmed by more recent studies. In 2003 Partan et al., stated that forearm fractures (mostly radius) were the most common fractures in children (7). Upper limb injuries are usually due to a fall on an outstretched hand (FOOSH). The incidence of hand fractures starts increasing from the age of 8 and is highest at about 13 years (12). A Swedish study done in 2010 by Hedstrom et al, similarly found that the most common fracture site in children and adolescents is the distal forearm, with a peak incidence in boys at age 14 and girls age 11. With regards to gender predilection, their study showed a 1.5:1 ratio of fracture incidence in boys vs. girls. The most common mechanism of injury was falls.

The authors postulate that mechanism of injury and activity patterns varies with age due to the motor and social skills development as well as the changing of activities that children engage in as they grow and mature (15).

Although mostly seen in older children and adolescents, scaphoid bone fractures make up 70% of carpal bone fractures (12). The elbow joint is a common site of injury in children with a wide spectrum of possible injuries. Supracondylar fractures are the most frequently encountered fracture in this region (58%), with fractures of the lateral condyle (second commonest; 13% of all elbow fractures), medial epicondyle (3rdnd commonest; 10% of elbow fractures) (16) and radial head occurring less commonly (7). Proximal humerus fractures are not very common in children (<5% of physeal injuries) (12).

Lower limb injuries occur less often than upper limb injuries in children (12). Distal tibia, distal fibula and phalangeal fractures are the most prevalent Salter Harris fractures of the paediatric ankle and foot, with the distal fibula fracture (Salter Harris type I) being the most common in adolescents. In terms of foot fractures, the 5th metatarsal is the most frequently fractured metatarsal bone in children (45% of metatarsal fractures) (13). Ankle injuries are common in athletes of all ages. Fractures are often misdiagnosed as ankle sprains in children. Due to the immaturity of children's skeletons, they have a higher likelihood of sustaining physeal injuries in acute ankle injuries (12).

Toddler's fractures are minimally or non-displaced spiral or oblique fractures of the tibial shaft that occur following minimal trauma. Non-accidental injury should be kept in mind in these types of fractures (7).

Children who are athletically active can be at risk of traumatic knee injuries, including tibial spine avulsion fractures and medial distal femoral physis fractures (the later being very rare, <1% of all fractures in children) (12).

1.5. Pitfalls of fracture diagnosis in the paediatric population

1.5.1. Anatomy: Growth plates and ossification centres

The presence of cartilaginous growth plates (physis), located in the distal parts of long bones is the most important anatomical difference between a child and an adult bone (12). The physis is located between the metaphysis and the distal epiphysis of long bones. This is where new bone is formed for growth (13). The cartilaginous physis is continuously remodelling and changing and is an area of relative weakness compared to the surrounding ligaments and tendons (12, 13). Chronic or traumatic stress across these structures subsequently leads to fractures, rather than soft tissue injury as is prevalent in adults (12).

The growth centres allow expansion and lengthening of long bones until skeletal maturity. They close from distal to proximal (12). The ossification centres appear and change from birth to age 13 or 14, until most of the long bones are ossified (17). It is this dynamic process of ossification of the growth centres that makes the radiological appearance of paediatric extremity radiographs challenging (7).

The type of skeletal injury prevalent in children differ from that in adults, not only because of the cartilaginous nature of the physis, but also due to the relatively thin cortex of the metaphysis, resulting in minimal resistance to force. The periosteum is thick however and often remains intact despite a force that fractures the underlying bone. This characteristic leads to the typical greenstick, torus and buckle fractures seen in childhood. In the ankle and foot, accessory ossicles (normal variants) exist, that are often confused with fractures or abruptions (7).

Due to the above described characteristics, injuries to paediatric joints often present only with soft tissue swelling and fat pad dislocations (subtle radiological signs), making diagnosis difficult (7). Comparison with images of normal skeletal development can be very helpful in these situations (7).

Although it is said that there is risk of growth disturbance / arrest in all growth plate fractures, more extensive injuries (more significant growth plate damage) have a greater probability to result in growth abnormalities. Despite injury severity, growth

disturbance/arrest probability is further influenced by skeletal maturity, age and anatomical site. Six to 30% of fractures in the paediatric population are physeal injuries (12). Most paediatric fractures are Salter Harris type II fractures (13).

"Awareness of normal anatomic features is crucial for the interpreter to be able to detect subtle signs of fracture" (18).

1.5.2. Missed fracture diagnoses in the Emergency Department

As mentioned previously, most EDs have no after hour radiology services, thus relying mainly on junior doctors to diagnose fractures on radiographs (2). Table 1.1 below summarises studies done on the most commonly missed fractures in the ED and Table 1.2, the accuracy of radiographic interpretation by the EM doctors.

Table 1.1. Most frequently missed injuries in Emergency Departments

Authors, date and location of study	Physician subpopulation Studied	Demographics of radiographs examined	Results: Most frequently missed fractures
Freed et al (2) 1984 New York, USA	Junior ED doctors	All adult and paediatric radiographs from Emergency Department	63% of all mistakes were missed fractures, most commonly: Rib fractures 14% Hand phalanges 12% Elbows 12%. 80% of paediatric missed fractures were of the upper extremities.
Halsted et al (19) 2004 Ohio, USA	Radiology trainees	All radiographs from Paediatric Emergency Department	69% of all mistakes involved the diagnosis of fractures or dislocations. 61% of all errors involved missed Salter Harris II (16%), buckle (31%), avulsion (5%) and transverse (9%) fractures. 47% of the missed buckle fractures were of the radius.
Mounts et al (20) 2011 Washington, USA	Paediatric Emergency Medicine Specialists	Paediatric extremity radiographs from Paediatric Emergency Department	Phalanges 16,4% Metatarsals 9,5% Distal radius 7,7% Tibia 7,3% Supracondylar 5,5% Foot phalanges 5,5%

Table 1.2. Accuracy of Emergency Department (ED) doctors' interpretation of radiographs

Author, date and location	Study objectives	Error rate or agreement rate (%)	Results
Gleadhill (21) 1980 Liverpool, England	-Accuracy of ED doctors' assessment of trauma x-rays -Doctor experience gauged by number of injuries seen over study period.	4.9% of all trauma injuries missed on radiographs	Number of errors decrease with increased experience, with error rates falling from 7.1% to 2.9% in all missed injuries and from 1.7% to 0.6% (1.2% average) in clinically significant injuries. -Injuries of distal extremities most often missed.
Vincent et al (22) 1988 London, England	-Accuracy of trauma doctors' assessment of radiographs -Doctor experience gauged by time spent in ED (in months)	2.8% of all trauma x-rays were misdiagnosed. Injuries missed when considering only abnormal radiographs is 35% (39% of these clinically significant)	Although more missed diagnoses occurred in the junior doctors' first month in ED, no significant improvement was proved in the following 5 months.
Mayhue et al (23) 1989 Illinois, USA	Correlation between physician confidence level in radiological diagnosis and diagnostic accuracy	Analysis of studies between 1971- 1987 that investigated inter-reader agreement between ED and Radiology doctors reveals a range of 83 -99%.	Increased physician confidence levels are found with increased level of training, but only resulted in increased diagnostic accuracy in some groups of radiographs (incl. chest and extremities). Thus the confidence with which an ED doctor interprets a radiograph cannot be used as gauge for diagnostic accuracy.
Minnes et al (24) 1995 Ontario, Canada	-Agreement between ED doctors and paediatric radiologist in diagnosis of paediatric extremity fractures (accuracy) -Types and sites of injuries with most disagreement.	83.3% – 84.8% agreement rate.	Types of fractures disagreed on: Buckle and non-displaced fractures of the phalanges, elbows, feet and hands. Predominant sites of disagreement were the ankle, elbow and knee.

The reasons for misdiagnosing paediatric extremity fractures on radiographs in the emergency setting are varied and include the following:

- Paediatric fractures can be very subtle, even though visible (25). These are typically plastic bending fractures, buckle fractures, Toddler's type 1 and 2 fractures, sternoclavicular dislocation and epiphyseal and metaphyseal (Salter Harris) injuries (26).
- Poor positioning when obtaining radiograph (25).
- Fracture blocked by splint (25).
- Image quality can be suboptimal in some instances (25).
- Where more than one fracture is present, not all fractures are picked up by initial evaluation (25).
- Where fractures are incidental abnormal findings on radiographs taken for another primary reason, they are often missed (2).
- Growth plates, the change in appearance of ossification centres at various ages and the small size of children's bones are confusing to inexperienced doctors (7, 20). The wide normal anatomical variation of paediatric bones (27) makes it difficult to diagnose, especially Salter Harris fractures (19).
- Some fractures, like subtle supracondylar fractures, are only diagnosed by identifying subtle signs like the presence of a posterior fat pad (20). Paediatric elbow injuries were shown in multiple studies to be exceptionally challenging for EM doctors to review radiologically and many fractures are missed (7, 24).
- Many doctors are trained primarily in assessing adult radiographs, making diagnosis of the unique injuries and fractures in children difficult (19).

Missing extremity fractures in children can have significant consequences such as growth disturbances, higher health care costs, prolonged period of pain, and missed school days for the child. It is also known that in terms of medical malpractice cases, the third most commonly involved diagnosis is fractures (20). For these reasons comparison views are deemed valuable by some in situations where subtle injuries are expected (27). These are commonly elbow injuries (12), knee injuries (27), ankle injuries (28) and subtle fractures like plastic bending (29), buckle (30), Toddler's and Salter Harris fractures (26).

1.6. This project in context: Comparison to literature on the topic

As outlined above, the value of CR in paediatric extremity fractures is a controversial topic (6). Even though some authors may advocate their routine use (12, 31), it is discouraged by most. The majority of studies on the subject suggest selective use of CR only (17, 32-34), while one study found that CR don't play a significant role in fracture diagnosis at all (17).

The difficulty of diagnosing some paediatric extremity fractures and the potentially serious consequences of missing these fractures cannot be denied (12). A balance between diagnostic accuracy and radiation exposure needs to be achieved (7).

As many of the doctors in South African government hospitals, particularly those working in EDs after hours are relatively junior (3), a significant potential for misdiagnosis of paediatric extremity fractures exists. In the current South African setting, radiological review within a reasonable time period or at all is not always available.

The question that arises is whether junior doctors, especially when working after hours with potentially no senior review at any point should be allowed routine CRs in an attempt to minimise missed fractures. Would this increase diagnostic accuracy in a South African public hospital setting or would fractures still be missed regardless of the use of CRs? If it is shown that accuracy is not influenced by routine CRs will physicians stop requesting them?

"The Ottawa Ankle Rule (OAR) states that ankle x-rays are necessary only if there is pain near the malleoli and one of the following: 1) inability to bear weight immediately after the injury and in the ED (four steps) or 2) bone tenderness at the posterior edge or tip of either malleolus. Foot x-rays are necessary only if there is pain in the midfoot and one of the following: 1) inability to bear weight as defined above and 2) bone tenderness over the navicular or base of the fifth metatarsal"(35) and was originally developed as a decision making tool regarding ankle and foot radiographs in the trauma setting by Stiell et al(36) . Multiple studies have shown the validity of the Ottawa Ankle Rule (OAR) in adults and in children (excluding children <5 years) (37, 38). In a 2010 study assessing the impact of the OAR, Petscavage showed that clinicians who are accustomed to following a certain manner of practice, are very resistant to change, in spite of evidence that their current way of doing has no benefit and is not efficient (39). This might be the case in the routine use of

comparison radiographs in children. Thus assessing the level of comfort when using comparison views versus no comparison views becomes relevant when assessed parallel to accuracy.

1.7. Study objectives

1.7.1. Aim

The aim of this study was to evaluate the ability of non-radiologist junior ED doctors (interns, community service doctors, medical officers, junior EM registrars) to diagnose selected common paediatric extremity fractures without and with the use of comparative views.

1.7.2. Objectives

- To assess and compare the ability of junior ED doctors to detect common paediatric extremity fractures on x-rays with comparative views available and without comparative views.
- To assess and compare the comfort level of these doctors in diagnosing common paediatric fractures on the radiographs, with and without comparative views,
- To perform subgroup analysis of anatomical sites radiographed both for accuracy of diagnosis and comfort level (as a Confidence Score, CS) of participants to diagnose common paediatric fractures at these sites,

2. Materials and Methods

2.1. Research paradigm

This was a prospective quantitative, cross sectional study.

2.2. Sample

The study population was all doctors that work in two different public sector EDs in South Africa. The units that participated were at Helen Joseph Hospital (Gauteng) and Kimberley Hospital Complex (Northern Cape).

2.2.1. Inclusion criteria

Only junior doctors that work in the above mentioned departments were considered for inclusion in the study. For the purpose of this study, "junior" was defined as interns, community service doctors, junior medical officers (two years or less experience as a medical officer) and junior (first year) EM registrars.

2.2.2. Exclusion criteria

- Doctors that were unable to view and complete the tick sheets for both sets of radiographs, for whatever reason (on leave, sick, etc) were excluded from the study.
- Doctors who did not consent to participate in the study were excluded.

2.3. Materials and methods

The radiographs that were used in this study were obtained from the electronic database on the Phillips Viewforum machine of the Rahima Moosa Mother and Child Hospital (RMMCH) radiology department. These radiographs were on the electronic system of the hospital already and had been requested by ED or orthopaedic doctors, as per their usual current practice, which includes a comparison view of all limbs. The machines used to obtain radiographs at RMMCH are the Phillips Digital Diagnost and the Stephanix Second Opinion System.

A paediatric radiologist and the Principle Investigator (PI) selected 30 extremity radiographs of children. These radiographs represented a selection of common paediatric injuries with a selection of obvious fractures, subtle fractures and no fractures. It included radiographs of the foot, ankle and lower leg (tibia/fibula) (referred to in results and discussion sections as: distal lower limb), hand, wrist and forearm (referred to in results and discussion sections as: distal upper limb), and elbow injuries. Radiographs of the femur, hip, spine, skull and shoulder were not included. The 30 radiographs chosen included 6 of the hand and wrist, 6 of the forearm), 6 of the elbow, 6 of the foot and ankle, and 6 of the lower leg (tibia and fibula). Of each region, there were two normal radiographs, two radiographs with subtle fractures and two radiographs with obvious fractures. The radiographs were anonymised with no personal identifiable information visible on the films. A model answer sheet was compiled by the PI and a paediatric radiologist. A second paediatric radiologist reviewed the images and the model answer sheet. Where the diagnosis on any of the radiographs was disputed, that radiograph was excluded from the sample and replaced by another one, until consensus was reached. This set of images with the model answer sheet was the gold standard against which the participating doctors were assessed.

The extremity radiographs that were chosen for use in this study were obtained from the radiology database of a public paediatric hospital in Johannesburg and deemed by the investigators to represent the normal scope of injuries seen after hours in a hospital emergency setting, ranging from normal, to no fractures with only soft tissue swelling present, to subtle fractures with or without soft tissue swelling, to obvious fractures. The radiographs equally represented all anatomical regions as described above.

These radiographs were organised into two PowerPoint presentations. The first presentation (Set 1) had the 30 cases without the CR and the second one (Set 2) had the same cases, but including the CR. The image sizes were the same on both the injured and comparison view slideshows to keep picture quality comparable throughout. Figure 2.1. below shows a selection of radiographs that were included in the PowerPoint presentations.

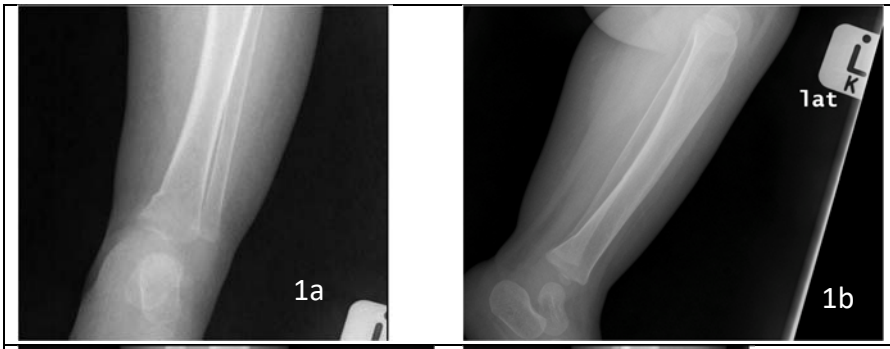
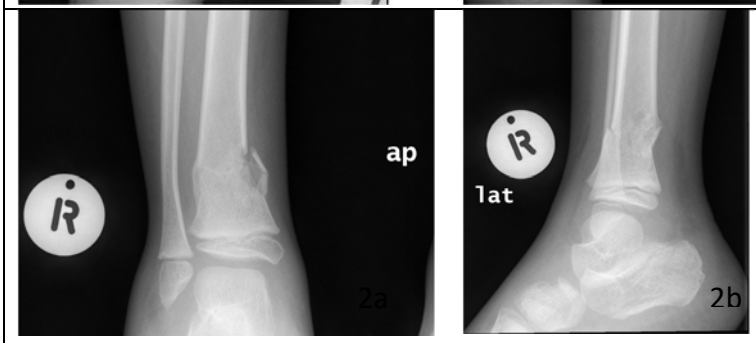
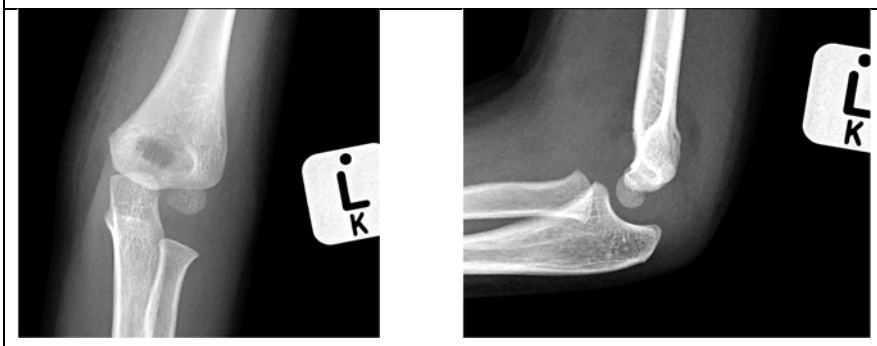
	**Image 1**: AP (a)and lateral (b) radiographs of left lower leg and ankle with a subtle torus fracture of the distal tibia
	**Image 2**: AP(a) and lateral (b) radiographs of the right ankle with an obvious fracture of distal tibia
	**Image 3**: AP (a) and lateral (b) radiograph of left elbow with a subtle left supracondylar fracture
	**Image 4**: AP radiograph of the left hand with obvious fracture of fourth proximal phalanx

Figure 2.1. Images to illustrate some of the radiographs that were included in the study (without CR)

The participants were informed about the aim of the study, and requested to participate. They all signed a participant consent form (Appendix B) before participating. No personal identifiable information is present on the tick sheet, but each participant was asked to indicate their level of experience on the tick sheet. Each set of tick sheets had a study number for data capturing purposes. A unique study number was generated by each participant at each set by a compilation of 5 characters made up as follows:

First character: First letter of your mother's name (eg. S if Sharon)

Second and third characters: Number of your birth month (eg, June = 06)

Fourth character: First letter of your first pet's name (eg. W if Whiskers)

Fifth character: Last letter of your phone number

Each of the participants initially received Set 1, containing radiographs WITHOUT the comparison views. They scrutinised these images and indicated on a tick sheet (Appendix C), whether or not there is a fracture on each of the radiographs (YES or NO) and also rated their level of comfort/confidence, on the scale provided (See table 2.1. and Appendix C), in making their diagnosis without a comparative radiograph of the contralateral limb. There was no time limit set on the amount of time spent looking at each radiograph (as there is no imposed time limit when viewing a radiograph in the clinical setting), but they were not allowed to use any external aids (textbooks, internet, journals, etc.) to assist with their diagnoses.

After completing the Set 1 tick sheet and handing it in, the same doctors received Set 2 (PowerPoint presentation), three to seven days later - containing the same radiographs, but this time WITH the comparison views. They once again filled in the same tick sheet (Appendix C) – indicating whether or not they thought a fracture was present or not and how confident they were in making the diagnosis now that they had comparison radiographs. After all the participants handed in the Set 2 tick sheet, the correct diagnoses were made available to and discussed with the participants, thus expanding their knowledge and experience in interpreting paediatric extremity radiographs.

The information on the tick sheets was captured in an Excel spread sheet for statistical analysis. The confidence level was captured as a score (Confidence Score, CS) using the scale below in table 2.1.

Table 2.1. Scale used to capture the confidence level as a score

	Confident there is a fracture and will manage as such	Suspect a fracture but would like further imaging	Not sure at all	Suspect no fracture but would like further imaging	Confident there is no fracture and will manage as such
If scored as Fracture	3	2	1		
If scored as No Fracture			1	2	3

2.4. Statistical analysis

2.4.1. Sample size calculation

This calculation was done with the main research question in mind, namely the comparison of sensitivity, specificity and comfort scores (all continuous variables) between the two sets of results (with and without comparative views). A paired t-test had to be used to achieve this. To detect small, medium and large effect sizes (corresponding to Cohen's d=0.2, 0.5 and 0.8), at 80% power and a 5% significance level, sample sizes of 199, 34 and 15 were required.

For the secondary objective of determining the difference in the three measures between anatomical sites (within a given view), a one-way repeated measure ANOVA (Analysis Of Variance) was required. To detect small, medium and large effect sizes (corresponding to f=0.10, 0.25 and 0.40) at 80% power and a 5% significance level, sample sizes of 121, 21 and 9 were required.

The study group composition was balanced (as far as possible) across all four doctor groups, to ensure that these groups were adequately represented in the overall study group. Considering then, the first two objectives, the determination of a medium effect size (effect size being the size of the difference in the mean of a variable (measurement) between two

groups, factoring in the within-group variability of that measurement) was considered sufficient, which then required a sample size of 34 doctors.
Sample size calculations were carried out in G*Power (40).

2.4.2. Statistical analysis

For each doctor (for each view scenario), the following scores were calculated (overall and per anatomical location):

- Sensitivity (% fractures correctly identified)
- Specificity (% non-fractures correctly identified)
- CS (mean of individual CS)

Descriptive analysis of the data was done in the following manner: Categorical variables were summarised by frequency and percentage tabulation, and illustrated by means of bar charts. Continuous variables were summarised by the mean, standard deviation, median and interquartile range, and their distribution illustrated by means of histograms.

The comparison of the sensitivity, specificity and CS between the one- and two-view scenarios was carried out using the paired t-test.

Within each of the one- and two-view scenarios, the comparison of the sensitivity, specificity and CS between fractures in different anatomical regions and subtlety classifications were carried out using the statistical technique of repeated measures Analysis of Variance (ANOVA) with sensitivity (or specificity or CS) as the outcome, anatomical region as the independent variable and doctor as the repeated measure.

Data analysis was carried out using Statistical Analysis Software (SAS). The significance level of 5% was used throughout, meaning that p-values <0.05 would indicate statistically significant results.

3. Results

3.1. Demographics

The doctors were fairly evenly distributed amongst the four groups selected for the study as shown in Figure 3.1. A total of 58 doctors participated, comprising of 16 interns, 16 community service doctors, 17 junior medical officers and 9 junior EM registrars.

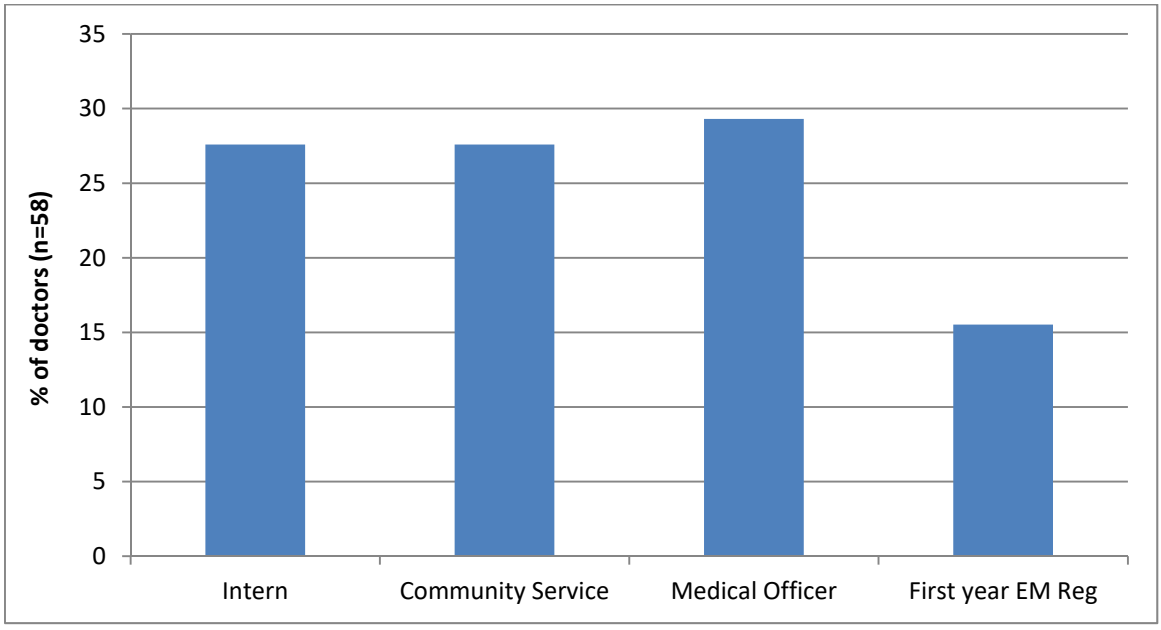


Figure 3.1. Distribution of participating doctors amongst the four subgroups selected for the study

3.2. Overall results

3.2.1. Sensitivity

The median sensitivity for the detection of fractures without CR was 80% (interquartile range (IQR) 70-90%; range 45-100%). When CR were added, the median sensitivity was also 80% (IQR 70-90%; range 45-100%). The distribution of the data are shown below in Figures 3.2. and 3.3.

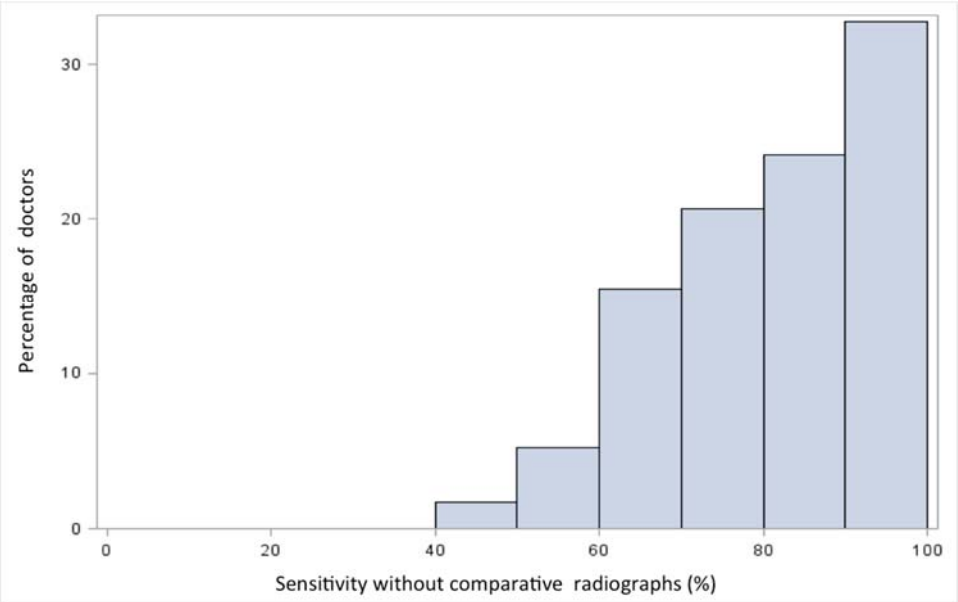


Figure 3.2. Median sensitivity of junior doctors for detecting fractures without comparative radiographs

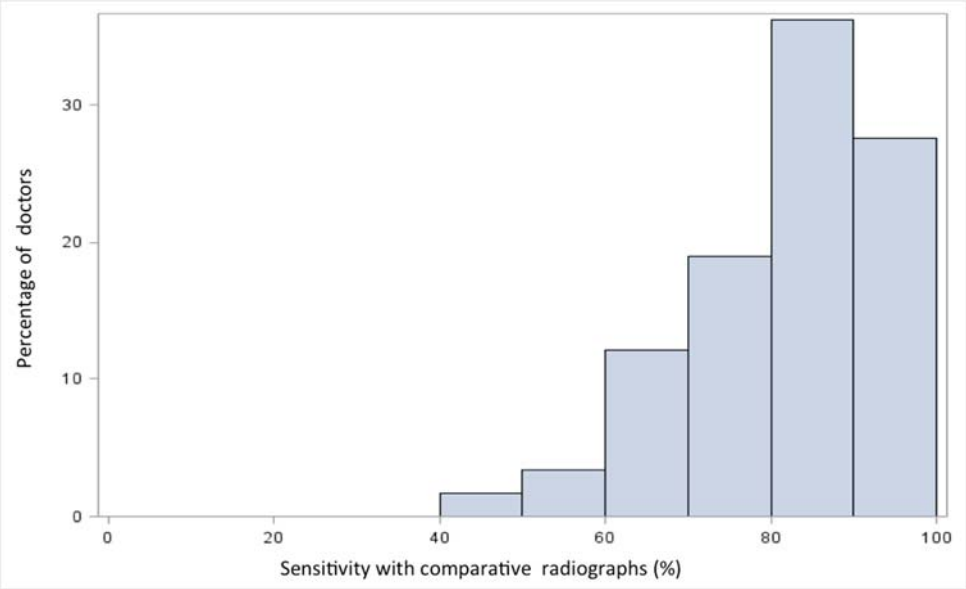


Figure 3.3. Median Sensitivity of junior doctors for detecting fractures with comparative radiographs

3.2.2. Specificity

The median specificity without CR was 80% (IQR 70-90%; range 10-100%), while with the addition of CR, the median specificity was 90% (IQR 90-100%; range 60-100%). The distribution of the data are shown below in Figures 3.4. and 3.5.

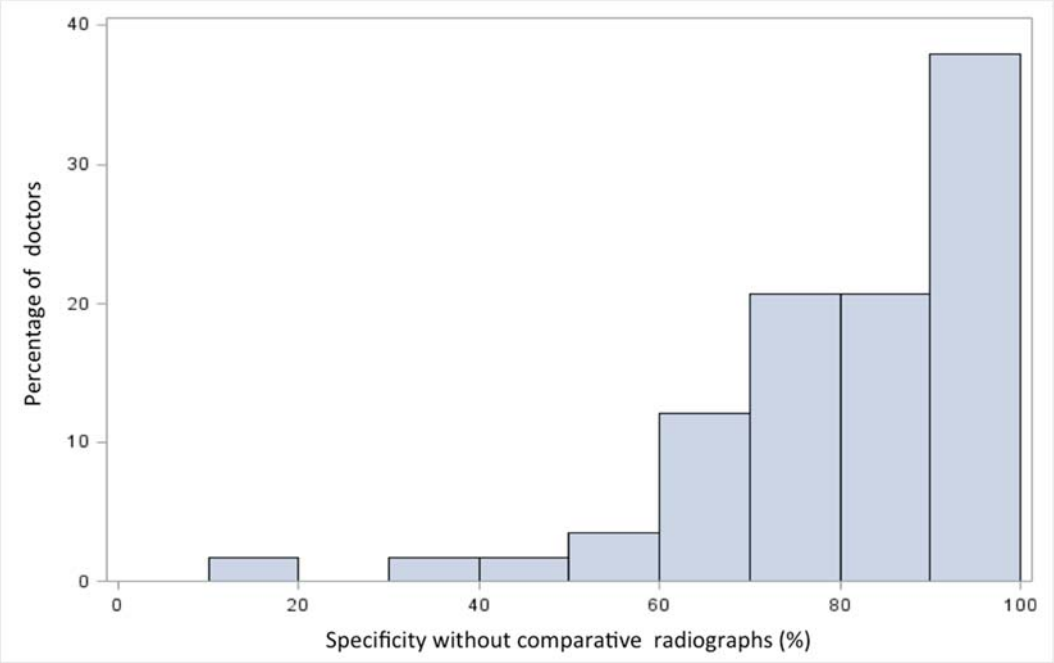


Figure 3.4. Median specificity of junior doctors for detecting fractures without comparative radiographs

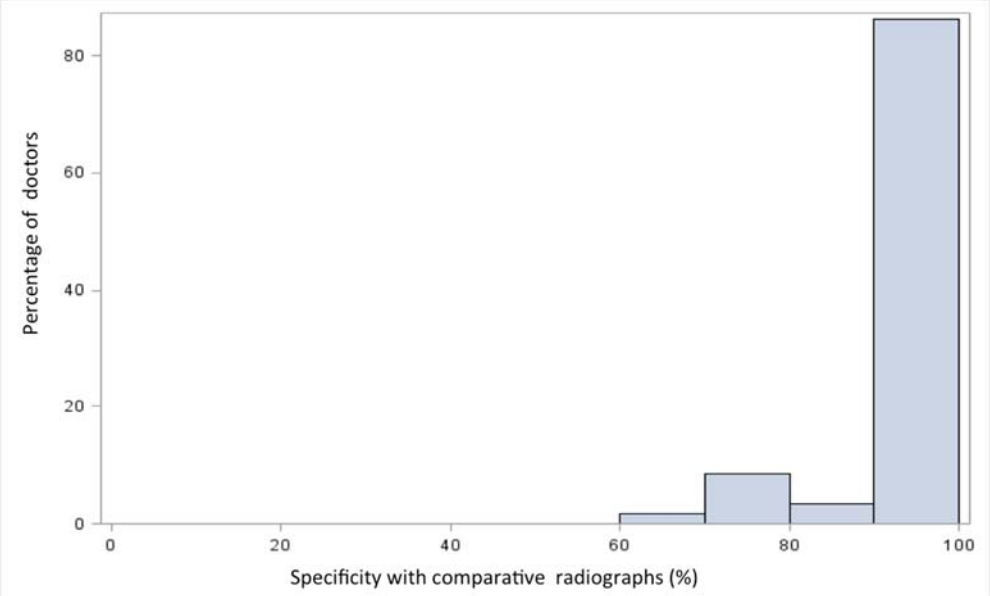


Figure 3.5. Median specificity of junior doctors for detection of fractures with the addition of comparative radiographs

3.2.3. Confidence score

The median CS without CR was 2.60 (IQR 2.43-2.73; range 1.97-2.97), while with CR, the median CS was 2.87 (IQR 2.73-2.93; range 2.30-3.00) The distribution of the data are shown below in Figures 3.6.and 3.7.

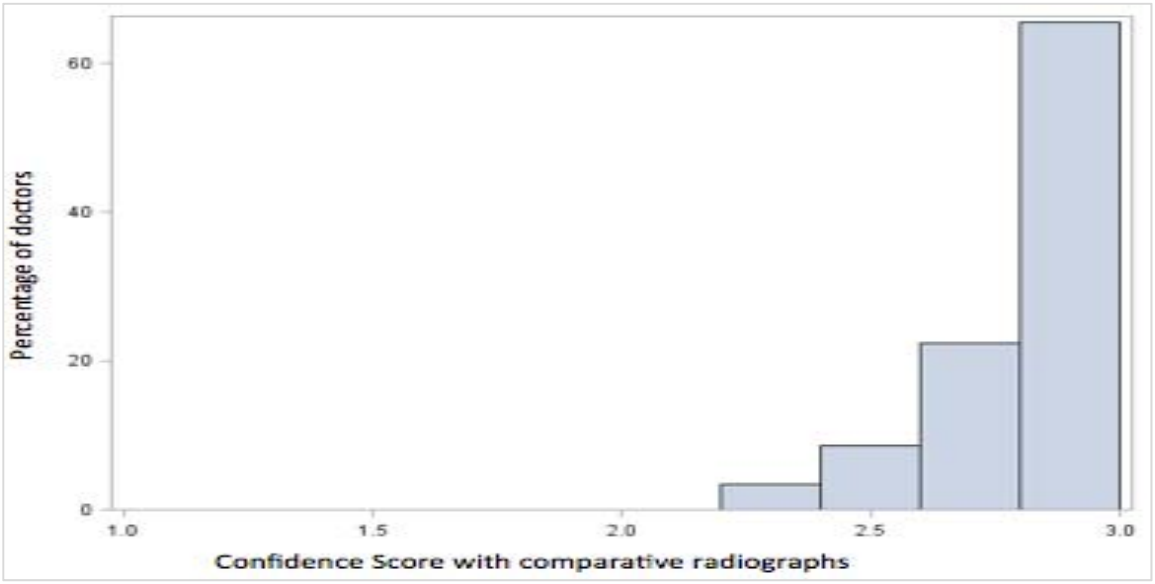


Figure 3.6. Median confidence score of junior doctors when evaluating paediatric extremity radiographs for fractures without comparative radiographs

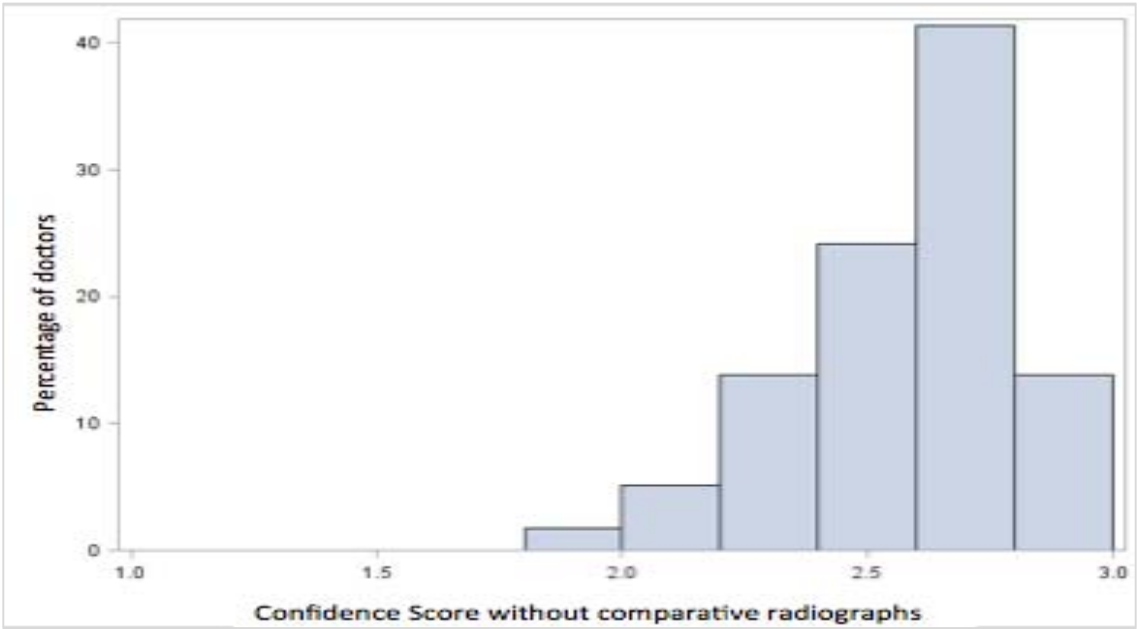


Figure 3.7. Median confidence score of junior doctors when evaluating paediatric extremity radiographs for fractures with the addition of comparison view

3.3. Comparison of overall sensitivity, specificity and confidence scores with and without comparative radiographs

Please note: The distribution of descriptive results above is negatively skewed (thus median was used), but for consistency of presentation, the mean is used throughout in the rest of the results and discussion.

3.3.1. Comparison of sensitivity

There was no significant change in sensitivity between interpretation of radiographs with and without CR (paired t-test; p=0.28). The sensitivity increased by a mean of 1.4% (95% CI: -1.1 to 3.9%; the CI includes zero and thus the change is not significant). This can also be illustrated by the profile plot for the 58 participants (Figure 3.8): The sensitivity increased for some, while it decreased for others. Table 3.1. details the comparison of sensitivity with and without CR.

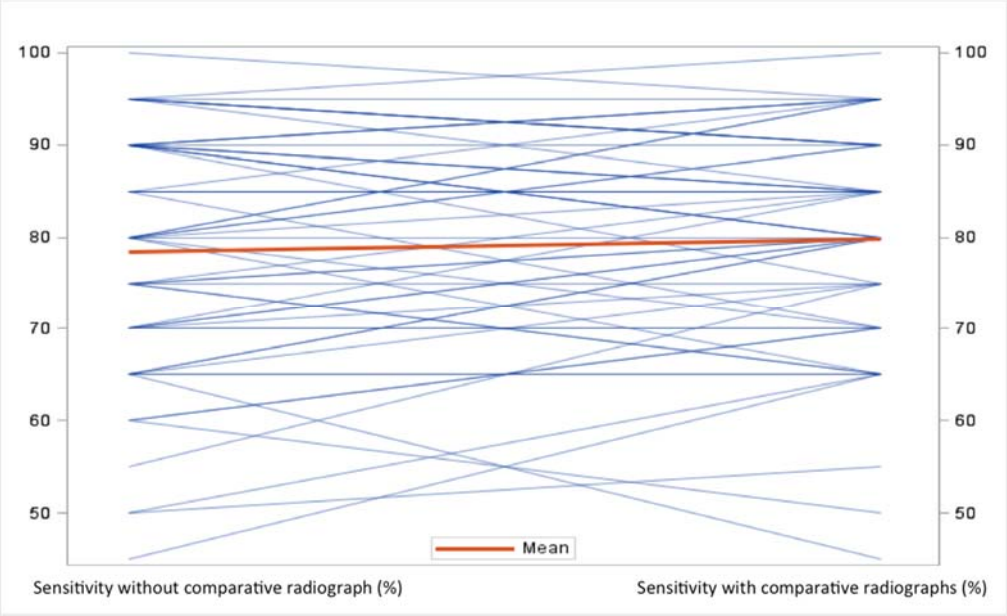


Figure 3.8. Comparison of sensitivity of fracture detection without and with comparative radiographs for each individual junior doctor and the mean

Table 3.1. Comparison of sensitivity with and without comparative radiographs

Mean Sensitivity		
	Without comparative radiographs	**With comparative radiographs**
Overall	78.4%	79.7%
Hand/wrist/forearm	82.5%	83.4%
Elbow	80.6%	88.4%
Foot/ankle/lower leg	73,1%	71.8%
Obvious fractures	91.7%	96.2%
Subtle fractures	65.0%	63.3%
Median Sensitivity		
Overall	80%	80%

3.3.2. Comparison of specificity

There was a significant increase in specificity when CR were added (paired t-test; p<0.0001). The specificity increased by a mean of 15.3% (95% CI: 10.7 to 20.0%). The effect size was large (d=0.87). The change can also be illustrated by the profile plot for the 58 participants (Figure 3.9.): The specificity increased for most doctors, while it decreased for only a few. Table 3.2. details the comparison of specificity with and without CR.

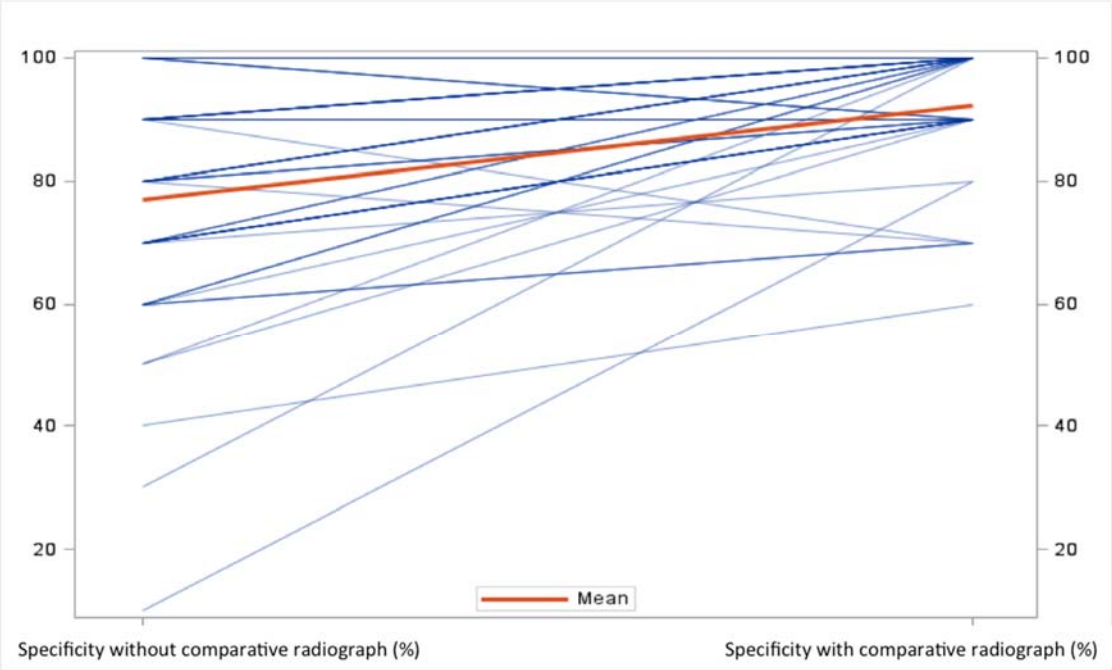


Figure 3.9. Comparision of specificity of fracture detection without and with comparative radiographs for each individual junior doctor and the mean

Table 3.2. Comparison of specificity with and without comparative radiographs

Mean Specificity		
	Without comparative radiographs	**With comparative radiographs**
Overall	76.9%	92.2%
Hand/wrist/forearm	92.2%	93.5%
Elbow	69.8%	89.7%
Foot/ankle/lower leg	65.0%	92.2%
Median Specificity		
Overall	80%	90%

3.3.3. Comparison of Confidence Score

There was a significant increase in overall CS when CR was added (paired t-test; $p<0.0001$). The CS increased by a mean of 0.24 points (95% CI: 0.19 to 0.29). The effect size was large ($d=1.4$). The change can also be illustrated by the profile plot for the 58 participants (Figure 3.10.): The CS increased for most doctors, while it decreased for only a few. Table 3.3. details the confidence score values with and without CR.

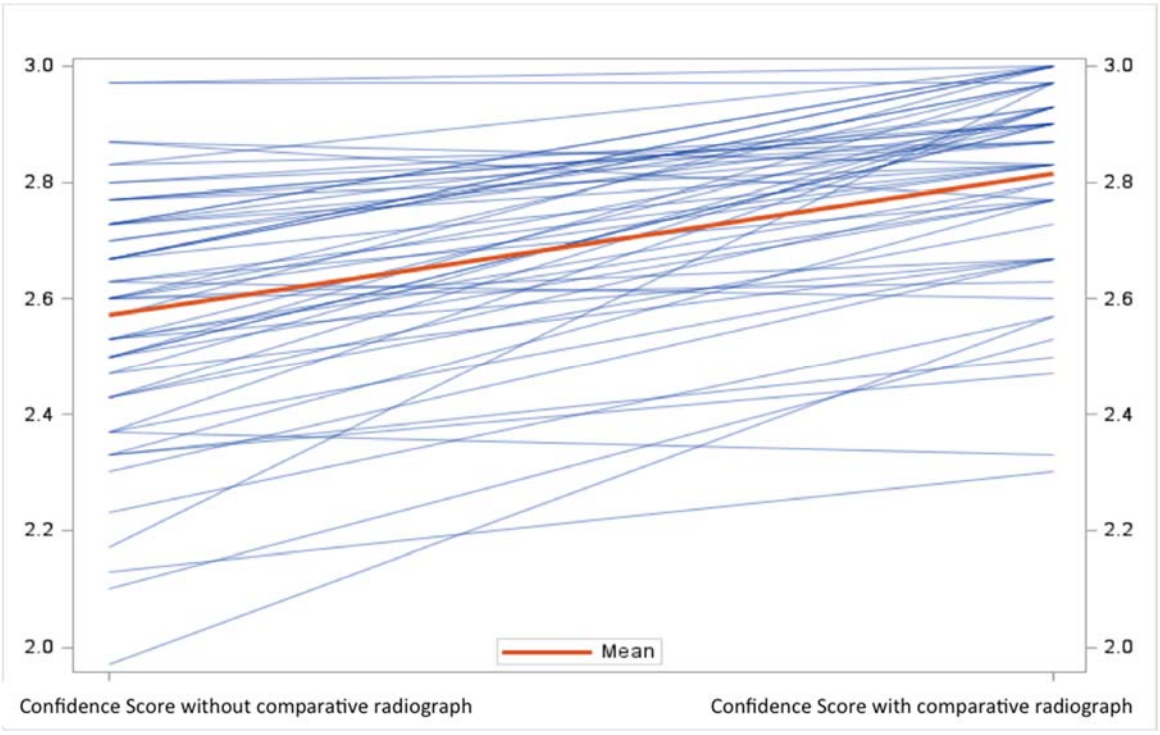


Figure 3.10. Comparison of confidence scores without and with comparative radiographs for each individual doctor and the mean

Table 3.3. Comparison of confidence scores with and without comparative radiographs

Mean Confidence Score		
	Without comparative radiographs	**With comparative radiographs**
Overall	2.57	2.81
Hand/wrist/forearm	2.65	2.85
Elbow	2.55	2.8
Foot/ankle/lower leg	2.51	2.78
Obvious fractures	2.8	2.89
Subtle fractures	2.49	2.72
No fractures (Normal)	2.42	2.83

3.3.4. Doctor Subgroup analyisis

The sample size was not large enough for this analysis to be statistically significant. Table 3.4. below summarises the average scores that each subgroup of doctors achieved in evaluating the two sets of slideshows.

Table 3.4. Accuracy /Average scores of doctor subgroups in evaulating paeditric extremity radiographs with and without comparative radiographs

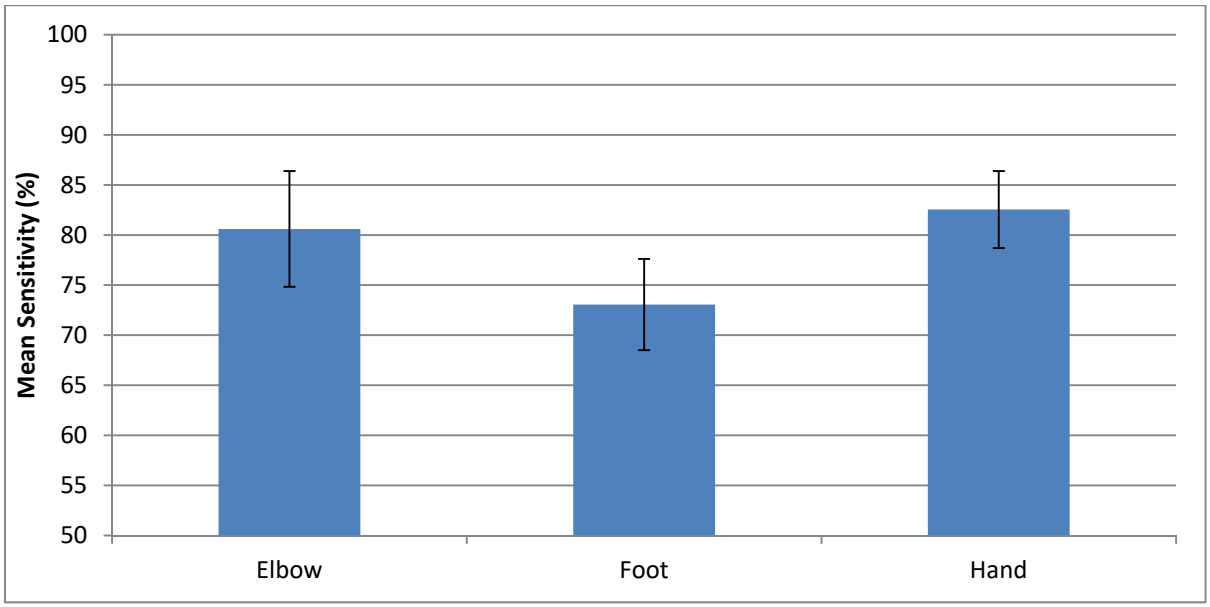
	Without CR	**With CR**
Interns	71%	78%
Community Service doctors	79%	86%
Junior Medical Officers	81%	86%
Junior Emergency Medicine Registrars	83%	87%

3.4. Analysis and comparision of anatomical sites

3.4.1 Sensitivity

3.4.1.1. Sensitivity without CR

The overall repeated measures ANOVA were significant (p=0.0067). Post-hoc tests showed that the mean sensitivity for distal lower limb (referred to as 'Foot' on Figure 3.11) radiographs. (73.1%) was significantly lower than that for distal upper limb (referred to as 'Hand' on Figure 3.11) radiographs (82.5%) (p=0.0053). The results are illustrated below in Figure 3.11. (The error bars illustrate the 95% confidence interval for the mean).

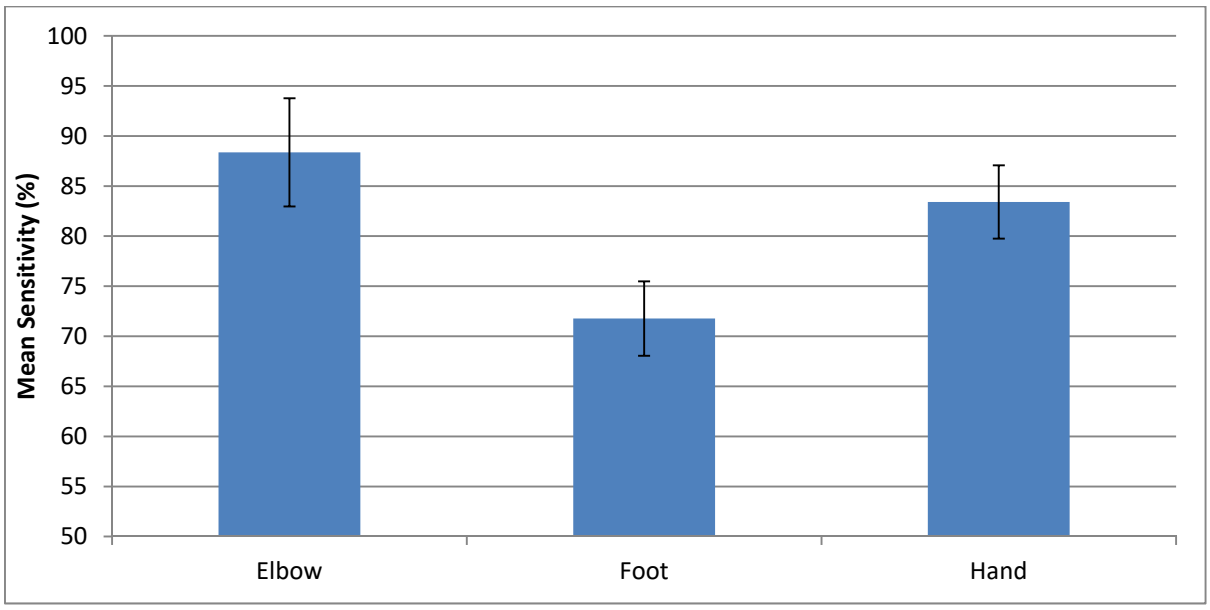


*Note: "Foot" refers to foot, ankle and lower leg (distal lower limb). "Hand" refers to hand, wrist and forearm (distal upper limb)

Figure 3.11. Sensitivity of fracture detection by junior doctors classified by anatomical site: Without comparative radiographs

3.4.1.2. Sensitivity with CR

The overall repeated measures ANOVA was significant (p<0.0001). Post-hoc tests showed that the mean sensitivity for distal lower limb (referred to as 'Foot' in figure3.14) radiographs (71.8%) was significantly lower than that for both distal upper limb (referred to as 'Hand' on Figure 3.14) radiographs (83.4%) and Elbow X-rays (88.4%) (both p<0.0001). The results are illustrated below in Figure 3.12. (The error bars illustrate the 95% confidence interval for the mean).



*Note: "Foot" refers to foot, ankle and lower leg (distal lower limb). "Hand" refers to hand, wrist and forearm (distal upper limb)

Figure 3.12. Sensitivity of fracture detection by junior doctors classified by anatomical site: With addition of comparative radiographs

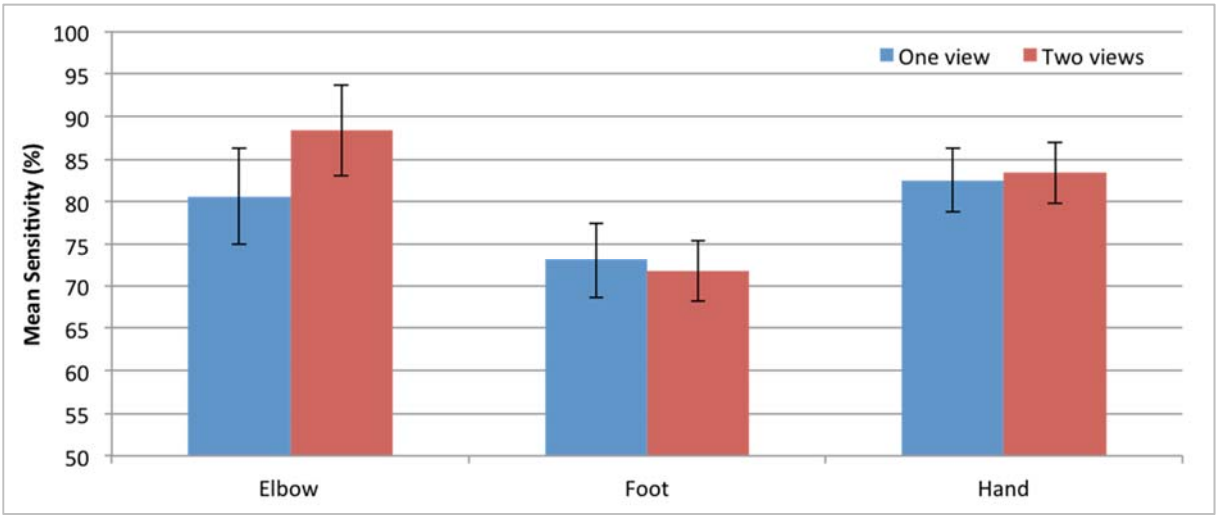
3.4.1.3.Comparision of sensitivity

There is a 7.8% (95% CI: 2.2-13.3) increase in sensitivity for elbow fractures (from 80.6% to 88.4%) when CR are added (p=0,0068). There is a small decrease in sensitivity for distal lower limb (referred to as ' Foot' in Fig 3.13) fractures (1.2%, p=0.53) and a small increase in distal upper limb (referred to as 'Hand' in Figure 3.13) fractures (0,9%, p=0.65) when CR are added. Table 3.5. below, details the values for comparison of sensitivity between the different sites with and without CR.

Table 3.5. Comparison of sensitivity (%) of fracture detection of junior doctors by site

	Distal upper limb (Hand/wrist/forearm)	Elbow	Distal lower limb (Foot/ankle/lower leg)
Sensitivity without CR	82.5%	80.6%	73.1%
Sensitivity with CR	83.4%	88.4%	71.8%

The above results are displayed in graphic format in Figure 3.13 below.



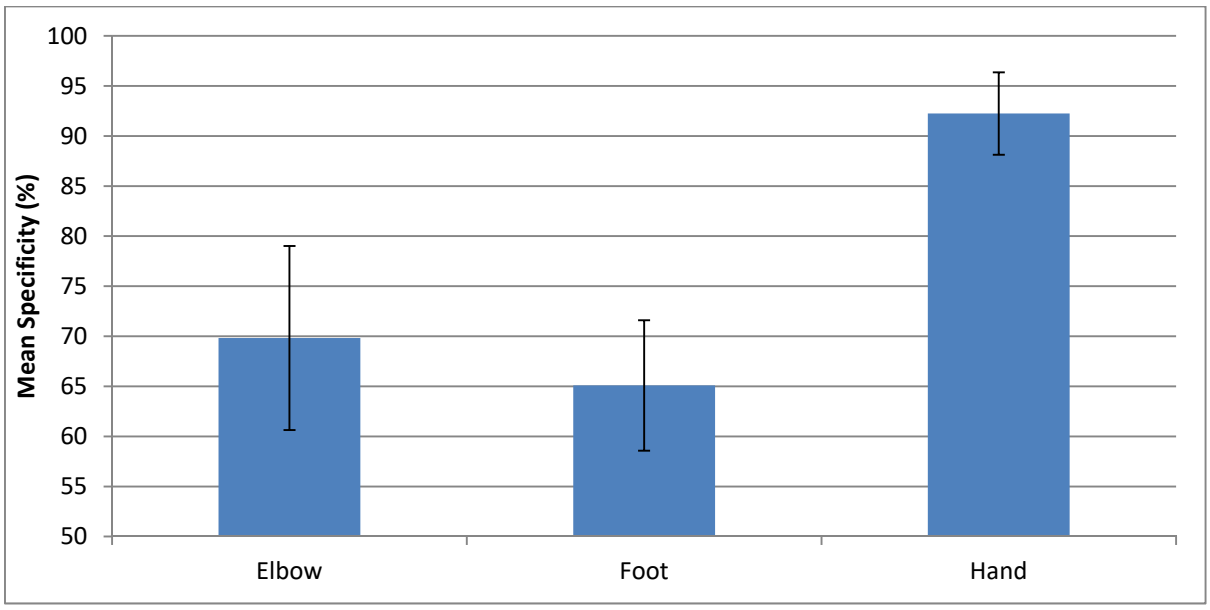
*Note: "Foot" refers to foot, ankle and lower leg (distal lower limb). "Hand" refers to hand, wrist and forearm (distal upper limb)

Figure 3.13. Comparison of sensitivity of specific anatomical site fracture detection by junior doctors with and without comparative radiographs

3.4.2. Specificity

3.4.2.1. Specificity without CR

The overall repeated measures ANOVA was significant ($p<0.0001$). Post-hoc tests showed that the mean specificity for distal lower limb (referred to as 'Foot' on Figure 3.14) radiographs (65.1%) and Elbow radiographs (69.1%) was significantly lower than that for distal upper limb (referred to as 'Hand' on Figure 3.14) radiographs (92.2%) (both $p<0.0001$). The results are illustrated below in Figure 3.14. (The error bars indicate the 95% confidence interval for the mean).



*Note: "Foot" refers to foot, ankle and lower leg (distal lower limb). "Hand" refers to hand, wrist and forearm (distal upper limb)

Figure 3.14. Specificity of fracture detection by junior doctors classified by anatomical site: Without comparative radiographs.

3.4.2.2. Specificity with CR

The overall repeated measures ANOVA was not significant (p=0.53). Thus, there was no significant different in the mean specificity between the three anatomical sites when CR were added.

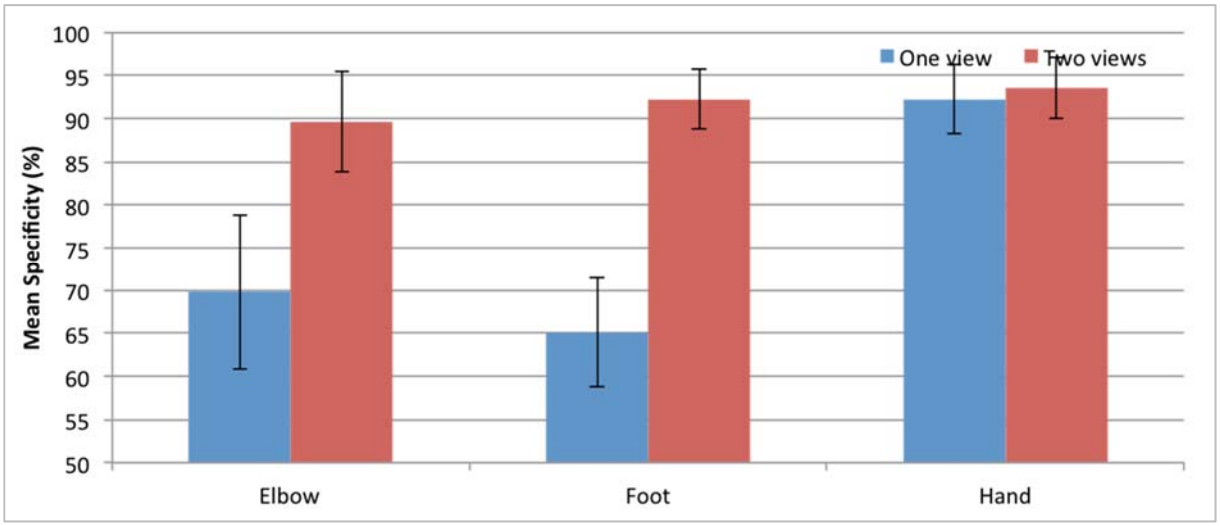
3.4.2.3. Comparison of specificity

With the addition of CR the specificity for elbow radiographs increases with 19.8% (95% CI: 10.6-20 and p<0.0001). The specificity for distal lower limb (referred to as 'Foot' in Figure 3.15) radiographs increases with 27.2% (95% CI: 20.3-34 and p<0.0001) when CR are added. The specificity for distal upper limb (referred to as 'Hand' in Figure 3.15) radiographs only increases by 1.3% (p=0.57). See Table 3.6. below, detailing the values for comparison of specificity between the sites with and without CR.

Table 3.6. Comparison of specificity of fracture detection by junior doctors by site

	Distal upper limb (Hand/wrist/forearm)	Elbow	Distal lower limb (Foot/ankle/lower leg)
Specificity without CR	92.2%	69.8%	65.1%
Specificity with CR	93.5%	89.7%	92.2%

The above results are displayed in graphic format in Figure 3.15 below.



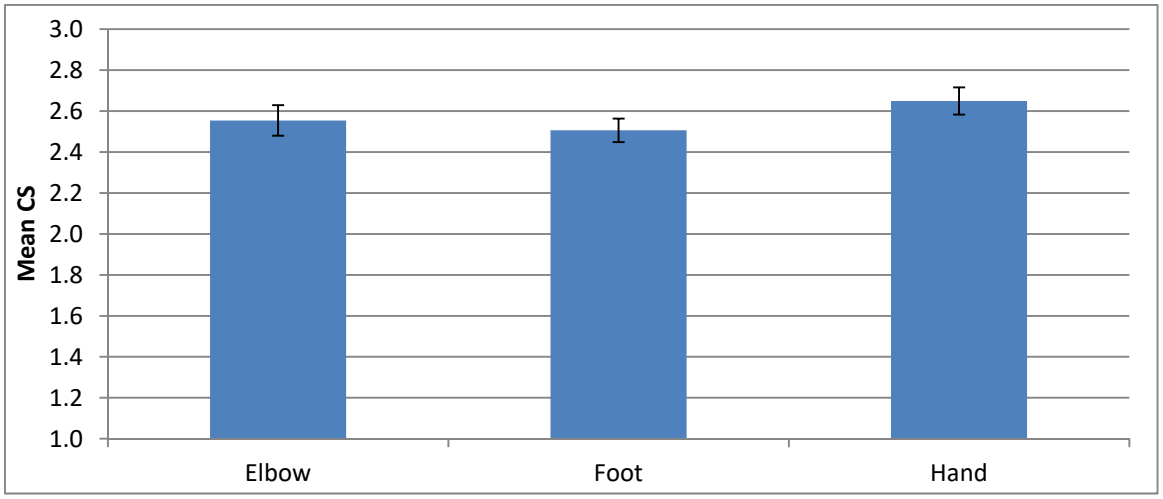
*Note: "Foot" refers to foot, ankle and lower leg (distal lower limb). "Hand" refers to hand, wrist and forearm (distal upper limb)

Figure 3.15. Comparison of spesificity of specific anatomical site fracture detection by junior doctors with and without comparative radiographs

3.4.3. Confidence score

3.4.3.1. Confidence Score without CR

The overall repeated measures ANOVA was significant (p=0.0057). Post-hoc tests showed that the mean CS for distal lower limb (referred to as 'Foot' on Figure 3.16) radiographs (2.5) was significantly lower than that for distal upper limb (referred to as 'Hand' on Figure 3.16) radiographs (2.7) (p=0.0038). The results are illustrated below in Figure 3.16. (The error bars illustrate the 95% confidence interval for the mean).



*Note: "Foot" refers to foot, ankle and lower leg (distal lower limb). "Hand" refers to hand, wrist and forearm (distal upper limb)

Figure 3.16. Confidence score of junior doctors classified by anatomical site: Without comparative views

3.4.3.2. Confidence Score with CR

The overall repeated measures ANOVA was not significant (p=0.085). Thus, there was no significant different in the mean CS between the three anatomical sites when CR were added.

3.4.3.3. Comparison of confidence scores

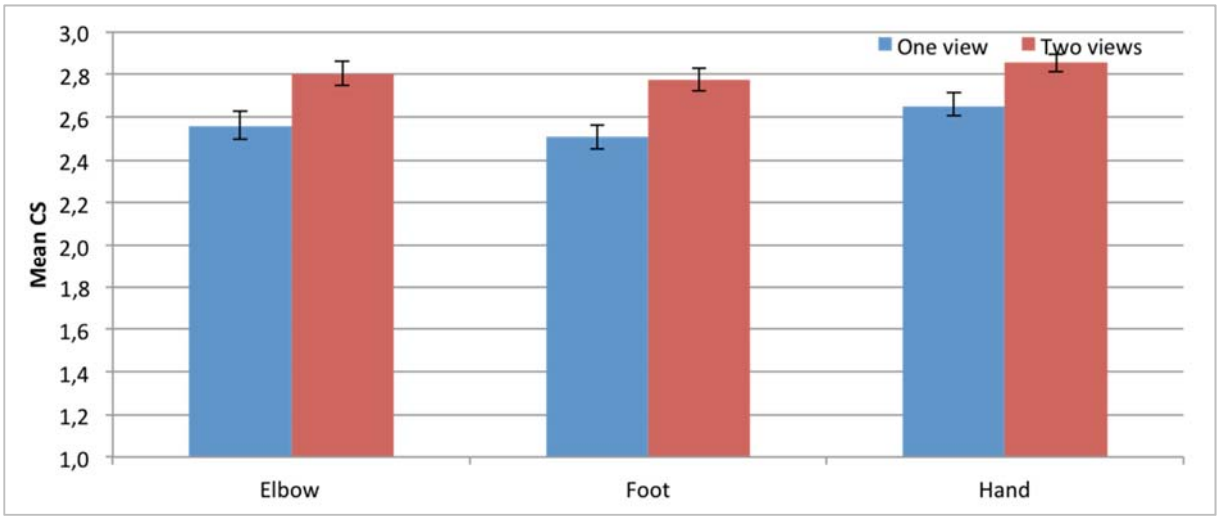
There is a significant increase in confidence scores for all three anatomical sites after the addition of CR (p<0.0001 for all three sites individually).

See Table 3.7. below, detailing the values for comparison of confidence scores between the different sites with and without CR.

Table 3.7. Comparison of confidence score of fracture detection by junior doctors by site

	Distal upper limb (Hand/wrist/forearm)	Elbow	Distal lower limb (Foot/ankle/lower leg)
CS without CR	2.65	2.55	2.51
CS with CR	2.85	2.80	2.78

The above results are displayed in graphic format in Figure 3.17 below.



*Note: "Foot" refers to foot, ankle and lower leg (distal lower limb). "Hand" refers to hand, wrist and forearm (distal upper limb)

Figure 3.17. Comparison of confidence scores of junior doctors in interpretation of radiographs of different anatomical sites with and without comparative radiographs

3.5. Analysis and comparison of subtlety classification of fractures (Obvious /Subtle/ No fracture)

Note:

- Analysis of Sensitivity, by definition, does not include 'No Fracture'.
- Analysis of Specificity, by definition, only includes 'No Fracture' and the results are thus the same as the comparison of Sensitivity for one and two views done earlier (and are not repeated here).

3.5.1. Sensitivity

3.5.1.1. Sensitivity without CR

The mean sensitivity for Obvious Fractures (91.7%) was significantly higher than that for Subtle Fractures (65.0%) ($p<0.001$). The results are illustrated below in figure 3.18. (The error bars denote the 95% confidence interval for the mean).

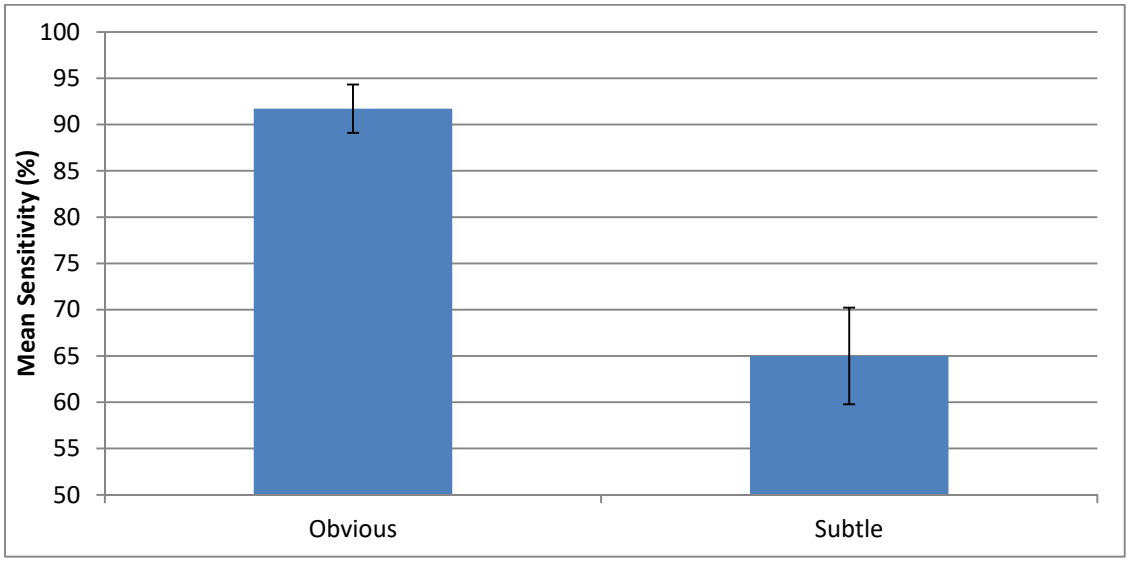


Figure 3.18. Sensitivity of fracture detection by junior doctors classified by subtlety of fracture (Without comparative radiographs)

3.5.1.2. Sensitivity with CR

The mean sensitivity for Obvious Fractures (96.2%) was significantly higher than that for Subtle Fractures (63.3%) ($p<0.001$). The results are illustrated below in Figure 3.19. (The error bars denote the 95% confidence interval for the mean).

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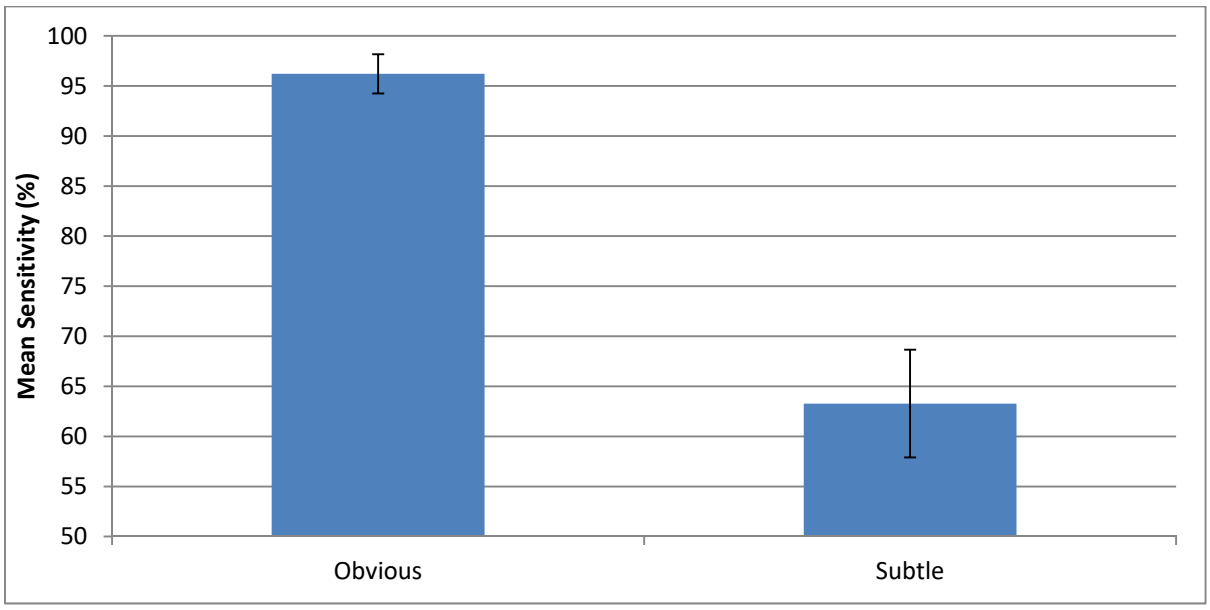


Figure 3.19. Sensitivity of fracture detection by junior doctors classified by subtlety of fracture (With addition of comparative radiographs)

3.5.1.3. Comparison of sensitivity

Table 3.8. below details the values for comparison of sensitivity between obvious and subtle fracture detection

Table 3.8. Comparison of sensitivity between obvious and subtle fractures with and without comparative radiographs

	Obvious	Subtle
Sensitivity without CR	91.7%	65.0%
Sensitivity with CR	96.2%	63.3%

3.5.2. Confidence scores

3.5.2.1. Confidence score without CR

The overall repeated measures ANOVA was significant ($p<0.0001$). Post-hoc tests showed that the mean CS for Obvious Fractures (2.8) was significantly higher than that for both Subtle Fractures (2.5) ($p<0.0001$) and No Fractures (2.4) ($p<0.0001$). The results are illustrated below in figure 3.20. (The error bars denote the 95% confidence interval for the mean).

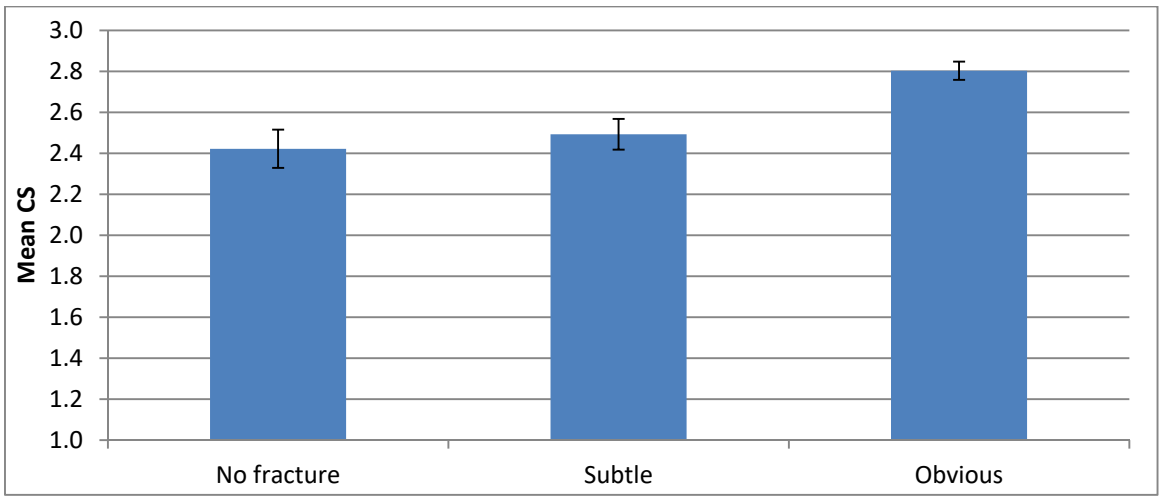


Figure 3.20. Confidence score of junior doctors classified by subtlety and presence/absence of fractures (Without comparative views)

3.5.2.2. Confidence scores with CR

The overall repeated measures ANOVA was significant (p=0.0002). Post-hoc tests showed that the mean CS for Obvious Fractures (2.9) was significantly higher than that for Subtle Fractures (2.7) (p=0.0001). The results are illustrated below in figure 3.21. (The error bars denote the 95% confidence interval for the mean).

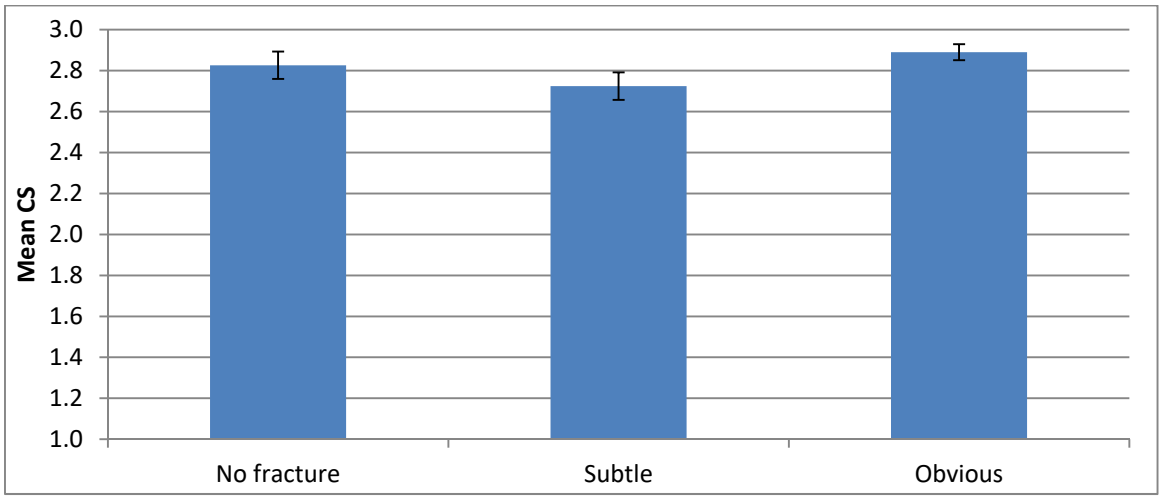


Figure 3.21. Confidence score of junior doctors classified by subtlety and presence/absence of fractures (With addition of comparative views)

3.5.2.3. Comparison of confidence scores

Table 3.9. below details the values of confidence scores of the junior doctors in diagnosing obvious, subtle and no fractures with and without CR.

Table 3.9. Comparison of confidence scores of junior doctors when diagnosing obvious, subtle and no fractures with and without fractures

	Obvious	Subtle	No fracture
CS without CR	2.80	2.49	2.42
CS with CR	2.89	2.72	2.83

4. Discussion

The conventional practice of routinely radiographing both limbs (the injured and corresponding unaffected limb) in a suspected extremity fracture in a child for comparison purposes is widespread in the emergency and other departments in South Africa. This leads to added radiation exposure and costs and is of questionable value. The aim of this study was to ascertain whether adequate diagnostic accuracy could be achieved by routinely radiographing only the affected extremity in an ED setting, where predominantly junior doctors are on duty. The ability to detect fractures (sensitivity) as well as to recognise when there are no fractures (specificity) were evaluated and compared with and without CR. The level of confidence with which these doctors make their diagnoses with and without CR were also assessed. An analysis and comparison between three main anatomical sites as well as between obvious and subtle fractures were done.

The results of this study, compared to similar studies in the literature, can be found in Table 4.1. and is an expansion on Table 1.2.

4.1. Results in context

4.1.1. EM doctor demographics

The subgroups of doctors were fairly evenly distributed, especially between the interns, community service doctors and junior medical officers. A little over half the amount of junior EM registrars participated, compared to the other groups. This is representative however of the clinical staffing situation in the EDs of the hospitals investigated. Kimberley hospital has no registrars in their ED and the ratio of registrars to the other junior doctor subgroups in the Helen Joseph Hospital EM is low (<1:2).

The sample size was not large enough to allow for statistically significant analysis between the four subgroups of junior doctors. A gross analysis of the accuracy of the different subgroups' interpretation of the radiographs was however done and suggests that generally the more senior doctors are more accurate in their diagnoses and rely less on CR.

4.1.2. Sensitivity

In terms of overall sensitivity (positive predictive value) of junior emergency department doctors in diagnosing paediatric extremity fractures, the data shows that 78.4% of true fractures were identified as fractures by these doctors without CR and 79.7% when CR were added (increase is not statistically significant, p = 0.28). Thus they missed almost the same amount of fractures, overall, even with the aid of CR. This correlates with the findings of Charcon et al in 1992, with a similar study design, which showed that CR in paediatric elbow injuries did not improve the accuracy of fracture diagnosis at all (17). In 1979 Merten also concluded that CR have a low diagnostic yield (4).

In contrast to the overall sensitivity and literature referred to above, it was found that in this study population, there is indeed a statistically significant increase of 7.8% in the detection rate of elbow fractures when CR were added (p=0.0068).

As the radiographs in the PowerPoint presentations that were shown to the participants were equally divided between obvious, subtle and no fractures, an additional analysis was done comparing the sensitivity between the different subtlety classifications.

Comparison of the sensitivity between obvious and subtle fractures was done both with and without CR. The mean sensitivity for obvious fractures (91.7%) was significantly higher than for subtle fractures (65%) ($p<0.0001$) without CR. Thus 8.3% of obvious fractures and 35% of subtle fractures were missed without CR. When comparative views were added the mean sensitivity was still higher for obvious fractures (96.2%) than for subtle ones (63.3%) ($p<0.0001$), meaning that now 3.8% of obvious fractures and 36.7% of subtle fractures were missed.

The junior doctors were more accurate in detecting obvious fractures than subtle ones, as expected. What was also proven was that the addition of CR does not increase the accurate identification of subtle fractures as was expected. Thus the participating doctors still missed roughly the same amount of subtle fractures with the help of additional views as without it. In 1980, the American Academy of Paediatrics acknowledged that a subtle fracture might be overlooked even if CR are done; despite this they adapted their recommendations against the routine use of comparison views, but acknowledged that exceptions can be made in

settings where there are no radiology services to review the images or where a patient cannot be easily followed up (1). In more recent literature, Swischuk et al., Merkel et al. and Tourquet et al., recommends CR to avoid missing subtle fractures (6, 12, 31). The findings in this study showed no evidence that this approach will improve the overall ability of junior emergency department doctors in South Africa to identify subtle paediatric extremity fractures.

4.1.3. Specificity

When analysing specificity (negative predictive value), there was an increase in median specificity from 80% without CR, to 90% when CR were added and a mean increase in specificity from 76.9% to 92.2% with CR. This translated to a mean increase in specificity of 15.3% (95% CI: 10.7 to 20% and $p<0.0001$). This means that 15% more radiographs without any fractures were correctly identified as not having fractures with the aid of CR. In practice this translates to 15% less paediatric patients being treated or referred unnecessarily (false positive) for extremity fractures. There are no previous studies found that evaluated this aspect.

4.1.4. Confidence levels

With regards to confidence levels of the participating doctors when faced with paediatric extremity radiographs, the data showed that there was a statistically significant ($p<0.0001$) increase in confidence score when CR were added. There was a mean increase of 0.24 points (12%) with a 95% CI: 0.19 to 0.29. The participants were thus more confident overall when CR were added, even though it did not improve their overall ability to identify fractures (sensitivity). These findings are similar to the results of McCauley et al in 1979, who also found that routine CR did increase the confidence with which the less experienced doctors were diagnosing fractures, but did not lead to more accurate diagnoses. The extremity CR thus had more of a psychological benefit on less experienced doctors (5). The study by Mayhue et al. in 1989 also echoes the finding that a doctor's level of confidence cannot be used as a gauge of radiological diagnostic accuracy (23).

As the radiographs in the PowerPoint presentations that were shown to the participants were equally divided between obvious, subtle and no fractures, an additional analysis was done comparing the confidence scores between the different subtlety classifications.

With regards to confidence levels without CR, the confidence scores were significantly higher for obvious fractures (2.8) than for both subtle (2.49) and no (2.42) fractures ($p<0.0001$). When CR were added the confidence score for diagnosing obvious fractures (2.89) was still significantly higher than for diagnosing subtle fractures (2.72) ($p=0.0001$). The confidence score for diagnosing no fracture with CR was 2.81. Junior doctors are thus more confident in diagnosing obvious fractures than subtle and no fractures. The addition of CR does increase the confidence level in making all diagnoses, but most markedly the diagnosis of subtle and no fractures

4.1.5. Anatomical sites

4.1.5.1. Sensitivity

In terms of the different anatomical sites – grouped as 3 broad categories (distal upper limb (hand, wrist, forearm) versus elbow versus distal lower limb (foot/ankle/lower leg)) – sensitivity (correctly identified fractures), when presented with only one view (without CR) was the highest for the diagnosis of distal upper limb fractures (82.5%). This is statistically significantly higher than for fractures of the distal lower limb (73.1%) ($p=0.0053$). The sensitivity for elbow fractures was 80.6%, not statistically significantly more or less than the other two sites. When there were CR available to the doctors, the sensitivity for detection of fractures of both the elbow (88.4%) and distal upper limb, (84.3%) was significantly higher than for the distal lower limb (71.8%) ($p<0.0001$).

From this we can see that the participating doctors were better at identifying fractures of the distal upper limb than of the distal lower limb.

When comparing the sensitivity between the different anatomical sites before and after CR, there is a statistically significant increase of 7.8% in sensitivity for elbow fractures ($p=0.0068$), but not for distal lower or upper limb fractures. This finding is the only evidence this study has found of significant increase in fracture detection abilities by junior EM doctors when CR are added.

4.1.5.2. Specificity

The specificity (correctly identifying the lack of fractures) was found to be statistically higher for distal upper limb injuries (92.2%) than for elbow (69.1%) and distal lower limb injuries (65.1%) when presented with radiograph of only the affected side. When the images were evaluated with CR there was no statistically significant difference in mean specificity between the different anatomical sites (elbow=89.7%, distal upper limb = 93.5% and distal lower limb = 92.2%).

We can thus see that a significant amount of elbow and distal lower limb injuries are misdiagnosed as fractures, without CR. The addition of CR significantly increases the specificity of fracture diagnosis overall ($p<0.0001$) as well as for elbows ($p<0.0001$) and distal lower limbs ($p<0.0001$). There is no statistical increase in specificity for distal upper limb radiograph evaluation with CR ($p=0.57$)

4.1.5.3. Confidence levels

The confidence scores without CR were significantly higher for the interpretation of distal upper limb injuries (2.65), than for distal lower limb injuries (2.51) ($p=0.0038$), with elbow injuries at confidence score of 2.55. When anatomical sites are compared in the situation where doctors had a CR at hand, the mean confidence scores had no statistical significant difference between the sites. The doctors felt more comfortable making diagnoses on distal upper limb injuries without CR, than with the other sites. The addition of CR increased the overall confidence score in radiographic decision-making in paediatric extremity radiographs, as well as for each individual anatomical site ($p<0.0001$).

4.1.5.4. Remarks

The above results prove that the junior emergency department doctors that participated in the study were more accurate (sensitivity and specificity) and confident in making diagnoses pertaining to the distal upper limb (hand/wrist/forearm) than to the distal lower limb (foot/ankle/lower leg), specifically without comparison views. The addition of comparison views increases the sensitivity in diagnosing elbow fractures significantly, but not of foot/ankle/lower leg fractures. The possible reasons for the obvious discordance between

the sites might be because of a deficiency in training and because of less exposure to lower limb injuries in children (as upper limb, specifically distal forearm, injuries are generally more common in children than lower limb injuries (14, 15)).

Table 4.1. Summary of studies on accuracy of Emergency Department doctors' interpretations of radiographs, including the results of this study.

Author, date and location	Study objectives	Error rate or agreement rate (%)	Results
Gleadhill (21) 1980 Liverpool, England	-Accuracy of ED doctors' assessment of trauma x-rays -Doctor experience gauged by number of injuries seen over study period.	4.9% of all trauma injuries missed on radiographs	Number of errors decrease with increased experience, with error rates falling from 7.1% to 2.9% in all missed injuries and from 1.7% to 0.6% (1.2% average) in clinically significant injuries. -Injuries of distal extremities most often missed.
Vincent et al (22) 1988 London, England	-Accuracy of trauma doctors' assessment of radiographs -Doctor experience gauged by time spent in ED (in months).	2.8% of all trauma x-rays were misdiagnosed. Injuries missed when considering only abnormal radiographs is 35% (39% of these clinically significant).	Although more missed diagnoses occurred in the junior doctors' first month in ED, no significant improvement was proved in the following 5 months.
Mayhue et al (23) 1989 Illinois, USA	Correlation between physician confidence level in radiological diagnosis and diagnostic accuracy	Analysis of studies between 1971- 1987 that investigated inter-reader agreement between ED and Radiology doctors reveals a range of 83 -99%.	Increased physician confidence levels are found with increased level of training, but only resulted in increased diagnostic accuracy in some groups of radiographs (incl. chest and extremities). Thus the confidence with which an ED doctor interprets a radiograph cannot be used as gauge for diagnostic accuracy.

Minnes et al (24) 1995 Ontario, Canada	-Agreement between ED doctors and paediatric radiologist in diagnosis of paediatric extremity fractures (accuracy) -Types and sites of injuries with most disagreement.	83.3 – 84.8% agreement rate.	Types of fractures disagreed on: Buckle and non-displaced fractures of the phalanges, elbows, feet and hands. Predominant sites of disagreement were the ankle, elbow and knee.
This study 2016 South Africa	-Comparison of accuracy and confidence levels of junior Emergency Department doctors' diagnosis of paediatric extremity fractures (with and without comparison views) - Comparison of accuracy and confidence of fracture diagnosis between anatomical sites	80% fractures identified (with and without comparison views): Sensitivity	No statistically significant increase overall in sensitivity of fracture diagnosis when CR added 15% increase in specificity when CR added 12% increase in confidence level when CR added (even though no decrease in amount of missed fractures) More fractures missed in lower limb (26,9%) (Foot, ankle, lower leg) than elbow (19.4%) and upper limb (17.5%) (Hand, wrist, forearm) – Without CR. With CR, 11.6% of elbow fracture are missed and 15.7% of upper limb and 28,2% of lower limb. Statistically significant increase (7.8%) in sensitivity for elbow fractures with CR.

4.2. Current applications

The use of CR in the diagnosis of paediatric extremity fractures is currently routine practice in most EDs in South Africa. This study found that although the use of CR amongst junior ED doctors increases the level of confidence with which they make their diagnosis, it does not significantly improve their ability to identify fractures overall, i.e. they miss roughly the same amount of fractures on paediatric extremities with and without. There is however a statistically significant increase in diagnostic accuracy of elbow fractures when CR are added. This indicates that CR is valuable in suspected elbow fractures when encountered by junior EM doctors.

The addition of CR does improve the junior doctors' overall ability to identify normal radiographs i.e. to rule out a fracture. Thus with the aid of CR there are more children (15%) that will not receive unnecessary treatment and referral. This appears to add to the value to the use of CR - in that they aid significantly in ruling out fractures in paediatric extremities. The implications of children without fractures being treated and/or referred to the orthopaedic department as fractures, has to be explored:

If a child is diagnosed with a fracture in the ED, standard treatment is usually immobilisation (41) and referral to the orthopaedic fracture clinic (usually within a week or less) (42) or to the orthopaedic surgeon on call for immediate definitive management depending on the type of injury and hospital protocols. It is well known however that not all fractures are immediately seen on radiographs and initial radiographs can be normal (43). Thus in an extremity injury where there is a clinical suspicion of a fracture, but that has a normal radiograph, immobilisation and orthopaedic follow up is appropriate as there is a real possibility of an occult fracture. (44). Many of these patients will not have an occult or any other fracture on orthopaedic follow up and in these cases the cost of returning to hospital and the discomfort of having an immobilised extremity are the main drawbacks to the patient. Similarly, if a fracture is diagnosed where there is none, and the limb is immobilised with short-term follow up, it does not significantly harm the clinical outcome of the child. This renders the significant increase in specificity with CR to be of less value than expected. These situations do contribute to overburdening of the orthopaedic service however.

Despite the increase in radiation dose and cost, the addition of CR does not improve the ability of junior doctors to identify extremity fractures in children overall and thus routinely obtaining them for all suspected fractures should be discontinued. In settings where there is no senior or radiologist review obtainable within a reasonable amount of time, or where uncertainty regarding correlation with clinical presentation is present, selective use of a CR could be beneficial in ruling out fractures and increasing the confidence with which the diagnosis is made. CR does increase the ability to detect elbow fractures significantly and routine use in this setting might be beneficial in this study population (Junior EM doctors).

The participants in this study missed 20% of all fractures regardless of CR. In light of the potentially serious consequences (growth disturbances, increased cost to family, increased levels of pain to child, etc.) of missed paediatric extremity fractures (26), this figure is somewhat alarming. The findings of this study suggest that there is an overreliance on CR for improving diagnostic accuracy in paediatric extremity fractures. It is clear that other methods to improve radiological diagnostic accuracy of junior EM doctors needs to be investigated.

4.3. Suggestions for overcoming challenges of missed paediatric fractures in the Emergency department: Debate surrounding comparison views.

4.3.1. Recommendations from the literature

Paediatric fracture diagnosis is a particular problem area for junior doctors (19). Although it is suggested in some literature that routine CR of extremities are obtained to aid doctors with fracture diagnosis (12, 31), majority of the studies discourage this practice (17, 32-34).

The main motivating factor in favour of routine CR is to not miss subtle fractures (31), which could potentially lead to complications if not treated (24). This is discouraged by most (33). In addition to increased radiation risk, routine CR are also criticized for the following reasons:

- Many fractures are visible on the radiograph of the affected side and the CR is irrelevant.

- To achieve a relevant CR, an exact replica of the radiograph of the affected limb has to be done. This is very often not possible due to pain and swelling and poor compliance of children, rendering comparison views less useful.
- Many subtle fractures may not result in a change in management.
- If reliable radiological opinion is available, contralateral views are unnecessary (33).

The value of CR in the emergency setting was challenged by a study done among residents, paediatric emergency physicians and paediatric radiologists assessing elbow radiographs in 1992. It concluded that the initial diagnosis was not changed by additional views. CR did not increase diagnostic accuracy in any of the subgroups. The residents and emergency physicians missed clinically relevant fractures despite CR being available. The outcome of this study advocates the use of CR only if the radiograph of the injured extremity (elbow) is inconclusive and to assist in achieving bony alignment if reduction of fracture is done (17).

A few alternative practices to CR are successfully being implemented in emergency units worldwide (33). For instance, many emergency units have a book/library of images of normal joints at various ages and stages of development (ossification), including normal variants (31, 33). One unit even has separate images for girls and boys (1 to 18 years) (45). These images can then be used as comparison to the injured limb's radiograph, preventing unnecessary radiation to the child (33).

Many studies concluded that timely (1-2 days, but debatable) radiological review of all paediatric radiographs is pertinent to decreasing misdiagnoses and alerting emergency staff of missed fractures. This however would imply implementation of a system where emergency doctors indicate on the request form if a fracture was diagnosed on initial interpretation (21, 24, 31). Another study suggested that review tasks should be the responsibility of senior emergency medicine doctors with additional radiological involvement if required (46). None of the literature reviewed advocated the immediate, on-site reporting of paediatric emergency radiographs (24, 31), but most emphasized the crucial role of official radiological review in the management of patients who do have pathology (22, 24, 31, 33).

Focused education and training of junior doctors were suggested in multiple studies (19, 24). Training programs must identify areas of weakness and specific diagnostic problem areas and allocated resources to improving skills targeted at these weaknesses. It is proven that in terms of paediatric emergency radiographs, the most frequent mistakes are being made in the diagnosis of fractures (19).

Inexperienced doctors must be exposed to the radiological varieties of a developing skeleton (7), normal and abnormal radiographs (22). Clinical assessment plays a very important role in evaluating trauma patients and should always be emphasized in teaching structures (21). It was found that clinical signs and symptoms, if picked up and interpreted correctly, would avoid 25% of lower extremity radiographs in children (32). Junior doctors must be allowed to first make an assessment regarding a radiograph and then be given feedback (22). Education regarding the most commonly missed fractures may increase index of suspicion for these fractures and could lead to more accurate diagnoses (20).

Other suggestions to decrease the amount of missed paediatric extremity fractures while also attempting to decrease radiation dose, include:

- Patients with fractures that are not apparent on the initial radiographs, but clinically suspected, should be managed conservatively and followed up radiologically in 7 to 10 days (7, 32, 47). Evidence of fracture healing or bone remodelling may be visible (periosteal reaction or sclerosing fracture line) (7, 47).
- Ultrasound is becoming more popular in diagnosis of musculoskeletal injuries including fractures. The value of ultrasound in the diagnosis of clavicle, forearm, diaphyseal fractures of the humerus and femur and even radiologically occult fractures have been shown and has the potential to replace additional/ follow up radiographs (7).

4.3.2. Recommendations from this study

In the context of South African public sector EDs, this study found that routine CR for all suspected extremity fractures does not lead to a decrease in missed paediatric extremity fractures overall, supporting the majority of the literature.

There is evidence for increased paediatric elbow fracture detection when CR are added and suggests that CR should be done for all suspected elbow fractures seen in EDs where predominantly junior doctors are on duty.

4.4. Limitations of the current study

- In the real time Emergency department setting, the doctors have the added benefit in examining the patients themselves to aid in their diagnosis. This could not be simulated in this study.
- Ages of patients were not supplied in the slideshows; some doctors thought that this would have been useful in heir decision making process.
- The images were static and could not be magnified or zoomed as some doctors are used to doing.
- The selected images and their classification of subtlety, etc., even though agreed upon by three radiology doctors, might still be subjective and if three other radiologists had to compile them, might be slightly easier or harder.
- The sample size of 58 doctors was not large enough to compare results between the different experience levels of doctors.
- Only 30 patients' radiographs were included in the PowerPoint presentations, representing a sample of common extremity injuries in children. More accurate results might be obtained if more radiographs were to be examined by the participants, however it would introduce some logistical difficulties.

4.5. Future applications

This study was aimed at evaluating the value of comparison radiographs in junior ED doctors in fracture diagnosis of paediatric extremities. The same study could be done using radiology or orthopaedic doctors as study subjects. In many centres the radiology doctors are in fact responsible and relied on for these diagnoses. This would serve to strengthen or refute the findings of this study and aid in developing best practise guidelines. Many times the final diagnosis rests on the shoulders of the orthopaedic doctors, especially where radiologists do not review all images. Decisions regarding definitive treatment are also made by this this group of doctors. If it is found that the orthopaedic surgeons do indeed benefit from comparative views (i.e. improvement in

diagnostic accuracy) then the recommendations will be different from the ones based on this study.

Future studies should ideally have larger sample sizes to compare diagnostic accuracy between the subgroups of doctors in terms of experience and seniority.

If the suggestions that are made by the findings of this study are implemented in an ED, an audit or similar study could be done to ascertain the effect of the cessation of routine CR acquisition.

5. Conclusion

The addition of CR of the contralateral limb when assessing extremity radiographs of injured children does not increase the overall fracture pick-up rate by junior emergency medicine doctors (20% of all fractures were still missed). The accurate detection of elbow fractures specifically, does increase significantly however. There is also a 15% increase in their ability to recognise normal radiographs, which doesn't change clinical outcome significantly.

Despite the fact that CR made no significant difference in the number of overall fractures that were recognised, their presence did increase the confidence with which these junior doctors made their diagnosis by 12%.

The recognition of subtle fractures did not increase with the addition of CR. Instead it decreased slightly. Thus the rationale of justifying routine CR to avoid missing subtle fractures specifically is not supported by this study.

Junior Emergency Medicine doctors are more accurate and confident in interpreting radiographs of the paediatric upper limb (hand/wrist/forearm) and least accurate in interpreting lower limb (foot/ankle/lower leg) radiographs.

The value of CR in diagnosis of paediatric extremity fractures, especially in the emergency department, is currently being overestimated. The results of this study do not support the routine use of CR. The additional radiation to the paediatric patient and increased financial cost cannot be justified by an increase in fracture recognition. Selective use is advocated, as there are some instances where a CR could potentially be helpful and this study suggests that all suspected paediatric elbow fractures warrants CR when evaluated in the ED by junior doctors.

Emphasis should be placed on improving junior EM doctors' skills in terms of interpreting paediatric extremity radiographs, especially of the lower limb. There are numerous ways to circumvent the perceived need for routine CR in the ED, such as the compilation of a library of normal radiographs of various ages to compare images with and the establishment of a functional review system.

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Appendix A: Ethics Clearance Certificate

R14/49 Dr Ilana Maria Viljoen et al

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M150909

NAME: (Principal Investigator)	Dr Ilana Maria Viljoen et al
DEPARTMENT:	University of the Witwatersrand, Department of Radiology Kimberley Hospital Complex, Northern Cape Helen Joseph Hospital, Gauteng
PROJECT TITLE:	The Value of Comparative Radiographs in the Diagnosis of Extremity Fractures in Children by Doctors in the Emergency Department
DATE CONSIDERED:	02/10/2015
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr Susan Lucas and Tanyia Pillay
APPROVED BY:	Professor P. Cleaton-Jones,Chairperson, HREC (Medical)
DATE OF APPROVAL:	04/12/2015

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 3rd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand. I/We fully understand the the conditions under which I am/we are authorised 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 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 review in September and will therefore be due in the month of September 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

Appendix B: Information document (Informed consent)

INFORMATION DOCUMENT

Study title: The Value of Comparative Radiographs in the Diagnosis of Extremity Fractures in Children by Doctors in the Emergency Department

Introduction:
I am doing research on the role of comparative radiographs on children in the emergency department. Research is just the process to learn the answer to a question. In this study we want to learn whether or not comparative radiographs of the extremities of children, when a fracture is suspected, truly adds to the accuracy of fracture diagnosis by junior doctors in the emergency department.

I am inviting you to take part in this research study

What is involved in the study?
You are requested to view two slideshows of radiographs. The first slideshow includes radiographs of injured extremities of children. The images will only be of the injured extremity, without comparison views of the uninjured contralateral limb.
You will be handed a tick sheet (Appendix C) on which you will indicate your current rank and an anonymous identifying code This code will be a five character code originated by yourself, consisting for example of the first letter of your mother's name, the numerical value of the month of your birthday and the first two letters of your home town (e.g. M04PR) . The details will be provided at the time of the slideshow initiation. The identifying code is to match your first and second tick sheets to each other without using any information to track the answers back to you. There are 30 slides to view and with each slide you are requested to state whether or not there is a fracture (yes/no) and indicate the level of confidence with which you come to your answer. There will be no time limit on viewing the radiographs.

3--7days later you will be asked to view the second slideshow and complete the same tick sheet. The second series of radiographs will however contain images of both the injured extremities and the images of the uninjured contralateral extremity.

This is a prospective study involving about 35 junior doctors (interns, community service doctors, medical officers and first year Emergency Medicine registrars), from South Africa who do after hours duty in any Emergency department.

There are no risks to the participants of this study.

Benefits of being in the study: After completion of the tick sheets, the radiographs in the slideshows will be discussed as an educational session on the diagnosis of extremity fractures in children.

The participant will be given pertinent information on the study while involved in the project and after the results are available.

Participation is voluntary. Refusal to participate will involve no penalty or loss of benefits to which the participant is otherwise entitled.

Confidentiality: A unique identifying code will be used to link the participants' two answer sheets, ensuring anonymity and thus confidentiality.

Contact details of researcher – for further information / reporting of study related adverse events: Ilana Viljoen (liana.m.viljoen@gmail.com) Tel: 0722460775

Contact details of HREC administrator and chair – for reporting of complaints / problems: Ethics Administrator: Augustina Hennessy Tel:(011) 274-9279

EMail: ahennessy@witshealth.co.za

Ethics Chair: Prof Cleaton Jones 011 717 2301

(Monday-Wednesday-Friday mornings)

I hereby agree to participate in this study

Name

Signature

Date

Appendix C: Tick sheet

Reader tick sheet Set 1 / Set 2 Participant number:

Rank: (Please select appropriate box):

Intern	Community service doctor	Junior Medical Officer	First year EM registrar

Please indicate your choice with a cross in the applicable box:

Case No	Fracture present?		How comfortable were you in making the diagnosis?				
	YES	NO	Confident there is a fracture and will manage as such	Suspect a fracture but would like further imaging	Not sure at all	Suspect no fracture but would like further imaging	Confident there is no fracture and will manage as such
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Appendix D: 'Turnitin' Report

MMedIlana20171031.docx

by Ilana Viljoen

Submission date: 30-Oct-2017 10:07PM (UTC+0200)
Submission ID: 871540183
File name: Ilana_Viljoen_889811_MMedIlana20171031.docx (11.57M)
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ORIGINALITY REPORT

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Appendix E: Note on referencing style

Please note that the referencing in this thesis is a modification of the Vancouver Referencing style, done according to the Faculty of Health Sciences Style Guide as set out by the Wits Health Sciences Library.

The information on this WHSL Vancouver Citation Style Guide for Theses, Dissertations and Research Reports is available from http://libguides.wits.ac.za/whsl-vancouver updated on 30 January 2017.