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OUTCOMES OF PAEDIATRIC DISTAL RADIUS FRACTURES MANAGED WITH OUR CURRENT PROTOCOL



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A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, in partial fulfillment of the requirements for the degree of Master of Medicine in Orthopaedic Surgery

Johannesburg, 2020

Declaration

I , Tlou Boshomane, declare that the research report that i'm submitting to the University of the Witwatersrand is my own work and I have never submitted it for another degree at this university or another university

Signed: ……..

Date: 07/10/2020…….

Dedication

To my husband, Sabelo, and children, thank you for your love and support throughout the time I spent working on this research.

To my parents, I thank you God for you and for all the sacrifices you have made.

To my ever supportive sisters, Mokgadi and Refilwe, thank you for being my cheerleaders

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Abstract

Background: Manipulation under anaesthesia and cast immobilisation is the accepted gold standard for management of distal radius metaphyseal fractures in children, with the use of Kirschner wires (K-wires) in cases with potential for instability. Redisplacement in a cast is a common complication during follow up. The causes of redisplacement during follow up are controversial and several risk factors have been proposed as predictors of redisplacement. The primary aim of this study was to determine the outcome of our current management of paediatric distal radius metaphyseal fractures. We also sought to identify possible risk factors for redisplacement during follow up. We reported on early post-operative complications and the frequency of K-wire use.

Methods: A retrospective study was conducted on 61 patients with displaced distal radius metaphyseal fractures in children under the age of 16 years who met the inclusion criteria. Fifty three patients were treated with manipulation and casting only, while eight patients had supplemental K-wire fixation. In the manipulation and casting group, the mean age was 8 ± 2.8 years (range 4 – 14 years). The primary outcome was redisplacement during follow up. Initial complete displacement, an associated ulna fracture, the quality of the reduction, cast and padding indices were assessed as possible risk factors for redisplacement. Statistical analysis was done using STATA version 14.0 package. Chi-squared test was used to study the association between redisplacement and all the risk factors. Multivariate logistic regression analysis was used to assess independent risk factors.

Results: A redisplacement rate of 18.8% (10 patients) was reported. We found a statistically significant association between redisplacement and non-anatomical reduction ($p = 0.001$), cast index > 0.8 ($p = 0.030$) and padding index > 0.3 ($p = 0.031$). Multivariate logistic regression analysis showed non-anatomical reduction to be an independent risk factor for loss of reduction with 23.6 times likelihood for redisplacement ($p = 0.008$) compared to anatomical reduction. Initial complete displacement and the presence of an ulna fracture had no effect on redisplacement. The frequency of K-wire use was 13.1% (eight patients) and the rate of early complications was 8.2% (five patients).

Conclusions: We conclude that our current treatment is safe and effective based on the redisplacement rate of 18.8% which is comparable with current literature standards. Poor casting technique and failure to achieve anatomical reduction were found to be significant predictors of redisplacement. We suggest that K-wires be used if anatomical reduction is not achieved in older children (> 10 years) with limited remodelling capacity to mitigate the risk of redisplacement.

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List of Abbreviations

AO: Arbeitsgemeinschaft für Osteosynthesefragen (Association for Osteosynthesis)

AO PCCF: AO paediatric comprehensive classification of long bone fractures

AP: Anterior-posterior

CMJAH: Charlotte Maxeke Johannesburg Academic Hospital

K-wire: Kirschner wire

LiLa: Licht and Lachen

MUA: Manipulation under anaesthesia

PACS: Picture archiving and communication system

PVA: Pedestrian vehicle accident

WHREC: Wits Human Research Ethics Committee

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

Forearm fractures are amongst the commonest skeletal injuries in childhood and the distal radius is the most common fracture site (1,2). The usual mechanism of injury is a fall on outstretched hand. Metaphyseal fractures are reported to be more common than diaphyseal fractures followed by epiphyseal fractures (1). Historically, closed reduction and cast immobilisation has been regarded as the gold standard for managing displaced distal radius fractures. However, maintaining adequate reduction in a cast prior to union remains a challenge. Although excellent results can be achieved with closed reduction and cast immobilisation, redisplacement rates as high as 25% – 39% have been reported (3).

The use of Kirschner wires (K-wires) offers an alternative for maintaining reduction in potentially unstable distal radius fractures where the risk of redisplacement is deemed high (2,4). However, it is important to guard against complications such as pin tract sepsis, pin migration, hypertrophic scars and osteomyelitis (2,5). In potentially high risk fractures, K-wires may, in addition to maintaining reduction, offer the advantage of avoiding possible remanipulation and a second anaesthetic procedure. In order to offer the best treatment, it is essential to identify factors that predict failure of conservative management. Several studies have identified factors such as the presence of ulna fracture, initial displacement, non-anatomic reduction and poor cast quality as potentially contributing to high redisplacement rates in fractures managed by closed reduction (3,6,7). Despite this, it is important to remember before using any invasive technique that children have a high remodelling potential and better tolerance to deformity (8). The current protocol for management of displaced paediatric distal radius metaphyseal fractures at Charlotte Maxeke Johannesburg Academic Hospital (CMJAH) is manipulation under anaesthesia (MUA) and above elbow cast immobilisation. K-wire fixation is generally not recommended except in a few selected cases with potential for instability. There are currently no strict guidelines to determine which fractures are unstable and hence require K-wire fixation. There is also no South African study to date that reports on redisplacement rates or outcomes of distal radius

metaphyseal fractures in children. It is therefore important to determine outcomes of our current management and identify risk factors for instablility in our setting.

1.2 BONE REMODELLING

An understanding of how the healing and remodelling process occurs is important in managing fractures in children. There are three stages of fracture healing in children and these have been described as (9):

- Inflammatory,
- Reparative and
- Remodelling.

Inflammatory phase is characterised by fibrin rich haematoma formation which is replaced by collagen scaffold, laying down the framework for eventual formation of woven or soft bone (9). During reparative phase, the initial callus is formed as haematoma is invaded by fibrovascular tissue. This type of callus is weaker and larger amounts are produced, hence it is also known as "quantity" bone (9). This process commonly lasts the first two to three months of fracture healing. Remodelling of a fracture or deformity is a process by which old bone is removed and new bone is formed. The process can last months and even years as provisional callus is replaced by "quality" bone that can support the normal activities of a child (9). Remodelling is influenced by a number of factors, including the following (10):

- Age - the younger the age, the better the remodelling potential
- Proximity to the physis - fractures closer to the physis remodel better than those away from the physis
- Plane of motion - deformities in the plane of joint motion remodel better than deformities outside the plane of motion
- The presence or absence of rotational deformity- rotational deformities do not remodel

The rate of remodelling differs depending on the location of the fracture. The metaphysis is an area of increased vascularity and osteogenic potential (9). In this area, large quantities of woven bone produced from the adjacent physis are eventually replaced by compact bone from the diaphysis (9). The diaphysis, on the other hand, is an area of less active osteogenesis

characterised by relatively avascular compact bone. The remodelling potential of fractures in this area is much less and healing is also prolonged as a result (9).

Remodelling process may occur to correct for angular deformity or discrepancy in length. If the fracture is closer to the physis, asymmetric growth in the physis drives the remodelling process. The concave side of the deformity is stimulated to grow faster than the convex side so that the physis is perpendicular to the long axis of the shaft (9). Symmetrical growth in the physis resumes once the physis is realigned. Remodelling of angular deformities in the diaphysis follows Wolff's law which states that bone will remodel in response to stress placed upon it (9). Therefore, in keeping with Wolff's law, bone on the compression or concave side is stimulated to grow while bone on the tensile or convex is resorbed (9). Figures 1.1 (a) and (b) demonstrate the remodelling changes in a 13 year old over a six month period. Longitudinal growth in both the distal and proximal physes contribute to remodelling. However, it is the large contribution towards longitudinal growth from the distal physes that explains the superior remodelling potential at the distal physis compared to the proximal physis. Both the distal ulnar and radial growth plates are reported to be responsible for 75% and 81% of growth, respectively (11). Fracture healing process also stimulates growth in length and this has been reported mainly in the femoral shaft. This overgrowth was postulated to be a result of increased blood flow to the area (9). Shapiro studied femoral overgrowth in children less than 13 years and found overgrowth to be independent of age, fracture level and position of the fracture at the time of healing (12).

Determinants of remodelling potential are remodelling speed and the expected number of months of growth remaining (13). Friberg found remodelling speed to be 0.9° per month on average in the dorsovolar plane (14). He also found that remodelling speed decreased with time, and that it is greater in greater angulations (14). This means that the higher remodelling speed in fractures with higher degrees of angulation compensates at least in part for the greater amount of remodelling needed for correction. Jeroense et al. studied the remodelling potential of 33 children with a mean age of nine years (range three to 14 years) with a distal radius fracture and malunion over 15° (15). The authors also found that rate of remodelling decreased exponentially over time. The mean initial remodelling speed was 2.5° per month but decreased exponentially over the 30-month time period (15). Fuller et al. reported complete remodelling in patients below five years presenting with malunion over 20° (16).

Only 50% of children between six and 10 years of age remodelled completely and no children between 11 and 14 years of age remodelled completely at final follow up (16). Despite failure to completely remodel, the older patients displayed no loss of function at the end of follow up period (16).

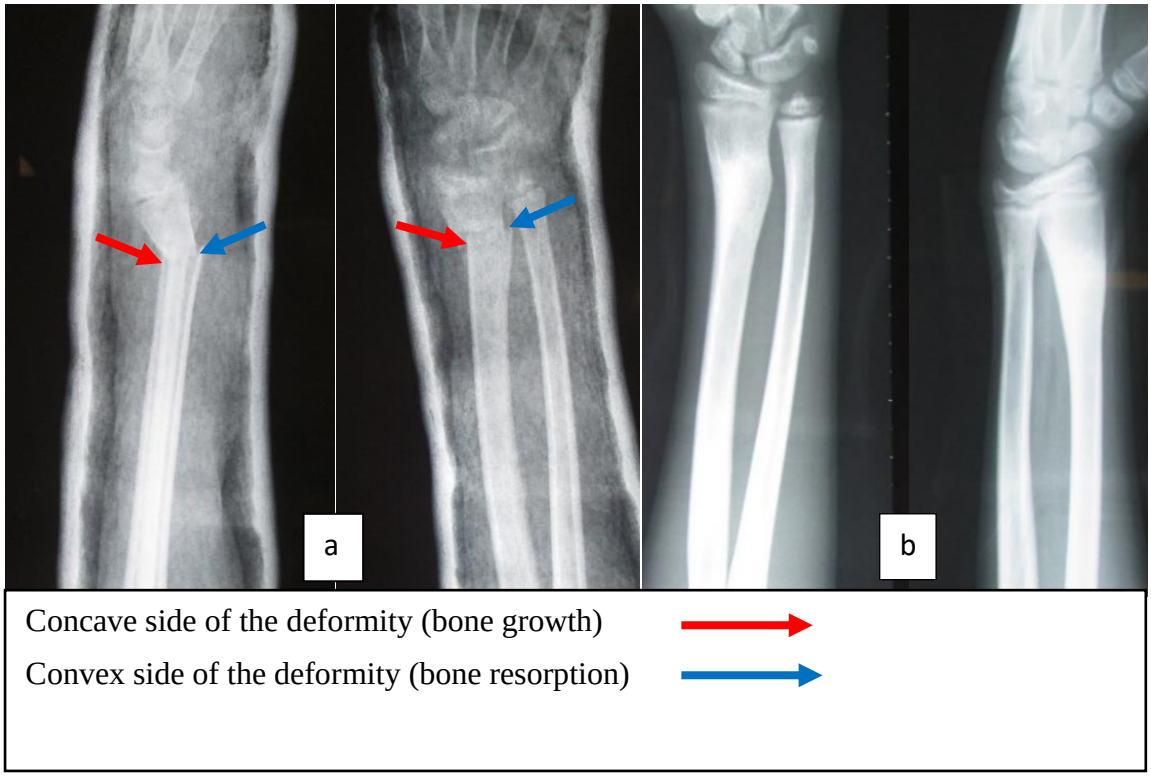


Figure 1.1: Illustration of distal radius remodelling in a 13 year old boy at (a) two weeks post injury and (b) six months later

There is currently no agreement in literature when it comes to the amount of reduction deemed acceptable for distal radius metaphyseal fractures. A wide criteria guided mainly by age is often applied with angulation of 10° – 30° in the sagittal plane and 5° – 20° in the coronal plane considered acceptable (17). While it is generally accepted by some authors that complete remodelling may not occur in patients with more than 20° angulation, it has also been shown that younger children have a higher capacity to remodel with limits ranging from 30° – 40° in the sagittal plane reported (14,17). The difference of opinion on what the limits of the remodelling are by various authors has resulted in the different criteria applied when deciding on what should be the acceptable alignment. However, it is generally agreed that distal radius metaphyseal fractures in children have excellent remodelling potential. The

important factors to take into consideration are the age of the child and amount of initial angulation which dictate the speed of remodelling (18). It is also essential to remember that radiological malunion does not always correspond with loss of function (18).

1.3 CLASSIFICATIONS

There is no universal classification system for forearm fractures in children. Distal forearm fractures are generally classified according to specific site involved, amount of cortical disruption, displacement, rotation and angulation (see Table 1.1). Specific fracture types such as greenstick and torus fractures have been defined as cortical disruption on the tensile and compression side, respectively.

Table 1.1: General classiffication of distal radius fractures (19)

Physeal or growth plate fractures

Metaphyseal fractures

Incomplete:
- Torus fracture
- Greenstick fracture

Complete:
- Undisplaced
- Displaced:
  - Dorsal angulation
  - Volar angulation

The Muller Association for Osteosynthesis (AO) system for classification of long bone fractures is a well known alpha-numeric system that can be used to classify fractures involving any bone in an adult by assigning numbers to the regions involved as well as bone segment and morphological characteristics. However, it does not address specific fracture patterns seen in children as it does not account for the presence of growth plates as well as the nature of the paediatric bone. The AO paediatric comprehensive classification for long bone fractures (AO PCCF) was introduced as a paediatric adaptation of the Muller classification in order to accommodate the differences between adult and paediatric bone by

recognising the different segments unique to paediatric bone (20). In 2011, Licht and Lachen introduced another classification (LiLa classification) for paediatric long bone fractures with similarities to the AO PCCF (21). Although both classifications are based on the original Muller classification, the LiLa classification was an attempt at a more simplified fracture classification in order to facilitate its use in clinical practice while still incorporating important aspects of paediatric fractures. In all three classifications, the metaphysis was defined using the "rule of the square" which states that the proximal and distal segments of long bones are defined by a square whose sides are the same as the widest part of the epiphysis (22). In the AO PCCF and AO classifications, the widths of both bones are used, while the reference lines are the epiphyseal plate and the end of the bone, respectively (22). In the LiLa classification, the width of a single bone was used with the epiphyseal plate being the reference line (22). This is the definition of the distal radius metaphysis applied in this research (see Figure 1.2).

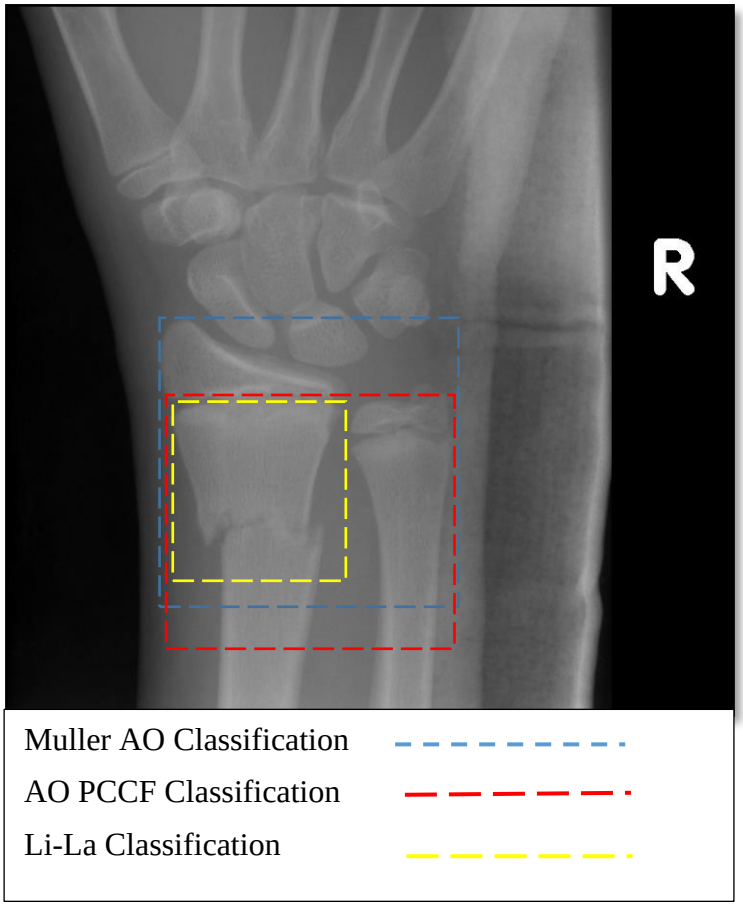


Figure 1.2: Illustration of the rule of the square to define the metaphysis according to different classifications (22)

1.4 EPIDEMIOLOGY

Forearm fractures in children are very common, accounting for up to 25% of all childhood injuries as well as 30% – 50% of all fractures in children (23). Boys are at a higher risk of sustaining fractures than girls with the reported fracture risk in children less than 16 years being 42% in males and 27% in females (23). Ethnic differences have not been shown to play any role in paediatric forearm fractures. The distal radius is the most common fracture site accounting for 20% – 30% of these fractures (1). Metaphyseal fractures are reported to be more common than diaphyseal fractures followed by epiphyseal fractures (1). Fractures of both the radius and ulna are more common than isolated fractures, with isolated ulna fractures being the least common (23).

The incidence of forearm fractures in children is increasing, even though the causes of this remain unclear. It is postulated in some studies that increased participation of children in sports is one of the possible contributing factors (24). Some authors have attributed this increased incidence of forearm fractures to improved access to healthcare as well as better detection of fractures (25). Up to 81% of the distal radius fractures occur in children older than five years (26). The peak age for girls occurs earlier than boys, with recent studies reporting 8 – 11 years for girls and 11 – 14 years for boys (26). The peak incidence of fractures appears to be closely related to bone mineral content during puberty. During puberty, increase in bone mineral content is relatively small in comparison to linear growth or bone lengthening (27). Skeletal growth at puberty occurs at a much higher rate for adequate mineralisation to take place, resulting in bones that are more prone to fractures. The dissociation between skeletal growth and mineralisation has been shown in previous studies, this is regarded by some authors as the explanation for the peak incidence of fractures during puberty (26–28). The common mechanism of injury is indirect trauma from a fall on outstretched hand, followed by direct trauma usually due to motor or pedestrian vehicle accidents (26).

1.5 TREATMENT OPTIONS

1.5.1 MANIPULATION AND CASTING

Manipulation and cast immobilisation is regarded as the gold standard for treatment of paediatric distal radius metaphyseal fractures. Unicortical fractures (i.e. torus or buckle fractures) are stable injuries that are quite common. Treatment is directed towards patient comfort and protection of the forearm from further injury. Immobilisation with a splint for three weeks without further follow up is sufficient for managing these injuries (19). A well moulded cast is recommended for complete fractures as they have greater propensity for secondary angulation and follow-up radiographs are therefore recommended. Friberg observed that in cases where there is atleast two years before skeletal maturity, a dorsal tilt of up to 20° will remodel (14). So long as the growth plate remains open, 50% of the remodelling occurs in the first six months, and the remaining 50% in the next 18 months (14). Deformity of more than 20° may also remodel, but is less predictable, especially in older children (> 10 years) (14). The guidelines for acceptable residual angulation are age dependent and serve only as a general indicator of expected results. In children less than nine years, dorsal angulation of up to 30° is acceptable, whereas in children older than nine years angulation less than 20° is considered acceptable (14). Bayonette apposition or overlapping of less than 1cm, does not block rotation and is acceptable in younger patients (14).

Dorso-volar deformities occur in the direction of movement of the wrist joint and as a result tend to remodel better than radio-ulnar deviation. Therefore, coronal plane deviation should be kept to less than 15° in patients less than 12 years and while values below 10° are considered ideal for those above 12 years (14). Undisplaced fractures do not require any manipulation, displaced fractures require manipulation which may be done under general anaesthesia or conscious sedation. Manipulation under anaesthesia has been shown to result in less redisplacement rates than conscious sedation (29). Traditionally, the use of above elbow cast was employed as a means to counter powerful muscle forces arising from the arm in order to mitigate possible loss of reduction during the course of treatment (30). Studies have shown that below elbow casts perform as well as above elbow casts in maintaining reduction of fractures in the distal third of the forearm in children, and the complication rates are similar (31). The protocol followed at our health institution for

displaced distal radius metaphyseal fractures is manipulation under general anaesthesia and a well moulded above elbow cast.

1.5.2 KIRSCHNER WIRES (K-wires)

K-wires have become a preferred method of treatment by some surgeons in order to aid in maintaining reduction and subsequently lower redisplacement rates. There is no clear consensus on the indications for K-wires amongst surgeons. Van Leemput et al. advocated MUA and K-wires as a safe and simple procedure, a high redisplacement rate of 45.8% was reported in cases without K-wires (32). The authors suggested that the use of K-wires mitigated some issues that might arise from casting alone such as:

- the need for weekly follow up
- possible second anaesthesia for remanipulation
- angular deformity as a result of malunion which may cause anxiety for parents
- the need for an above elbow cast.

Jordan et al. also recommended the use of K-wires for patients in whom suboptimal initial reduction was obtained (2). The fact that young children have excellent remodelling potential has led to some authors not considering the use of K-wires. Bae et al. concluded that children over the age of 10 years should be stabilised with a K-wire if there was initial complete displacement or initial angulation over 15° (33). Firth and Robertson reported absolute indications for stabilisation using percutaneous K-wires to be (18):

- irreducible fractures requiring open reduction
- multiple ipsilateral upper limb fractures
- open fractures
- associated neurovascular compromise

1.5.3 COMPLICATIONS

While closed manipulation and cast immobilisation is largely regarded as having low rates of complications, several retrospective studies demonstrate high redisplacement rates in fractures managed with closed reduction and cast alone (3,7,34). The most commonly reported complication of manipulation and cast immobilisation alone is redisplacement or

loss of reduction. There are no clear indications for secondary reduction in children with redisplacement, factors such as the age of the child and hence the remodelling potential have to be taken into account. The long term effects of angular deformities resulting from redisplaced fractures seem to be minimal. Some studies report similar functional outcomes between children with redisplaced fractures who undergo secondary treatment and those who do not (35,36). Other complications of manipulation and casting alone include pressure sores, neuropraxia, malunion and refracture (37).

The use of K-wires decreases redisplacement rates but additional minor as well as major K-wire complications remain a concern. Some of the reported K-wire complications include wire migration, superficial infections, hypertrophic scar and chronic osteomyelitis (5,18,33). Battle et al. reported an overall infection risk following the use of K-wires to be 7.9% and the overall rate of deep infection involving bone was 2% (38). A review of 5884 children who had K-wires inserted reported 12 infections, only one was from a distal radius fracture and was associated with a superficial abscess (5).

Ramoutar et al. reviewed management of 248 children with distal radius metaphyseal fractures over a five year period (8). The authors showed that although good results were obtained with stabilisation using K-wires, there was a significant complication rate mainly due to wound complications and K-wire migration resulting in problematic removal. Due to the excellent capacity to remodel generally seen in children, this study cautioned against unnecessary K-wire use. Firth and Robertson cautioned against routine use of K-wires after distal radius fracture manipulation in younger patients with substantial remodelling potential particularly when taking into account the risk of complications that may arise from using K-wires (18). The study recommended selective K-wiring when there is complete initial displacement of the fracture or when anatomic reduction is not achieved, particularly in older children (18).

1.6 RISK FACTORS FOR REDISPLACEMENT

The parameters for redisplacement or loss of reduction vary amongst different authors and so does the threshold for secondary intervention or remanipulation. Proctor et al. defined redisplacement as the occurrence of more than 20° angulation or more than 50% translation (34). Mclaughlin et al. used similar values to define redisplacement as well dictating secondary treatment (4). According to Miller et al., angulation of more than 25° or complete displacement was regarded as loss of reduction requiring secondary manipulation (36). Alemadaroglu et al. considered significant redisplacement requiring remanipulation to have occurred if there was (7):

- more than 20° of dorsal angulation alone
- more than 10° of radial deviation alone
- more than 4mm of translation alone
- more than 10° of dorsal angulation and either more than 5° of radial deviation or 3mm of translation.

The more simplified criteria used by Proctor (> 20º angulation or > 50% translation) was used to define redisplacement in this study. In 2010, a systematic review by Mazzini et al. looked into factors below as important contributors towards loss of reduction (1):

1. Fracture associated factors: initial displacement, location, distance from the physis, associated ulna fracture and obliquity of the fracture.
2. Surgeon related: inadequate initial closed reduction and poor casting technique
3. Patient related factors: Muscle atrophy and resolution of swelling while in a cast

Fracture and surgeon related factors have been a focus of multiple studies and will be discussed extensively below.

1.6.1 INITIAL DISPLACEMENT

Initial complete displacement of a fracture is considered to be one of the significant factors that predict future redisplacement. This has been postulated to be due to the fact that periosteal stripping, which is linked to complete displacement of a fracture, is regarded as a key factor in determining stability (34). In the absence of periosteal support, loss of

reduction may be more likely due to underlying instability. Completely displaced fractures may also cause some degree of trauma to the soft tissues which often resolves in a cast rendering it inadequate in preventing redisplacement (29,39). Alemadaroglu et al. reported that fractures that were completely displaced initially were 11.7 times more likely to redisplace than angulated but incompletely displaced fractures (7). However, other studies have shown that severe angulation of more than 30° is more predictive of redisplacement than complete displacement or translation (17). The presence of both severe angulation and initial complete displacement has been reported as an important pre-operative risk factor for redisplacement especially in children over the age of 10 years (36).

1.6.2 DISTANCE FROM THE PHYSIS

Fenton et al. reviewed 73 children with distal radius metaphyseal fractures managed with manipulation with or without K-wires (40). The distance between the most distal portion of the fracture and the physis was measured. Increased distance from the physis was found to be a significant risk factor for redisplacement (40). The authors found that the distance of the fracture from the physis showed significant correlation with radial reangulation, thus radial reangulation increases as the distance from the physis is increased (40). This finding has not been reproduced in other studies.

1.6.3 OBLIQUITY OF THE FRACTURE

In their study analysing risk factors for redisplacement of radius fractures in children, Alemadaroglu et al. looked at the significance of fracture geometry in preventing or contributing to loss of reduction (7). The authors were able to show that an oblique fracture is more likely to redisplace than a transverse fracture. In their findings, 10° of obliquity increased the likelihood of redisplacement 2.22 times; 20° of obliquity increased the likelihood 4.93 times and 30° of obliquity increased the likelihood 10.94 times (7). The inherent fracture stability was therefore shown to be determined by the degree of obliquity which was also predictive of redisplacement (7). This finding was not reproduced by subsequent studies nor was it explored in our study.

1.6.4 ULNA FRACTURE

The presence of ipsilateral ulna fracture has been reported as one of the factors contributing to distal radius instability (6,41). This is contratry to the study by Roy et al. that found instability in distal radius metaphseal fractures without an ulna fracture as well as associated difficulty obtaining and maintaining reduction (42). Gibbons et al. reviewed similar cases and reported the need for secondary reduction in 91% of the children managed with MUA and cast immobilisation only while remanipulation was not necessary in all cases with supplemental K-wire use from the outset (43). The authors considered this fracture pattern to be unstable and recommended application of K-wires for all distal radius metaphseal fractures without an ulna fracture. Other studies have reported no significant association between the presence of an ulna fracture and loss of reduction (4).

1.6.5 INITIAL REDUCTION

The quality of fracture reduction plays a key role in predicting whether a fracture loses reduction during follow up or not (34). Alemdaroglu et al. reported that the likelihood of reduction loss in fractures that are not perfectly reduced is five times more when compared to cases where a perfect reduction is obtained (7). A retrospective review by Proctor et al. recommended K-wire fixation in patients whom anatomical reduction could not be achieved due to higher redisplacement rates when an imperfect reduction was obtained (34). The authors also reported that if an incompletely displaced fracture is perfectly reduced, there is a 5% chance of redisplacement compared to 43% in a poorly reduced fracture. The reported equivalent figures for completely displaced fractures were 20% and 73%, respectively (see Table 1.2). Monga et al. reported non-anatomical reduction as an independent risk factor for redisplacement and further postulated that anatomical reduction results in accurate interdigitation of bony spikes which prevents redisplacement (44).

Table 1.2*:* Rate of redisplacement according to reduction accuracy and fracture type as reported by Proctor et al.(34)	
	Redisplacement (percentage)
Perfect reduction:	
Incompletely displaced fractures	5%
Completely displaced fractures	20%
Imperfect reduction:	
Incompletely displaced fractures	43%
Completely displaced fractures	73%

1.6.6 CASTING TECHNIQUE

Poor casting technique is one of the factors that has been shown to contribute to redisplacement. The chances of reduction loss can be mitigated by application of a cast with adequate padding as well as appropriate moulding technique. Before a well-moulded cast can be applied, an appropriate fracture reduction technique must be employed. The correct reduction technique includes first worsening the initial deformity in order to disimpact the fracture followed by traction. A well-moulded cast requires application of pressure in some areas such that the original deforming forces are neutralised in order to lower the risk of redisplacement (45,46). Various radiological indices have been described as a way of measuring the different aspects of what constitutes a good cast.

The cast index was introduced on the premise that the oval shape of the cast at fracture site as opposed to round is critical in minimising redisplacement (47). The original description of this index set the cut-off point at 0.7 (47). Cast index (45,47,48) takes measurements at the fracture site as ratio A/B where "A" refers the cast breadth in the lateral radiographic view whereas "B" is the cast breadth in the anterior-posterior (AP) view . The more round the shape of the cast is, the closer "A" gets to "B" resulting in the ratio nearing the value of one

(see Figure 1.3). However, this index does not take into account inadequate moulding in the coronal plane which may also contribute to loss of reduction. Cast index was found to be associated with loss of reduction for both bone fractures as well as distal radius only fractures (49). It was also reported to have a good inter-rater and intra-rater reliability (50). A cut-off point of 0.8 has been found to be more suitable than the above-mentioned 0.7 for this index (7).

Padding index (see Figure 1.4) can be defined using X/Y where "X" represents the lateral view padding thickness and "Y" is the maximum interosseous distance measured in the AP view (45). A high "X" value occurs if there is excessive padding, leading to failure of treatment due to a cast that is too loose to sustain any soft tissue tension at the fracture site (45).

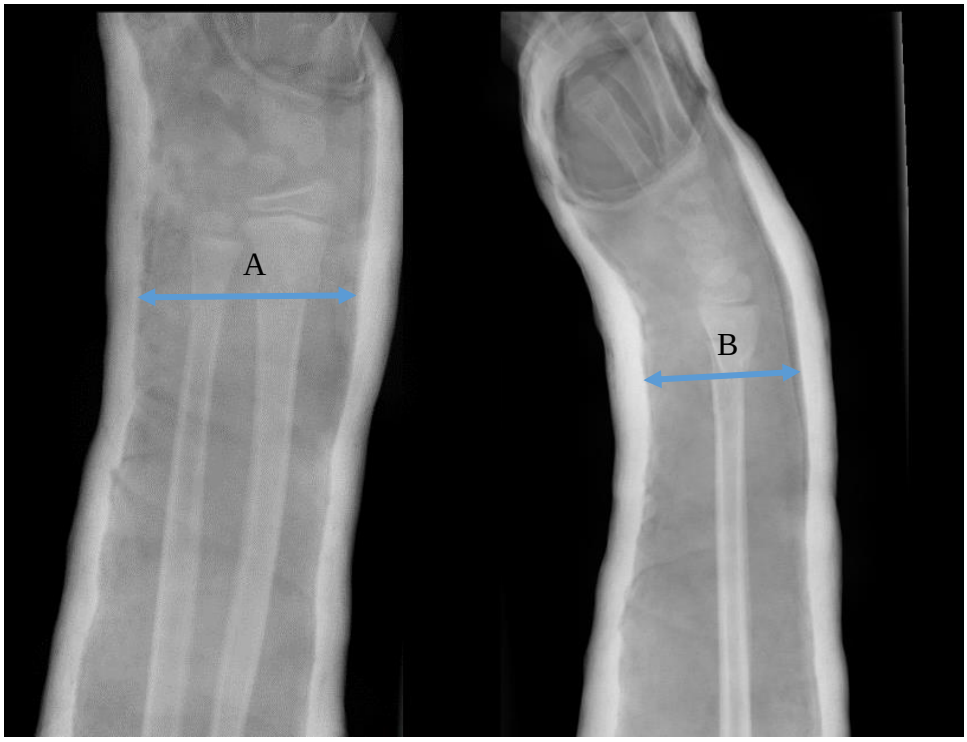


Figure 1.3: Illustration of cast index = A/B (45,51)



Figure 1.4: Illustration of padding index = X/Y (45,51)

Canterbury index is the sum of both the cast and padding indices (45). In both shaft and metaphyseal fractures, the padding and the Canterbury indices can be used to aid in measuring the quality of cast technique. The two indices were reported to have poor sensitivity by Alemadaroglu et al., and the authors also demonstrated that both indices are comparable in terms of redisplacement rates (7). Despite their limitations, both cast and padding indices were regarded as easy to use radiographic measures of assessing the risk of redisplacement following closed reduction (45). A recent study found that high padding, Canterbury and cast indices showed an association with redisplacements in distal forearm fractures (49).

The gap index is calculated by taking measurements of the gaps in the cast at the fracture site divided by the breadth of the cast measured in both AP and lateral views (45). Although it was originally thought that this index would fair better than the ones previously discussed, it was not simple enough for every day use in clinical practice due to the complex calculations involved (52). Moreover, it was also reported to have poor sensitivity and a low positive predictive value (52). Only measurements done at the site of the fracture are taken into account when applying the gap index, resulting in inability to account for failure of

moulding occurring either proximal or distal to the fracture. On the contrary, Ranvier et al. found that a higher displacement delta in antero-posterior and lateral views for both bone fractures showed an association with a high gap index (49). The authors concluded that cast oval moulding without excessive padding may prevent redisplacements in paediatric distal forearm fractures (49).

The three-point index was found to be a more reliable predictor of loss of reduction in comparison to other indices (7). In keeping with the original principle by Charnley on how a cast should be moulded, this index is calculated by taking complex measurements at the fracture site as well as both proximal and distal to the fracture (7,46). Although it was shown to be useful as a predictor of redisplacement, it is considered not practical for use in a clinical setting due to the complex calculations involved (7,51). A retrospective review of 43 patients with distal radius metaphseal fractures also found this index to be sensitive but not specific as a measure of fracture displacement and not practically applicable to influence management of these fractures (51). Ranvier et al. concluded that there was no association between the three-point index and redisplacemet risk (49).

There are multiple risk factors implicated in redisplacement of paediatric distal radius metaphyseal fractures, however, only a few have been validated in large scale studies. A review by Mazzini et al. concluded that initial complete displacement, non-anatomical reduction and obliquity of the fracture line were the most important risk factors for redisplacement (1). The authors cautioned against looking at the radiological indices as a separate entity but rather interpreting them in conjunction with fracture characteristics and patient factors (1). Mani et al. conducted a retrospective review of 94 children with distal radius fractures treated by closed reduction and plaster (39).

It was reported that the amount of initial translation (apposition) of the radius was the single most predictor of outcome (39). More than 60% failure rate was reported in patients with more than 50% initial translation compared to 8% reported in patients with less than 50% initial translation (39). In a retrospective study of 68 patients, Proctor et al. reported that initial complete displacement of a fracture and failure to achieve a perfect reduction were both associated with significant increase in the chance of redisplacement (34). The presence

of an ulna fracture was not reported to increase the rate of redisplacement. A 2008 prospective study of 75 children with displaced distal radius fracture reported that the two significant predictors of loss of reduction were fracture obliquity and complete displacement before manipulation (7). A literature review by Firth and Robertson concluded that the most important risk factors for redisplacement in distal radius fractures in children appear to be complete initial displacement, non-anatomic reduction and poor plaster application technique (18).

1.7 Motivation and Objectives of the study

1.7.1 Motivation of the study

The current protocol for management of displaced paediatric distal radius metaphyseal fractures at CMJAH is manipulation under anaesthesia (MUA) and above elbow cast immobilisation as the treatment of choice. K-wire fixation is generally reserved for cases with potential for instability. There are currently no strict guidelines to determine which fractures are unstable and hence require K-wire fixation. It is therefore important to determine outcomes of our current management and identify risk factors for instability in our setting. This will enable us to identify patients in whom MUA and cast immobilisation alone is likely to fail due to recognisable risk factors. It will also allow us to refine our current management guidelines in children with distal radius metaphyseal fractures and identify patients in whom K-wire fixation from the outset would be more appropriate.

1.7.2 Research question

Is our current protocol for management of distal radius metaphyseal fractures in children safe and effective?

1.7.3 Study Objectives

1.7.3.1 Primary objective:

- To assess on follow up radiological loss of reduction or redisplacement (as defined by reangulation and translation)

1.7.3.2 Secondary objectives:

- To measure the degree of initial fracture displacement
- To assess the quality of initial reduction as measured by the degree of displacement and angulation
- To evaluate plaster moulding using cast and padding indices
- To evaluate identifiable and significant risk factors for loss of reduction
- To report on immediate post-operative complications
- To record the frequency of K-wire use

CHAPTER TWO: MATERIALS AND METHODS

2.1 Study Design

A retrospective study of paediatric patients who were admitted with distal radius metaphyseal fractures at Charlotte Maxeke Johannesburg Academic Hospital (CMJAH) between March 2016 and April 2017.

2.2 Selection Criteria

2.2.1 Inclusion criteria:

- Children aged less than 16 years with an open physis
- Children with displaced distal radius metaphyseal fractures (metaphysis was defined according to LiLa classification)
- Children treated by our current protocol of MUA and cast immobilisation with or without K-wire fixation

2.2.2 Exclusion criteria:

- Children with:
    - Open fractures
    - Pathological fractures
    - Polytrauma patients
    - Undisplaced fractures
    - Refractures

2.3 Methodology

Approval for the study was granted by the Wits Human Research Ethics Committee (Medical) (clearance number: **M151179 –** see Appendix C) and the CMJAH Medical Advisory Committee. Relevant data was collected from review of theatre records, patient files and picture archiving and communication system (PACS) software was used for for digital radiographic images. Composite data was tabulated in a standard data collection sheet (see Appendices A and B). Patients were assigned unique identification numbers in order to maintain confidentiality and anonymity. Children aged less than 16 years who met the inclusion criteria were identified by reviewing admission records, patient notes and radiographic images. All patients were treated with manipulation under anaesthesia and cast immobilisation as per our management protocols. The use of supplemental K-wires was at the discretion of the treating surgeon.

A total of 71 patients were identified from the records and 10 were excluded from the study. Nine patients were excluded from the study due to incomplete radiographic data and one due to polytrauma. A retrospective review of patient records was done for the remaining 61 patients who met the inclusion criteria. For all patients, data regarding age, sex, mechanism of injury and side of injury was obtained from the records. Radiographs were reviewed post initial injury, after MUA and in the clinic during the first two weeks. Theatre notes as well as post-operative notes documenting complications were also reviewed. Five patients managed with below elbow casts were also included in the study.

From the AP and lateral radiographs taken before MUA, the amount of initial displacement or translation was measured (see Appendix A - data collection sheet 1). Translation was expressed as a ratio of the displacement distance to the overall bone breadth measured at the fracture site (17).

The amount of translation was then graded according to Mani et al. criteria (39) as:

- No translation or 100% apposition (Grade 1)
- Incomplete (Grade 2 - less than 50% translation or Grade 3 - more than 50% translation)
- Complete or 100% translation (Grade 4)

The presence of an associated ulna fracture was also documented.

From the immediate post-operative AP and lateral views, the quality of reduction was measured and graded in line with previous studies (34,39,44) as:

- Anatomical - no angulation or translation
- Acceptable - less than 50% translation and/or less than 20º angulation
- Poor - more than 50% translation and/or more than 20º angulation

Angulation in the sagittal plane was measured by first finding the mid-diaphyseal or metaphyseal lines proximal and distal to the fracture . The intersection between these two lines defined the angle of angulation (17). The cast quality was assessed using the cast and padding indices. The cast index (see Figure 1.3) was measured as a ratio B/A as illustrated in the AP and lateral view radiographs. A cut-off of 0.8 was used instead of the original 0.7 which was used as it has been shown to be more reliable (7).

The padding index (see Figure 1.4), was calculated as the ratio of X/Y as illustrated in the AP and lateral view radiographs. A cut-off of 0.3 was used. Immediate post operative complications were documented. In cases where the cast was split, the fractures were routinely managed with remanipulation and re-application of another cast in theatre. The final casts applied during remanipulation were considered to be the initial treatment of these fractures for the purposes of taking our measurements. The frequency of K-wire use was also recorded. Patient follow up radiographs were reviewed in the first two weeks and redisplacement, which was our primary outcome, was measured on AP and lateral views. We defined redisplacement as more than 20º angulation in the sagittal plane and more than 50% translation (8,34,53). Remanipulation cases were also recorded. All radiographic measurements were done by a single observer using the PACS software and digital images.

CHAPTER THREE: DATA ANALYSIS AND RESULTS

The STATA version 14.0 statistical package was used for data analysis. Descriptive statistics were used to analyse the demographic profile of the participants. The mean and standard deviation were calculated where continuous variables were used. In cases where categorical variables were analysed, percentages and frequency values were calculated. Inferential statistics was carried out using unpaired t-test, Pearson's Chi-squared test and Logistic regression. The unpaired t-test was used to evaluate the significance of the difference of the means between the independent groups in terms of age. Redisplacement, our primary outcome, was analysed for correlation with a number of risk factors which are initial displacement, presence of ulna fracture, reduction quality and cast quality as measured using cast and padding indices. To compare participants with redisplacement to those without redisplacement in terms of risk factors, Pearson Chi-squared test was applied. In cases where statistically significant associations were detected, further analyses were carried out using logistic regression analysis. Univariate analysis was carried out first and factors found to be significant were further analysed using multivariate logistic regression in order to determine independent predictors for loss of reduction. *P*-values below 0.05 were regarded as significant while *p*-values below 0.001 were deemed highly significant.

Sixty one patients with distal radius metaphyseal fractures who met the inclusion criteria were enrolled (see Figure 3.1). Eight children (13.1%) had K-wires inserted intra-operatively and were not included in the final analysis. The reasons for K-wire use were not stated in the post-operative notes.

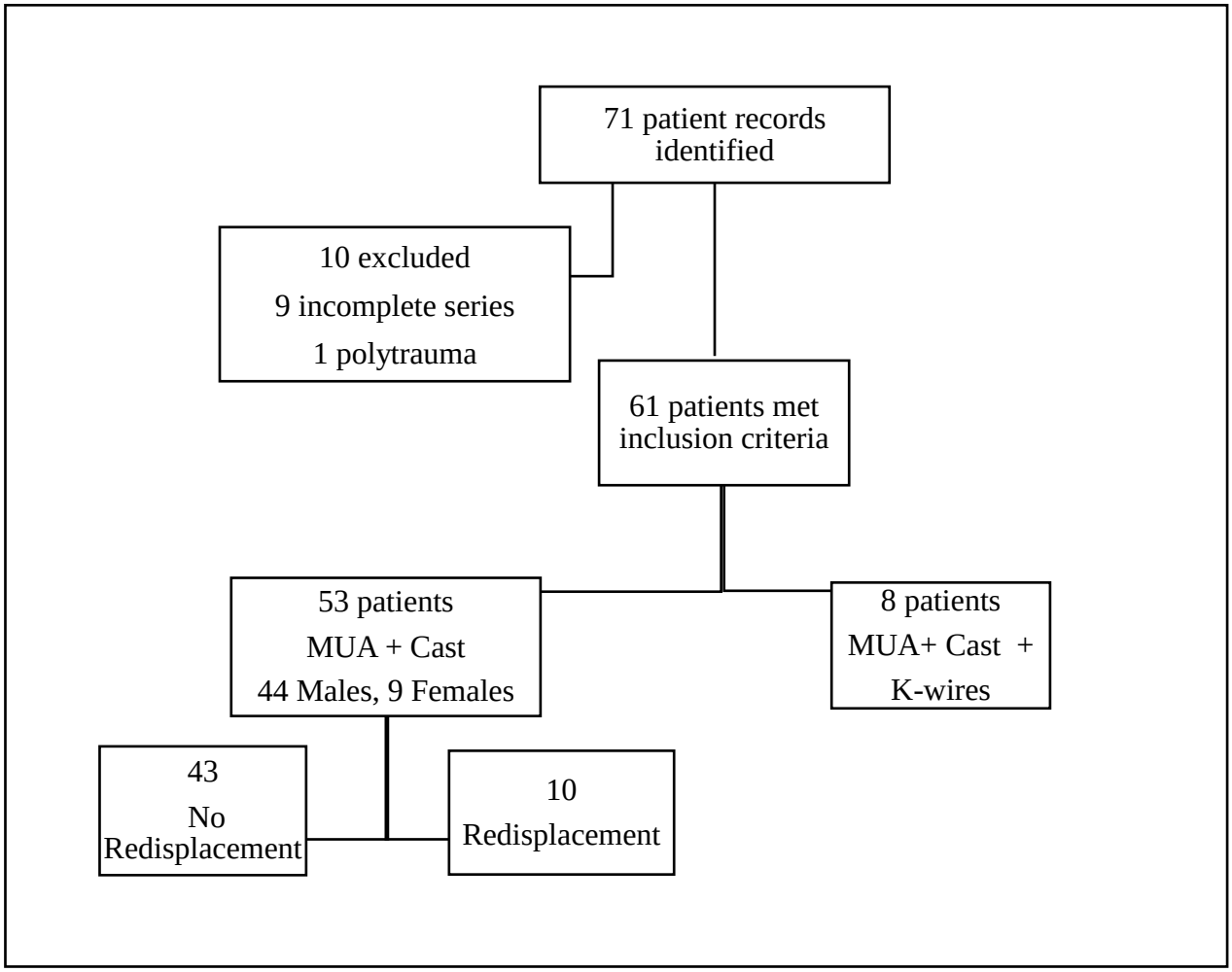


Figure 3.1: Flowchart of study population and outcomes

Fifty three children were included in the final analysis and the group demographic profile is summarised in Table 3.1. There were 44 boys (83%) and nine girls (17%), with a mean age of 8 ± 2.83 years (range four to 14 years). Thirty six children (68%) were between the ages of five and 10 years, 11 children were over the age of 10 years (21%) while six children were below the age of five years (11%). The mechanism of inury was related to a fall in 51 patients (96%) and pedestrian vehicle accident (PVA) in two patients (4%). Fifty five percent of the fractures (29 patients) occurred on the left side while 45% (24 patients) occurred on the right side. The age distribution for the entire group and the different age group categories are summarised in Figure 3.2 and Figure 3.3, respectively.

Table 3.1: Summary of study demographic profile and variables

Variables	**Number (N = 53)**	**Redisplacement**		***P*-value**
		No	Yes	
Sex				
Male	44 (83.02%)	35 (81.4%)	9 (90.0%)	1.000†
Female	9 (16.98%)	8 (18.6%)	1 (10.0%)	
Age (Mean age +/- SD)	8 ± 2.83	8.2 ± 2.9	7.6 ± 2.5	0.580*
Injured side				
Left	29 (54.72%)	23 (53.49%)	6 (60.0%)	1.000†
Right	24 (45.28%)	20 (46.51%)	4 (40.0%)	
Mechanism of injury				
Fall	51 (96.23%)	42 (97.67%)	9 (90.0%)	0.345†
PVA	2 (3.77%)	1 (2.33%)	1 (10.0%)	

p-values determined using Chi-squared test† and Unpaired or two sample t test*

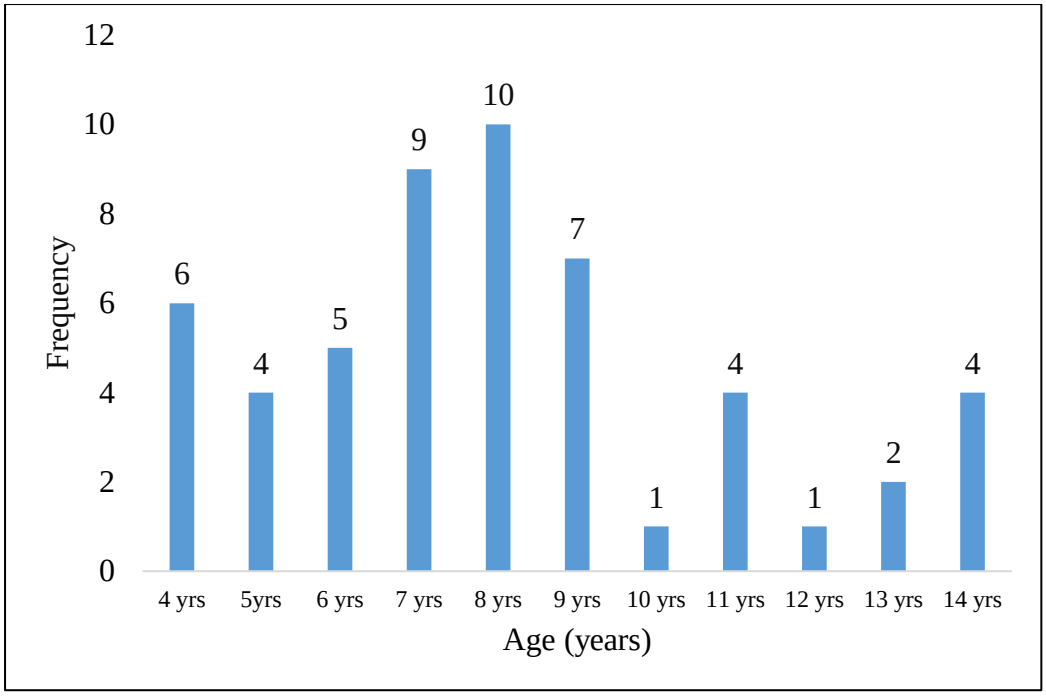


Figure 3.2: Age distribution of the patients

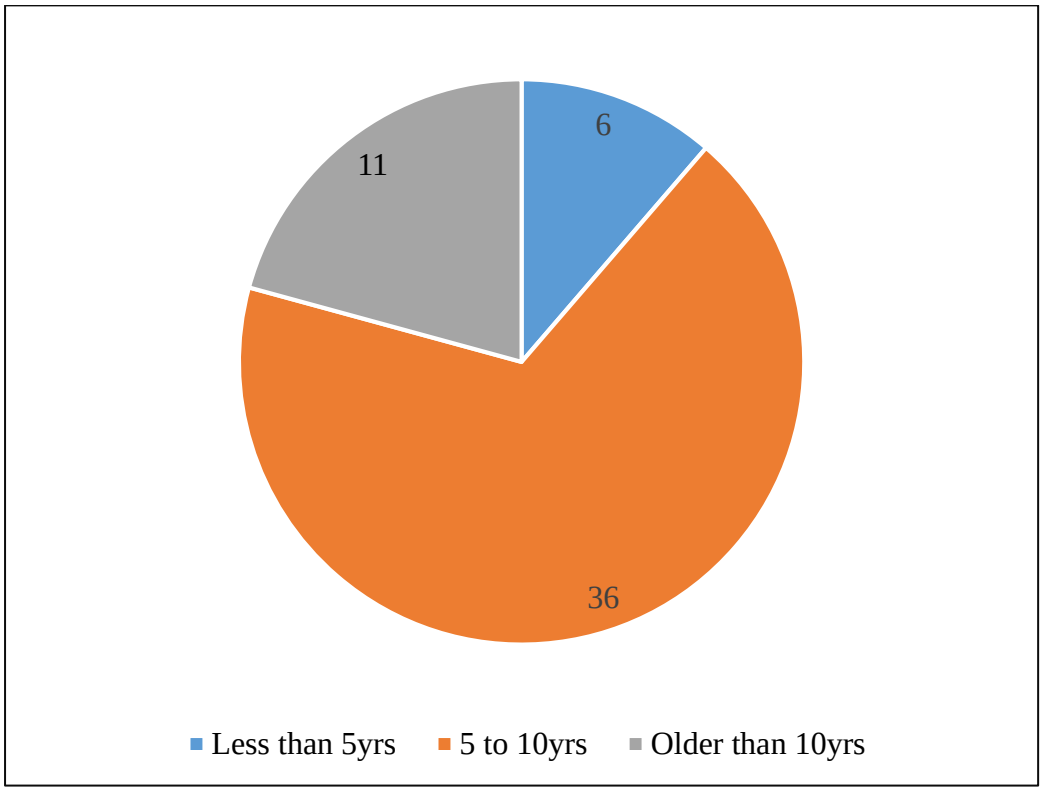


Figure 3.3: Categorical age distribution of patients

All patients were treated in theatre according to our protocol of manipulation under anaesthesia and cast immobilisation. Pre-operative radiographs revealed complete displacement in 34 patients (64.2%) and incomplete displacement in 19 (35.8%). In all patients, the quality of reduction achieved was deemed satisfactory. Anatomical reduction was achieved in 30 fractures (56.6%). Acceptable reduction was achieved in 23 fractures (43.40%) and there were no cases of poor reduction. The distal ulna was fractured in 25 patients (58%) while 18 patients (42%) had an intact ulna. Cast index of less than 0.8 was achieved in 33 patients (62.3%) and 20 patients (37.7%) had cast index more than 0.8. Twenty three patients (43.4%) had padding index less than 0.3 and 30 patients (56.6%) had padding index more than 0.3.

Redisplacement occurred in 18.8% (10 patients) during follow up. There were no cases that underwent secondary reduction or remanipulation as potential for future remodelling was deemed acceptable by the treating surgeons. There was no statistically significant association between redisplacement and any of the patient characteristics. The mean age in the redisplacement group was 7.6 ± 2.5 years and 8.2 ± 2.9 years in the group without redisplacement. Two sample t-test revealed no statistically significant difference between the two groups in terms of redisplacement ($p = 0.58$). Chi-squared test showed no significant difference in redisplacement between the three age category groups ($p = 0.57$).

There was no statistically significant difference between the group with redisplacement and the group without redisplacement with regards to sex, mechanism of injury and side injured (see Table 3.1). Table 3.2 shows the association between redisplacement and potential risk factors. There was a statistically significant difference between the two groups with regards to the reduction quality ($p = 0.001$), padding ($p = 0.031$) and cast ($p = 0.030$) indices. Although 60% of patients with redisplacement had initial complete displacement, this was not statistically significant when compared to the group with incomplete displacement (40% *versus* 60%, $p = 1.00$). The presence of ulna fracture did not result in statistically significant differences between the two groups (40% *versus* 60%, $p = 1.00$).

Table 3.2: Association between risk factors and outcomes			
Parameter	**No Redisplacement Number (%)**	**Redisplacement Number (%)**	***P*-value †**
Initial displacement			
Incomplete	15 (34.88%)	4 (40.0%)	1.000
Complete	28 (65.12%)	6 (60.0%)	
Ulna fracture			
No	18 (41.86%)	4 (40.00%)	1.000
Yes	25 (58.14%)	6 (60.00%)	
Reduction quality			
Anatomical	29 (67.44%)	1 (10.00%)	0.001
Acceptable	14 (32.56%)	9 (90.00%)	
Cast index			
Good (< 0.8)	30 (69.77%)	3 (30.00%)	0.030
Poor (> 0.8)	13 (30.23%)	7 (70.00%)	
Padding index			
Good (< 0.3)	22 (51.16%)	1 (10.00%)	0.031
Poor (> 0.3)	21 (48.84%)	9 (90.00%)	
p-values determined using Chi-squared test†			

Univariate logistic regression revealed that patients with acceptable or non-anatomical reduction quality were 18.6 times more likely to have redisplacement compared to patients with anatomical reduction quality (odds ratio 18.6, $p = 0.008$, 95% CI 2.145 – 162.012) (see Table 3.3). Patients with a poor cast index were 5.4 times more likely to have redisplacement compared to patients with a good cast index (odds ratio 5.38, $p = 0.028$, 95% CI 1.200 – 24.154). Patients with a poor padding index were 9.42 times more likely to develop redisplacement compared to patients with a good padding index (odds ratio 9.42, $p = 0.041$, 95% CI 1.097 – 81.006).

Table 3.3: Univariate analysis of potential risk factors for redisplacement			
	Odds ratio	***P*-value**	**95% Confidence interval**
Initial displacement			
Incomplete	1	0.761	0.195 – 3.298
Complete	0.80		
Ulna fracture			
No	1	0.914	0.265 – 4.291
Yes	1.08		
Reduction quality			
Anatomical	1	0.008	2.145 – 162.012
Acceptable	18.6		
Cast index			
Good (< 0.8)	1	0.028	1.200 – 24.154
Poor (> 0.8)	5.38		
Padding index			
Good (< 0.3)	1	0.041	1.097 – 81.006
Poor (> 0.3)	9.42		

Multivariate logistic regression showed reduction quality as the only independent risk factor for redisplacement (see Table 3.3). Patients with acceptable or non-anatomical reduction quality were about 23.6 times more likely to have redisplacement compared to patients with anatomical reduction quality (odds ratio 23.6, $p = 0.008$, 95% CI 2.292 – 243.428) (see Table 3.4).

Table 3.4: Multivariate analysis of potential risk factors for redisplacement			
Variables	**Odds ratio**	***P*-value**	**95% Confidence interval**
Reduction quality			
Anatomical	1	0.008	2.292 – 243.428
Acceptable	23.6		
Cast index			
Good (< 0.8)	1	0.143	0.594 – 36.214
Poor (> 0.8)	4.69		
Padding index			
Good (< 0.3)	1	0.309	0.290 – 50.211
Poor (> 0.3)	3.81		

There was also no redisplacement reported in patients in whom K-wires were used. Five patients developed swelling that required splitting of the cast. These patients underwent MUA and reapplication of a new cast in theatre and this was regarded as the immediate post operative cast for the purpose of our measurements. There was no redisplacement in these five cases on follow up. No other immediate post-operative complications were reported.

CHAPTER FOUR: DISCUSSION

The treatment of choice for displaced paediatric distal radius metaphyseal fractures is manipulation and casting (33,54). Although good results can be achieved, maintaining a good reduction in a cast until fracture union is challenging. The primary aim of this study was to determine the radiological outcomes of our current management of distal radius metaphyseal fractures in children, by looking at redisplacement rates on follow up. In addition, we also sought to determine the association between redisplacement rates and potential risk factors such as initial complete displacement, failure to achieve anatomical reduction, presence of an ulna fracture and poor casting technique assessed using cast and padding indices (7,29,32,34,39).

Redisplacement rates between 24% and 45.8% have been reported on follow up by numerous studies on distal radius metaphyseal fractures (29,34,36,39,54). In our study, a redisplacement rate of 18.8% (10 patients) was found, with a highest redisplacement rate of 11.3% within the five to 10 years age group compared to 3.7% each in children less than five years and and more than 10 years of age. The differences in redisplacement rates between the three age groups were not found to be statistically significant. Previous studies have shown higher redisplacement rates in children over 10 years (36), however, the lack of consensus on the definition of redisplacement in various studies is an important factor to consider in order to contextualise the different study outcomes. Moreover, 68% of children in our series were between the ages of five and 10 years, resulting in a relatively smaller sample size of older children (> 10 years) to make any meaningful conclusion. Based on these results, our study reported redisplacement rates comparable and on the lower range of what is commonly reported in literature.

On follow up, none of the patients with redisplaced fractures were remanipulated and we believe the treating surgeons accepted the potential for future remodelling given their age as the majority of these children were under the age of 10 years. A study by Colaris et al. recommended secondary reduction for every case where there was loss of reduction, but in the series, only 56.7% of redisplaced fractures actually underwent manipulation (55). The authors attributed this to the consideration by the different surgeons of the remodelling potential in children and avoiding the unnecessary burdern of a second surgery. Ozcan et al.

reported a 50% redisplacement rate in patients treated with manipulation and casting, none of the cases were remanipulated (35). Despite higher redisplacement rates reported in literature, there is generally a higher threshold for remanipulation due to excellent remodelling potential in children with distal radius metaphyseal fractures, avoidance of repeat surgery and possibly lack of consensus on the definite criteria for remanipulation. However, in addition to parental anxiety over angular deformity, the possibility of poor functional outcomes especially in older children with limited remodelling capacity should not be ignored. We found no significant association between redisplacement and sex, side injured and mechanism of injury which is consistent with previous literature (34,36,44), although one study has previously identified males with injury on the right to be at higher risk of redisplacement (56).

Initial complete displacement has been shown to be an important risk factor for loss of reduction by several authors (7,29,32,34,39). Mani et al. postulated that in severely translated distal radius metaphyseal fractures, there is loss of periosteal hinge with resultant lack of restraint and therefore greater propensity for rotational deformity to occur (39). Severely displaced (more than 50% displacement) fractures were found to be highly predictive of failure than mildly (less than 50% displacement) displaced fractures (39). In another study, the likelihood of redisplacement was reported to be 24.7 times more in children who presented with complete displacement (29). There was no significant difference between patients with initial complete displacement and those with incomplete initial displacement in our study. However, six of the 10 of patients with redisplacement had initial complete displacement compared to four with initial incomplete displacement. All four patients with initial incomplete displacement had dorsal angulation of more than 30º. Completely displaced and severely angulated fractures (> 30º) have been reported as unstable and also having a tendency to result in redisplacement that necessitates a secondary reduction especially in children over the age of 10 years (36). This finding may explain why incompletely displaced but severely angulated fractures demonstrated redisplacement rates that are not statistically different from completely displaced fractures in our study given that we used translation only to define initial complete displacement. A study by Alemadaroglu et al. showed the most important predictor for loss of reduction to be complete displacement or translation (7). When compared to incompletely displaced fractures with severe angulation, translated or completely displaced fractures were more likely to lose reduction (7). In defining initial displacement, some studies emphasise that a more reliable factor in

forecasting redisplacement risk is translation as opposed to angulation (44,57). However, some studies found that initial angulation is a better indicator of future redisplacement instead of translation or displacement (17). Miller et al. regarded both initial complete translation and severe angulation as predictive of high risk of redisplacement (36).

The impact of the presence or even absence of an associated ulna on redisplacement rates is a contentious issue in literature. Zamzam et al. found an associated ulna fracture to be a significant risk factor for redisplacement (29), but this was not supported by other studies (7,34). Distal radius fractures associated with an intact ulna were reported to be unstable and at higher risk of redisplacement than distal radius fractures associated with an ulna fracture (43). Mazzini et al. reported that fractures with an intact ulna are more difficult to reduce due to a higher residual translation following reduction when compared to those with an associated ulna fracture (1). In our series, although six out of 10 fractures with redisplacement had an associated ulna fracture, this was not found to be statistically significant.

The quality of reduction has been accepted as an important factor in predicting redisplacement. Several studies found that a perfect anatomical reduction is a significant factor in preventing loss of reduction (7,34,53). Proctor et al. reported a significant chance of redisplacement in cases where a perfect anatomical reduction was not achieved (34). The authors recommended the use of K-wires in cases where a perfect reduction coud not be achieved to mitigate the high risk of redisplacement. Alemdaroglu et al. found that compared to anatomically reduced fracture, the risk of redisplacement is five times higher for a fracture with imperfect reduction (2). Jordan and Westacott reported that there is a significant risk of redisplacement as long as optimal reduction is not achieved, which the authors described to be translation of 10% or less as well as and angulation of 5º or less (2). This study attempted to set a new threshold for the amount of reduction necessary to prevent high redisplacement rates which was not necessarily anatomical or perfect reduction. The authors reported a 40% redisplacement rate if that criteria was not met. Our study compared anatomical and acceptable or non-anatomical reduction (< 50% translation and < 20º angulation) as defined by previous studies (2,8,44). We found a statistically significant association between redisplacement and failure to achieve anatomical reduction. Our study was able to show non-

anatomical reduction as an independent risk factor for loss of reduction. The risk of redisplacement was 23.6 times compared to cases where anatomical reduction was achieved.

Several radiographic tools used to evaluate cast quality have been described, but our study focused only on the cast index and padding index. The cast index, asseses the cast shape in an 'axial' plane such that low values (< 0.8) correspond to a cast oval section at fracture site, while high values (> 0.8) reveal a more cylindrical cast shape (49). An oval shape is believed to prevent supination and pronation movements that could potentially results in loss of reduction (49). Our study used a cut-off of 0.8 reported by Alemadaroglu et al. as being the most reliable due to higher sensitivity and specificity when compared to the original cut-off of 0.7 proposed by Chess et al. (2,47). We found a statistically significant association between between cast index of more than 0.8 and high redisplacement rates, a finding consistent with other studies (49). However, multivariate analysis did not show cast index to be a significant predictor of redisplacement on follow up. Alemadaroglu et al. did not find cast index to be a significant factor in predicting redisplacement and this was attributed to its failure to identify poor moulding on the radial or ulna side as it considers the measurements at the fracture site only (7).

Padding index was first defined by Bhatia and Housden as a radiological tool to evaluate the cast quality in paediatric fractures involving both the shaft and the metaphysis (58). There was significant association in our study between a high padding index and redisplacement, a finding consistent with other previous studies (44,45,58). However, Alemadaroglu et al. found no such association and instead found the three-point index to be a significant factor in predicting redisplacements (7). The authors suggested that padding index is better suited for evaluating shaft fractures rather than metaphyseal fractures (7). This was attributed to the fact that the maximum interosseous distance which is key when evaluating padding index, is a measurement that better defines fracture reduction in the shaft as opposed to the metaphysis (58).

Despite criticism of both the cast and padding indices for not taking into account three-point fixation, the use of this principle as a measure of cast adequacy has not been supported by other more recent studies (49,58). McQuinn and Jaarsma attributed this to the inclusion of patients with above elbow casts in their study, which effectively reduced redisplacement risk as a result of limited pronation and supination movements (57). Three-point fixation was still

considered more important for short casts as deforming forces arising from above the elbow were not neutralised (57). In our sample of 53 radiographs where immobilisation and casting only was used, five below elbow casts were used and none of the fractures redisplaced on follow up. Although our protocol is MUA and above elbow cast, five patients were treated with below elbow casts despite the protocol. However, these patients were not excluded from the study as they were considered part of protocol under review and their results did not affect the final outcomes of the study. A study by Ranvier et al. showed that despite the use of only below elbow casts, cast and padding indices were found to be more significant predictive factors when compared to the three-point index (58).

Percutaneous K-wires were used in eight out of 61 (13.1%) patients who met the inclusion criteria. On follow up there were no cases with K-wires that redisplaced, this finding is in keeping with previous studies that support the role of K-wires in preventing redisplacement (2,8,36). In cases where K-wires were used in our study, the reasons were not stated and there is no defined criteria for the use of K-wires in our centre. The general consensus is that K-wire stabilisation be reserved for potentially unstable cases in order to avoid K-wire related complications in children as well as the possibility of subjecting a child to a second surgical procedure (32). However, the criteria for instability is not well defined in literature. Ramatour et al. reported a 2% redisplacement rate in the group with K-wires and warned that redisplacement can still occur despite K-wire stabilisation particularly in the presence of a poor initial reduction (8).

In our study, five out of 53 patients in the cast only group developed swelling that required splitting of a cast within 24 hours. These patients were remanipulated in theatre and a new above elbow cast was reapplied. No other early complications were reported and none of these patients redisplaced on follow up. There were no early cast related complications in the K-wire group. In the cast only group, 18% of patients redisplaced whereas no patients redisplaced in the K-wire group. Our findings are consistent with previous research by McLauchlan et al. who reported that seven from 33 patients treated with just manipulation required a further procedure compared with none from 35 treated with manipulation and insertion of K-wires (4).

4.1 LIMITATIONS

The involvement of multiple surgeons in management of patients in this study resulted in lack of strict adherence to the recommended protocol. Data collection was restricted by availability of patient records as this was a retrospective study. Nevertheless, the clinical notes obtained were deemed adequate enough to extract data required to answer our research questions. There was a relatively smaller number of children above the age of 10 years for us to draw any reliable conclusions from our results in that important subset of patients. There was incomplete radiographic data which resulted in some cases being excluded from the study. The radiological measurements were done only once for each case by a single observer, so the presence of any inter-observer or intra-observer reliability was not taken into account.

CHAPTER FIVE: CONCLUSION

Our current management of paediatric distal radius metaphyseal fractures is safe and effective as we reported redisplacement rate (18.8%) comparable to current literature standards as well as an overall low rate of early cast related complications (8.2%). Non-anatomical reduction was shown to be a significant as well as an independent risk factor for loss of reduction. A significant association was found between redisplacement rates and both the padding and cast indices. Initial complete displacement and the presence of an associated ulna fracture were not found to be significant predictive factors for redisplacement. The frequency of K-wire use was 13.1% and no redisplacement was reported in the K-wire group, in keeping with literature. Although our study was unable to adequately define the indications for K-wire use in our population, the presence of risk factors for redisplacement in older children with limited remodelling potential may deem supplemental K-wire fixation from the outset appropriate.

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APPENDICES

Appendix A: Data Collection Form 1: Admission-Discharge

Study Number				
Age				
Date of Admission (yyyy/mm/dd)				
Gender				
Distal Radius Fracture (please tick)	Left	Right		
Pre-operative Parameters				
Initial translation/displacement (please tick)	No translation	<= 50%	> 50%	Complete translation
Associated Ulna Fracture (please tick)	Absent	Present		
Post-operative Parameters				
Quality of reduction (please tick)	Anatomical	Acceptable	Poor	
Quality of Cast Moulding				
Internal cast width (lateral)				
Internal cast width (AP)				
Cast Index				
Dorsal gap at the fracture site (lateral)				
Maximum Interosseous distance (AP)				
Padding Index				
Complications (please tick)	Yes	No		
If yes above please state the complication				
Remanipulation (please tick)	Yes	No		
K wire use (please tick)	Yes	No		
If yes above please state reason				

Appendix B: Data collection Form 2: Clinic Follow Up-Radiological Outcomes

Study Number	
Age	
Date of Admission (yyyy/mm/dd)	
Gender	
Follow-up week (no. of weeks post surgery)	

	Left	Right
Distal Radius Fracture (please tick)		

Redisplacement

	Less than 20°	More than 20°
Angulation		

	Less than 50%	More than 50%
Translation		

	Yes	No
Complications (please tick)		

If yes above please state the complication ----------

	Yes	No
Remanipulation (please tick)		

Appendix C: Human Research Ethics Committee Clearence Certificate

R14/49 Dr Tlou Boshomane

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M151179

NAME: (Principal Investigator)	Dr Tlou Boshomane
DEPARTMENT:	Orthopaedic Surgery Chris Hani Baragwanath Academic Hospital Charlotte Maxeke Johannesburg Academic Hospital
PROJECT TITLE:	Outcomes of Paediatric Distal Radius Fractures Managed with our Current Protocol
DATE CONSIDERED:	27/11/2015
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Prof A Robertson
APPROVED BY:	Professor P Cleaton-Jones,Chairperson, HREC (Medical)
DATE OF APPROVAL:	12/02/2016

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 in Room 10004, 10th floor, Senate House/2nd Floor, Phillip Tobias Building, Parktown, University of the Witwatersrand. I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**.

Principal Investigator Signature — Date 28/02/2016

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES