

The treatment of tibia fractures by intramedullary nails at Charlotte Maxeke Johannesburg Academic Hospital



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Declaration:

I *Alexis Sian Whitehead* declare that this Research Report is my own, unaided work. It is being submitted for the Degree of Master of Medicine in the branch of Orthopaedic surgery at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.



Signed 12 day of April 2021 in Johannesburg.

Dedication

Dedicated to my husband, for his unwavering support of my career
and academic efforts.

Secondly, to my mother, for encouraging me to read and be curious from a young
age.

Abstract

Background: Tibial shaft fractures are the most common long bone fractures in young adults, and intramedullary nailing of these fractures consumes a considerable amount of theatre resources at Charlotte Maxeke Johannesburg Academic Hospital. Although there is substantial international literature on the accuracy of this treatment method, no prior study has been conducted at this institution to determine whether our results are comparable with international norms. We conducted this study to assess whether tibial fractures are being treated appropriately with intramedullary nails at Charlotte Maxeke Johannesburg Academic Hospital, with adequate reductions that do not undergo early loss of reduction.

Methods: A retrospective review of patient files and radiographs was done on patients who received a tibial nail between 01 April 2016 and 31 March 2018. Demographic and injury data were collected from the files. Radiographs were measured digitally at two time points, immediately post-operatively and after the six weeks' follow-up. The data were analysed to determine whether these fractures were adequately reduced at both time points. We then conducted a statistical analysis to ascertain if there were any factors that were correlated with unacceptable reductions.

Results: There were 158 patients with 163 tibial fractures that met our inclusion criteria. The majority of tibial fractures occurred in young male patients (65.82%) and the most common mechanism of injury was a pedestrian vehicle accident (49.69%). The majority of these fractures were closed injuries involving the midshaft of the tibia (42.33%). Surgeon experience was shown to be significant both for theatre time usage and also for the adequacy of reduction, although this did not follow a linear pattern. Multiple procedures done in one sitting were also associated with a longer surgical time, but not with the quality of the reduction. There were 46 (22.28%) patients who were identified to have inadequate reductions at follow-up, 15 (9.20%) of whom had lost reduction from their initial post-operative measurements. Malalignment was most common in fractures of the proximal third of the tibia.

Conclusion: The majority of patients had adequate reductions that were maintained until follow-up. The rate of unacceptable reductions is in keeping with the international data.

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Table of Contents

Declaration:	i
Dedication	ii
Abstract	iii
Acknowledgements	iv
Table of Contents	v
List of figures	vii
List of tables	viii
Nomenclature	x
Chapter 1	1
1. Introduction and Literature Review	1
1.1 Background	1
1.2 Literature Review	2
1.2.1 Relevant Anatomy	2
1.2.2 Treatment of tibial fractures	6
1.2.3 Complications of tibial nailing	7
1.2.4 Reamed <i>versus</i> Unreamed nails	8
1.2.5 Treatment of open fractures of the tibia	9
1.2.6 Challenges particular to proximal tibial fractures	10
1.2.7 Challenges particular to distal tibial fractures	11
1.2.8 Measurement of angles on radiographs	13
1.2.9 The effects of surgeon experience and time of day	13
1.2.10 Theatre time usage for emergency orthopaedic cases	15
1.3 Study aim and objectives	15
Chapter 2	16
2. Methodology	16
2.1 Research Question	16
2.2 Research Design	16
2.3 Materials and Methods	16
2.4 Sample	17
2.5 Data Collection	18
2.6 Data Analysis	19

Chapter 3	21
3. Results	21
3.1 Demographics	21
3.1.1 Mechanisms of injury	22
3.2 Injury characteristics	23
3.3 Characteristics of surgical procedure	25
3.3.1 Use of adjuncts	25
3.4 Time Usage and time of day	26
3.5 Adequacy of reduction	27
Chapter 4	45
4. Discussion	45
4.1 Demographics	45
4.1.1 Mechanism of injury	46
4.2 Injury Characteristics.....	47
4.3 Use of adjuncts	51
4.4 Time Usage and time of day	52
4.5 Adequacy of reduction	53
4.5.2 Significant factors associated with malalignment.....	54
4.6 Limitations	55
4.7 Recommendations	55
Chapter 5	57
5. Conclusion	57
6. References	58
7. Appendices	61
7.1 Appendix A: Ethics approval	61
7.2 Appendix B: Hospital Permission Letter	62
7.3 Appendix C: Data Collection Sheet from theatre registers and clinical notes..	63
7.4 Appendix D: Data Collection Sheet from PACS images:.....	64
7.5 Appendix E: Protocol Approval Letter	66

List of figures

Table	Title	Page
Figure 3.1:	Mechanism of Injury	22
Figure 3.2:	Distribution of soft tissue injury as classified by Gustilo-Anderson	23
Figure 3.3:	Distribution of fractures in thirds of the tibia	24
Figure 3.4:	Distribution of fracture patterns as classified by the AO system	24

List of tables

Table	Title	Page
Table 1.1:	Gustilo-Anderson Classification of Open Fractures	4
Table 1.2:	AO Foundation Classification of Tibial Fractures	5
Table 3.1:	Demographic Data of patient sample	21
Table 3.2:	Summary of treatment features	25
Table 3.3:	Time utilisation breakdown	27
Table 3.4:	Adequacy of Reduction	28
Table 3.5:	Breakdown of malalignment by type	29
Table 3.6:	Characteristics of patients with unacceptable reductions at follow-up	30
Table 3.7:	Characteristics of patients with unacceptable reductions post-operatively	32
Table 3.8:	Pairwise Correlations with Outcome Variables	34
Table 3.9:	Factors associated with varus/valgus alignment post-operatively	35
Table 3.10:	Factors associated with procurvatum/recurvatum alignment postoperatively	36
Table 3.11:	Factors associated with varus/valgus alignment at follow-up	37
Table 3.12:	Factors associated with procurvatum/recurvatum alignment at follow-up	38
Table 3.13:	Factors associated with shortening post-operatively	39
Table 3.14:	Factors associated with shortening alignment at follow-up	40
Table 3.15:	Associations between patient characteristics and alignment post operatively	41
Table 3.16:	Associations between patient characteristics and alignment at follow-up	43
Table 4.1:	Comparison of percentages of mechanism of injury	47
Table 4.2:	Percentage of wounds per Gustilo-Anderson classification	48
Table 4.3:	Percentage of fractures by third of the tibia	49

Table 4.4:	Percentage of fractures by third of the tibia including junctional areas.	49
Table 4.5:	Percentage of fractures by broad AO categories	50
Table 4.6:	Percentage of fractures by detailed AO categories	51
Table 4.7:	Comparison of rates of malalignment in the literature	54

Nomenclature

AO	<i>Arbeitsgemeinschaft für Osteosynthesefragen</i> – Association for the Study of Internal Fixation
CMJAH	Charlotte Maxeke Johannesburg Academic Hospital
DIST	Distal
GA	Gustilo and Anderson classification
GSW	Gunshot wound
HREC	Human Research Ethics Committee
MBA	Motorbike accident
MIPO	Minimally invasive plate osteosynthesis
MVA	Motor vehicle accident
PACS	Picture Archiving and Communication System
PRO	Procurvatum
PROX	Proximal
PVA	Pedestrian vehicle accident
REC	Recurvatum
SA	South Africa
SPRINT	Study to Prospectively Evaluate Reamed Intramedullary Nails in Patients with Tibial Fractures
UK	United Kingdom
USA	United States of America
VAL	Valgus
VAR	Varus

Chapter 1

1. Introduction and Literature Review

1.1 Background

Tibial fractures are amongst the most common long bone fractures, and frequently occur in young, healthy patients who are of working age. There are no published epidemiological data specific to South Africa (SA), but international studies show tibial shaft fractures to be the second most frequent long bone fracture after humeral fractures and the most common long bone fracture in young adults.⁽¹⁾ Estimates of occurrence in the population vary from 6.4/10,000 population in Australia to 1.69/10,000 in Denmark.^(1, 2) Additionally SA has a high burden of trauma, particularly interpersonal violence and motorised vehicle accidents, which disproportionately affect young, working age men.⁽³⁾

An examination of statistical data at Charlotte Maxeke Johannesburg Academic Hospital (CMJAH) shows that tibia fractures accounted for 18% of all adult orthopaedic admissions. Intramedullary nailing of the tibia has been the most common long bone trauma procedure performed over the last three years and made up 10.6% of all orthopaedic emergency surgeries.

Due to the large burden of trauma in SA, it is essential to examine whether tibial fractures are being treated efficiently, as this has implications both for theatre time use as well as financial cost. It is also necessary to interrogate whether our current protocols produce adequate results in terms of patient outcomes and complication and re-operation rates.

1.2 Literature Review

1.2.1 Relevant Anatomy

Located subcutaneously in the lower leg, the tibia is the primary weight bearing bone, responsible for taking around 80% of the body weight when walking. The fibula carries the remaining 20% and is important distally for ankle stability and, more proximally, it provides attachment for musculature of the leg.⁽⁴⁾ The shaft of the tibia has an extremely strong cortex which is triangular in shape; this flares proximally and distally into a wider, more pyramidal shape which is made of relatively weaker metaphyseal bone.⁽⁴⁾ Normal tibial torsion results in the ankle joint being externally rotated by approximately twenty degrees relative to the knee joint, and thus it is impossible to get a true antero-posterior view of both the knee and the ankle on the same radiograph.⁽⁴⁾ The normal distal articular surface is 90° to the shaft, while the proximal articular surface is angulated in slight varus alignment of approximately 87°.⁽⁴⁾

Fractures of the tibia are frequently open fractures because of its thin soft tissue envelope. The tibial blood supply is also more easily damaged than other long bones as it is not surrounded by a thick sheath of muscle on all sides.⁽⁵⁾ This is significant as good vascular supply is essential for bone healing. The tibia has both periosteal and endosteal blood supply, with the former supplying the outer third of the bone and the latter supplying the remaining inner two-thirds.⁽⁴⁾ The primary nutrient artery enters the tibia in its proximal third and is a branch of the posterior tibial artery. This artery forms the main endosteal supply.⁽⁴⁾ The periosteal supply is formed from branches of the arteries that supply the surrounding soft tissues. This supply is extremely vulnerable to soft tissue stripping which may occur at the time of injury or during surgical fixation of the bone.⁽⁴⁾ After stripping of the periosteal supply, the outer third of the bone is dependent on centrifugal flow from the endosteal system to survive, which is significant if the endosteal supply has also been disrupted by the injury pattern.⁽⁴⁾ Thus, fractures of the tibia are more challenging to treat than other long bones and more frequently result in non-union.⁽⁵⁾

The severity of the soft tissue injury is closely related to the risk of poor healing in tibia fractures, with high energy open fractures having a particularly high risk of infection,

non-union and wound complications.⁽⁶⁾ There have been several systems proposed to describe the wounds associated with open fractures, of which the updated Gustilo-Anderson classification is the most widely used.⁽⁶⁾ It divides wounds into three categories based on size, and further subdivides the third category into three more subdivisions based on soft tissue and wound factors (refer to Table 1.1 below). Type 1 injuries are open fractures with clean wounds smaller than one centimetre, whereas Type 2 are wounds greater than one centimetre but without any severe soft tissue damage, tissue loss or flaps.⁽⁶⁾ Type 3 injuries are divided into: type 3A where there is an extensive laceration or flap, but adequate soft tissue available to cover the bone; type 3B where there is loss of soft tissue cover with periosteal stripping, and type 3C where there is an arterial injury requiring repair.⁽⁷⁾ Additionally gunshot wounds and farm injuries are included in type 3 injuries as the high energy nature of gunshot wounds causes significant soft tissue injury, even when the skin wound is small, and farm injuries are highly contaminated.⁽⁶⁾

Table 1.1: Gustilo-Anderson Classification of Open Fractures ^(6, 7)

Type		Description
Type 1		Clean wound < 1 cm
Type 2		Wound >1 cm, no soft tissue stripping or flaps
Type 3	3A	Extensive laceration with sufficient soft tissue to cover bone. High energy injury regardless of wound size.
	3B	Extensive laceration with bone exposure or periosteal stripping without adequate soft tissue cover.
	3C	Associated with arterial injuries requiring repair

More severe soft tissue injury is associated with a higher risk of non-union, with open fractures being higher risk than closed fractures, and Type 2 and 3 wounds having a progressively higher risk than type 1.^(6, 8)

Tibial shaft fractures can be classified according to the *Arbeitsgemeinschaft für Osteosynthesefragen* (AO) foundation classification system which assigns the number 42 to the tibia, and then subdivides fractures by pattern type, namely *simple*, *wedge* or *comminuted* fractures. Fractures can be further qualified by where they occur in the bone, and whether they are in the proximal, middle or distal thirds of the shaft.⁽⁹⁾

Table 1.2: AO Foundation Classification of Tibial Fractures ^(10, 11)

Simple Fractures	42 – A1 Spiral	42 – A2 Oblique (> 30°)	42-A3 Transverse (< 30°)	Qualifications		
				a - Proximal 1/3		
				b - Middle 1/3		
				c - Distal 1/3		
Wedge Fractures		42 – B2 Intact Wedge Fracture	42 – B3 Fragmentary Wedge Fracture	a - Proximal 1/3		
				b - Middle 1/3		
				c - Distal 1/3		
Complex Fractures		42 – C2 Intact segmental fracture	42 – C3 Fragmentary segmental fracture	i - Proximal diaphyseal-metaphyseal		
				j - Pure diaphyseal		
				k - Distal diaphyseal-metaphyseal		

Fracture pattern is associated with the risk of developing a non-union, with obliquity, comminution and segmental fractures being associated with a higher risk of non-union, and cortical continuity of less than 25% being predictive of non-union.⁽¹²⁾ Additionally Bhandari *et al.* found in their study of the predictors and reoperation that the co-existence of multiple risk factors, for example a high Gustilo-Anderson grade and comminuted fracture pattern, substantially increased the risk of having a non-union and requiring secondary procedures to achieve fracture healing.⁽¹²⁾

There are a variety of acceptable parameters for reduction of tibial fractures quoted in the literature.^(9, 13) Older studies have accepted angular deformities of up to 10° and shortening of up to 2 cm. However, the most frequently used values within the recent literature are within the following ranges:

1. Varus/valgus < 5°
2. Procurvatum/recurvatum < 5°
3. Rotation < 10°
4. Shortening < 1 cm ⁽¹³⁻¹⁸⁾

However, some authors are more exacting in their criteria, and will only accept angular deformities of less than 5°.^(9, 13)

Rotational malalignment is more poorly tolerated than other types of malalignment, particularly those closer to the ankle joint, as it alters the joint mechanics significantly and may predispose the patient to early osteoarthritis of the ankle.^(9, 19)

1.2.2 Treatment of tibial fractures

Historically, most tibial fractures were treated non-surgically with a plaster cast followed by functional bracing. However, this was associated with poor functional results as patients frequently developed malunions and stiffness of the knee and ankle joints.⁽¹⁹⁾

The first intramedullary tibial nails were introduced in the 1930's by Gerhard Küntscher and consisted of straight steel rods that have either a V-shape or cloverleaf cross section.⁽⁵⁾ They were later modified by Herzog to have a proximal bend to allow for easier access of the medullary canal when starting from an anterior entry point.⁽⁵⁾ In the 1970's various nails were developed with interlocking screws which prevented rotation around the nail and allowed for their use in more proximal and distal fracture patterns.⁽⁵⁾

While intramedullary nailing is now a well-accepted modality for the treatment of midshaft tibia fractures, its use remains controversial in very proximal and distal fractures of the tibia, with a high rate of malunion in these areas.⁽¹⁵⁾ There has also

been controversy regarding the use of reamed *versus* unreamed nails, as well as the use of primary intramedullary nailing of open fractures.^(8, 20, 21)

1.2.3 Complications of tibial nailing

Complications of tibial nailing can be divided into intra-operative, early post-operative and late groups. Intra-operative complications include propagation of the fracture and difficulty inserting the interlocking screws, resulting in poor purchase of the screw in the bone.⁽²²⁾

Early post-operative complications include: haematoma formation at the nail insertion site and compartment syndrome.⁽²²⁾ Fat embolism syndrome, pulmonary embolism, deep vein thrombosis as well as pneumonia have all been recorded in post-operative patients.⁽²³⁾ Common peroneal nerve palsy post-operatively is a relatively frequent complication (~30%), with a small percentage of these failing to resolve (~3-6%).^(13, 22) Malalignment with the tibia in an unacceptable degree of angulation or with an unacceptable amount of shortening or distraction may require revision surgery in the early post-operative stage.^(12, 23)

Late complications are the most common group, with complications related to bone and soft tissue healing, loss of position, as well as hardware problems. Soft tissue complications include superficial and deep soft tissue infection, and patellar tendinitis.^(13, 23) Bone complications include delayed or non-union, and the development of chronic osteomyelitis.^(13, 23) Loss of position or initial malalignment may result in malunion, or an unacceptable degree of shortening.^(13, 23) Hardware complications include breakage of nails, bending or breakage of screws, screws backing out or joint penetration by hardware.⁽²³⁾

The most common indications for re-operation are delayed or non-union, and these are commonly treated by dynamisation, exchange nailing with or without bone graft, bone grafting alone or removal of the nail and plating with bone grafting.⁽²³⁾ Implant removal is occasionally necessitated by infection or symptomatic hardware,⁽²²⁾ but this does carry the risk of re-fracture.⁽²³⁾

Patients may still have symptomatic pain at the fracture site despite successful fracture healing, as well as chronic anterior knee pain, regardless of the nail insertion approach used.^(20, 24)

1.2.4 Reamed *versus* Unreamed nails

Reaming allows for the use of a larger diameter nail, which provides greater stability.⁽²¹⁾ However, reaming damages the important endosteal blood supply, which may contribute to non-union and deep sepsis at the fracture site.⁽²⁰⁾ There is also concern that reaming causes thermal necrosis of the bone, which may lead to deep sepsis at the fracture site, even in closed fractures.⁽²⁵⁾

Kakar *et al.* performed a prospective study to evaluate the use of unreamed nails in open tibial fractures and they found a relatively high rate of pain at the fracture site after clinical and radiological evidence of healing, as well as a high rate of screw breakage.⁽²⁰⁾ A cadaveric study was performed by Fairbank *et al.* which directly compared the biomechanical stability of reamed *versus* unreamed nails by inserting one of each into each tibia of the cadaver specimens. They found less stability in the unreamed nail construct with more motion at the fracture site, and an increase in screw bending and breakage in the unreamed group due to the smaller diameter of the nails and consequent smaller diameter of the interlocking screws.⁽²⁶⁾

Coles *et al.* performed a review of the treatment and complications of tibial shaft fractures and found that reamed nails were associated with a lower risk of delayed or non-union and a lower risk of malunion when compared to unreamed nails.⁽²³⁾ They found an equal risk of fat embolism syndrome in both reamed and unreamed nails, and this risk was not higher than for tibial fractures treated with plate fixation.⁽²³⁾ There was a higher risk of superficial infection with reamed nails but in their combined analysis of complications reamed nails were shown to have a lower risk of complications overall when compared to unreamed nails.⁽²³⁾

Likewise, the Study to Prospectively Evaluate Reamed Intramedullary Nails in Patients with Tibial Fractures (SPRINT) supported the use of reamed nails over unreamed nails. The authors also found that delaying secondary procedures for six months resulted in fewer reoperations for both groups, as many delayed unions ultimately progressed to union without the need for further surgery.⁽²¹⁾ However, a later follow-

up of the patients in this study showed no difference in functional outcome at one year post surgery.⁽²⁷⁾

Gaebler *et al.* performed a prospective study to compare reaming to maximal canal width with a more conservative minimal reaming approach. They did not find an increase in complications with the smaller diameter nails used in the minimal reaming group, but did find a trend of earlier return to normal activity in the maximally reamed group.⁽²⁸⁾

1.2.5 Treatment of open fractures of the tibia

As stated previously, the tibia is particularly vulnerable to open fractures due to its subcutaneous position. Additionally, in SA both high energy pedestrian vehicle accidents (PVA) and gunshot wounds (GSWs) are common mechanisms for fracture of the tibia, and both cause significant soft tissue injury.^(29, 30) Early fracture stabilisation is important for soft tissue healing and the prevention of wound sepsis.⁽³¹⁾ Historically this was achieved with a plaster cast after debridement, but that method was associated with a high risk of wound sepsis and malunion.⁽³¹⁾ Various methods of surgical fixation have been trialled, with internal plate fixation generally not recommended due to the increased periosteal stripping and consequent increased risk of non-union and wound sepsis,⁽²⁰⁾ although this method is being revisited with the advent of modern minimally invasive plate osteosynthesis (MIPO) techniques.^(15, 32, 33)

External fixation then became the treatment of choice for open fractures as it allows for rapid fracture stabilisation, leaves the wound area open for wound care and dressings, and does not further damage the soft tissues at the wound site.⁽³¹⁾ However, external fixation also has many complications, mainly pin tract sepsis and loosening of pins, as well as delayed or non-union.⁽³¹⁾ Some of these hardware complications can be avoided by exchanging the external fixator for an intramedullary nail but this is still associated with a high risk of osteomyelitis at the pin sites.⁽³¹⁾ Thus interest in immediate definitive fixation with intramedullary nailing has grown.⁽²⁰⁾ Hilton *et al.* performed a retrospective review of tibial nails done for GSWs at a South African institution and concluded that low Gustilo-Anderson grade gunshot injuries can be effectively treated by immediate intramedullary tibial nail with few complications.⁽²⁹⁾

Unfortunately, this study had small patient numbers, and only a 59% follow-up rate, so it is possible that some complications were missed.⁽²⁹⁾

Howard *et al.* conducted a study in Kwa-Zulu Natal to establish whether HIV positive patients are at higher risk for wound sepsis following an open fracture of the tibia, and they concluded that the risk is the same as for HIV negative patients.⁽³⁴⁾

Phaff *et al.* examined the question of whether orthopaedic implants for open fractures are more risky for delayed infection in the HIV positive population in SA and concluded HIV positive patients do not have a higher risk of delayed deep infection and that routine hardware removal is not needed.⁽³⁰⁾

1.2.6 Challenges particular to proximal tibial fractures

Extra-articular fractures of the proximal tibia have a high risk of displacement when treated with tibial nails.⁽³⁵⁾ This is due to the bony anatomy as well as the pull of muscle attachments on the proximal tibia.⁽³⁶⁾ The wide metaphyseal area tapers into the canal which is slightly lateral to the midpoint of the tibial plateau. This wide proximal area allows the proximal fragment to rotate about the nail, as it does not fill the canal as it does more distally in the shaft. The pull of the patellar tendon tends to displace the fragment into procurvatum, particularly when the knee is flexed beyond ninety degrees as it is in a typical infrapatellar approach to the tibia.⁽³⁷⁾ Likewise, the pull of the pes anserinus on the medial side of the proximal tibia tends to pull the fragment medially, displacing the fracture into valgus.⁽³⁶⁾ These displacing forces may interfere with fracture reduction, as well as improper canal preparation and consequent malalignment once the nail is inserted.⁽³⁶⁾

In order to avoid these problems one can use a plate and screw construct to fix the fracture instead of an intramedullary nail. These two methods were compared in a retrospective study by Lindvall *et al.* and they found that procurvatum deformities were common in both groups. They found that additional surgical techniques were frequently needed in the intramedullary nail group, while problematic hardware requiring removal was more common in the plating group.⁽¹⁸⁾ However, this study had small numbers and was a case control study, not a prospective trial. Mueller *et al.* assessed the biomechanical stability of intramedullary nails *versus* plates in the proximal tibia in a cadaveric study, and found that centrally placed nails tolerated

higher loads without bony deformity than the eccentrically placed plates.⁽³⁸⁾ As in the Fairbank *et al.* study above, they compared the two interventions in the two matched tibiae of the individual cadaver specimens.⁽³⁸⁾

Use of a suprapatellar entry portal is advantageous in proximal tibial fractures as it allows the nail to be inserted with the knee in a semi-extended position, thus relaxing the pull of the patellar tendon on the proximal fragment.⁽³⁵⁾ Chan *et al.* performed a prospective study to compare suprapatellar *versus* infrapatellar nails and showed that outcomes in terms of knee pain and range of motion were equal between the two different entry portals.⁽³⁹⁾ Although this was a small study, it was prospective and did not find evidence to support the theoretical concern that nail insertion through the knee joint would lead to an increased incidence of post-operative knee pain.⁽³⁹⁾

A valgus deformity can be avoided by careful attention to the entry point on the tibial plateau, ensuring that it is not too medial,⁽³⁷⁾ or by using Poller blocking screws to narrow the effective canal width and prevent the fragment from tilting to one side.⁽⁴⁰⁾ However, this technique must be used with caution in osteoporotic bone and with GSWs as considerable force is exerted on the screws during nail insertion which may cause further fractures or propagation of occult fracture lines.⁽³⁶⁾

1.2.7 Challenges particular to distal tibial fractures

Zelle *et al.* published a systematic review of 16 studies with a total of 1,125 distal third tibia fractures without articular involvement.⁽⁴¹⁾ This review focused on the outcomes of different treatment modalities, including intramedullary nailing *versus* plating, and suggested that rates of non-union and malalignment are similar between the two treatment methods.⁽⁴¹⁾ However, they identified concerns about using tibial nails to treat distal tibia fractures because of the difference in diameter between the diaphysis and the metaphysis creating a greater risk for malalignment, as well as the risk of propagating a distal tibia fracture into the ankle joint.⁽⁴¹⁾

Other treatment modalities they examined for proximal and distal fractures include internal fixation with plates and screws, external fixation or non-surgical treatment using casts or braces. However, rates of non- and malunion are higher for non-surgical treatment of tibia fractures.⁽⁴¹⁾ A weakness of this systematic review is that the majority

of the included studies were case series, and had no direct comparison between different treatment modalities.

Vallier *et al.* published a randomised, prospective comparison of plate *versus* intramedullary nail fixation for distal tibia shaft fractures.⁽¹⁷⁾ Their study included 104 patients who presented to a level one trauma centre with extra-articular distal tibia fractures, who were then randomised to receive either an intramedullary nail or a large fragment medial plate. In their study they standardised the nailing technique to a patellar splitting approach and the use of two distal interlocking screws.⁽¹⁷⁾ They found similar rates of infection, non-union and a need for revision procedures between the two groups, with the biggest risk factor for both outcomes being an open fracture at the initial presentation. However, rates of malalignment were higher in the intramedullary nail group at 23.0% *versus* 8.3%, although both groups had higher rates of malunion in the presence of open fractures.⁽¹⁷⁾

They noted that fibula plating at the time of intramedullary nailing was associated with a lower risk of malalignment of the tibia, but there was a trend towards a non-union in the presence of fibula plating. However, 85% of the patients who had received intramedullary nails had not had fixation of their concomitant fibula fractures, making it difficult to draw any firm conclusions regarding fibula plating from this study as the numbers were small.⁽¹⁷⁾

Githens *et al.* subsequently performed a retrospective matched cohort study at a single level one trauma centre to examine this issue.⁽¹⁶⁾ They included 166 patients who had received intramedullary nails along with concomitant fibular plates, and matched them to 174 patients who had received intramedullary nails alone. They found no difference in time-to-union when the fibula was plated at the same time as tibia fracture fixation *versus* patients who had no fibular fixation.⁽¹⁶⁾ This indicates that concomitant fibular plating may be a useful technique for increasing the accuracy of reduction of distal tibia fractures.

There are numerous other adjunctive techniques described to aid in getting an acceptable reduction, such as the use of pointed reduction clamps or unicortical plates to hold the reduction while the nail is being placed.⁽¹⁴⁾ Likewise, Poller blocking screws

can be used to narrow the effective size of the canal and thus aid in correcting translation and angulation. Poller blocking screws have also been shown to increase the mechanical stability of the construct and thus reduce the chances of late loss of reduction in metaphyseal areas.⁽⁴²⁾

1.2.8 Measurement of angles on radiographs

Freedman and Johnson published a study assessing malalignment following tibial nail insertion.⁽⁹⁾ They used lines drawn perpendicular to the joint surface to determine the axis of the bone.⁽⁹⁾ However, this approach has its drawbacks as the radiographs may not have been taken perfectly perpendicular to the joint and the tibial plateau is not perpendicular to the tibial shaft.⁽⁴⁾ Modern software tools allow for more sophisticated measurement of digital radiographs, such as IMATRI (imatri Medical – Johannesburg, South Africa).⁽⁴³⁾ IMATRI software uses circles placed in such a way that their curve is tangential to the outer cortex of the bone. The centre of the circle then falls on the centre of the bone. Joining two such centres produces a line down the central anatomical axis of the bone.⁽⁴³⁾ This allows for accurate measurement of the angle formed between the two axes of the fragments.⁽⁴³⁾

1.2.9 The effects of surgeon experience and time of day

At CMJAH most intramedullary nails of the tibia are done on the orthopaedic emergency theatre list. This list is performed by registrars and medical officers who can request consultant assistance if necessary; additionally, many of these surgeries are done after hours and without a surgical assistant. No previous analysis has been done to establish whether intramedullary nails are being performed to an adequate standard under these circumstances.

There is evidence from the general surgery literature that suggests that surgeries performed after hours are associated with a higher risk of complications than when done during normal day time hours.⁽⁴⁴⁾ However, there are few studies available that examine this issue in an orthopaedic context.⁽⁴⁵⁾

Bosma *et al.* performed a retrospective study looking at complications of pertrochanteric fractures in relation to the time of day of surgery. They did not find any significant differences; however, their hospital set-up is different from ours, with all surgeries being performed, or directly supervised, by a super-specialist orthopaedic trauma surgeon, regardless of the time of day.⁽⁴⁶⁾ In addition, the co-morbidities common in patients with pertrochanteric fractures may mean that the benefits of urgent fracture fixation and mobilisation outweigh the negatives of late night surgery.⁽⁴⁶⁾

Williams *et al.* included an analysis of surgeon experience and time of day in their study of complications of tibial nailing, and did not find any significant difference between the surgeries performed by registrars and those performed by consultants.⁽¹³⁾ They also quote a mean surgery time of 120 minutes, with no difference in time usage between surgeries done during the day *versus* those done after hours.⁽¹³⁾ Likewise, Gaebler *et al.* did not find any difference in technical complications between those procedures performed by a registrar *versus* those performed by a consultant.⁽²⁸⁾ Guo *et al.* included an analysis of theatre time consumption in their article comparing IMN with MIPO, and concluded that IMN was statistically significantly quicker, although they did not include any information regarding the time of day the surgery took place, or the level of experience of the surgeon performing the surgery.⁽³³⁾

Larsen *et al.* examined this issue in relation to outcomes after tibial nailing. They found no difference in long term outcome when comparing patients operated on during the day *versus* at night, or patients operated on by specialists *versus* trainees.⁽⁴⁵⁾ They did note a 25% increase in length of hospital stay when patients were operated on by a trainee at night compared with during the day. This relationship was reversed for specialists but they noted that in their hospital particularly complex cases are kept until day time and are done by a specialist, which explains why those patients require a longer hospital stay.⁽⁴⁵⁾ Again, their definition of a specialist is a super-specialised orthopaedic trauma surgeon with five years of experience in orthopaedic trauma, with the trainee group consisting of both residents and orthopaedic specialists who have not completed trauma super-specialisation.⁽⁴⁵⁾ Thus, this study is not directly applicable to our setting as our trainee group includes surgeons who may be less experienced than those included in the trainee group in this study.

1.2.10 Theatre time usage for emergency orthopaedic cases

Operating theatre inefficiency is a global concern and is particularly relevant in single payer healthcare systems such as we have in the state sector in SA, as theatres consume a large percentage of hospital budgets.⁽⁴⁷⁾

Inefficient use of theatre time is commonly related to four factors, namely a delayed starting time, long turnaround times between cases, prolonged time taken transferring patients from the ward to the operating suite and procedures taking longer than planned.^(47, 48)

This is relevant as inefficient time usage leads to cases being cancelled⁽⁴⁸⁾, and a prolonged waiting time for patients needing surgery. Although tibial fractures are emergency procedures, the emergency list is frequently long, and patients may wait several days for their surgery. A better understanding of the time needed to complete the procedure should allow for better list planning and more efficient use of theatre time to minimise patient waiting times and theatre costs.⁽⁴⁷⁾

1.3 Study aim and objectives

The aim of this study was to assess the treatment of tibial fractures with intramedullary nails at Charlotte Maxeke Johannesburg Academic Hospital (CMJAH).

Specific objectives were to:

1. Analyse the adequacy of reduction of tibial fractures as performed at CMJAH.
2. Identify factors correlated with poor reductions
3. Identify possible causes of early loss of reduction.

Chapter 2

2. Methodology

2.1 Research Question

Are tibial fractures being treated appropriately with intramedullary nails at Charlotte Maxeke Johannesburg Academic Hospital (CMJAH), with adequate reductions that do not undergo early loss of reduction?

2.2 Research Design

This was a retrospective record and radiograph review of patients treated surgically for tibial shaft fractures at CMJAH – a large level one trauma centre located in Johannesburg.

2.3 Materials and Methods

Ethics approval was obtained from the University of the Witwatersrand's Human Research Ethics Committee (HREC)(Medical) prior to data collection (refer to Appendix A). Permission to conduct the study was obtained from the hospital's CEO (refer to Appendix B). Each patient was assigned a study number to maintain patient anonymity and confidentiality

Digital images of the radiographs of patients who met the entry criteria were retrieved from the hospital's Picture Archiving and Communication System (PACS), and their hospital files were reviewed.

These images were then measured using IMATRI software to establish whether the reductions were acceptable, as per the following criteria:

1. Varus/valgus < 5°
2. Procurvatum/recurvatum < 5°
3. Rotation < 10°
4. Shortening < 1 cm ⁽¹³⁻¹⁸⁾

A subset of 30 of the included radiographs was independently analysed by a qualified consultant surgeon. No significant differences in measurements were found between those taken by the principal researcher and the consultant surgeon.

2.4 Sample

The sample was chosen from all the adult patients who had received a tibial nail for the treatment of a midshaft tibial fracture over a two-year period from 01 April 2016 to 31 March 2018. These patients were identified by reviewing theatre registers for the study time period. The selection criteria are given below.

Inclusion Criteria:

1. Skeletally mature patients, 16 years of age and older, treated with intramedullary nailing of the tibia
2. Adequate pre- and post-operative radiographs available on the PACS
3. At least one follow-up radiograph taken at least six weeks post-surgery available on the PACS
4. All patterns of shaft fracture were included, provided the initial treatment was with an intramedullary nail

Exclusion criteria:

1. Patients with intra-articular fractures
2. Patients who underwent exchange nailing after an initial treatment with external fixation
3. Patients with previous fractures of the tibia

2.5 Data Collection

A retrospective review of files and radiographs was conducted from the database of patients identified according to the above criteria. A total of 274 patients were evaluated for inclusion in the study, 17 were excluded due to a complete lack of radiographs being available on the PACS, with a further 23 missing immediate post-operative radiographs, and 71 missing follow-up radiographs. One other patient was excluded as his/her tibial nail was done as a delayed procedure following failed conservative treatment.

A total of 162 patients with 167 tibial nails were found to meet the criteria for inclusion in the study. Their hospital files were then retrieved from the hospital records department and reviewed to collect their age and gender. Information relating to the injury was recorded, the mechanism of injury, as well as the Gustilo and Anderson classification of the soft tissue component of the injury. The details of the surgery were recorded, the experience of the primary surgeon, expressed as their year of registrar study, the time of day at which the surgery occurred, as well as the duration of the surgery and whether this was a single surgery or part of multiple surgeries performed at one sitting. An example of the data collection sheet is attached (refer to Appendix C).

The radiographs were then reviewed, and the fracture pattern was classified according to the AO classification, as well as whether the fracture fell into the proximal, middle, or distal third of the tibia. A further four patients were excluded at this point due to their radiographs being unsuitable for measurement.

Post-operative alignment was measured using IMATRI software and the adequacy of reduction was assessed, according to the criteria detailed above.

The number of distal interlocking screws was recorded, as well as whether or not the fibula was plated during the same surgery. The diameter of the nail recorded in the operative notes was used to set the scale for measurement in the software. The size of the canal at its narrowest point was measured on the digital radiographs and the ratio of nail to canal size was calculated.

Each patient had four radiograph images measured using IMATRI software, initial post-operative images and follow-up images taken at least six weeks post-operatively. An antero-posterior and a lateral image was evaluated at each time point.

On the antero-posterior image we measured angulation in the coronal plane, and on the lateral image we measured angulation in the sagittal plane. Shortening was measured on both images and the greatest amount of shortening was recorded. These measurements were taken twice, once on the immediate post-operative images and again on the follow-up images. An example of the radiograph data collection sheet is attached (refer to Appendix D).

2.6 Data Analysis

The data were captured using Microsoft Excel and analysed using Stata version 15 software. Overall, patient characteristics were described using frequencies and percentages for categorical variables and are presented in the Results chapter. Mean and standard deviation were used to describe normally distributed numeric variables, while median and interquartile range were used to describe non-normal data.

Using a correlation matrix, we explored the correlation of numeric variables with the following outcome variables: shortening post-operatively and at follow-up, valgus/varus post-operatively and at follow-up, and procurvatum/recurvatum post-operatively and at follow-up. We used a Bonferroni correction to adjust for multiple-comparison error within the correlation matrix.

We used the Student's T-test and analysis of variance (ANOVA) as appropriate, to explore the relationship between categorical variables with the outcome variables listed above. The Student's T-test was used for categorical variables with only two categories and ANOVA was used for categorical variables with three or more categories. For variables that were not normally distributed, the Kruskal-Wallis test was used to compare categorical variables and outcome variables, and the median and interquartile range were reported instead of the mean and standard deviation.

Alignment was defined as varus/valgus $< 5^{\circ}$ and procurvatum/recurvatum $< 5^{\circ}$. The rotation criterion was not used as this was not measured in the study. Alignment was also described using frequencies and percentages. We explored associations

between loss of reduction (varus/valgus $> 5^\circ$ and procurvatum/recurvatum $> 5^\circ$) and patient characteristics using Fisher's exact tests. A p-value of < 0.05 was considered to be statistically significant.

Chapter 3

3. Results

3.1 Demographics

In total we had 158 patients with 163 tibia fractures who met the inclusion criteria for the study. There was a male preponderance with 124 males (78.48%) and 34 females (21.51%). Polytrauma patients made up 48 (30.38%) of the cases, with the remaining 110 (69.62%) being isolated single tibia injuries.

The age range of the patients was from 16 to 71 years of age with the majority of patients being young adults, 128 (81.01%) at, or under, 40 years of age.

A large number of the admissions took place over the weekend, with 22 (13.92%) on Fridays, 32 (20.25%) on Saturdays and 31 (19.62%) on Sundays. The remaining weekdays accounted for 73 (46.20%) of the total admissions with an average of 18.25 (11.55%) daily.

Table 3.1: Demographic Data of patient sample

Demographic		
Characteristic	Mean (SD)	N (%)
Age	32 years (27 – 39)	
Sex		
Male		124 (78.48%)
Female		34 (21.51%)
Side		
Left		84 (51.53%)
Right		79 (48.47%)
Polytrauma		
Yes		48 (30.38%)
No		110 (69.62%)

3.1.1 Mechanisms of injury

The most common mechanism of injury was motorised vehicle accidents (MVAs) (64.15%), with pedestrian vehicle accidents (PVAs) forming the largest group (79, 49.69%), followed by car accidents (15, 9.43%), and motorbike accidents (MBAs) (8, 5.3%).

Interpersonal violence accounted for a further 15.09% of fractures, including gunshot wounds (9, 5.66%) and assault (15, 9.43%).

The remainder of the injuries were caused by falls from a height (17, 10.69%), soccer injuries (12, 7.55%) and a blunt object falling on the patient (2, 1.25%).

There were 84 fractures in the left tibia (51.53%) and 79 fractures in the right tibia (48.47%).

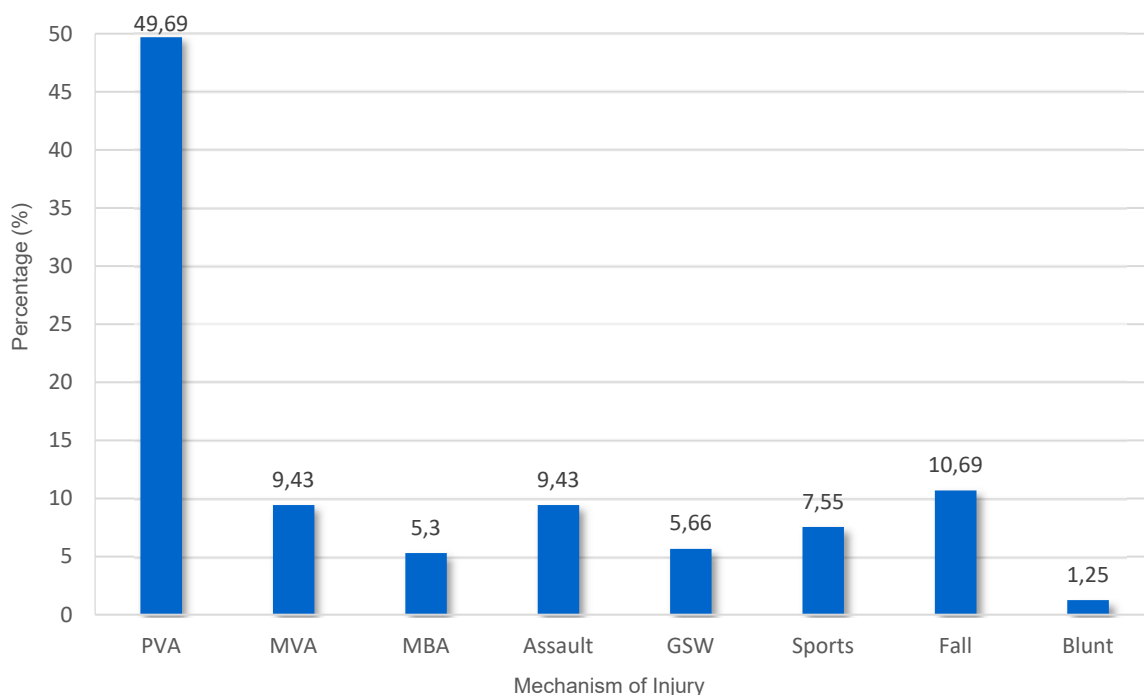


Figure 3.1: Mechanism of Injury

3.2 Injury characteristics

The majority of fractures were closed injuries (97, 59.50%). Of the 66 open fractures, 25 were Gustilo and Anderson (GA) type 1 open fractures (37.88%), 26 were GA type 2 open fractures (39.39 %), 14 were GA type 3A open fractures (21.21%), and 1 was a GA type 3B open fracture (1.52%). There were no GA type 3C fractures that were treated primarily with an intramedullary nail.

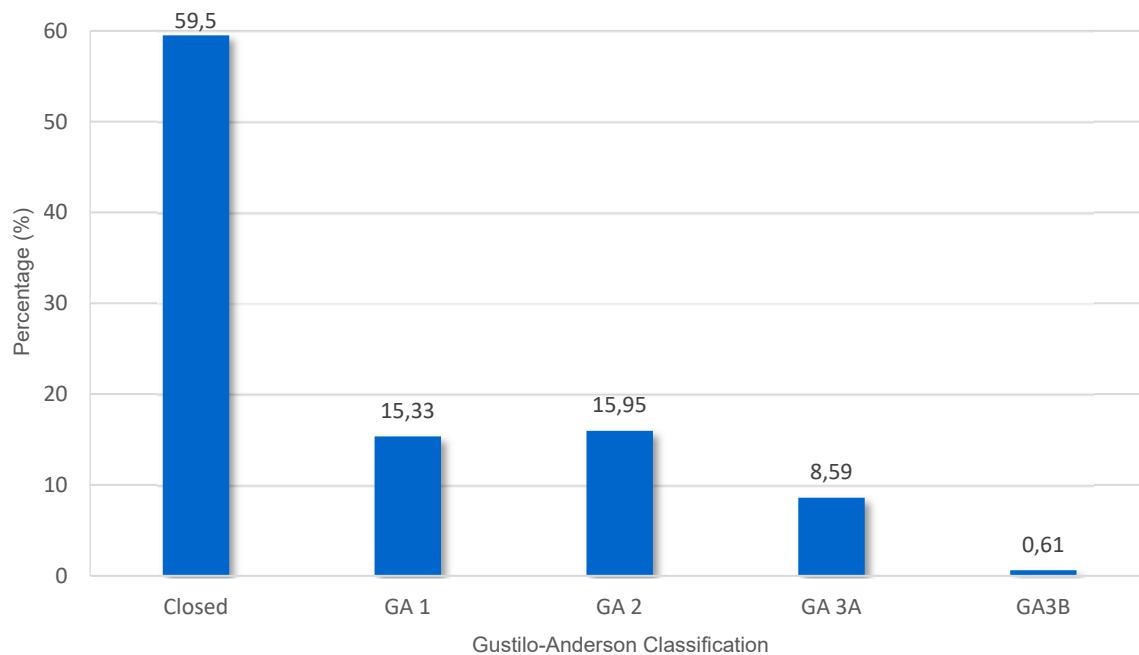


Figure 3.2: *Distribution of soft tissue injury as classified by Gustilo-Anderson*

When assessing the fracture patterns, we found that the majority of the fractures were in the midshaft (67, 41.10%) and midshaft to distal junction (41, 25.15%). Distal fractures made up 32 (19.63%) of the cases, with the remainder being proximal to midshaft junction (7, 4.29%), proximal (1, 0.61%) and segmental (15, 9.20%).

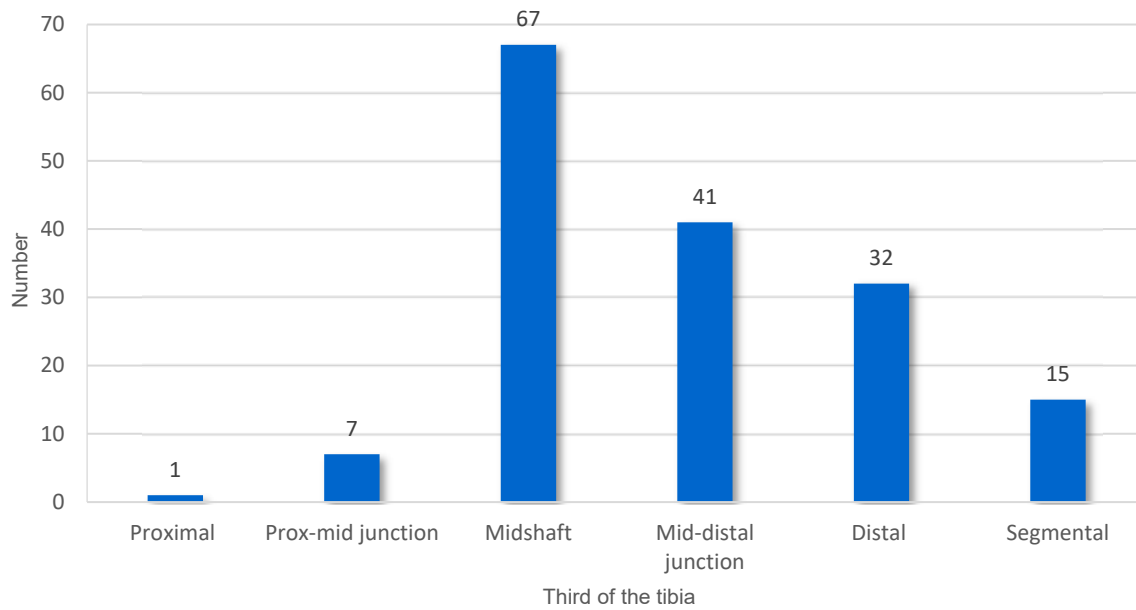


Figure 3.3: Distribution of fractures in thirds of the tibia

The most common fracture pattern as classified by the AO foundation was a 42-B2-b (31, 18.34%) followed by a 42-A3-b (30, 17.75%).

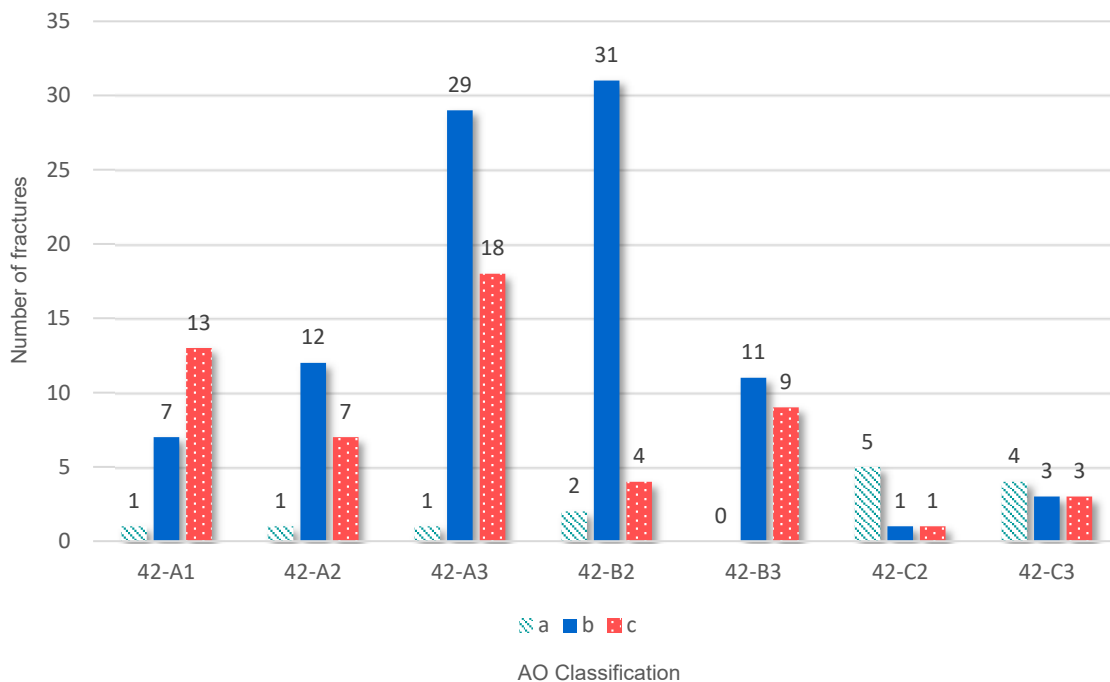


Figure 3.4: Distribution of fracture patterns as classified by the AO system

3.3 Characteristics of surgical procedure

The majority of the surgeries were single leg tibial nails 125 (76.22%). Six patients had bilateral tibial nails done (3.66%). There was a range of other orthopaedic procedures performed concurrently with a tibial nail, including intra-medullary nailing of the femur (7), insertion of a Steinmann pin into the femur (4), open reduction and internal fixation (ORIF) of the ankle (5), ORIF of an upper limb fracture (7), external fixation of the opposite tibia (2) and debridement of wounds not located on the injured leg (3). There were two patients who underwent a laparotomy by the trauma surgical team and who then had intramedullary nailing of the tibia at the same sitting.

As this was a retrospective review, the surgical implant used was not standardised. However, in 128 (78.05%) of the cases the Trigen Meta-Nail (Smith and Nephew) was used, in 11 (6.71%) the T2 Tibial Nail (Stryker) was used, in 3 (1.83%) the Expert T.N. Tibial Nail (Synthes) was used and in 22 (13.41%) the implant used could not be determined from the notes.

Table 3.2: Summary of treatment features

Treatment feature	Mean (SD)
Nail diameter	10.00 mm (10.00 – 10.00)
Diameter of canal on AP view	12.93 mm (11.83 – 14.48)
Diameter of canal on lateral view	12.86 mm (11.90 – 14.52)
Average canal diameter	12.98 mm (11.94 – 14.47)

3.3.1 Use of adjuncts

There were only six (18.75%) of 32 distal third cases in which fibular plating was done. Only one surgeon made use of Poller screws in one case. It was not possible to determine from the notes whether other adjunctive techniques such as the use of pointed reduction clamps were used, as these were not documented. Of the fractures involving the proximal third of the tibia, 5 (26.32%) were done with a standard nailing

technique and 11 (57.89%) were done with a suprapatellar entry technique. There were 3 cases (15.79%) where the entry technique was not documented.

3.4 Time Usage and time of day

The average total theatre time for an isolated tibia case was 151.11 minutes (80 – 260). The total time for polytrauma patients varies widely due to the number and variety of procedures performed concurrently, as described above (120 – 625).

The average tourniquet time, which approximates operating time, for an isolated tibia case was 88.22 minutes (45 – 155). However, the average tourniquet time for tibial nails done as part of a polytrauma surgery was 101.26 minutes (60 – 130), which is 13.04 minutes longer than the time taken for an isolated tibia case. This was statistically significant ($p < 0.001$). The average time used for anaesthesia and positioning was 62.59 minutes (15 – 140).

The time taken to complete the surgery varied by year of surgeon experience, and this was statistically significant ($p = 0.033$). Medical officers took, on average, 101.44 minutes (60 – 155), first year registrars took an average of 91.54 minutes (45 – 130), and second year registrars took an average of 80.50 minutes (45 – 150). The average time climbed again after the second year of training, with third year registrars taking an average of 85.00 minutes (60 – 145) and fourth year registrars taking an average of 88.40 minutes (50 – 160).

There were no significant differences in the time taken between male and female surgeons at the same level of experience.

There was a statistically significantly longer time taken when the procedure was done with an assistant surgeon *versus* when it was done alone with a single surgeon ($p = 0.029$). Overall, 45.28% of the surgeries were done during daytime hours (07:00 – 16:00) and 54.71% were done outside of these hours. Of the daytime surgeries, 59.72% were done with an assistant, and 40.28% were done with no assistant. Of the after-hours surgeries, 43.68% were done with an assistant and 56.32% were done without an assistant. There was no statistically significant difference in the time taken between daytime surgeries and after-hours surgeries of the same type.

Table 3.3: Time utilisation breakdown

Time Utilisation			
By Year of study	Minutes	Range	p-value
Medical officer	101.44	60 - 155	0.033
Year 1	91.54	45 - 130	
Year 2	80.50	45 - 150	
Year 3	85.00	60 - 145	
Year 4	88.40	50 - 160	
Consultant	102.30	80 - 125	
Single vs multiple			
Single tibia	88.22	45 - 155	<0.001
Multiple surgeries	101.26	60 - 130	
Assistant			
Yes	98.34	45 - 210	0.029
No	84.06	45 - 145	
Day vs After Hours			
Day overall	94.04	45 - 155	0.166
After hours overall	90.10	50 - 210	
Day single tibia	92.30	45 - 155	
After hours single tibia	83.20	50 - 145	
Day polytrauma	103.08	75 - 130	
After hours polytrauma	103.45	60 - 130	
Gender of surgeon			
Male	90.14	45 - 155	0.873
Female	91.18	45 - 140	

3.5 Adequacy of reduction

We analysed the adequacy of the reduction at two time points, immediately post-operatively and at follow-up according to the criteria outlined above. Unless all three

of the measurable criteria were met, the reduction was deemed to be inadequate. Overall, 52 (31.90%) patients were found to have inadequate reductions at any time point, 37 (22.70%) at their initial post-operative measurements and 46 (28.22%) at their follow-up measurements.

Table 3.4: Adequacy of Reduction

Characteristic	N (%)
Alignment post-operatively	
Acceptable	126 (77.30)
Unacceptable	37 (22.70)
Alignment at follow-up	N (%)
Acceptable	117 (71.78)
Unacceptable	46 (28.22)

Of the patients who had unacceptable alignment at their initial post-operative measurements, 31 remained unacceptable at follow-up. An additional 15 (9.20%) patients who had initially had an acceptable alignment had lost position such that they were unacceptable at follow-up.

At the initial post-operative measurement, 22 (13.50%) patients had procurvatum $> 5^{\circ}$, 4 (2.45%) had recurvatum $> 5^{\circ}$, 4 (2.45%) had varus malalignment $> 5^{\circ}$, 8 (4.91%) had valgus malalignment $> 5^{\circ}$, 4 (2.45%) had shortening > 1 cm, and 1 (0.61%) had distraction > 1 cm. There were 7 (4.29%) patients who had malalignment in two categories, and no patients with malalignment in three categories.

Of the 6 patients whose position improved, 3 had procurvatum deformities which were $< 5^{\circ}$ at follow-up, 2 had recurvatum deformities that were $< 5^{\circ}$ at follow-up and 1 had a valgus deformity that was $< 5^{\circ}$ at follow-up.

At the follow-up measurement, 27 (16.56%) patients had procurvatum $> 5^{\circ}$, 3 (1.84%) had recurvatum $> 5^{\circ}$, 4 (2.45%) had varus malalignment $> 5^{\circ}$, 13 (7.98%) had valgus malalignment $> 5^{\circ}$, 5 (3.07%) had shortening > 1 cm, and 1 (0.61%) had distraction > 1 cm. There were 8 (4.91%) patients who had malalignment in two categories, and no patients with malalignment in three categories.

Table 3.5: Breakdown of malalignment by type

	Post-operative N (%) Total = 37	Follow-up N (%) Total = 46
Sagittal plane	26 (70.27)	30 (65.22)
Procurvatum	22 (59.46)	27 (58.70)
Recurvatum	4 (10.41)	3 (6.52)
Coronal plane	8 (21.62)	7 (15.22)
Varus	4 (10.41)	4 (8.70)
Valgus	8 (21.62)	13 (28.26)
Axial plane	12 (32.43)	17 (36.96)
Shortening	4 (10.81)	5 (10.87)
Distraction	1 (2.70)	1 (2.17)
Multiple planes	7 (18.92)	8 (17.39)
2 planes	7 (18.92)	8 (17.39)
3 planes	0 (0.00)	0 (0.00)

There were three patients who had revision procedures post the index procedure. The patient with unacceptable distraction was revised to close the fracture gap, one patient was revised to plate their distal fibula fracture because although their tibial alignment was acceptable, there was a concern for ankle stability, and one patient was revised to replace a prominent interlocking screw. None of the other patients with radiographically unacceptable alignment were revised during the course of this study.

Table 3.6: *Characteristics of patients with unacceptable reductions post-operatively*

Age	Time of day	Surgeon experience	Gustilo Anderson	Third	AO	Deformity
25	Day	Y3	Closed	Segmental	42-C2-i	5.22 pro
24	Day	Y2	Closed	Segmental	42-C2-i	9.95 pro
71	AH	Y4	GA 3B	Distal	42-A3-c	9.64 pro
35	AH	MO	Closed	Middle	42-A1-b	6.00 pro
34	AH	Y2	Closed	Middle	42-B2-b	6.3 pro
38	Day	Y4	GA 2	Distal	42-B3-c	6.75 pro
59	Day	Y2	Closed	Segmental	42-C3-k	10.9 mm short
36	Day	Y3	GA 1	Middle	42-B3-b	5.98 pro
31	Day	Y3	Closed	Middle	42-B2-b	5.85 pro
29	Day	Y3	GA 1	Middle	42-A2-b	5.06 pro
67	AH	Y4	Closed	Middle	42-B2-b	5.67 val
60	AH	Y3	Closed	Segmental	42-C3-i	8.38 val
32	AH	Y1	GA 1	Distal	42-B3-c	5.80 rec, 11.62 short
34	Day	MO	Closed	Distal	42-A1-c	6.12 var
40	Day	Y1	GA 2	Distal	42-A3-c	9.76 rec
33	AH	MO	Closed	Distal	42-A2-c	5.22 val
35	Day	MO	GA 1	Middle	42-B2-b	5.68 pro
36	Day	Y1	GA 2	Middle	42-A2-b	8.15 pro
29	AH	Y3	GA 3A	Segmental	42-C3-i	5.06 var
26	Day	MO	GA 2	Middle	42-A3-b	5.44 pro
27	AH	Y3	GA 3A	Middle	42-B3-b	7.66 var, 11.73 short
21	Day	MO	GA 2	Distal	42-B3-c	12.03 distraction
36	Day	Y1	GA 2	Distal	42-A3-c	7.30 pro, 7.60 val
28	AH	Y2	Closed	Mid-distal	42-B2-b	5.19 pro
27	Day	Y2	Closed	Segmental	42-C2-i	5.01 pro

54	Day	Y1	GA 2	Middle	42-B2-b	5.19 pro
17	Day	Y1	Closed	Segmental	42-C2-i	8.53 pro
23	Day	Y1	Closed	Middle	42-A3-b	5.38 pro
28	Day	Y4	Closed	Segmental	42-C3-i	11.36 pro
19	Day	Y1	Closed	Middle	42-B3-b	6.05 pro
28	AH	Y1	Closed	Proximal	42-A2-a	5.62 rec, 8.85 val
36	Day	MO	Closed	Segmental	42-C2-i	6.29 pro
33	AH	Y4	Closed	Distal	42-B2-c	5.70 var
32	Day	Y1	Closed	Mid-distal	42-A1-c	9.57 val
22	Day	Y1	GA 1	Middle	42-B2-b	5.73 pro
29	Day	Y2	GA 1	Mid-distal	42-A3-c	6.13 rec, 5.74 val
39	Day	Y1	Closed	Middle	42-B2-b	5.77 val

Abbreviations: pro = procurvatum; rec = recurvatum; var = varus; val = valgus

Table 3.7: Characteristics of patients with unacceptable reductions post-operatively

Age	Time of day	Surgeon experience	Gustilo Anderson	Third	AO	Deformity
25	Day	Y3	Closed	Segmental	42-C2-i	5.28 pro
31	AH	Y1	GA 1	Distal	42-B3-c	7.81 pro
32	Day	MO	Closed	Prox-mid	42-A2-b	11.69 pro
24	Day	Y2	Closed	Segmental	42-C2-i	12.11 pro, 5.37 val
71	AH	Y4	GA 3B	Distal	42-A3-c	10.33 pro
42	AH	Y1	Closed	Mid-distal	42-A3-c	5.95 pro
34	AH	Y2	Closed	Middle	42-B2-b	6.32 pro, 5.20 val
38	Day	Y4	GA 2	Distal	42-B3-c	8.18 pro
59	Day	Y2	Closed	Segmental	42-C3-k	11.28 short
34	Day	Y1	GA 3A	Mid-distal	42-B3-c	11.76 short
36	Day	Y3	GA 1	Middle	42-B3-b	6.12 pro
31	Day	Y3	Closed	Middle	42-B2-b	6.13 pro
29	Day	Y3	GA 1	Middle	42-A2-b	5.01 pro
67	AH	Y4	Closed	Middle	42-B2-b	5.10 pro, 6.78 val
32	AH	Y1	Closed	Middle	42-B2-b	6.17 val
33	Day	MO	Closed	Distal	42-A1-c	5.62 rec
60	AH	Y3	Closed	Segmental	42-C3-i	6.32 val
32	AH	Y1	GA 1	Distal	42-B3-c	5.27 rec, 12.01 short
34	Day	MO	Closed	Distal	42-A1-c	7.63 var, 11.49 short
40	Day	Y1	GA 2	Distal	42-A3-c	6.79 rec
35	Day	MO	GA 1	Middle	42-B2-b	5.58 pro
36	Day	Y1	GA 2	Middle	42-A2-b	8.85 pro
29	AH	Y3	GA 3A	Segmental	42-C3-i	5.03 var
26	Day	MO	GA 2	Middle	42-A3-b	6.18 pro

27	AH	Y3	GA 3A	Middle	42-B3-b	10.54 var, 11.38 short
21	Day	MO	GA 2	Distal	42-B3-c	5.67 var, 12.86 dist
36	Day	Y1	GA 2	Distal	42-A3-c	9.09 pro, 9.15 val
28	AH	Y2	Closed	Mid-distal	42-B2-b	5.68 pro
31	Day	Y2	GA 2	Prox-mid	42-A3-a	5.52 val
27	Day	Y2	Closed	Segmental	42-C2-i	9.38 val
54	AH	Y2	GA 2	Distal	42-A2-c	5.41 pro
45	Day	Y4	Closed	Distal	42-A2-c	5.69 var
17	Day	Y1	Closed	Segmental	42-C2-i	9.40 pro
23	Day	Y1	Closed	Middle	42-A3-b	5.81 pro
28	Day	Y4	Closed	Segmental	42-C3-i	11.55 pro
25	AH	Y4	Closed	Middle	42-A3-b	5.28 pro
19	Day	Y1	Closed	Middle	42-B3-b	6.65 pro
33	AH	Y4	Closed	Distal	42-B2-c	5.43 pro
30	Day	Y3	Closed	Distal	42-B3-c	5.68 val
32	Day	Y1	Closed	Mid-distal	42-A1-c	7.93 val
54	Day	Y3	Closed	Distal	42-A1-c	5.38 var
33	Day	Y1	Closed	Middle	42-B3-b	6.64 pro
22	Day	Y1	GA 1	Middle	42-B2-b	6.67 pro
31	AH	Y3	GA 3A	Segmental	42-C3-k	6.79 pro
38	AH	Y2	GA 1	Distal	42-A3-c	5.38 val
39	Day	Y1	Closed	Middle	42-B2-b	5.19 val

Abbreviations: pro = procurvatum; rec = recurvatum; var = varus; val = valgus

Using the correlation matrix (refer to Table 3.4), we found that the number of proximal screws was weakly associated with procurvatum/recurvatum post-operatively ($r = 0.32$, $p = 0.003$). There were no associations between all other numerical variables in the matrix with the outcome variables.

Table 3.8: Pairwise Correlations with Outcome Variables

	Age	Distal screws	Proximal Screws	Nail diameter	AVG diameter	Fibula Plate	Poller screws	Theatre start time	Cu
Shortening at follow-up	0.20	0.04	0.20	0.09	0.15	0.00	0.00	0.05	-0.
Varus/valgus postop	0.03	0.01	-0.01	-0.01	0.14	-0.04	0.01	0.0392	-0.
Procurvatum Recurvatum postop	-0.08	-0.06	0.32*	0.16	0.20	-0.12	-0.04	-0.1843	-0.
Varus/valgus at follow-up	0.09	0.05	0.13	0.12	0.18	-0.02	0.02	-0.0873	-0.
Procurvatum Recurvatum at follow-up	0.01	0.05	0.25	0.10	0.14	-0.13	-0.05	-0.1137	-0.

Using ANOVA and T-tests, we explored associations between outcome variables and categorical patient characteristics. We found that the number of proximal screws was significantly associated with procurvatum/recurvatum post-operatively ($p < 0.001$) and at follow-up ($p = 0.005$), with patients who had three screws having the greatest procurvatum/recurvatum. Patients with both orthopaedic and trauma surgeries had the greatest procurvatum/recurvatum post-operatively ($p = 0.029$) and at follow-up ($p = 0.001$), and these associations were statistically significant.

Table 3.9: Factors associated with varus/valgus alignment post-operatively

Varus/Valgus Post-op			
Variable	Mean (SD)	Median (SD)	p-value
Sex			
Male		2.05 (1.1 – 3.2)	0.406
Female		1.11 (0.46 – 3.88)	
Surgeon year of study			
Medical officer		1.68 (1.17 – 2.93)	0.604
Year 1		2.01 (0.91 – 3.54)	
Year 2		1.88 (0.86 – 3.35)	
Year 3		1.79 (0.67 -3.28)	
Year 4		2.15 (1.06 – 3.11)	
Consultant		2.13 (1.01 – 3.25)	
Single/Multiple			
Isolated tibia		1.96 (0.98 – 3.26)	0.179
Orthopaedic polytrauma		1.73 (0.69 -3.31)	
Orthopaedic and trauma surgeries		1.29 (0.81 – 1.77)	
Distal screws			
2		1.81 (0.86 – 3.06)	0.874
3		2.84 (1.67 -1.67)	
Proximal screws			
1		5.60 (5.60 – 5.60)	0.936
2		1.85 (0.87 – 3.15)	
3		2.14 (0.68 – 3.28)	

Table 3.10: Factors associated with procurvatum/recurvatum alignment post-operatively

Procurvatum/recurvatum Post-op			
Variable	Mean (SD)	Median (SD)	p-value
Sex			
Male	2.83 (2.10)		0.585
Female	2.61 (1.86)		
Surgeon year of study			
Medical officer	2.43 (1.81)		0.268
Year 1	3.43 (2.41)		
Year 2	2.77 (1.95)		
Year 3	2.33 (1.80)		
Year 4	2.60 (2.00)		
Consultant	3.08 (1.63)		
Single/Multiple			
Isolated tibia	2.63 (2.08)		0.029
Orthopaedic polytrauma	3.13 (1.71)		
Orthopaedic and trauma surgeries	6.14 (2.12)		
Distal screws			
2	2.88 (2.14)		0.401
3	2.49 (2.07)		
Proximal screws			
1	1.97		< 0.001
2	2.61 (1.89)		
3	5.00 (3.08)		

Table 3.11: Factors associated with varus/valgus alignment at follow-up

Varus/Valgus at Follow-up			
Variable	Mean (SD)	Median (SD)	p-value
Sex			
Male	2.56 (2.07)		0.685
Female	2.40 (1.93)		
Surgeon year of study			
Medical officer	2.13 (1.56)		0.734
Year 1	2.64 (2.39)		
Year 2	2.61 (1.94)		
Year 3	2.70 (2.40)		
Year 4	2.40 (1.82)		
Consultant	4.08 (0.07)		
Single/Multiple			
Isolated tibia	2.58 (2.20)		0.786
Orthopaedic polytrauma	2.36 (2.20)		
Orthopaedic and trauma surgeries	1.91 (1.48)		
Distal screws			
2	2.45 (2.03)		0.482
3	2.77 (2.07)		
Proximal screws			
1	2.65		0.216
2	2.41 (1.86)		
3	3.37 (3.32)		

Table 3.12: Factors associated with procurvatum/recurvatum alignment at follow-up

Procurvatum/recurvatum at follow-up			
Variable	Mean (SD)	Median (SD)	p-value
Sex			
Male	3.18 (2.30)		0.875
Female	3.11 (2.52)		
Surgeon year of study			
Medical officer	2.95 (2.33)		0.463
Year 1	3.37 (2.60)		
Year 2	3.11 (2.20)		
Year 3	2.55 (1.97)		
Year 4	3.45 (2.52)		
Consultant	1.99 (2.01)		
Single/Multiple			
Isolated tibia	3.05 (2.22)		0.001
Orthopaedic polytrauma	3.21 (2.40)		
Orthopaedic and trauma surgeries	9.07 (1.78)		
Distal screws			
2	3.15 (2.43)		0.522
3	3.49 (2.19)		
Proximal screws			
1	2.75		0.005
2	3.01 (2.21)		
3	5.11 (3.30)		

Table 3.13: Factors associated with shortening post-operatively

Shortening Post-op			
Variable	Mean (SD)	Median (SD)	p-value
Sex			
Male	0.07 (3.87)		0.823
Female	-0.09 (2.61)		
Surgeon year of study			
Medical officer	0.01 (3.29)		0.809
Year 1	0.13 (4.25)		
Year 2	-0.22 (3.04)		
Year 3	0.80 (4.34)		
Year 4	-0.28 (3.22)		
Consultant	-2.43 (2.04)		
Single/Multiple			
Isolated tibia	0.33 (3.88)		0.147
Orthopaedic polytrauma	-1.09 (2.16)		
Orthopaedic and trauma surgeries	-0.88 (2.83)		
Distal screws			
2	-0.22 (3.49)		0.421
3	0.45 (4.81)		
Proximal screws			
1	-2.21		0.042
2	-0.34 (3.45)		
3	2.31 (5.75)		

Table 3.14: Factors associated with shortening at follow-up

Shortening at follow-up			
Variable	Mean (SD)	Median (SD)	p-value
Sex			
Male	-0.05 (3.84)		0.756
Female	0.18 (2.80)		
Surgeon year of study			
Medical officer	0.09 (3.39)		0.859
Year 1	0.15 (4.18)		
Year 2	-0.28 (3.59)		
Year 3	0.69 (3.73)		
Year 4	-0.50 (3.10)		
Consultant	-1.69 (0.86)		
Single/Multiple			
Isolated tibia	0.24 (3.92)		0.212
Orthopaedic polytrauma	-1.03 (1.84)		
Orthopaedic and trauma surgeries	1.03 (4.44)		
Distal screws			
2	-0.19 (3.45)		0.649
3	0.19 (5.13)		
Proximal screws			
1	-2.21		0.042
2	-0.34 (3.45)		
3	2.31 (5.75)		

Surgeon level of experience, time of day the surgery occurred, and number of proximal screws were significantly associated with alignment post-operatively (refer to Table 3.15) and at follow-up (refer to Table 3.16). Daytime surgeries had a higher rate of malalignment at both post-operative ($p = 0.039$) and follow-up measurements ($p =$

0.015). Higher numbers of proximal screws were also associated with a higher risk of malalignment post-operatively ($p < 0.001$) and at follow-up ($p = 0.012$).

Fractures that occurred in the proximal third were more likely to be malaligned, this was statistically significant post-operatively ($p = 0.010$) but not at follow-up ($p = 0.862$).

The number of patients who lost alignment between the post-operative measure and the follow-up measurement was greatest in the distal third, but this was not statistically significant ($p = 0.175$).

There was a trend towards patients who had both orthopaedic and trauma surgeries being at a higher risk of malalignment, but this did not reach statistical significance ($p = 0.043$).

Table 3.15: Associations between patient characteristics and alignment post-operatively

Alignment post-operatively			
	Acceptable	Unacceptable	
	N (%)	N (%)	p-value
Sex			
Male	97 (75.19)	32 (24.81)	0.256
Female	29 (85.29)	5 (14.71)	
Mechanism			
PVA	60 (73.17)	22 (26.83)	0.133
MVA	13 (76.47)	4 (23.53)	
MBA	7 (87.50)	2 (12.50)	
Assault	10 (66.67)	5 (33.33)	
GSW	7 (77.78)	2 (22.22)	
Fall	16 (88.89)	2 (11.11)	
Sport	11 (91.67)	1 (8.33)	
Blunt trauma	2 (100.00)	0 (0.00)	
Side			
Left	62 (73.81)	22 (26.19)	0.273
Right	64 (81.01)	25 (22.73)	
Polytrauma			
Yes	41 (77.36)	12 (22.64)	0.851
No	85 (77.27)	25 (22.73)	
Surgeon year of study			
Medical Officer	26 (78.79)	7 (21.21)	

Year 1	28 (71.79)	11 (28.21)	0.012
Year 2	35 (85.37)	6 (14.63)	
Year 3	18 (72.00)	7 (28.00)	
Year 4	17 (77.27)	5 (22.73)	
Consultant	2 (100.00)	0 (0.00)	
Single/Multiple surgery			
Isolated tibia	95 (76.61)	29 (23.39)	0.445
Multiple orthopaedic	30 (81.08)	7 (18.92)	
Orthopaedic and trauma surgeries	1 (50.00)	1 (50.00)	
Time of Day			
Daytime surgery	58 (69.88)	25 (30.12)	0.039
After hours surgery	65 (84.42)	12 (15.58)	
Which 1/3 of tibia			
Proximal	9 (50.00)	9 (50.00)	0.010
Midshaft	52 (77.61)	15 (22.39)	
Distal	65 (83.33)	13 (16.67)	
Distal screws			
2	109 (77.86)	31 (22.14)	0.788
3	17 (73.91)	6 (26.09)	
Proximal screws			
2	121 (81.76)	27 (18.24)	< 0.001
3	5 (33.33)	10 (66.67)	
Fibula plate			
Yes	6 (100.00)	0 (0.00)	0.338
No	120 (76.43)	37 (23.57)	
Poller screws			
Yes	1 (100.00)	0 (0.00)	1.000
No	125 (77.16)	37 (22.84)	

Table 3.16: Associations between patient characteristics and alignment at follow-up

Alignment at follow-up			
	Acceptable	Unacceptable	
	N (%)	N (%)	p-value
Sex			
Male	93 (72.09)	36 (27.91)	0.834
Female	24 (70.59)	10 (29.41)	
Mechanism			
PVA	55 (67.07)	27 (32.93)	0.209
MVA	13 (76.47)	4 (23.53)	
MBA	7 (87.50)	1 (12.50)	
Assault	8 (53.33)	7 (46.67)	
GSW	5 (55.56)	4 (44.44)	
Fall	16 (88.89)	2 (11.11)	
Sport	11 (91.67)	1 (8.33)	
Blunt trauma	2 (100.00)	0 (0.00)	
Side			
Left	58 (69.05)	26 (30.95)	0.424
Right	59 (74.68)	20 (25.32)	
Polytrauma			
Yes	38 (71.70)	15 (28.30)	0.865
No	79 (71.82)	31 (28.18)	
Surgeon year of study			
Medical Officer	27 (81.82)	6 (18.18)	0.038
Year 1	25 (64.10)	15 (38.46)	
Year 2	33 (80.49)	8 (19.51)	
Year 3	15 (60.00)	10 (40.00)	
Year 4	15 (68.18)	7 (31.82)	
Consultant	2 (100.00)	0 (0.00)	
Single/Multiple surgery			
Isolated tibia	87 (70.16)	37 (29.84)	0.043
Multiple orthopaedic	30 (81.08)	7 (18.92)	
Orthopaedic and trauma surgeries	0 (0.00)	2 (100.00)	
Time of Day			
Daytime surgery	52 (62.65)	31 (37.35)	0.015
After hours surgery	62 (80.52)	15 (19.48)	
Which 1/3 of tibia			
Proximal	9 (50.00)	9 (50.00)	0.862
Midshaft	51 (76.12)	16 (23.88)	
Distal	57 (73.08)	21 (26.92)	

Distal screws			
2	102 (72.86)	38 (27.14)	0.460
3	15 (95.22)	8 (34.78)	
Proximal screws			
2	111 (75.00)	37 (25.00)	0.012
3	6 (40.00)	9 (60.00)	
Fibula plate			
Yes	6 (100.00)	0 (0.00)	0.186
No	111 (70.70)	46 (29.30)	
Poller screws			
Yes	1 (100.00)	0 (0.00)	1.000
No	115 (70.99)	47 (29.01)	

Chapter 4

4. Discussion

4.1 Demographics

The majority of patients in our study were young males and this is consistent with other studies in the South African literature pertaining to traumatic injuries.^(3, 29) Overall, 78.48% of our patients were male, which is similar to the 71.3% found by Nicol *et al.* and 84.6% found by Hilton *et al.*, both studies were conducted in Cape Town.^(3, 29) Comparably, we had 81.01% who were 40 years of age or younger, and Nicol *et al.* had 74.6% in the same age group.⁽³⁾ In concordance with the Nicol *et al.* study, we found a higher percentage of young patients in the male group (84.67%) than the female group (67.64%).⁽³⁾

This is in keeping with the international literature with Williams *et al.* based in the United Kingdom (UK) finding 80% of tibia fractures in males, Freedman *et al.* based in the United States of America (USA) finding 75.2% males, Bhandari *et al.* based in Canada reporting 73% males, and the large, multicentre, USA based SPRINT trial finding 73.7% males.^(9, 12, 13, 21) These studies also identified tibial fractures to be more common in younger patients, with Williams *et al.* reporting a mean age of 31, Freedman *et al.* reporting a mean age of 34 years, Bhandari *et al.* reporting a mean age of 38 years, and the SPRINT trial reporting a mean age of 39.5 years.^(9, 12, 13, 21) Likewise, Larsen *et al.* in their epidemiological study of tibial fractures, found that the peak of tibial fractures occurred in an older age group for females *versus* males.⁽²⁾ In contrast, Yoon *et al.* also based in the USA, found a lower proportion of males, at 56.7%, and a higher mean age at 44 years.⁽¹⁵⁾

This preponderance of young and male patients probably reflects the high levels of interpersonal violence in this group, as well as high levels of alcohol consumption and its resultant effects on high risk behaviour.⁽³⁾ Likewise, the high number of admissions on weekends *versus* weekdays might be a reflection of higher alcohol consumption on weekends *versus* weekdays. As this was a retrospective study, we were limited by the

data already present in the file, and very few files had any information regarding whether the patient had consumed alcohol prior to the injury or not, therefore this was not a variable we could include in the present study, although it would be an interesting one to include in any future prospective studies on this topic.

4.1.1 Mechanism of injury

PVAs were the most common mechanism of injury in our study at 49.69%, and this is in contrast to Nicol *et al.* at 8.74% although their study was a trauma surgery study, and thus not limited to patients with orthopaedic injuries.⁽³⁾ However, international studies report far lower levels of PVAs, with Williams *et al.* reporting 10.54%, Freedman *et al.* reporting 36.84%, Bhandari *et al.* reporting 28.13%, and the SPRINT trial reporting 20.23%.^(9, 12, 13, 21) In contrast, Yoon *et al.* reported 43% of fractures were caused by a PVA, which is similar to our finding.⁽¹⁵⁾ These differences may represent regional difference in road safety as well as pedestrian behaviour.⁽²⁾

Other motorised vehicle accidents followed a similar pattern. We found motor vehicle accidents (MVAs) as the cause in 9.3% of injuries and motorbike accidents (MBAs) in 5.3%. Whereas, in the SPRINT trial, the authors reported higher numbers of MVAs (20.88%) and MBAs (11.66%).⁽²¹⁾ Williams *et al.* reported a lower number of car accidents (1.86%) and a higher number of MBAs (13.64%).⁽¹³⁾ Freedman reported a similar number of MVAs at 9.77%, but a higher number of MBAs at 28.57%.⁽⁹⁾ Yoon *et al.* and Bhandari *et al.* both reported a higher number of car accidents at 30%, and 31.25%, respectively, neither of these studies included MBAs as a separate category.^(12, 15) This variation may be explained by different groupings, i.e.: combining car and motorbike accidents into one category, and regional variations in wealth and access to cars and motorbikes.⁽²⁾

We found a somewhat higher rate of GSWs (5.66% *versus* 4.79%) and a lower rate of assault (9.43% *versus* 37.94%) than the Nicol *et al.* study. This is likely because their study was on general trauma and not confined to patients with fractures.⁽³⁾

The majority of international studies did not include a category for GSWs or assault, and thus it is difficult to make any comparison with international findings. Yoon *et al.* found a slightly higher rate of GSWs (5.66% *versus* 10.00%) but this comparison is limited by the small size of their study sample.⁽¹⁵⁾

Falls and sports injuries accounted for only 10.69% and 7.55%, respectively, of injuries in this study, and this is in contrast to international studies where these mechanisms are a more common cause of injury.^(9, 12, 13, 21) This is most likely explained by the lower rate of interpersonal violence as a cause for injury in these countries.⁽³⁾

Table 4.1: Comparison of percentages of mechanism of injury ^(3, 9, 12, 13, 15, 21)

Study	PVA	MVA	MBA	GSW	Assault	Fall	Sports	Blunt
Present study	49.69	9.30	5.30	5.66	9.43	10.69	7.55	1.26
Nicol <i>et al.</i> (ZA)	8.74	10.00	-	4.79	37.94	18.40	-	0.41
Williams <i>et al.</i> (UK)	10.54	1.86	13.64	-	-	20.00	40.00	-
SPRINT (USA)	20.23	20.88	11.70	-	-	29.00	-	6.85
Bhandari <i>et al.</i> (Canada)	28.13	31.25	-	-	-	10.42	-	4.17
Freedman (USA)	36.84	9.77	28.57	-	-	9.77	9.02	0.75
Yoon (USA)	43.00	30.00	-	10.00	-	7.00	-	10.00

4.2 Injury Characteristics

Our rate of closed to open fractures is in keeping with the international literature. We found a rate of 59.50% closed fractures, and Bhandari *et al.* reported a rate of 59.90%, Egol *et al.* reported 59.72%, Koval *et al.* reported 48%, and the SPRINT trial reported 67.5% closed fractures.^(12, 14, 21, 22)

We identified two studies which looked at open fractures of the tibia in SA and found that our distribution of wound severity was somewhat different. We found GA 1 wounds in 37.88%, in line with their 37.65%, but had a higher number of GA 2 wounds (39.39% *versus* 28.24%) and a lower number of GA 3 wounds (22.73% *versus* 34.12%) than the Howard *et al.* study.⁽³⁴⁾ The Hilton *et al.* study reported 46.15% GA 1 wounds, 46.15% GA 2 wounds and 7.69% GA 3 A wounds; however, all of their patients were gunshot victims, and this is not in keeping with Gustilo-Anderson's classification of GSWs as GA 3 type injuries.^(7, 29)

Likewise, our findings differed from those in the international literature. Although we found broadly similar rates of open *versus* closed fractures (40.50% *versus* 59.50%) to both the Egol *et al.* study (40.27% *versus* 59.72%) and the SPRINT trial (32.5% *versus* 67.5%), the breakdown of our open fracture group differed.^(14, 21) These differences are presented in Table 4.2.

Table 4.2: Percentage of wounds per Gustilo-Anderson classification ^(14, 20-22, 34)

Study	GA 1	GA 2	GA 3 total	GA 3A	GA 3B	GA 3C
Present study	37.88	39.39	22.73	21.21	1.52	0.00
Howard <i>et al.</i> (ZA)	37.65	28.24	34.12	-	-	-
Egol <i>et al.</i> (USA)	20.69	13.78	65.54	41.40	24.14	0.00
Koval <i>et al.</i> (USA)	91.67	8.33	0.00	-	-	-
Kakar <i>et al.</i> (USA)	23.08	39.86	37.06	26.57	10.49	-
SPRINT trial (USA)	26.60	39.70	33.80	26.40	7.40	0.00

These differences may represent:

- Differences in study design, as the Egol *et al.* study only looked at fractures in the distal third of the tibia; or
- Differences in the era in which the study was completed, as nailing indications have expanded since the Koval *et al.* study; and
- Changes in local protocols with regards to nailing *versus* external fixation for higher grades of injury.^(14, 22)

When analysing the fracture patterns, we classified the data in two ways, firstly by determining which third of the tibia the fracture fell into, and secondly by classifying it according to the AO foundation. Neither of the two South African studies reported the fracture pattern or classified them according to AO in their studies.^(29, 34) Turning to the international literature, we found that of the two studies reporting in which third the fracture occurred had similar groupings to us, Gaebler *et al.* had a similar distribution to ours, whereas Freedman *et al.* had a larger number of midshaft fractures, although they did not have a separate category for segmental fractures.^(9, 28)

Table 4.3: Percentage of fractures by third of the tibia ^(9, 28)

Study	Proximal	Midshaft	Distal	Segmental
Present study	4.90	41.10	44.78	9.20
Gaebler <i>et al.</i>	2.00	45.00	52.00	1.00
Freedman <i>et al.</i>	9.00	52.00	39.00	-

However, those that included the junctions between the proximal and middle third, and the middle and distal third as separate categories had somewhat different distributions to our data.^(21, 22, 32) Williams and Schenk, based in the UK, and the SPRINT trial both found a larger percentage of fractures falling into the middle to distal third junction at 35.00% and 42.7%, respectively, compared with our 19.63%.^(21, 32) They also found a smaller number falling into the middle third at 35.00% and 24.5%, respectively, in contrast to our 41.10%.^(21, 32) In contrast, Koval *et al.*, based in the USA, found a higher number of midshaft fractures and a lower number of middle to distal junction fractures, at 55.00% and 15.00%, respectively.⁽²²⁾

Table 4.4: Percentage of fractures by third of the tibia including junctional areas ^(21, 22, 32)

Study	Proximal	Proximal middle junction	Midshaft	Middle distal junction	Distal	Segmental
Present study	0.61	4.29	41.1	25.15	19.63	9.2
Williams and Schenk (UK)	5.00	10.00	35.00	35.00	10.00	5.00
SPRINT (USA)	2.50	8.30	24.50	42.70	22.00	-
Koval <i>et al.</i> (USA)	6.67	6.67	55.00	15.00	16.67	-

Both the Williams and Schenk, and the Koval *et al.* studies were smaller than ours, which may explain the difference in distribution, whereas the SPRINT trial was very

large. It also had a lower proportion of PVAs and a higher proportion of MVAs and MBAs, and that may account for the difference in common fracture types.^(21, 22, 32)

When classifying the fractures according to the AO foundation, we found two of the studies reported on the AO classification in detail and two gave only the broad groupings.^(15, 21, 39, 45) The most common fracture type in our series was a 42-A2-b, midshaft oblique, and a 42-B2-b, midshaft intact wedge. Both Larsen *et al.* and the SPRINT trial reported intact wedge fractures as the most common group, although they do not specify in which part of the bone the fractures occurred.^(21, 45)

Table 4.5: Percentage of fractures by broad AO categories ^(21, 45)

	Present study	Larsen <i>et al.</i>	SPRINT trial
42-A1	12.88	33.7	17.3
42-A2	12.27	16.8	20.4
42-A3	29.45	13.8	18.5
42-B2	22.70	23.5	20.8
42-B3	12.27	2.6	8.8
42-C2	4.29	5.7	9.9
42-C3	6.13	3.6	4.4

Likewise, both Yoon *et al.* and Chan *et al.* reported a high number of intact wedge fractures, although they reported them as being in the distal part of the tibia, in contrast to our finding a higher number in the midshaft.^(15, 39) However, Yoon *et al.* reported a higher incidence of segmental fractures than what we found.⁽¹⁵⁾

Table 4.6: Percentage of fractures by detailed AO categories ^(15, 39)

	Present study	Yoon <i>et al.</i>	Chan <i>et al.</i>
42-A1-a	0.61	0.00	0.00
42-A1-b	4.29	0.00	4.00
42-A1-c	7.98	0.00	0.00
42-A2-a	0.61	0.00	4.00
42-A2-b	7.36	4.55	16.00
42-A2-c	4.29	4.55	8.00
42-A3-a	0.61	4.55	4.00
42-A3-b	17.79	0.00	8.00
42-A3-c	11.04	4.55	8.00
42-B2-a	1.23	0.00	4.00
42-B2-b	19.02	4.55	8.00
42-B2-c	2.45	13.64	16.00
42-B3-a	0.00	0.00	0.00
42-B3-b	6.75	4.55	0.00
42-B3-c	5.52	0.00	4.00
42-C2-i	3.07	9.09	4.00
42-C2-j	0.61	4.55	8.00
42-C2-k	0.61	22.73	0.00
42-C3-i	2.45	0.00	4.00
42-C3-j	1.84	22.73	0.00
42-C3-k	1.84	0.00	0.00

4.3 Use of adjuncts

There were relatively few surgeons who made use of adjunctive techniques to achieve a good reduction, despite them being well described in the literature.^(14, 40, 42) This may represent surgeon unfamiliarity with the techniques or a lack of intraoperative recognition that they are indicated. However, Lindvall *et al.* examined the use of adjuncts in their study and found no statistical difference in the quality of alignment between patients in whom adjuncts were used *versus* those where adjuncts were not used.⁽¹⁸⁾

4.4 Time Usage and time of day

In contrast to Williams *et al.*, we did find a difference in the time taken to complete the surgery when correlated with surgeon experience.⁽¹³⁾ They reported a mean surgery time of 120 minutes (60 – 240 minutes). However, they did not state if this was the total time in theatre or the cutting time only.⁽¹³⁾ Our average total time in theatre was 151.11 minutes (80 – 260 minutes) and our average cutting time was 88.22 minutes (45 – 155) for isolated tibia surgeries. We found that second year registrars were the fastest surgeons, with an average cutting time of 80.50 minutes (45 – 150 minutes), with less experienced medical officers taking an average of 101.44 minutes (60 – 155 minutes) and more experienced fourth year registrars taking an average of 88.40 minutes (50 – 160 minutes). These differences are most likely due to the organisation of training rotations in our hospital as registrars begin with trauma for the first 18 months to two years of their registrar training time before moving on to cold orthopaedic rotations. Thus, second year registrars have had full exposure to orthopaedic trauma and are still doing trauma procedures on a daily basis compared to fourth year registrars who are involved with cold orthopaedic procedures daily and who perform trauma procedures only when on call.

Guo *et al.* based in China, reported an average cutting time in line with ours, although with a smaller range, at 81.20 minutes (77.72 – 84.73 minutes).⁽³³⁾ None of the other articles reviewed for this research study had reported their operating times.

There was no statistically significant difference in time usage between surgeries that took place during the day *versus* after hours, although a trend for longer cutting times was observed for procedures done during the day. This may be explained by the unit policy of complex cases being deferred until daylight hours if this is deemed to be safe by the on-call surgeon, as well as daytime lists being used more for teaching purposes. During the daytime, inexperienced surgeons may be allowed to perform part or all of the procedure under the guidance of a senior surgeon, thus increasing the overall cutting time. In contrast, after hours lists are frequently done by a single surgeon with no assistant, as 59.72% of daytime surgeries are done with an assistant whereas only 43.68% of after-hours surgeries are done with an assistant.

4.5 Adequacy of reduction

Overall, we had a rate of 28.22% of tibias that resulted in an unsatisfactory position at follow-up. This is in keeping with the international literature. We had 3.07% of patients with shortening at follow-up, 0.61% with distraction, 18.40% with sagittal plane malalignment, and 4.29% with coronal plane malalignment. We had 4.91% of patients with malalignment in two planes, and none with malalignment in three planes.

Williams *et al.* reported a 48.96% malalignment rate, with 7.45% of patients experiencing shortening, 10.64% distraction, 7.45% sagittal plane malalignment, and 17.02% coronal plane malalignment.⁽¹³⁾ They also reported that 37.23% of patients had malalignment in more than one plane.⁽¹³⁾ Lindvall *et al.*, in their study of proximal fractures, reported a 45.45% rate of malalignment, with 36.36% of patients having procurvatum deformities, and 9.09% of patients having coronal deformities.⁽¹⁸⁾ Vallier *et al.*, in their study of distal tibia fractures, reported an overall rate of 23% malalignment, with the majority of them being coronal malalignment (70%).⁽¹⁷⁾ We found that patients who had their fibula plated were less likely to have malalignment, although this did not reach statistical significance ($p = 0.338$). Similarly, Vallier *et al.* reported the same finding in their study, where 20% of patients who had fibula plating developed malalignment, and 28.9% of patients who did not have fibula plating developed malalignment.⁽¹⁷⁾

Conversely, both Githens *et al.* and Gaebler *et al.* reported lower rates of malalignment, with 6% and 5%, respectively. Both studies only reported on the total number of malaligned cases, defining malalignment as $> 5^\circ$ in any plane, and neither gave a detailed breakdown of the types of malalignment found.^(16, 28) These were both studies done at level one trauma centres, with patient numbers comparable to ours.

Table 4.7: Comparison of rates of malalignment in the literature ^(13, 16-18, 28)

	Total	Sagittal plane	Coronal plane	Axial plane
Present study	28.22	18.40	4.29	10.43
Williams <i>et al.</i>	48.96	7.45	17.02	18.09
Lindvall <i>et al.</i>	45.45	36.36	9.09	-
Vallier <i>et al.</i>	23.00	-	16.10	-
Githens <i>et al.</i>	6.00	-	-	-
Gaebler <i>et al.</i>	5.00	-	-	-

4.5.2 Significant factors associated with malalignment

We found a significant relationship between the surgeon's level of experience and malalignment, but this was not distributed in a meaningful way, as there was no correlation between increasing surgeon experience and increasing or decreasing success in obtaining a good reduction. This is in contrast to Williams *et al.*, Larsen *et al.* and Gaebler *et al.*, who all reported no significant differences between senior surgeons and trainees in their studies.^(13, 28, 45) However, all of the mentioned studies compared qualified trauma super specialists with non-trauma specialised orthopaedic consultants and trainees. In our study, we had only two cases completed by orthopaedic specialists, and thus the numbers were too small to analyse differences between specialists and trainees.

The time of day when the surgery occurred was also significantly associated with malalignment both post-operatively ($p = 0.039$), and at follow-up ($p = 0.015$). However, this relationship is opposite to what we expected, with cases done during the day having a higher risk of malalignment. A possible explanation for this phenomenon is that complicated cases that are predicted to be difficult are frequently postponed to daytime hours. This is borne out by the observation that 64.29% of segmental fractures, and 62.50% of all AO grade C fractures were operated on during the day. This finding is in contrast to Larsen *et al.* and Williams *et al.*, where both studies reported no difference in the accuracy of reduction for surgeries performed during the day *versus* those done after hours.^(13, 45)

Increasing numbers of proximal screws were also associated with a higher risk of malalignment post-operatively ($p < 0.001$) and at follow-up ($p = 0.012$). This is most likely due to the fact that we found a higher rate of malalignment in proximal third fractures than in the study population as a whole (50.00% *versus* 28.22%), and the majority of cases (80.00%) in which three screws were used were segmental fractures involving the proximal third, or fractures of the proximal tibia. Thus, this finding most likely reflects the known tendency of these proximal fractures to displace into procurvatum, and the third screw being inserted in order to obtain greater stability in these unstable fracture patterns.⁽³⁵⁾

4.6 Limitations

As this was a retrospective review, we were limited by the data already documented in the files and the radiographs already taken. There was a high exclusion rate of 40.51% as many patients who received tibial nails during the study period did not have sufficient or adequate radiographs available on the PACS. Additionally, the radiographs were taken for clinical treatment purposes and were not standardised for measurement, thus they may have been taken from a slightly different angle at each time point and this may have affected the accuracy of the measurements performed.

The surgical technique employed was not standardised, and different surgeons may have employed different techniques at their discretion. A further weakness is that although we categorised surgeon experience by the year of study, this does not truly reflect the totality of a surgeon's experience. Some surgeons have extensive operative experience as medical officers in outlying hospitals and join the academic circuit already very skilled, whereas others may join the circuit relatively soon after completing their community service year and may not have any significant surgical experience prior to taking up medical officer positions at the academic hospital.

4.7 Recommendations

We recommend the study be repeated with a prospective research design, whereby many of the limitations of the current study could be addressed. Capturing patient data

prospectively would allow for the inclusion of alcohol ingestion as a variable, as well as other data pertinent to injury demographics, such as whether the patient is employed and what type of work they do. Capturing surgeon data prospectively would allow for a more detailed exploration of surgeon experience as it relates to surgical outcomes.

Chapter 5

5. Conclusion

Tibial shaft fractures occur predominantly in males younger than 40 years of age and are most commonly the result of road traffic incidents. The most common mechanisms of injury are PVAs, MVAs, falls and assault.

The majority of fractures treated by a tibial nail were closed injuries or Gustilo-Anderson 1 or 2 open fractures. The most common fracture patterns were midshaft oblique and intact wedge fractures.

Our analysis of the adequacy of reduction of tibial fractures at CMJAH concluded that we have a rate of acceptable reduction that is in keeping with the international standards. The majority of patients had reductions that were acceptable, and of the patients whose reductions were not satisfactory, the majority were minor deviations of a few degrees.

Factors correlated with poor reductions were proximal third fractures requiring three proximal screws and complex cases done during daytime hours. However, these malaligned proximal third fractures did not have a higher rate of loss of reduction than fractures in other areas of the bone.

We had a small minority of patients who lost reduction between their initial post-operative radiographs and their follow-up radiographs. The majority of patients had satisfactory reductions that were maintained throughout the follow-up period.

Distal third fractures had a higher rate of loss of reduction than those found in other parts of the bone, but this was not statistically significant. No other factors were identified that were consistently correlated with early loss of reduction.

From the above, we conclude that tibial shaft fractures are being treated appropriately with intramedullary nails at CMJAH.

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7. Appendices

7.1 Appendix A: Ethics approval



R14/49 Dr AS Whitehead

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL) CLEARANCE CERTIFICATE NO. M181052

NAME: Dr AS Whitehead
(Principal Investigator)
DEPARTMENT: School of Clinical Medicine
Department of Surgery
Division of Orthopaedic Surgery
Helen Joseph Hospital

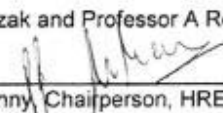
PROJECT TITLE: The treatment of tibia fractures by intramedullary nails
at Charlotte Maxeke Johannesburg Academic Hospital

DATE CONSIDERED: 26/10/2018

DECISION: Approved unconditionally

CONDITIONS:

SUPERVISOR: Dr J Pietrzak and Professor A Robertson

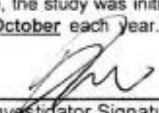
APPROVED BY: 
Dr CB Penny, Chairperson, HREC (Medical)

DATE OF APPROVAL: 04/01/2019

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

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on 3rd floor, Phillip V Tobias Building, Parktown, University of the Witwatersrand, Johannesburg.
I/We fully understand 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. When a funder requires annual re-certification, the application date will be one year after the date of the meeting when the study was initially reviewed. In this case, the study was initially reviewed in October and will therefore reports and re-certification will be due early in the month of October each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).


Principal Investigator Signature

07/01/2019
Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

7.2 Appendix B: Hospital Permission Letter



GAUTENG PROVINCE

HEALTH
REPUBLIC OF SOUTH AFRICA

CHARLOTTE MAXEKE JOHANNESBURG ACADEMIC HOSPITAL

Enquiries:
Ms. N. Mzila
Office of the Clinical Director
Email: Nolwazi.Mzila@gauteng.gov.za
Tell: (011): 488-4812
05 October 2018

Dear Dr. A. S. White Head

STUDY TITLE: The Treatment of Tibia Fractures by Intramedullary Nails at Charlotte Maxeke Johannesburg Academic Hospital.

Permission to conduct the above mentioned study is provisional approved. Your study can only commence once Ethics approval is obtained. Please forward a copy of your Ethics Clearance Certificate as soon as the study is approved by the Ethics Committee for the CEO's office to give you the final approval to conduct the study.

Supported / ~~not supported~~

Dr. M.I. Mofokeng
Clinical Director
DATE: 9/10/2018

Approved / ~~not approved~~

Ms. G. Bogoshi
Chief Executive Officer
DATE: 10/10/2018

7.3 Appendix C: Data Collection Sheet from theatre registers and clinical notes.

Study Number	
Age	
Hospital file number	
Gender	
Mechanism of injury	
Primary surgeon year of training	
Time of surgery	
Duration of surgery	
Single or multiple procedures	
Surgical assistant present (y/n)	

7.4 Appendix D: Data Collection Sheet from PACS images:

Adequate images on PACS (y/n)	
Classify pattern according to AO	
Proximal, middle, or distal 1/3	
Post op angles – procurvatum/recurvatum	
Post op angles – varus/ valgus	
Shortening in mm	
Number of distal screws	
Number of proximal screws	
Diameter of nail	

Diameter of canal	
Fibula plated or not (y/n)	
Follow-up angles – procurvatum/ recurvatum	
Follow-up angles – varus/ valgus	
Follow-up shortening in mm	

7.5 Appendix E: Protocol Approval Letter



Private Bag 3 Wits, 2050
Fax: 027117172119
Tel: 02711 7172076

Reference: Mrs Sandra Benn
E-mail: sandra.benn@wits.ac.za

03 December 2018
Person No: 0100476E
PAG

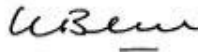
Dr AS Whitehead
122 Karen Road
Illoindale
1609
South Africa

Dear Dr Alexis Whitehead

Master of Medicine in Orthopaedic Surgery: Approval of Title

We have pleasure in advising that your proposal entitled *The treatment of tibia fractures by intramedullary nails at the Charlotte Maxeke Johannesburg Academic Hospital* has been approved. Please note that any amendments to this title have to be endorsed by the Faculty's higher degrees committee and formally approved.

Yours sincerely

A handwritten signature in black ink, appearing to read 'S. Benn'.

Mrs Sandra Benn
Faculty Registrar
Faculty of Health Sciences