

Functional Outcomes and Quality of Life Following Complex Tibial Fractures Treated with Circular External Fixation: A Comparison between Proximal, Midshaft, and Distal Tibial Fractures

Jaco J Naude¹, Muhammad A Manjra², Franz Birkholtz³, Annette-Christi Barnard⁴, Kevin Tetsworth⁵, Vaida Glatt⁶, Erik Hohmann⁷

ABSTRACT

Aim and objective: The purpose of this study was to compare clinical results following complex proximal, midshaft, and distal tibial fractures and investigate whether there are differences in outcomes between these locations.

Materials and methods: Patients between 18 years and 65 years of age and minimum follow-up of 12 months with complex tibial fractures treated with a circular ring fixator were included. Functional outcomes were assessed using the Association for the Study and Application of Methods of Ilizarov (ASAMI) functional and bone scores, Foot Function Index (FFI), Four Step Square Test (FSST), and Timed Up and Go Test (TUG). Quality of life was assessed by the EQ-5D score.

Results: A total of 45 patients were included: proximal fractures, $n = 11$; midshaft fractures, $n = 17$; and distal fractures, $n = 17$. ASAMI functional ($p = 0.8$) and bone scores ($p = 0.3$) were not different. Excellent and good bone scores were achieved in $>90\%$ in all groups. FFI was $30.9 + 24.7$ in the proximal group, $33.9 + 27.7$ in the midshaft group, and $28.8 + 26.9$ in the distal group ($p = 0.8$). TUG was $9.0 + 2.7$ sec in the proximal group, $9.0 + 3.5$ in the midshaft group, and $8.5 + 2.0$ in the distal group ($p = 0.67$). FSST was $10.7 + 2.5$ sec in the proximal, $10.3 + 3.8$ in the midshaft, and $8.9 + 1.8$ in the distal fracture groups ($p = 0.5$). EQ-5D index value was highest in the distal (0.72), lowest in the proximal (0.55), and 0.70 in the midshaft fracture groups ($p = 0.001$). EQ-5D VAS was significantly different between the proximal (65) and midshaft (82.3) ($p = 0.001$) and between the distal (75) and proximal (65) fracture groups ($p = 0.001$).

Conclusions: The results of this study suggest that the functional outcomes between proximal, midshaft, and distal complex tibial fractures are comparable. Their ability to ambulate afterward is comparable to age-related normative data, but complex tasks are more difficult and better compared to the ambulating ability of a healthy population aged 65 to 80 years. Patients with proximal tibial fractures had significantly more disability by at least one functional level and/or one health dimension.

Keywords: Circular external fixation, Clinical outcomes, Complex tibial fractures.

Strategies in Trauma and Limb Reconstruction (2021): 10.5005/jp-journals-10080-1506

INTRODUCTION

High-energy complex tibial fractures are often difficult to manage, with correspondingly high complication rates typically reported.¹⁻⁴ The relatively poor blood supply to the distal third fracture and the lack of muscle cover over the anterior medial aspect make the tibia more susceptible to open fractures, and associated bone loss with resulting non-union and deep infection is not uncommon.⁵

Current treatment options include intramedullary nailing, plate fixation, and external fixation.^{5,6} However, the complication rates for all of these treatment options are high, including late amputation (4%), wound infection (23%), osteomyelitis (9%), and non-unions (31%).⁷ Webb et al. reported similar figures for intramedullary nailing, with a non-union rate of 31 and 15% for deep infection. With the use of monolateral external fixation, a combined prevalence of 40% for both non-union and infection was observed.⁶ Dickson et al. reported that plate fixation resulted in comparable complication rates, with 17% non-union and 11% deep infection, while the incidence for both non-union and infection was lower at 11%.⁵ In contrast, circular external fixation of grade 3 open tibial fractures had only a 2% rate of non-union and a 1% rate of deep infection, although complicated by a superficial pin site infection in 31% of cases.⁵ However, functional outcomes are limited with all techniques and approximately one-third of patients with healed complex tibial fractures had difficulties with walking or

^{1,2,3}Department of Orthopaedic Surgery, University of Pretoria, Pretoria, South Africa

⁴Walk-A-Mile Centre for Advanced Orthopaedics, Centurion, South Africa

⁵Department of Orthopaedic Surgery, Royal Brisbane and Women's Hospital, Herston, Queensland, Australia; Department of Surgery, School of Medicine, University of Queensland, Herston, Queensland, Australia; Queensland University of Technology, Brisbane, Queensland, Australia; Orthopaedic Research Centre of Australia, Brisbane, Queensland, Australia

⁶University of Texas Health Science Center, San Antonio, Texas, USA

⁷School of Medicine, University of Pretoria, Pretoria, South Africa; Department of Orthopaedic Surgery and Sports Medicine, Valiant Clinic/Houston Methodist Group, Dubai, United Arab Emirates

Corresponding Author: Erik Hohmann, School of Medicine, University of Pretoria, Pretoria, South Africa; Department of Orthopaedic Surgery and Sports Medicine, Valiant Clinic/Houston Methodist Group, Dubai, United Arab Emirates, Phone: +971507130282, e-mail: ehohmann@houstonmethodist.org

How to cite this article: Naude JJ, Manjra MA, Birkholtz F, et al. Functional Outcomes and Quality of Life Following Complex Tibial Fractures Treated with Circular External Fixation: A Comparison between Proximal, Midshaft, and Distal Tibial Fractures. *Strategies in Trauma and Limb Reconstr* 2021;16(1):32-40.

Source of support: Nil

Conflict of interest: None

Level of evidence: Therapeutic level III

pain.⁵ Interestingly, patients treated with circular fixation reportedly obtained superior outcomes.⁵

Circular external fixation using combinations of wires and half pins provides stable fixation of almost any fracture configuration.⁸ These constructs provide high axial, bending, and rotational stiffness allowing patients to weight-bear immediately.^{9–11} The resulting axial micromotion provides a favorable environment for bone healing.^{9–11} Hexapod circular fixators are versatile variants of the Ilizarov circular fixator, spanning the fracture with six telescopic struts connecting two or more rings across the fracture site.^{12,13} They are often applied using multiple half pins rather than tensioned wires, subtly influencing the mechanical environment of the fracture site. Adjusting these struts with their six degrees of freedom allows fracture reduction, as well as correction of multiplanar deformities such as angulation, rotation and translation, and leg lengthening to a nearly unlimited degree.^{8,14} These corrections can be performed either acutely or gradually, with the assistance of available Web-based software programs.¹³

Attal et al. reported that the rate of delayed union at one year was 6% for proximal, 17% for midshaft, and 11% for distal third fractures.¹⁵ Functional outcomes were not reported, and there is no published literature reporting the functional and radiological outcomes for complex tibial fractures when treated with circular external fixation. The purpose of this study was therefore to compare functional outcomes and quality of life as measured by the EQ-5D of complex proximal, midshaft, and distal tibial fractures and investigate whether there are differences in outcomes between these locations.

MATERIALS AND METHODS

Patient Identification and Data Collection

This study was performed on data obtained retrospectively from a consecutive series of high-energy tibial fractures. All patients who had complex tibial fractures treated with hexapod circular fixators between November 2010 and July 2015 were identified from the database of a single center specialized in orthopedic trauma and limb reconstruction. The study received prior approval from the Institutional Review Board and Human Research Ethics Committee, and all patients gave written informed consent to participate. Patients were included if they were aged between 18 years and 65 years, sustained a complex comminuted open or closed tibial single-level fracture with or without bone loss, were treated definitively using a circular hexapod external fixator, and had a minimum of one-year follow-up after fixator removal. Patients were classified by the OTA/AO classification and subdivided into proximal (AO41) (Fig. 1), midshaft (AO42) (Fig. 2), and distal (AO43) (Fig. 3) tibial fractures. Exclusion criteria included children, polytrauma patients or patients with added chest or abdominal trauma, neurological disorders and vertebral fractures, spinal cord injury, closed head injuries, ipsilateral fractures of the femur, ankle, or foot, and patients requiring acute lower limb amputation. Patients with segmental and intra-articular tibial fractures or extra-articular fractures with intra-articular extensions were also excluded.

Patient Management

Open fractures were classified according to the Gustilo-Anderson classification.¹⁶ All hexapod ring fixators were applied by two orthopedic trauma surgeons trained and specialized in limb reconstruction. A standard protocol was applied to all cases, which have been described previously.¹⁷ Briefly, it consists of eight

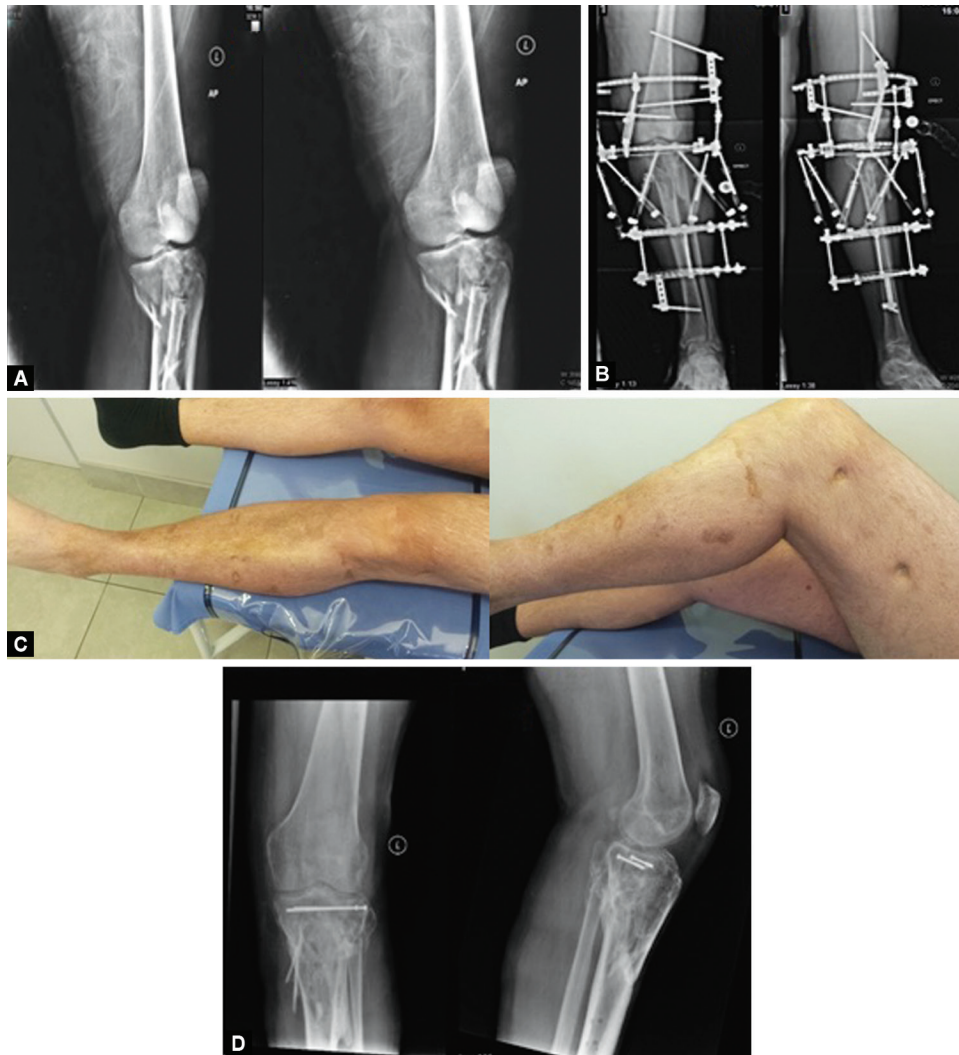
sequential steps and follows the principles of staged management for complex tibial trauma: (1) Debridement, PMMA spacer following the Masquelet technique if required, and provisional stabilization with external fixation; (2) soft tissue coverage and wound closure; (3) definitive fracture fixation with a hexapod circular frame; (4) removal of the PMMA spacer and corticotomy if required; (5) latency period and gradual distraction into Masquelet membrane when required; (6) docking site modification; (7) functional rehabilitation; and (8) frame removal and long-term surveillance. In patients who sustained closed injuries without bone loss, the first two steps were generally omitted. The surgical technique consisted of the “rings first” method, placing the rings orthogonal to the proximal and distal bone segments, and acute adjustment of fracture alignment was achieved using the six adjustable struts. Web-based software was used to modify the position of the rings for those fractures that did not have an accurate initial reduction. Postoperatively, patients conducted their own pin site care, first daily and then weekly cleaning with alcohol and chlorhexidine. Early mobilization with weight-bearing as tolerated was encouraged and monitored by a dedicated physiotherapist. Psychological assistance was available as needed.

Outcome Measures

Patient demographics were recorded including age, gender, BMI, and comorbidities. Time to union (defined as time in frame), complications, mechanism of injury, and fracture type were also recorded. Periodic clinical assessment included wound healing, signs of sepsis or infection, and knee and ankle range of motion. Outcome measures included the ASAMI score, the Foot Function Index (FFI), and the EQ-5D. The ASAMI score assesses both bone and functional results.¹⁸ ASAMI functional results are based on five categories: pain; need for walking aids or braces; foot, ankle, or knee deformity or contracture; ankle and subtalar loss of range of motion; and the ability to return to normal activities of daily living (ADL) and work. Bone results are based on five categories, including union, infection, deformity, leg length discrepancy of less than 2.5 cm, and the cross-sectional area of union of the regenerate bone and docking site. The FFI is a self-administered questionnaire that evaluates the foot and ankle in three domains via 17 questions, including pain, disability, and activity restriction.¹⁹ The EuroQol Group developed a standardized measure, the EQ-5D, to provide a simple measure of general health and perceived quality of life.²⁰ The EQ-5D-5L index score has five categories (mobility, self-care, usual activities, pain/discomfort, and anxiety/depression) and five levels (no, slight, moderate, severe problems, and inability). The patient can also score their perceived general health on a score chart from 0 (“worst imaginable health”) to 100 (“best imaginable health”), comprising the EQ VAS score.

Functional tests included the FSST and TUG. The FSST measures the duration (in seconds) of a patient stepping and changing direction over a low object in a square, assessing dynamic standing balance and mobility.^{21,22} The Timed Up and Go (TUG) test measures (in seconds) the time to stand up from a chair, walk a short distance, turn around, and return to the chair. This is an objective test to assess function and balance and requires minimal equipment, training, and expenses.²³

At the latest follow-up visit, long-leg weight-bearing radiographs were assessed for alignment using the Bone Ninja iPad mobile application (Apple Inc., Cupertino, CA, USA). Bone Ninja is an iPad application that has been verified and compared to PACS systems and found to be reliable in measuring limb length



Figs 1A to D: Proximal tibia fracture treated with ring fixation

differences and angles for preoperative planning and deformity education.²⁴ Deviations of 5 degrees in any plane were considered significant. Union was defined as bridging callus on at least three of the four tibial cortices.²⁵ Once adequate bony healing was confirmed radiographically, the hexapod frame was removed, and the total time in the fixator was then defined as the time to union.

Statistical Analysis

Descriptive statistics were used to describe patient demographics. Categorical variables (ASAMI, EQ-5D-5L) were analyzed using the χ^2 test, and continuous variables (FFI, functional tests, and radiographic outcomes) were analyzed with one-way ANOVA. An a priori sample size analysis was conducted based on the ASAMI scoring system using the following parameters: effect size 0.3, $p = 0.05$, β error 0.2, power of 0.8, $Df = 4$. The sample size calculation was performed with a goodness-of-fit model and contingency tables. The sample size calculation based on these parameters indicated that a minimum of 44 patients were required to provide 80% statistical power. The critical χ^2 values were calculated to 9.48. All analyses were conducted using STATA SE (Version 12.0; StataCorp, College Station, Texas, USA) for Windows.

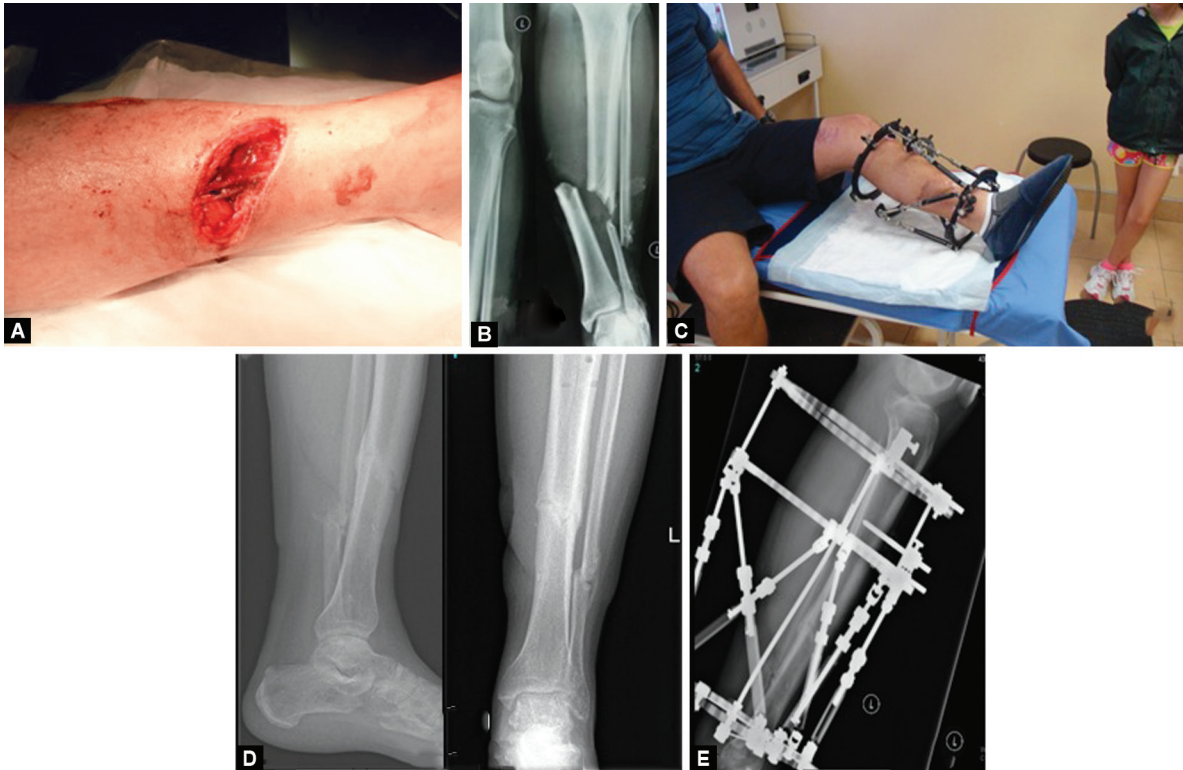
RESULTS

Patient Demographics

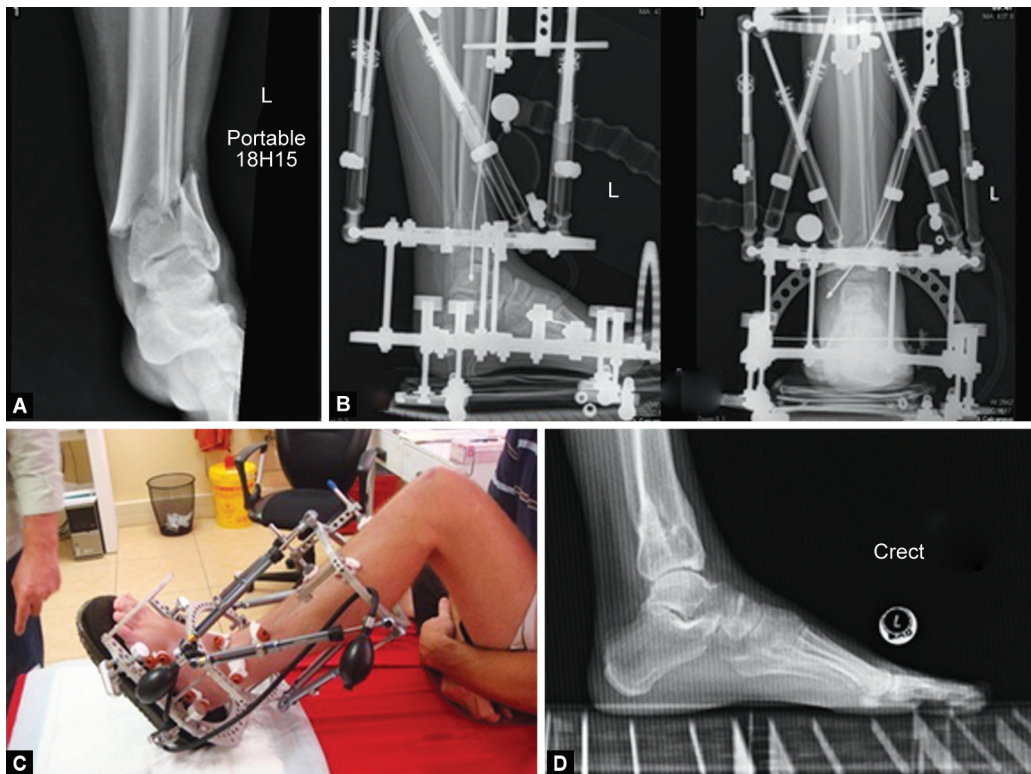
From November 2010 to July 2015, a total of 45 patients met the inclusion criteria. There were 11 proximal, 17 midshaft, and 17 distal tibial fractures. [Table 1](#) summarizes the demographic details of all patients. The mean age of the study group was 38.2 ± 11.5 , and the mean follow-up was $32.4 + 13.2$ months. Thirty-nine (87%) patients were male, with a total of 18 (40%) smokers. The demographics between the three groups were similarly distributed. Twenty-two patients (49%) were involved in a motorcycle injury indicating a high-risk group of patients, with a 71% incidence of open fractures. Seven patients who sustained random other mechanisms of injuries (falling downstairs, slipping or falling when jumping, a golf cart falling on leg, bicycle fall) all sustained distal tibial fractures.

Outcome Measures—Scores

The results of the ASAMI bone and functional scores are shown in [Table 2](#). All three groups had between 91% and 100% excellent and good bone scores. The proximal fracture group had the lowest percentage of good and excellent ASAMI functional



Figs 2A to E: Midshaft open tibia fracture treated with ring fixation



Figs 3A to D: Distal tibia fracture treated with ring fixation

Table 1: Comparison between proximal, midshaft, and distal tibial fractures

Item	Proximal (AO41)	Midshaft (AO42)	Distal (AO43)	Total
Demographics				
Patients	11	17	17	45
Age	34.6+10.5 (27–62)	38.4+12.6 (20–62)	34.6+10.1 (15–57)	38.2+11.5 (20–62)
Male	9	15	15	39 (87%)
BMI	30.1 (±5)	27.3 (±3)	28.3 (±5)	28.3 (±4)
Comorbidities	5	5	9	19 (42%)
Smoking	6	7	5	18 (40%)
Alcohol	5	5	8	18 (40%)
Mechanism of injury				
Motorcycle accident	7	9	6	22 (49%)
Injury on duty	0	3	1	4 (9%)
Motor vehicle accident	2	2	1	5 (11%)
Pedestrian vehicle accident	1	2	0	3 (7%)
Fall from height	1	0	1	2 (4%)
Gunshot wounds/assault	0	1	1	2 (4%)
Others	0	0	7	7 (16%)
Fracture classification				
Closed fractures	4	2	7	13 (29%)
Open grade 1 and grade 2	4	5	6	15 (33%)
Open grade 3	3	10	4	17 (38%)
Follow-up				
Days	925 ± 469	1099 ± 430	895 ± 289	
Range	436–1680	458–1859	404–1292	
99% CI	930–1120	944–1192	901–1076	
Weeks	132.1	157	127.9	

Table 2: ASAMI bone and functional results

ASAMI bone	Proximal (AO41)	Midshaft (AO42)	Distal (AO43)	ASAMI functional	Proximal (AO41)	Midshaft (AO42)	Distal (AO43)
Excellent	7 (64%)	7 (41%)	13 (76%)	Excellent	5 (46%)	13 (76%)	13 (76%)
Good	3 (27%)	10 (49%)	4 (24%)	Good	3 (27%)	3 (18%)	2 (12%)
Fair	0	0	0	Fair	0	1 (6%)	0
Poor	1 (9%)	0	0	Poor	3 (27%)	0	2 (12%)

scores (73%), followed by 88% for the distal fracture group, and 94% for the midshaft fracture group. The χ^2 test for the ASAMI functional score revealed that these differences were not significant (chi-square statistic 4.8731, $p = 0.874$) and were not significant for the ASAMI bone score (chi-square statistic 1.9205, $p = 0.382$). The FFI was similar in all three groups. In the proximal fracture group, the score was 30.9 + 24.7, in the midshaft fracture group 33.9 + 27.7, and in the distal fracture group 28.8 + 26.9 (Table 3). One-way ANOVA revealed that these differences were not significant ($p = 0.874$, F -Ratio = 9.88). The EQ-5D index value was highest in the distal fracture group (0.72) and lowest in the proximal fracture group (0.55) (Table 3). One-way ANOVA revealed that the differences between the proximal and distal fracture groups were significant ($p = 0.001$, F -Ratio = 157.794). For the EQ-5D VAS, significant differences were observed between the proximal and midshaft fracture groups ($p = 0.001$, F -Ratio = 84.184) and the distal and proximal fracture groups ($p = 0.001$, F -Ratio = 42.934) (Table 3).

Table 3: Foot function index and functional tests

Functional score	Proximal (AO41)	Midshaft (AO42)	Distal (AO43)
Foot function index	30.9 (±24.7)	33.9 (±27.7)	28.8 (+26.9)
EQ-5D index value	0.55 (±0.2)	0.70 (±0.2)	0.72 (+0.2)
EQ-5D VAS*	65 (±20.3)	82.3 (±16.6)	75 (+22.7)
Time up and go	9.0 (±2.7)	9.0 (±3.5)	8.5 (±2.0)
Four step square test	10.7 (±2.5)	10.3(±3.8)	8.9 (±1.8)

*Visual analogue score

Outcome Measure—Functional Tests

The mean time for the TUG in the proximal fracture group was 9.0 (±2.7) seconds, in the midshaft fracture group 9.0 (±3.5) seconds, and in the distal fracture group 8.5 (±2.0) seconds. ANOVA revealed that the differences between the proximal, midshaft, and distal fracture groups were not significant ($p = 0.66$, F -Ratio = 37.050). In



the proximal fracture group, the time for the FSST was 10.7 (± 2.5) seconds, in the midshaft group 10.3 (± 3.8) seconds, and in the distal fracture group 8.9 (± 1.8) seconds. ANOVA revealed that the differences between the proximal, midshaft, and distal fracture groups were not significant ($p = 0.55$, F -Ratio = 9.880).

Time to Union

In the proximal fracture group, the time to union was 189 ± 96 days, including one patient who underwent a 73 mm bone transport via distraction osteogenesis. Union was achieved in 91%, and the mean time of follow-up was 925 ± 469 days. The time to union in the midshaft fracture group was 256 ± 111 days, including five patients who underwent bone transport via distraction osteogenesis of 40, 55, 74, 97, and 105 mm. Successful union was achieved in 100%, and the mean time of follow-up was 1099 ± 430 days. Union was achieved in 206 ± 89 days in the distal fracture group, including three patients who underwent distraction of 20, 29, and 66 mm. Union was achieved in 94%, and the mean time of follow-up was 895 ± 289 days. The difference in the time to union between the proximal and midshaft fracture groups was significant ($p = 0.0001$, F -Ratio = 49.403). However, these results need to be interpreted with caution, as five patients in the midshaft fracture group compared to one patient in the proximal fracture group underwent distraction osteogenesis, resulting in longer times in frame. Unfortunately, subgroup analysis by removing these cases would result in a type II error, and this was not performed.

Radiographic Outcomes

In the proximal fracture group, 4 (36%) patients had an axis deviation of more than 5 degrees in either the coronal or sagittal plane (Table 4). However, the mean axis deviation was less than 5 degrees and within accepted levels (coronal $3.6 \pm 1.6^\circ$; sagittal $3.5 \pm 2.7^\circ$). Similarly, in the distal fracture group, 4 (23%) patients had an axis deviation of more than 5 degrees in either the coronal or sagittal plane, but the mean axis deviation was less than 5 degrees (coronal $3.0 \pm 2.1^\circ$; sagittal $2.7 \pm 3.4^\circ$). In the midshaft fracture group, the largest number of patients with axis deviation in either the coronal or sagittal plane was observed ($n = 10$, 59%); the mean angulation for the coronal plane was 5.3 ± 4.5 and 4.0 ± 2.6 for the sagittal plane (Table 4). Deformities greater than 10 degrees were not observed in any patient.

Complications

In the proximal tibial fracture group, 7 patients had complications, consisting of 5 superficial pin site infections (45%) and 2 deep infections (18%). One of these patients also needed an Achilles' tendon lengthening, and one patient needed an amputation for chronic pain after resolution of the infection and removal of frame. The midshaft fracture group had 7 patients with complications: 6 patients had superficial pin site infection (35%), there were no deep infections, and 3 patients needed Achilles' tendon lengthening. Eight patients had complications in the distal

fracture group, including 7 superficial infections (41%) and 1 deep infection (6%). One patient also had dorsal foot paraesthesia that did not resolve, and another patient required an Achilles' tendon lengthening. The χ^2 test revealed that these differences were not significant (chi-square statistic 4.4426, $p = 0.108$).

DISCUSSION

The results of this study suggest that there are no relevant differences for the ASAMI functional and bone scores, FFI, functional walking tests, time to union, or complication rates, but the EQ-5D instrument indicated that the quality of life in patients with complex proximal tibial fractures was significantly inferior to the other two groups. Midshaft fractures had a higher degree of residual radiographic deformity.

The ASAMI bone scores had good and excellent outcomes of 91, 90, 100%, and the ASAMI functional scores had good and excellent outcomes of 73, 94, and 88% for the proximal, midshaft, and distal fracture groups, respectively. The chi-square statistic for both scores was below the critical χ^2 values of 9.48, demonstrating that the data did fit the model. The only patient with a poor outcome was observed in the proximal fracture group. Following a type 3B open fracture sustained in a motor vehicle accident, he required daily analgesia, constant knee bracing, could not kneel or run, and was unable to return to work. Several authors have reported similar results in cases such as this.^{5,8,26} These results are similar to those reported in other published studies. Henderson et al. reported 87% good and excellent outcomes in the lowa knee evaluation and 77% excellent and good outcomes in the ankle evaluation rating in a heterogeneous group of 55 patients with tibial shaft fractures.⁸ In a small case series, Dickson et al. demonstrated 76% good and excellent outcomes in patients with diaphyseal tibial fractures treated with circular hexapod external fixation.⁵ Giotakis et al. treated 20 patients with segmental tibial fractures and reported good and excellent outcomes in all patients demonstrating with mean lowa knee and ankle evaluation rating scores of 89.5 and 84.8, respectively.²⁷ In a larger study, Foster et al. treated 40 consecutive tibial shaft fractures with the Ilizarov fixator and achieved a mean OMAS of 75 across a heterogeneous cohort of open and closed fractures.²⁸

The FFI is a valid and responsive clinical index that measures foot and ankle function, where high scores indicate pain and disability.¹⁹ Castellani et al. treated distal tibial fractures and reported the FFI at a mean of 3.8 years following surgery ranged between 14 and 21.²⁹ In patients with calcaneal fractures, the mean FFI ranged between 15 and 23 following surgical treatment,³⁰ and in patients with rheumatoid arthritis, a mean FFI of 28 was observed.¹⁹ The mean FFI in patients with chronic foot and ankle disorders was 28 and correlated well with the SF36 scoring system.³¹ In this study, the FFI ranged from 29 to 34, with no significant differences between the three groups. These scores suggest that following complex tibial fractures patients still have substantial clinical symptoms, similar to patients treated for calcaneal fracture or individuals with chronic moderate foot and ankle disorders. The differences between ASAMI and FFI here are surprising, possibly reflecting the fact that the FFI includes a disability scale and investigates any activity limitations, in contrast to the ASAMI functional score, which has a focus on stiffness and pain.

Interestingly, the functional walking tests did not suggest any objective limitations, and the times measured to complete the tasks were not different between the three groups. The TUG test

Table 4: Radiological results

	Proximal (AO41)	Midshaft (AO42)	Distal (AO43)
Patients with axis deviation >5° and <10°	4	10	4
Coronal view deviation	3.6° ($\pm 1.6^\circ$)	5.3° ($\pm 4.5^\circ$)	3.0° ($\pm 2.1^\circ$)
Sagittal view deviation	3.5° ($\pm 2.7^\circ$)	4.0° ($\pm 2.6^\circ$)	2.7° ($\pm 3.4^\circ$)

is a simple tool to assess mobility, including static and dynamic balance.³² Reference values are age dependent and range between 8 seconds and 11 seconds in healthy individuals over 60 years of age.³² A recent study by Kear et al. has shown that the normative values by decade for the ages 20 to 59 years are very similar, ranging between 6 seconds and 12 seconds with mean values from 8.56 seconds in the 20s to 9.9 seconds in the 50s.³³ The FSST incorporates fast stepping while rapidly changing direction in a specific sequence and provides a good measure of dynamic standing, balance, and mobility.³⁴ The results for this test are also age dependent and range from under 6 seconds in active adults under 30 years, to 7.5 seconds in adults between 50 years and 65 years, to 10 seconds or less in healthy adults aged 65–80 years.³⁵ The results of this study ranged from 8.8 to 9 seconds for the TUG and 8.9 to 10.7 seconds for the FSST. Following these complex and challenging injuries, patients can easily perform the simple activities of the TUG test as well as the normal population. However, more complex tasks such as the ability to step over objects forward, sideways, and backwards, thereby testing dynamic balance, are more difficult, and here, they instead perform at a level comparable to a healthy population aged 65–80 years.

The results for the EQ-5D quality of life ranged from 0.55 in the proximal tibial fracture group, to 0.70 in midshaft, and 0.72 in distal tibial fractures. These differences between the proximal, midshaft, and distal fractures were significant, demonstrating that patients with a proximal fracture had a significantly lower quality of life. Similarly, the EQ-5D subscores for the VAS scale for the proximal tibial fracture group demonstrated significantly more pain when compared to both midshaft and distal tibial fractures. A potential explanation for these findings could be that proximal fractures may have an element of intra-articular chondral and meniscal injuries. In addition, the impact for proximal fractures is close to the tibial plateau and surely some of the forces dissipate through the tibial plateau resulting in further damage. Transitions between two health states and the smallest health transitions, which differ only by one functional level or one health dimension or attribute, were reported by Luo et al.³⁶ They determined that the minimal meaningful difference for the EQ-5D was 0.04 for the US algorithm and 0.082 for the UK algorithm. In this study, the difference between proximal and midshaft respectively distal tibial fracture group was 0.15 respectively 0.17. Despite near normal functional walking tests and no significant differences for the objective outcome scores, patients with proximal tibial fractures had significantly more disability than the other fracture locations by at least one functional level or one health dimension and/or attribute. This highlights the importance of adding patient-reported outcome scores into the study design, as objective pathology-specific outcome scores may miss perceived lower function and disability in any group of patients. A multicenter study by the Canadian Orthopaedic Trauma Society in 2006 indicated that PROMs are more sensitive than other evaluations in this group of patients with substantial residual limb-specific and general health deficits.³⁷

Similar data were examined by Elsoe et al. who reported that in patients with complex tibial fractures, the EQ-5D scores for all fractures treated were 0.71 and 76 for the VAS subscores.³⁸ Ramos et al. reported the results for both proximal and distal tibial fractures and demonstrated EQ-5D values of 0.80 for both complex proximal and distal tibial fractures.^{39,40} Dickson et al. compared the EQ-5D VAS score in patients with grade 3 open tibial shaft fractures treated

with a circular frame to the UK population norm and reported a difference of 3.1 with a score of 79.7 in the study group.⁵ However, the benefit of using QOL questionnaires in these complex injuries has been questioned as coping and readjustment strategies are not captured.^{41,42}

It could be argued that both plate fixation and intramedullary nailing will provide similar results and avoid prolonged external fixation devices. Unfortunately, poor soft tissue environment, open fractures, bone loss and fracture comminution, plating and intramedullary nailing are associated with higher complication rates.^{4–7} The reported non-union rates for plate fixation are 17 and 31% for intramedullary nailing compared to 2% for circular external fixation.^{5,6} Similar, deep infection rates are higher for plating (11%) and intramedullary nailing (15%), whereas circular external fixation has published deep infection rates of 1%.^{5,6} Acceptably superficial infection rates are significantly higher for external fixation and range from 10 to 31%.^{4–6} However, these superficial infections can be easily treated and resolve with antibiotic treatment. The versatility of circular external fixation systems allowing to treat almost any fracture configuration, preservation of both endosteal and periosteal blood supply, and the construct stability allowing immediate weight-bearing suggest that these techniques are ideally placed to treat these complex injuries.

LIMITATIONS

This study has several inherent limitations. The retrospective data collection may have resulted in selection bias. The sample size was small, but similar to other studies reporting on limb salvage and treatment of fractures with hexapod circular external fixation. These are uncommon injuries, and unless multicenter studies are performed, pooling data, it would be difficult to reach significance. An a priori sample size calculation was performed, based on the ASAMI scores. None of these comparisons reached the critical χ^2 value, indicating that the collected data did fit the model and were not underpowered for this comparison. However, it cannot be entirely excluded that the other comparisons lacked appropriate statistical power. For the FFI, TUG, and FSST tests, the differences were not significant, but the F-Ratio suggests variation between the three groups. The study was performed at a single center specialized in limb reconstruction and orthopedic trauma, and all cases were treated by experienced fellowship-trained trauma surgeons, limiting the external validity of the study. The complex nature of this injury with both open and closed fractures, resulting in variability in fracture patterns, severity of soft tissue injuries, and bone loss, makes comparisons difficult and may introduce an amount of bias. The mean final follow-up in all three groups was similar and ranged from 30 to 36 months, although it is acknowledged that these differences may have subtly influenced clinical outcomes. Henderson et al. and Dickson et al. both reported that treatment of complex tibial fractures with a circular frame produced good and excellent outcomes at a minimum of 12 months when patients were treated by a specialized limb reconstruction team.^{5,8} Most importantly, O'Toole et al. reported that the final outcome following severe lower extremity injuries is determined by two years.⁴³ Considering all the clinical outcomes used here for study purposes which were obtained well beyond 24 months, it is unlikely that the minor differences in final follow-up times introduced any appreciable measurement bias.

CONCLUSION

The results of this study suggest that the functional outcomes between proximal, midshaft, and distal complex tibial fractures are similar. The ability to ambulate is comparable to age-related normative data, but complex tasks are more difficult and better compared to the ambulating ability of a healthy population aged 65–80 years. Patients with proximal tibial fractures had significantly more disability by at least one functional level and/or one health dimension.

REFERENCES

- Court-Brown CM, Wheelwright EF, Christie J, et al. External fixation for type III open tibial fractures. *J Bone Joint Surg Br* 1990;72(5):801–804. DOI: 10.1302/0301-620X.72B5.2211760.
- van der Merwe L, Birkholtz F, Tetsworth K, et al. Functional and psychological outcomes of delayed lower limb amputation following failed lower limb reconstruction. *Injury* 2016;47(8):1756–1760. DOI: 10.1016/j.injury.2016.05.027.
- Van Niekerk AH, Birkholtz FF, de Lange P, et al. Circular external fixation and cemented PMMA spacers for the treatment of complex tibial fractures and infected nonunions with segmental bone loss. *J Orthop Surg* 2017;25(2):2309499017716242. DOI: 10.1177/2309499017716242.
- Molepo M, Barnard AC, Birkholtz F, et al. Functional outcomes of the failed plate fixation in distal tibial fractures. *Eur J Orthop Surg Traumatol* 2018;28(8):1617–1624. DOI: 10.1007/s00590-018-2231-x.
- Dickson DR, Moulder E, Hadland Y, et al. Grade 3 open tibial shaft fractures treated with a circular frame, functional outcome and systematic review of literature. *Injury* 2015;46(4):751–758. DOI: 10.1016/j.injury.2015.01.025.
- Webb LX, Bosse MJ, Castillo RC, et al. Analysis of surgeon-controlled variables in the treatment of limb-threatening type-III open tibial diaphyseal fractures. *J Bone Joint Surg Am* 2007;89(5):923–928. DOI: 10.2106/JBJS.F.00776.
- Harris AM, Althausen PL, Kellam PL, et al. Complications following limb-threatening lower extremity trauma. *J Orthop Trauma* 2009;23(1):1–6. DOI: 10.1097/BOT.0b013e31818e43dd.
- Henderson D, Barron E, Hadland Y, et al. Functional outcomes after tibial shaft fractures treated using the Taylor spatial frame. *J Orthop Trauma* 2015;29:54–59. DOI: 10.1097/BOT.0000000000000192.
- Ilizarov GA. The tension-stress effect on the genesis and growth of tissues. Part I. The influence of stability of fixation and soft-tissue preservation. *Clin Orthop Relat Res* 1989;238:249–281.
- Gasser B, Boman B, Wyder D, et al. Stiffness characteristics of the circular Ilizarov device as opposed to conventional external fixators. *J Biomech Eng* 1990;112(1):15–21. DOI: 10.1115/1.2891120.
- Henderson DJ, Rushbrook JL, Harwood PJ, et al. What are the biomechanical properties of the Taylor Spatial Frame? *Clin Orth Relat Res* 2017;475(5):1472–1482. DOI: 10.1007/s11999-016-5182-8.
- Hasler C, Krieg A. Current concepts on leg lengthening. *J Child Orthop* 2012;6(2):89–401. DOI: 10.1007/s11832-012-0391-5.
- Ferreira N, Birkholtz F. Radiographic analysis of hexapod external fixators: fundamental differences between the Taylor spatial frame and Truelok-hex. *J Med Eng Technol* 2015;39(3):173–176. DOI: 10.3109/03091902.2015.1025993.
- Dammerer D, Kirschbichler K, Donnan L, et al. Clinical value of the Taylor spatial frame: a comparison with the Ilizarov and Orthofix fixators. *J Child Orthop* 2011;5(5):343–349. DOI: 10.1007/s11832-011-0361-3.
- Attal R, Hansen M, Kirjavainen M, et al. A multicentre case series of tibial fractures treated with the expert tibial nail (ETN). *Arch Orthop Trauma Surg* 2012;132(7):975–984. DOI: 10.1007/s00402-012-1502-y.
- Kim PH, Leopold SS. Gustilo-Anderson classification. *Clin Orth Relat Res* 2012;470(11):3270–3274. DOI: 10.1007/s11999-012-2376-6.
- Hohmann E, Birkholtz F, Glatt V, et al. The “Road to Union” protocol for the reconstruction of isolated complex high-energy tibial trauma. *Injury* 2017;48(6):1211–1216. DOI: 10.1016/j.injury.2017.03.018.
- Paley D, Catagni MA, Argnani F, et al. Ilizarov treatment of tibial nonunions with bone loss. *Clin Orthop Relat Res*;241:146–165.
- Budiman-Mak E, Conrad KJ, Roach KE. The foot function index: a measure of foot pain and disability. *J Clin Epidemiol* 1991;44:561–570. DOI: 10.1016/0895-4356(91)90220-4.
- EuroQol Group. EuroQol – a new facility for the measurement of health-related quality of life. *Health Policy* 1990;16(3):199–208. DOI: 10.1016/0168-8510(90)90421-9.
- Dite W, Temple VA. A clinical test of stepping and change of direction to identify multiple falling older adults. *Arc Phys Med Rehabil* 2002;83(11):1566–1571. DOI: 10.1053/apmr.2002.35469.
- Blennerhassett JM, Jayalath VM. The four square step test is a feasible and valid clinical test of dynamic standing balance for use in ambulant people post stroke. *Arch Phys Med Rehabil* 2008;89(11):2156–2161. DOI: 10.1016/j.apmr.2008.05.012.
- Wall JC, Bell C, Campbell S, Davis J. (2000) The timed get-up-and-go test revisited: Measurement of the component tasks. *J Rehabil Res Dev*; 37:109-113
- Whitaker AT, Gesheff MG, Jauregui JJ, et al. Comparison of PACS and Bone Ninja mobile application for assessment of lower extremity limb length discrepancy and alignment. *J Child Orthop* 2016;10(5):439–443. DOI: 10.1007/s11832-016-0761-5.
- Whelan DB, Bhandari M, McKee MD, et al. Interobserver and intraobserver variation in the assessment of the healing of tibial fractures after intramedullary fixation. *J Bone Joint Surg Br* 2002;84(1):15–18. DOI: 10.1302/0301-620x.84b1.11347.
- Nieuwoudt L, Ferreira N, Marais LC. Short-term results of grade III open tibia fractures treated with circular fixators. *SA Orthop J* 2016;15(3):20–26. DOI: 10.17159/2309-8309/2016/v15n3a2.
- Giotakis N, Panchani SK, Narayan B, et al. Segmental fractures of the tibia treated by circular external fixation. *J Bone Joint Surg Br* 2010;92(5):687–692. DOI: 10.1302/0301-620X.92B5.22514.
- Foster PA, Barton SB, Jones SC, et al. The treatment of complex tibial shaft fractures by the Ilizarov method. *J Bone Joint Surg Br* 2012;94(12):1678–1683. DOI: 10.1302/0301-620X.94B12.29266.
- Castellani C, Riedl G, Eberl R, et al. Transitional fractures of the distal tibia: a minimal access approach for osteosynthesis. *J Trauma* 2009;67(6):1371–1375. DOI: 10.1097/TA.0b013e31818866fd.
- Gaskill T, Schweitzer K, Nunley J. Comparison of surgical outcomes of intra-articular calcaneal fractures by age. *J Bone Joint Surg Am* 2010;92(18):2884–2889. DOI: 10.2106/JBJS.J.00089.
- SooHoo NF, Samimi DB, Vyas RM, et al. Evaluation of the foot function index in measuring outcomes in patients with foot and ankle disorders. *Foot Ankle Int* 2006;27(1):38–42. DOI: 10.1177/107110070602700107.
- Bohannon RW. Reference values for the timed up and go test: a descriptive meta-analysis. *J Geriatr Phys Ther* 2006;29(2):64–68. DOI: 10.1519/00139143-200608000-00004.
- Kear BM, Guck TP, McGaha AL. Timed Up and Go (TUG) test: normative reference values for ages 20 to 59 years and relationships with physical and mental health risk factors. *J Prim Care Community Health* 2017;8(1):9–13. DOI: 10.1177/2150131916659282.
- Moore M, Barker K. The validity and reliability of the four square step test in different adult populations: a systematic review. *Syst Rev* 2017;6(1):187. DOI: 10.1186/s13643-017-0577-5.
- Langford Z. The four square step test. *J Physiotherapy* 2015;61(3):162. DOI: 10.1016/j.jphys.2015.03.005.
- Luo N, Johnson J, Coons SJ. Using instrument-defined health state transitions to estimate minimally important differences for four preference-based health-related quality of life instruments. *Med Care* 2010;48(4):365–371. DOI: 10.1097/mlr.0b013e3181c162a2.
- Canadian Orthopaedic Trauma Society. Open reduction and internal fixation compared with circular fixation for bicondylar tibial plateau fractures. Results of a multicentre, prospective, randomized clinical trial. *J Bone Joint Surg Am* 2006;88(12):2613–2623. DOI: 10.2106/JBJS.E.01416.
- Elseo R, Larsen P, Petruskevicius J, et al. Complex tibial fractures are associated with lower social classes and predict early exit from employment and worse patient-reported QOL: a prospective observational study of

- 46 complex tibial fractures treated with a ring fixator. *Strat Traum Limb Recon* 2018;13(1):25. DOI: 10.1007/s11751-017-0301-y.
39. Ramos T, Ekholm C, Eriksson BI, et al. The Ilizarov external fixator – a useful alternative for the treatment of proximal tibial fractures. A prospective observational study of 30 consecutive patients. *BMC Musculoskelet Disord* 2013;14:11. DOI: 10.1186/1471-2474-14-11.
40. Ramos T, Karlsson J, Eriksson BI, et al. Treatment of distal tibial fractures with the Ilizarov external fixator – a prospective observational study in 39 consecutive patients. *BMC Musculoskelet Disord* 2013;14:30. DOI: 10.1186/1471-2474-14-30.
41. Schauer MS, Aravind MS, Chung KC. A qualitative study of recovery from type III-B and III-C tibial fractures. *Ann Plast Surg* 2011;66(1):73–79. DOI: 10.1097/SAP.0b013e3181d50eba.
42. Harms L, Talbot M. The aftermath of road trauma: survivors' perception of trauma and growth. *Health Soc Work* 2007;32(2):129–137. DOI: 10.1093/hsw/32.2.129.
43. O'Toole RV, Castillo RC, Pollak AN, et al. Determinants of patient satisfaction after severe lower-extremity injuries. *J Bone Joint Surg Am* 2008;90(6):1206–1211. DOI: 10.2106/JBJS.G.00492.