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Residual Deformity and Outcome in Non-surgically Treated Tibial Shaft Fractures in Adolescents Nearing Skeletal Maturity: A Cross-sectional Study

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ABSTRACT

Background. Anatomic reduction is crucial to avoid malalignment in tibial shaft fractures in adolescents quickly approaching physeal closure. While surgical treatment is becoming more common, casting and immobilization are still widely done for appropriately selected fractures. Local radiographic and clinical outcomes of non-surgical treatment need to be explored.

Objective. The primary objective of this study was to report residual lower limb deformity of tibial shaft fractures treated non-surgically in adolescents nearing skeletal maturity. The study also identified factors or fracture characteristics that may predict these deformities and reported the clinical outcomes using the Lower Extremity Functional Scale.

Methodology. This was a cross-sectional study of 31 adolescents nearing skeletal maturity at the time of injury with acute closed tibial shaft fractures treated non-surgically at the Philippine Orthopedic Center from 2017 to 2020. Skeletal maturity and residual sagittal & coronal angulation were analyzed through radiographs. Rotational alignment and leg length discrepancies were evaluated clinically. Functional outcome was measured using the Lower Extremity Functional Scale (LEFS).

Results. Coronal plane angulation (r = -0.397; p = 0.05) and leg length discrepancy (r = -0.394; p = 0.05) were inversely correlated with Lower Extremity Functional Scale (LEFS) scores. Coronal plane angulation was also correlated with ipsilateral fibular fractures (p = 0.007). Lower Extremity Functional Scale (LEFS) scores were 79.39 on average (range 75 to 80).

Conclusion. Among adolescents nearing skeletal maturity with isolated acute tibial shaft fractures, closed reduction and casting followed by close monitoring remains useful and effective.

Keywords. Filipino, IKDC, translation, validation, PROM

INTRODUCTION

Tibial fractures comprise 15.1% of all long bone fractures in children, with 6.2% of fractures occurring at the shaft. Around 70% of these cases are isolated injuries, while ipsilateral fibular fractures occur in 30% of tibial fractures.[1]

Tibial development involves three ossification centers – one in each physis and one in the shaft. The proximal epiphyseal center unites with the shaft between 14 to 16 years of age, while the distal epiphyseal ossification center closes at around 14 to 15 years of age. On the other hand, the distal fibular physis closes at 16 years of age, while the proximal fibular physis closes between 15 and 18 years of age.[1] Linear bone growth is complete in 99% of girls at a bone age of 15 years,

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while boys reach this stage at a bone age of 17 years.[2] The Risser staging is a reliable marker of remaining skeletal growth, with a Risser stage 5 determining skeletal maturity. Menarche has also been a useful marker of skeletal maturity in females, coinciding with the end of peak height velocity and skeletal maturity in girls.[1]

Most uncomplicated tibial shaft fractures in children are treated with closed manipulation and casting. However, some surgeons prefer to manage these cases surgically to attain better alignment, especially in adolescents. Acceptable parameters vary, but the following general guidelines may be used: 1) varus and valgus angulation up to 10 degrees in children younger than eight years old, and up to five degrees in children older than eight years old; 2) at least 50% of apposition; 3) up to 10 degrees of apex anterior angulation and minimal apex posterior angulation; 4) up to 1 cm of shortening.[1] Reduction to acceptable parameters is typically followed by immobilization in a long leg cast for a period of four to six weeks, before being shifted to partial weight-bearing cast or boot for another three to five weeks. Full bony union is typically expected at around eight to 12 weeks.[3] While closed reduction and casting is effective with uncomplicated tibial shaft fractures, close monitoring is required to catch compartment syndrome or loss of reduction. Complications such as a limp with an out-toeing gait after cast removal are regularly observed. Muscle weakness, muscle atrophy, and joint stiffness are also transient but expected effects of cast immobilization.[1]

Nonoperative management necessitates a functional reduction since the tibial shaft remodels poorly. Tibial shaft fractures with associated fibular fractures may also develop valgus malignment, while 60% of tibial shaft fractures with an intact fibula will develop varus angulation in the first two weeks. Deformities in a single plane are more likely to remodel, especially apex anterior and varus angulation. On the other hand, apex posterior angulation, valgus malalignment, and multiplanar deformities have less remodeling potential. Rotational deformities do not remodel. Any symptomatic malrotational malunion greater than 10 degrees requires a derotational osteotomy.[3] A systematic review and meta-analysis by Stenroos et al. showed a malunion rate of 4% in non-surgically treated tibial shaft fractures in children.[4]

A retrospective review of 57 adolescents with displaced closed tibial shaft fractures treated with closed reduction and casting reported that failure is predicted by 20% displacement and concurrent fibular fractures. Of these cases, 40% required surgical stabilization. Patients treated with intramedullary nailing had a better final alignment (92.5% vs. 72.4%, $p = 0.10$) but had longer hospitalization (5.4 vs. 1.9 d, $p < 0.001$), and a higher incidence of anterior knee pain (20% vs. 0%, $p < 0.01$).[5]

In a large Finnish epidemiological study that involved 296 patients under 16 years old treated for tibial shaft fractures across six years, 47% of children were treated with casting at the emergency department, 22.3% underwent closed manipulation under anesthesia, and 30.4% were treated with surgery. Patients treated surgically were more likely to have a concomitant fibular fracture (46/66 vs 52/214, $p < 0.001$), were older (13.08 ± 2.4 vs 6.4 ± 3.7, $p < 0.001$), and had greater primary angulation (6.9 ± 5.8 vs 0.48 ± 3.1, $p < 0.001$). In the group who underwent casting at the emergency room, the median primary angulation of tibia fractures was 0° (range 0° to 5°). The group who underwent closed manipulation under anesthesia had a median primary angulation of 3° and a median primary displacement of 3 mm. The surgically treated group had a median primary angulation of 6.7° and a median primary displacement of 7 mm.[6] In another national database study in the United States from 2000 to 2012 covering 24,166 tibial shaft fractures, 15,621 (67.7%) were treated surgically and multivariable regression showed that increasing age was associated with an increased rate of surgical treatment ($p < 0.001$).[7]

Given the increasing trend of surgical treatment of tibial shaft fractures, especially among adolescents, this study presents the adequacy of reduction, alignment, and functional outcomes of closed tibial shaft fractures treated non-surgically in our institution.

The main objective of this study was to report residual lower limb deformity (defined as any angular deviation from the normal long bone axis) of tibial shaft fractures treated non-surgically in adolescents nearing skeletal maturity, identify factors or fracture characteristics that may predict these deformities, and report the clinical outcomes using the Lower Extremity Functional Scale.

METHODOLOGY

This cross-sectional study investigated non-surgically treated tibial shaft fractures in adolescents nearing skeletal maturity at the Philippine Orthopedic Center from 2017 to 2020 through a purposive sampling method. The study included Filipino adolescents aged 11 to 16 years old with acute tibial shaft fractures treated non-surgically with closed manipulation and casting at our institution's Emergency Department [ED] and have reached skeletal maturity at the time of the investigation. Closed reduction and casting at the ED were selected by the respective attending orthopaedic surgeons based on their clinical assessment. The age range was chosen to ensure that, theoretically, no more bone remodeling will likely take place after investigation and that the radiographic and clinical measurements will be carried over into adulthood. Patients nearing skeletal maturity were defined as those with Risser stages 0 to 4 on pelvis anterior-posterior (AP) radiographs taken at the initial consult and a Risser stage 5 on the day of evaluation for the study. To check for skeletal maturity, full-length radiographs of both legs were obtained and the proximal epiphysis was checked for complete closure in both lateral and anteroposterior radiographs, along with a Risser score of 5 on final pelvis AP radiographs.

Excluded from the study were patients with polytrauma, open fractures, other lower extremity injuries, neuromuscular disorders, muscular dystrophy, connective tissue disorders, metabolic conditions, and other systemic conditions that affect bone growth.

After approval was obtained from the Ethics Review Board, patients were selected based on the established inclusion and exclusion criteria and consent was obtained. Data collection was done through a retrospective chart and radiographic review, along with patient interviews.

Demographic information was collected, including age, gender, affected extremity, number of days from injury to treatment, fracture pattern (simple transverse, simple oblique, simple spiral, or multifragmentary), presence of ipsilateral fibular fracture, time to radiographic union, and time to full weight-bearing. Time to full weight-bearing was assessed from the patient's recall of the physician's instruction of full weight-bearing ambulation. For females, the age of menarche was also documented.

Radiographic measurements were taken from the most recent whole-leg radiograph accessed through our institution's PACS system. Tibial torsion or rotation was measured clinically using the tibial-foot angle, performed by the principal investigator, and compared with the contralateral lower extremity. Leg length discrepancy was measured using the standard measurement of true leg length, using the anterior superior iliac spine, patella, and medial malleolus as markers. This was compared with the contralateral lower extremity on the day of examination.

Functional outcomes of all patients were measured using the Lower Extremity Functional Scale (LEFS) administered by the principal investigator on the day of the investigation, a patient-reported outcome measure shown to be reliable, valid, and responsive in assessing patients who sustained tibial shaft fractures.[8,9]

Sample size calculation

The minimum number of patients was determined based on the reported incidence of tibial shaft fractures in children at 1.1%.[1] At a confidence level = 95% and a margin of error of 5%, the number of patients required to provide correlation was 20. This number considers a 15% allowance for anticipated dropout.

Statistical analysis

Data were encoded and tallied in SPSS version 23 for Windows. The data were analyzed through descriptive statistics using means and standard deviation to describe the demographic, radiographic, and functional outcome scores of each patient. Descriptive statistics were generated for all variables. For nominal data, frequencies and percentages were computed. For numerical data, mean ± SD was generated, as well as the range. Bivariate correlation of the coronal and sagittal angulation was done using Pearson Correlation. Comparison of fracture pattern with LEFS score, coronal angulation, and sagittal angulation were analyzed using T-test. Finally, a comparison between the presence of fibular fracture coronal and sagittal angulation was done using the Mann-Whitney U test and T-test.

RESULTS

A total of 31 adolescents nearing skeletal maturity with non-surgically treated tibial shaft fractures at the Philippine Orthopedic Center from 2017 to 2020 were included in the study. Their age ranged from 11 to 16 years with a mean of 13.45 years (SD = 1.71 years) (Table 1). Time from injury to consult ranged from 0 to 6 days with a mean of 2.68 days (SD = 2.16 days). Among the 31 patients, 6 (19.4%) were females and 25 (80.6%) were males. Of the female patients, 3 (50%) had menarche at 13 years, 2 (33.3%) at 14 years, and 1 (16.7%) at 15 years, with an average age of menarche of 13.67 years old. Most cases were caused by vehicular accidents (VA) at 58.1%, followed by sports injuries and falls at 38.7% and 3.2%, respectively. Left tibia injuries were more predominant at 54.8%, as opposed to right tibia injuries at 45.2%.

Oblique fractures were the most common fracture patterns at 64.5%, followed by 11 (35.5%) spiral fractures. There were no transverse fractures seen in the pool of patients. Fibular fractures were noted in 11 (35.5%) patients (Table 2). Weeks to cast removal ranged from 12 to 16 weeks with a mean of 13.55 weeks, while weeks to full weight bearing ranged from 12 to 24 weeks with a mean of 14.32 weeks.

The tibial-foot angles of injured extremities ranged from 8 to 20 degrees, with a mean of 12.90 degrees. While the tibia-foot angles of uninjured extremities ranged from 5 to 20 degrees, with the same mean at 12.90 degrees. Three (9.7%) had leg length discrepancies, two cases had a 1 cm shortening of the injured leg and one had a 1 cm lengthening of the injured

Table 1. Demographic and clinical characteristics of subjects

	Frequency (%); Mean ± SD (n=31)
Age (in years)	13.45 ± 1.71
11	4 (12.9%)
12	8 (25.8%)
13	4 (12.9%)
14	5 (16.1%)
15	5 (16.1%)
16	5 (16.1%)
Sex	
Male	25 (80.6%)
Female	6 (19.4%)
Days from injury	2.68 ± 2.16
Menarche (age in years)	13.67 ± 0.82
Mechanism of action	
Fall	1 (3.2%)
Sports	12 (38.7%)
VA	18 (58.1%)
Laterality of tibia fracture	
Left	17 (54.8%)
Right	14 (45.2%)

leg. Twenty-two (71.0%) subjects had no coronal plane (i.e. varus or valgus) angulations, while 9 (29%) subjects had valgus angulations. Three (9.7%) subjects, on the other hand, had posterior angulations, with the remaining 28 (90.3%) having no sagittal plane angulation. Finally, Lower Extremity Functional Scale (LEFS) scores ranged from 75 to 80 with a mean of 79.39 (Table 3).

LEFS was significantly correlated with coronal plane (i.e. varus or valgus) angulation and leg length discrepancy (Table 4). Significant inverse correlations were noted, which means that as coronal plane (i.e. varus or valgus) angulation (r = -0.397; p = 0.05) or leg length discrepancy (r = -0.394; p = 0.05) increases, LEFS increases, and vice versa. On the other hand, no significant correlation was noted between LEFS and sagittal plane (anterior or posterior) angulation (r = 0.056; p = 0.76) or LEFS and tibial-foot angle (injured) (r = -0.145; p = 0.44).

There was no significant difference in the LEFS of patients with oblique or spiral patterns, (p = 0.55) (Table 5). Coronal and sagittal angulation did not correlate with fracture pattern (p >0.05) (Table 6). The presence of a concurrent fibular fracture correlated with coronal angulation (p = 0.007), but not with sagittal angulation (p = 0.94) (Table 7).

DISCUSSION

This study showed that non-surgical management of isolated tibial shaft fractures in children nearing skeletal maturity remains effective and reliable in providing acceptable radiographic outcomes and good clinical outcomes. All 31 patients had acceptable reductions.[1] Long cast immobilization was prescribed for four to six weeks, at which point the patients were transitioned to partial weight bearing with cast boot or short leg immobilization. In this cohort, however, 14 (45.20%) of them surpassed 12 weeks,[3] probably due to the out-patient scheduling, patient logistical concerns, availability of resources, or surgeon's preference of extending immobilizations. Unfortunately, interval data showing conversion immobilization and initiation of partial weight-bearing were not readily available. This points to an

Table 2. Fracture characteristics and clinical progress

	Frequency (%); Mean ± SD (n=31)
Fracture pattern	
Oblique	20 (64.5%)
Spiral	11 (35.5%)
Fibular fracture	
Yes	11 (35.5%)
No	20 (64.5%)
Weeks to cast removal	13.55 ± 1.84
12	17 (54.8%)
14	4 (12.9%)
16	10 (32.3%)
Weeks to full weight-bearing	14.32 ± 2.64
12	13 (41.9%)
14	5 (16.1%)
16	11 (35.5%)
18	1 (3.2%)
24	1 (3.2%)

Table 3. Clinical and functional outcomes

	Frequency (%); Mean ± SD (Range) (n=31)
Tibial-foot angle injured (degree)	12.90 ± 2.30 (8 – 20)
Tibial-foot angle uninjured (degree)	12.90 ± 2.40 (5 – 20)
Leg length injured (cm)	88.10 ± 4.04 (76 – 93)
Leg length uninjured (cm)	88.13 ± 3.93 (77 – 92)
Leg length discrepancy	
Yes	3 (9.7%)
No	28 (90.3%)
Coronal angulation (degree)	1.03 ± 1.88
0	22 (71.0%)
1 – 5	8 (25.8%)
6 – 10	1 (3.2%)
Sagittal angulation (degree)	0.26 ± 0.82
0	28 (90.3%)
1 – 5	3 (9.7%)
6 – 10	0 (0.0%)
Lower Extremity Functional Scale (LEFS)	79.39 ± 1.38 (74 – 80)

Table 4. Pearson correlation of LEFS with coronal and sagittal angulation

	Correlation coefficient	*P* value
LEFS and coronal angulation	-0.397	0.05 (S)
LEFS and sagittal angulation	0.056	0.76 (NS)
Leg length discrepancy	-0.394	0.05 (S)
Tibial foot angle (injured)	-0.145	0.44 (NS)

Table 5. Distribution of diagnoses

	n	Mean ± SD	*P* value
Fracture pattern			
Oblique	20	79.50 ± 1.36	0.55 (NS)
Spiral	11	79.18 ± 1.47	

*p >0.05 – Not significant; p ≤0.05 – Significant; T-test

Table 6. Comparison of coronal and sagittal angulation according to fracture pattern

		n	Mean ± SD	*P* value
Coronal angulation	***Fracture pattern***			
	Oblique	20	0.85 ± 2.01	0.48 (NS)
	Spiral	11	1.36 ± 1.69	
Sagittal angulation	***Fracture pattern***			
	Oblique	20	0.15 ± 0.67	0.33 (NS)
	Spiral	11	0.46 ± 1.04	

*p >0.05 – Not significant; p ≤0.05 – Significant; T-test

Table 7. Comparison of varus/valgus and anterior/posterior angulation according to fibular fracture

		n	Mean ± SD	*P* value
Varus/valgus angulation	***Fibular fracture***			
	Yes	11	2.55 ± 2.30	0.007 (S)†
	No	20	0.20 ± 0.89	
Anterior/ posterior angulation	***Fibular fracture***			
	Yes	11	0.27 ± 0.90	0.94 (NS)‡
	No	20	0.25 ± 0.78	

*p >0.05 – Not significant; p ≤0.05 – Significant; †Mann Whitney U test; ‡T- test

opportunity to refine our protocols to maximize earlier cast removal and weight-bearing once fracture healing allows.

Clinical outcomes, based on the Lower Extremity Functional Scale (LEFS) scores, showed excellent results. A significant inverse correlation was found between coronal angulation and LEFS score, and leg length discrepancy and LEFS score. This was supported by literature showing that varus malalignment and shortening affect clinical outcomes in tibia fractures.[10] The correlation between sagittal angulation and thigh-foot angle with LEFS, on the other hand, was shown to be non-significant. This was in contrast with evidence supporting the correlation between malrotation and poor satisfaction in pediatric tibial shaft fractures.[11] Fracture pattern was not found to correlate with LEFS score, coronal angulation, and sagittal angulation.

Finally, the presence of fibular shaft fracture showed a significant correlation with coronal angulation, typically valgus. This supports the established risk factor of valgus malalignment and eventual malunion in tibial shaft fractures with concomitant fibular shaft fracture.[10,11] The correlation between fibular fracture and sagittal angulation was non-significant.

However, these results should be viewed with reservations. First, due to the small sample population of this study. Among the 112 patients identified to be within our inclusion criteria, only 31 responded. Second, there may be selection bias in recruitment due to the purposive sampling method utilized. This meant that the patients that were included were already deemed to be ideal candidates for non-surgical management. Patients with more comminuted fracture patterns, those with greater initial angulations, or those who failed closed reduction at the Emergency Department and subsequently underwent surgical management were not included. There is an opportunity for a larger, randomized study to evaluate and compare different treatment options. Finally, there is a gap in information between the initial consult and the time of this study's investigation. No data regarding interval follow-ups were collected.

This study shows the good outcomes with casting and immobilization in appropriately selected tibial shaft fractures in the adolescent population. With the increase in non-surgical management of these injuries during the COVID-19 pandemic due to different government guidelines,[12] the efficacy of this treatment option remains reliable and easily applicable. A continuation of this investigation to monitor the radiographic and clinical outcomes of these patients may be warranted to further evaluate its efficacy and reliability in the background of its extended indication during these times.

CONCLUSION

The radiographic and clinical outcomes of adolescents nearing skeletal maturity with isolated acute tibial shaft fractures treated non-surgically showed that the current method of closed reduction and casting followed by close monitoring provides good clinical outcomes. This further establishes the role of non-surgical management in appropriately selected cases of tibial shaft fractures in adolescents. A larger randomized study comparing non-surgical with surgical management may provide more conclusive results.

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AUTHORS DISCLOSURE

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