Treatment of Closed Tibia Shaft Fractures in Children: A Systematic Review and Meta-Analysis

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Abstract

Tibia fractures are among the most common long-bone fractures in children. Despite this, there is no current consensus on the optimal treatment strategy for closed displaced tibia shaft fractures in the pediatric patient population. The aim of this study is to compare the reported complications and outcomes of reduction and cast immobilization versus flexible intramedullary nailing in the treatment of pediatric tibia shaft fractures. We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement when conducting and reporting this prospectively registered systematic review. Eleven studies were included. Quality of the studies was assessed using the Coleman methodology score. Mantel–Haenszel cumulative odds ratios were used to compare the risk of complication between different methods of treatment. Eleven studies including 1,083 patients with diaphyseal fractures of the tibia met the inclusion criteria. The most common fracture type was simple 42-A (782; 91%). Majority (75%) of the patients were treated nonoperatively. The total complication rate was higher among operatively treated patients (24 vs. 9%; $p < 0.05$). Satisfactory fracture alignment had to be restored surgically in 5% of the primarily nonoperatively treated patients. The evidence levels of the included studies were II (1), III (2), and IV (7). Three-fourths of closed diaphyseal fractures of the tibia in children are still treated with reduction and cast immobilization. Flexible intramedullary nailing is associated with significantly higher complication rate than nonoperative treatment.

Keywords

- tibia fracture
- children
- elastic intramedullary nailing of tibia
- flexible intramedullary nailing of tibia
- pediatric lower leg fractures

Introduction

There are numerous publications defining treatment strategies of tibia shaft fractures in adults,[1] but there is very limited information about the optimal treatment of displaced diaphyseal fractures of the tibia in children and adolescents.

Most shaft fractures of the tibia in pediatric patients have been traditionally treated with reduction and cast immobilization with good long-term outcomes.[2–5] Surgical treatment has been considered in patients who have sustained an open fracture or multiple injuries.[6,7] However, children and adolescents with comminuted or unstable fractures may benefit from internal or external fixation.[7] Internal fixation can be performed with flexible intramedullary nails (FINs), rigid intramedullary nails (RIN), plates, screws, or pins. FIN has recently gained more and more popularity in the treatment of tibia shaft fractures in pediatric patients who weigh less than 50 kg. RIN is advocated in heavier adolescents close to skeletal maturity.[8]

The aim of this study is to answer the following questions. What is the most common fracture type and method of

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treatment in closed isolated tibia fractures? What is the risk of complications and poor outcomes with nonoperative treatment and FIN? Do fractures that have been internally fixed heal faster than fractures treated with cast-immobilization? What is the quality of the available literature?

Materials and Methods

Protocol and Registration

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement when conducting and reporting this prospectively registered systematic review (PROSPERO registration ID: CRD42018110734). We included in the analysis only those fractures that were treated with FIN or cast immobilization due to the small number of patients treated with other methods.

Eligibility Criteria

Studies were included in this systematic review if they matched the following criteria: (1) the article was written in English, (2) the article was published in a peer-reviewed journal, (3) the series reported had a minimum of 20 closed isolated tibia shaft fractures, (4) open fractures and other fractures than diaphyseal tibia fractures could be separated in the body of the text, (5) all patients included in the study were younger than 18 years, (6) the minimum follow-up was 6 months, (7) patients treated with external fixation, pins, or plates could be separated, and (8) complications and adverse events were reported.

Two authors (A. S. and J. K.) separately assessed all identified publications for eligibility and resolved any disagreements by consensus, after which one of the authors (J. P.) reviewed the results and approved the selected studies based on the aforementioned criteria.

Sources and Data Search

To answer the question about the outcomes of closed tibia fractures in children, in October 2018, we searched Medline, the Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials (CENTRAL), Embase, and CINAHL. The search terms were "Lower leg fractures in children," "Tibia fractures in children," "Elastic Intramedullary nailing of tibia," Flexible intramedullary nailing of tibia" "Pediatric tibia fractures," "Pediatric lower leg fractures," and "Pediatric lower extremity fractures." There were no restrictions on the publication date. Additionally, we assessed the reference lists of the included articles and related reviews to identify any other studies that were missed in the electronic database search. We also searched the World Health Organization International Clinical Trials Registry Platform (WHO ICTRP) (www.who.int/ictrp) in October 2018 for registrations of the included RCTs, possible completed but unpublished RCTs, and ongoing RCTs.

Data Extraction and Quality of the Studies

All data were extracted to a customized worksheet separately by two authors. Researchers (A. S. and J. K.) independently assessed the quality of the studies using the Coleman methodology score (CMS).[9] Where differences were encountered, agreement was achieved by consensus. The presented scores are those that were set by agreement. Furthermore, CMSs and interobserver reliabilities were examined.

Data Synthesis and Analysis

We extracted the following information regarding the study characteristics and participants: study objectives, inclusion and exclusion criteria, number of patients, follow-up time, sex distribution, mean age, mechanism of injury, indications for surgery, method of treatment, and reported harms. When possible fractures were grouped according to the AO classification,[9] none of the chosen studies used the pediatric AO classification.[10]

Complications were classified into minor and major complications. A minor complication was defined as an event that might not require an unplanned surgical intervention and would not affect future growth and/or function. This includes but is not limited to mild malunion,[2] superficial wound infection, loss of fracture alignment in operatively treated patient, nail migration, and delayed union. A major complication was defined as a problem requiring unplanned surgical intervention, with potential sequela on future growth and/or function, including redo operations, nonunion, major malunion, refracture, and deep infection. The acceptable alignment criterion cited by Heinrich et al and Canavese et al[11] was used (under the age of 8 years/over the age of 8 years): valgus 5/5 degrees, varus 10/5 degrees, procurvatum 10/5 degrees, recurvatum 5/0 degrees, shortening 10/10 mm, and rotation 5/5 degrees. Fasciotomy was not registered as a complication; unnoticed compartment syndrome was regarded as a major complication.

Where possible, pooling of data was undertaken, and means and 95% confidence intervals were calculated. Linear regression analysis was performed to determine if there was a trend in treatment pattern over time. Fisher's exact test was used to assess the significance of differences between complication rates in different methods of treatment. A cumulative meta-analysis fixed effects model was then constructed with the Mantel–Haenszel technique to describe the odds of complication by the type of treatment. We performed meta-analyses of clinically homogenous studies. For interrater reliability, intraclass correlation (ICC) estimates and their 95% confident intervals were calculated using SPSS statistical package based on a mean rating ($k = 3$), consistency, and two-way mixed-effects model. All analyses were performed using SPSS 22 for Windows (Released 2013, IBM Statistics for Windows, Version 22.0, IBM Corp., Armonk, New York, United States).

Results

The literature search yielded 1,922 reports after exclusion of duplicates. After full-text review, 10 publications[5,10–18] were included (►Fig. 1). A thorough review of the bibliographies of the remaining studies was performed, and one[8] additional publication was identified through this method. Of the 11 included studies, 4 studies[10,11,17,18] included both

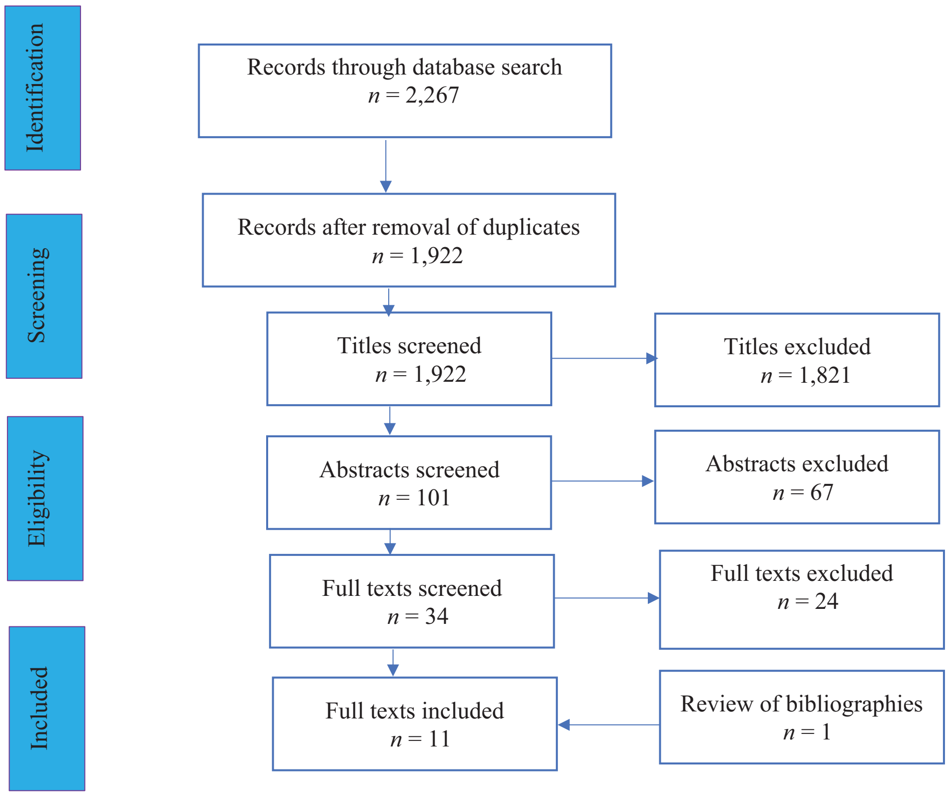

Fig. 1 Study accrual flow chart.

nonoperative treatment and operative treatment, 4 studies[5,12–14] treated all isolated closed fractures nonoperatively, and 2 studies[8,16] included only patients who were treated with FIN. One study[15] compared early and late weightbearing in nonoperatively treated patients.

Of the excluded full texts, the most common reason for exclusion was that open fractures could not be separated (10 studies)[19–28] followed by studies with too small population (7 studies).[29–35] In two studies,[36,37] distal tibia fractures were no distinguishable from diaphyseal fractures, and two studies[38,39] reported only the incidence of compartment syndrome. Three additional studies reporting only epidemiological data,[40] surgical technique,[41] and long-term outcomes,[42] respectively, were excluded.

Demographic Data

Eleven studies including 1,108 fractures of the tibia met all of the inclusion criteria. Two studies[10,18] included 32 duplicate patients, who were excluded from analyses. Gender information was provided for 1,057 patients (nine studies[8,10,11,13,16,18]), of whom a vast majority were boys (753, 71%). The mean patient age ranged from 8 to 14 years, and the weighted average age at the time of injury was 9.7 years (range: 0–17 years). The mean follow-up ranged from 12 to 324 months (►**Table 1**).

Information of fracture types according to the AO classification was provided in eight studies ($n = 866$).[8,10,11,16–18] The most common fracture type was simple 42-A (782, 91%) followed by wedge 42-B (53; 6%) and comminute 42-C (31; 3%). Six studies[10,11,13,14,16,18] divided type A fractures further into spiral, oblique, and transverse. The most common type A fracture was spiral (392; 62%) followed by oblique (152; 23%) and transverse (95; 15%).

Data on associated fibula fracture were provided in four studies,[10,14,17,18] and two studies[11,13] included only patients with intact fibula. In the studies that provided data on fibula fracture ($n = 660$), 267 (40%) patients had an associated fibula fracture.

Treatment

Majority of the patients were treated nonoperatively (75 vs. 25%). (►**Table 2**), though patients with dislocated fractures were more likely treated with FINs (60 vs. 40%; $p < 0.05$). Patients treated with FIN were more likely to be older than conservatively treated (12.6 vs. 9.3 years; $p < 0.05$). When comparing patients with intact fibula and fibula fracture, patients with associated fibula fracture were more likely treated operatively than patients with intact fibula (50 vs. 20%; $p < 0.05$). Length of immobilization was provided in six studies ($n = 604$).[5,10,11,14,15,18] There was great variation in immobilization times among nonoperatively treated patients, and the mean immobilization ranged from 4.9 to 17.4 weeks. The weighted average immobilization was 8.5 weeks.

Loss of Reduction

All but one study[16] reported the loss of fracture reduction during the follow-ups. Fracture alignment was partially lost (5- to 15-degree varus or recurvatum) during the first 3 weeks of follow-up in 198 (24%) nonoperatively treated

Table 1 Demographics of studies meeting inclusion criteria

Author	Year	Country	Study period	Study size	Female/male	Mean age	Level of evidence
Hansen et al	1978	Denmark	1971–1972	85	33/69		IV
Yang and Letts	1997	Canada	1990–1993	95	34/61	8.11 (0–17)	IV
Griffet et al	2011	France	2000–2006	86	19/67	11.8 (2.5–17)	IV
Silva et al	2012	United States	2007–2009	81		10.5 (1–15)	II
Palmu et al	2014	Finland	1980–1989	94	30/64	9 (0–15)	IV
Ho et al	2015	United States	2002–2008	75	18/57	13.3 (10–17)	IV
Marengo et al	2015	France	2010–2014	26	7/19	13.5 (11–16)	IV
Kinney et al	2016	United States	2004–2011	74	11/63	14.2	III
Canavese et al	2016	France/Italy	2010–2012	80	24/56	9	III
Stenroos et al	2018	Finland	2010–2015	266	63/141	8.1 (1–15)	IV
Stenroos et al	2018	Finland	2010–2014	164	49/115	8.1 (1–15)	IV

Table 2 Comparison of methods of treatment in the included studies

Author	Cast immobilization, *n*	Mean age	Fibula fracture, *n*	Finland, *n*	Mean age	Fibula fracture, *n*
Hansen et al	85					
Yang et al	89	8.1				
Griffet et al				86	11.8	33
Silva et al	81	10.5				
Palmu et al	89	9				
Ho et al	75	13.3	23			
Marengo et al				26	13.5	
Kinney et al	57	13.9	42	6	15.2	9
Canavese et al	54	8		26	11.1	
Stenroos et al	211	7.7	35	55	12.7	39
Stenroos et al	87	10	31	77	13.5	55
Total	828	9.3	131	278	12.6	136

patients and in seven FIN-treated patients (2%). In nonoperatively treated patients, satisfactory alignment was retained in 153/198 cases in the outpatient clinic by remanipulation or by wedging the cast. Of all primarily nonoperatively treated patients, 45 (5%) had eventually their fractures internally fixed because satisfactory fracture alignment could not be maintained by cast immobilization. When analyzing the data from studies that provided data on fibula fracture, the fracture alignment was more likely lost among patients with fibula fracture than in patients with intact fibula (38 vs. 21%; $p < 0.05$).

Adverse Events

The total complication rate was higher among operatively treated patients (24 vs. 9%; $p < 0.05$) (►Table 3). All nonunions ($n = 4$) were among children with operative treatment, and operatively treated patients were more likely to suffer from delayed union (13 vs. 4%; $p < 0.05$). Mean time to union was impossible to measure due to diverse methods and definitions of union in different studies, but all studies agreed that time to union was longer in older children.

All major malunions (4; 0.4%) were registered in operatively treated patients, whereas nonoperatively treated patients were more likely to suffer from mild malunion (4 vs. 0.3%; $p < 0.05$). Twelve patients had reactive bursitis or pain at nail tip site, which led to unplanned removal of the nails in eight patients. Four (1%) patients had a superficial wound infection. No deep infections were recorded.

A cumulative fixed-effects model was calculated using the Mantel–Haenszel technique to determine cumulative odds of a major complication by method treatment. The odds of both nonunion and major malunion in operative treatment compared with that in nonoperative treatment was 8.0 ($p < 0.05$). The same model was used to assess the risk of minor complications and nonoperatively treated patients

Table 3 Comparison of complications between nonoperative treatment and operative treatment

	Major complications			Minor complications					
	Nonunion	Malunion major	Redo operations	Cast score	Delayed union	Malunion mild	Unplanned operation due to nail pain	Wound infection	Total
Cast			3 (0.4%)	7 (0.8%)	34 (4%)	35 (3%)			79 (9%)
FIN	4 (1%)	4 (1%)	5 (2%)	2 (0.7%)	38 (13%)	4 (1%)	8 (3%)	4 (1%)	69 (24%)

Abbreviation: FIN, flexible intramedullary nail.

were 6.2-fold more likely to suffer from mild malunion ($p = 0.01$), whereas FIN-treated patients were 36.8-fold more likely to suffer from delayed union ($p < 0.05$).

Fasciotomy was performed in 22 (8%) surgically treated patients with clinically evident or suspected compartment syndrome. Five of these 22 fasciotomies were performed within 24 hours after the primary procedure, requiring an additional anesthesia. Normalization of muscle color was registered intraoperatively in all 22 cases, and no permanent injuries were recorded.

Quality Assessment

There was minimal disagreement regarding grading of the quality of the studies between the two examiners. The ICC was 0.96, indicative of substantial agreement between the two examiners. Disagreement occurred only in two studies.[8,11] After agreement was obtained, the values presented are those set by agreement between the two examiners (A. S. and J. K.). The mean CMS for the 11 studies was 32.5 of 100 (standard deviation = 14.2; range: 19–64), indicative of poor methodological quality. CMS score was poor in all but one study.[15] Only two studies recruited patients.[5,15] The remaining nine studies retrospectively reviewed patients' medical records. Only one of the studies included a validated outcome measure,[15] and none of the studies included a general health quality measure. Funnel plots were also created to assess publication bias, and symmetric plots with no significant publication bias were found. We also regressed the number of patients by year of publication to assess for publication bias by year; this regression found no significant publication bias by year ($p = 0.6$).

Discussion

This systematic review was performed to answer the following questions. What is the risk of complications in nonoperative versus operative treatment of pediatric tibial shaft fractures? Do internally fixed fractures heal faster than fractures treated with cast immobilization?

The patients treated with FIN had a higher rate of complications than nonoperatively treated patients. The lower rate of complications in nonoperatively treated children can be at least partially explained by the relatively younger age and often more benign fracture type compared with the children treated with FIN. The most common complication among all children was delayed union, but 93% of the children with delayed union were from the same study.[17] We tried to contact the authors to determine the definition of delayed union in their study. Also, most nonoperatively treated patients (72%) with mild malunion were from one study.[12] Undoubtedly, there is subtle variation between study populations that may account for union rates, even among similar operative treatment modalities. The complication rate was still significantly higher in operatively than nonoperatively treated children (12 vs. 2%) if the two aforementioned studies were excluded. These results should be, however, interpreted with caution due to differences in the methodology of the 11 different studies that were included in this meta-analysis.

The results of this review imply that a partial loss of fracture alignment in nonoperatively treated patients is relatively common. Multiple follow-up radiographs and outpatient visits, ability to wedge the cast, performing a remanipulation, or treating the fracture surgically to ensure healing in satisfactory alignment are required. Nonoperatively treated patients should thus be counseled that a transition to surgical treatment might be necessary. Risk factors for failed nonoperative treatment are somewhat unclear. Kinney et al[17] found that associated fibula fracture and initial fracture displacement greater than 20% represent independent risks factors for operative treatment, whereas three studies[10,11,13] proposed that an intact fibula can lead to varus angulation and therefore to operative treatment. The results in this meta-analysis imply that associated fibula fracture can be a risk factor for lost fracture alignment among conservatively treated patients.

This review indicates that the majority of the closed tibial shaft fractures are treated with cast immobilization, but the rate of operative treatment is significantly higher among patients with dislocated fractures and/or associated fibula fracture. In general, the primary indication for operative treatment is the inability to achieve and maintain acceptable alignment by nonoperative means until union occurs.[7] However, the indications for operative treatment were poorly documented in all 11 studies included in this review. We noted that internal fixation of displaced pediatric tibial shaft fractures has become more popular than before. In studies conducted from the 1970s to 2000s,[5,12,13] all closed fractures were treated with cast immobilization, whereas in recent publications, the rate of surgical treatment varies between 29 and 100%.[8,10,11,14,16–18]

This systematic review cannot answer the question of whether internal fixation of pediatric tibial shaft fractures heal faster than fractures treated nonoperatively because the heterogeneity of the measurement methods made it impossible to draw any reliable conclusions. However, younger children (<10 years old) were generally associated with more rapid fracture union despite the method of treatment. This suggests that when treating tibia fractures, it is appropriate to distinguish between younger and older children. The age of 10 years may serve as a cutoff for this purpose.[18]

There was a large variation in immobilization times and when weightbearing is allowed. Ho et al[14] reported that 59% patients had more than 3 months (range: 92–218 days) of immobilization, whereas in one study,[18] the longest immobilization time was 10 weeks. Early weightbearing was seldom allowed, although early weightbearing is possible and probably beneficial for FIN-treated patients with transverse fractures. The explanation to this dilemma might be the tradition to immobilize children with fractures. Indications for postoperative casting after FIN were not reported in any of the studies. Some patients might benefit from additional stability provided with a cast due to the semirigid fixation with FIN, but in two studies,[8,16] all patients were treated successfully without postoperative cast immobilization. To our knowledge, there are no studies comparing outcomes on patients with or without postoperative immobilization.

We noted that literature describing treatment and outcomes of closed tibial fractures in children is of poor quality. It consists mostly of retrospective analyses based on patients' medical records. Results were usually presented in a nonsystematic way, and several different methods of treatment were used for similar conditions. Indications for operative treatment were poorly documented, and most often the method of treatment was chosen according to treating surgeon's preference. Due to the aforementioned reasons, we could not point out the optimal treatment for closed tibial shaft fractures and removed it from the original aims of this systematic review. Optimal treatment of closed tibial fractures in children remains a complex orthopedic challenge. Further research is needed to improve our understanding of the interaction between biological age, severity of injury, and type of fracture fixation and how they relate to time to union and complications. Therefore, carefully designed randomized controlled trials including a large number of children in different age groups with closed tibial fractures are needed. Patients should be assessed by the rate of reoperations and complication and by the time to union. A patient-reported outcome measure would be essential. Assessment of pain, absence from school, return to normal activities, and social aspects should be performed.

There are limitations to this study. We did not have access to the raw data for each study, which limited our analysis or prevented further stratification, including outcome according to associated fibula fracture. It would have been interesting to categorize fractures into isolated tibia fractures and fractures with associated fibula fractures. A systematic review of this nature is inherently limited by the heterogeneity of the individual studies in terms of fracture classification, means of initial displacement, outcome scoring systems, and cataloging of complications. Furthermore, problems with inference, including bias, confounding, and random chance inherent to the individual observational retrospective studies utilized in this review, are not improved by pooling the data.

Conclusion

Three-fourths of closed diaphyseal fractures of the tibia in children are still treated with reduction and cast immobilization. Flexible intramedullary nailing is associated with significantly higher complication rate than nonoperative treatment. The quality of studies reporting on tibia fractures in the pediatric population is poor. Better quality prospective studies are required to quantify the effects of different treatment methods.

Conflict of Interest
None declared.

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