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REVIEW

Pediatric tibia and femur fractures in patients weighing more than 50 kg (110 lb): mini-review on current treatment options and outcome

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Abstract

The main objective of this paper is to review the current literature on treatment of tibial and femur fractures in children and adolescents guided by body weight in patients weighing 50 kg (110 lb) or more. A secondary aim of this mini-review was to determine, as per literature review, whether weight > 50 kg (110 lb) is an identifiable factor associated with increased complication rate. A search of the PubMed/MEDLINE, EMBASE and Cochrane Database of Systematic Reviews databases from 1954 to September 2017 was performed to identify papers related to pediatric tibia and femur fractures in children weighing more than 50 kg (110 lb). Abstracts were screened, and relevant full-text articles were retrieved for further review. Reference sections of identified papers were also screened to identify further literature. All levels of evidence were included. Overall, seven full-text articles dealing with pediatric tibia or femur fractures in patients weighing more than 50 kg (110 lb), and one article reporting on both femur and tibia fractures in this patients' population, have been identified ($n = 8$ full-text article included). The articles reviewed a total of 679 children. In particular, 48/438 femur shaft fractures (mean weight: 51.7 kg or 113.9 lb) and 91/241 tibia fractures (mean weight: 53.3 kg or 117.5 lb) met the inclusion criteria. The overall rate of complications was 27.9%. In particular, the rate of complication was 51.7 and 29.6% in children with femur and tibia fracture weighing more than 50 kg (110 lb), respectively ($p < 0.05$). Elastic stable intramedullary nailing (ESIN) has become the treatment of choice for displaced tibia and femur shaft fractures in children between six and 12–15 years of age. Unstable fracture pattern, higher age and higher weight have been reported as potential risk factors associated with poor outcomes in children and adolescents treated with ESIN for displaced long bone fractures of the lower extremity, in particular femur shaft fractures. Despite these findings, data reporting exclusively on ESIN-treated long bone fractures in children weighing 50 kg (110 lb) or more remain scant.

Keywords Tibial shaft fractures · Femur shaft fractures · Overweight · Children · Elastic stable intramedullary nailing

Purpose

Obesity in children and adolescents is fast becoming a public health problem worldwide. WHO estimates from 2008 indicated that more than 40 million children under the age of five were overweight and that prevalence of obesity had practically doubled since 1980 [1]. The number of fractures in obese children is also increasing—fracture risk rate is an estimated 1.6 times higher in obese children than in the general population [2–4], and the incidence of femoral fractures is higher in overweight children [5–7].

As in adults, obesity is also known to increase risk of surgical and anesthetic complications [8] associated with orthopedic surgeries in the pediatric population, including increased rates of wound healing problems, pressure sores [4], refractures, nonunion, malunion and minor respiratory complications. Moreover, obese patients with lower extremity fractures tend to have more severe injuries which may predispose them to greater inpatient morbidity and mortality compared to non-obese patients [4–10]. Taylor et al. [11] described a higher prevalence of reported fractures, musculoskeletal discomfort, impaired mobility

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and lower extremity malalignment in overweight than non-overweight children and adolescents.

After forearm fractures, tibial and femur shaft fractures are the most common long bone injuries in children, accounting for 15 and 2% of all pediatric fractures, respectively. Furthermore, femoral fracture is the most common pediatric orthopedic injury requiring hospitalization [12–14].

Even though elastic stable intramedullary nailing (ESIN) has become the treatment of choice for displaced tibial and femur shaft fractures in children between 6 and 12–15 years of age, childhood and adolescent obesity has heightened interest and controversy over standard of care, and there is little quality evidence to support any one specific surgical treatment modality [15–18].

The main objective of this paper is to review the current literature on treatment of tibial and femur fractures in children and adolescents guided by body weight in patients weighing 50 kg (110 lb) or more. A secondary aim of this mini-review was to determine, as per literature review, whether weight > 50 kg (110 lb) is an identifiable factor associated with increased complication rate.

Methods

The search of the following bibliographic databases, PubMed/MEDLINE, EMBASE and Cochrane Database of Systematic Reviews, from 1954 to September 2017, was performed to identify papers related to pediatric tibia and femur fractures in children weighing more than 50 kg (110 lb).

The following search terms, "femur," "tibia," "fracture," "weight," "50 kilograms" and "110 lb," were used, including combinations of index and free-text terms, as recommended in the Cochrane Handbook for Systematic Reviews of Interventions. Abstracts were first screened, and relevant full-text articles were subsequently retrieved for further analysis. Reference sections of identified papers were also screened to identify further literature. No authors were contacted, and all levels of evidence were included.

In particular, only studies meeting the following eligibility criteria were selected for analysis: (a) studies involving femoral and tibial shaft fractures in children and adolescents weighing more than 50 kg (110 lb), (b) studies considering the relationship between body weight and outcome and (c) studies with a focus on elastic stable intramedullary nailing. Exclusion criteria were: (a) studies involving patients over the age of 18 years old, (b) studies in which the primary treatment was non-operative and (c) not-English languages studies.

Results

Overall, seven full-text articles dealing with pediatric tibia or femur fractures in patients weighing more than 50 kg (110 lb), and one article reporting on both femur and tibia fractures in this patients' population [19], have been identified ($n = 8$ full-text article included).

Selected articles included a total of 438 patients with femoral shaft fractures (male/female = 2.7:1) and 241 with tibial shaft fractures (male/female = 4:1). In particular, 48 out of 438 patients (11%) with femoral shaft fractures (Table 1) and 91 out of 241 patients (38%) (Table 2) met the inclusion criteria.

The average patient age at the time of injury was 13 and 12.8 years in femur and tibial shaft fracture, respectively. The mean weight was 51.7 kg (113.9 lb) and 53.3 kg (117.5 lb) in patients with femoral and tibial fracture, respectively.

The overall rate of complications was 27.9%. In particular, the rate of complication was 51.7 and 29.6% in 139 children with femur and tibia fracture weighing more than 50 kg (110 lb), respectively ($p < 0.05$).

Tables 1 and 2 compile all published works dealing with pediatric femur and tibia fractures in children weighing more than 50 kg (110 lb) (Tables 1, 2).

Discussion

A few studies have investigated the outcome of children weighing more than 50 kg (110 lb) with femur and tibia shaft fracture treated by ESIN.

This mini-review found eight such studies, all of which were retrospective case series (level IV of evidence). In particular, 48 patients (Table 1) sustained a femur shaft fracture and weighed more than 50 kg (110 lb); similarly, 91 patients (Table 2) had a tibia shaft fracture and weighed more than 50 kg (110 lb). All studies agree that overweight children have increased rate of complication. In particular, the average rate of complication was 51.7 and 29.6% in femur and tibial shaft fracture, respectively [7, 8, 15, 19–23]. In patients weighing more than 50 kg (110 lb), the complication rate was significantly higher in those with femur shaft fracture compared to those with tibia shaft fracture ($p < 0.05$).

Prevalence of childhood obesity is increasing worldwide; in particular, it is becoming a serious public health problem in almost all industrialized countries. However, some differences exist among geographic areas due to auxologic, genetic, race and/or socioeconomic factors [24]. As confirmed from recent studies, about 20% of European

Table 1 Published studies dealing with pediatric femur fractures in children and adolescents over 50 kg

Study	Total number of patients	Number of patients weighing over 50 kg or obese	Mean age (years)	Mean weight (kg)	Mean follow-up (months)	Treatment method	Overall complication rate (%)	Results
Deakin et al. [19][a]	15	9	12.9 (11–16)	53.4 (32–88)	7.2	ESIN	27.3	All complications occurred in patients weighing 60 kg or more
Canavese et al. [20]	117	20	13.1 (11.7–14.5)	54.2 (50–70)	27.4	ESIN	45	The rate of complications was 67% in children weighing 55 kg or more, 35% in children weighing 50–54 kg and 12.8% in children weighing < 50 kg
Leet et al. [8]	103	6	9.3 (6–14)	33.1 (18–68)	6.3	External fixation (58/103) Intramedullary rods (45/103)	14.5	Complication rate for obese children was significantly higher ($p = 0.004$) than that for non-obese children (50 vs. 12%)
Moroz et al. [15]	229	N/A	10.3 (3–18)	41.9 (17–95.2)	14.2	ESIN	47.9	Patients with weight > 49 kg were 5 times more likely to have poor outcome
Weiss et al. [7]	71	13	9.25 (4–14)	35.5 (14.4–97.3)	N/A	ESIN	23	The complication rate was 17% in children weighing < 50 kg and 46% in children weighing > 50 kg ($p = 0.03$)

ESIN elastic stable intramedullary nailing, *N/A* not applicable

[a]Article dealing with both femur and tibia shaft fractures

Table 2 Published studies dealing with pediatric tibia fractures in children and adolescents over 50 kg

Study	Total number of patients	Number of patients weighing over 50 kg or obese	Mean age (years)	Mean weight (kg)	Mean follow-up (months)	Treatment method	Overall complication rate (%)	Results
Deakin et al. [19][a]	21	11	12.9 (11–16)	53.4 (32–88)	7.2	ESIN	27.3	All complications occurred in patients weighing 60 kg or more
Sankar et al. [22]	19	9	12.2 (7.2–16)	48.6 (30–67.2)	15.7	ESIN	36.8	No significant differences in terms of coronal and sagittal plane angulation were found between patients weighing > 50 kg and those weighing < 50 kg
Marengo et al. [21]	106	26	13.5 (11.3–16.1)	57 ± 8 (50–80)	23 ± 8	ESIN	15.4	The only major complication involved a patient weighing > 60 kg
Goodbody et al. [23]	95	45	12.1 (6–16)	50.2 (21–122)	N/A	ESIN	20	No significant differences in the rate of malunion or time to healing between lighter and heavier patients

ESIN elastic stable intramedullary nailing, *N/A* not applicable

[a]Article dealing with both femur and tibia shaft fractures

school-age children are overweight and 5% are obese while in North America, the USA in particular, about 1 in 5 children aged 6–19 years has increased BMI and/or obesity [10, 25, 26]. According to these trends, the number of overweight and/or obese children sustaining lower extremity fractures will increase in future. It is important to note that the rate of complications of tibial and femur shaft fractures was already reported as significantly higher for obese children (especially in those with femoral fractures) than non-obese patients [7, 8, 10, 27].

Tibial and femur shaft fractures are relatively common in children and adolescents. However, the optimal method of fixation has not been clearly identified. Moreover, the global spread of childhood obesity has raised controversy over the management of these fractures. Generally speaking, several factors must be considered when dealing with skeletally immature patients with tibia and femur shaft fractures. Mechanism of trauma, soft tissue condition, the presence of other injuries, patient and family compliance and surgeon preference have to be taken into account. However, fracture location, age and weight of the child at the time of injury are the main factors influencing the treatment choice. In particular, the choice of treatment varies according to age and weight of the child, and it includes casting, ESIN, external fixation, compression plating, submuscular bridge plating or rigid intramedullary rods.

Not all surgical options are feasible in skeletally immature patients. In particular, rigid intramedullary rod systems should not be used in children with open proximal tibial growth plate (to avoid iatrogenic injury), while open reduction and internal fixation with plate and screws should be avoided because of the periosteal damage and

the large exposure. On the other hand, ESIN is a common method of treatment of lower extremity fractures even though pediatric tibial shaft fractures, in particular, are treated surgically in less than 5% of cases.

ESIN is currently considered an effective treatment for displaced and unstable tibial and femur shaft fractures in children aged more than 6 years old, and ideally weighing less than 50 kg [5, 6, 28–30].

Although ESIN is widely used, only a few studies with a relatively low number of patients have investigated the ability of ESIN to maintain alignment and ensure optimal outcome in children and adolescents with increased BMI [7, 8, 19, 31].

Several reports have identified unstable fracture pattern, higher age and higher weight as potential risk factors for poor outcomes in children and adolescents with displaced tibia and femur fractures managed by ESIN [19–22]. However, data concerning exclusively ESIN-treated fractures in children weighing 50 kg (110 lb) or more are reported in retrospective studies (level IV of evidence) including a limited number of patients [10, 15, 30, 32].

Ramseier et al. did not find any association between age and/or body weight and complication rate in children and adolescents treated for femur shaft fractures, whereas Moroz et al. found that patients weighing more than 49.3 kg were some five times more likely than lighter patients (less than 49.3 kg) to have poor outcomes following ESIN for femur shaft fractures [15, 31]. Weiss et al. [7] showed that complication rate was 46% in children who weighed more than 50 kg (6/13 patients) but just 17% in children who weighed less than 50 kg (10/58 patients). They also found a statistically significant difference in complication rate between non-obese (17%) and obese children (46%), and observed that rate of complications appeared to be related to simple weight rather than body mass index (BMI), as all the obese patients except one weighed more than 50 kg [10, 33, 34]. Canavese et al. analyzed outcomes in children weighing 50 kg (110 lb) or more with ESIN-treated displaced femur shaft fractures and concluded that complication rate was higher in heavier children (67% in children weighing 55 kg or more, 35% in children weighing 50 to 54 kg and 12.8% in children weighing less than 50 kg). In particular, the rate of major complications was 50% in children weighing 55 kg or more, but just 7% in children weighing between 50 and 54 kg ($p = 0.05$) [20].

Shaha el al. analyzed the relationship between patient weight and alignment at radiographic union following Ender's FIMN of the pediatric femoral shaft in children > 100 lb, but found no significant difference between heavier and lighter groups on shortening (3.3 vs. 3.5 mm), coronal angulation (0.8° vs. 3.0°) or sagittal angulation (0.7° vs. 3.2°) at radiographic union [32].

In contrast to data in displaced femoral shaft fractures where overweight represents a risk factor for higher complication rate and poor outcome, there is no evidence to confirm the same for displaced tibia shaft fractures.

In the largest individual series of pediatric patients treated with ESIN for a tibial shaft fracture by Goodbody et al. [23], no significant difference in the rate of malunion or time to healing was found between younger and older patients or between lighter and heavier patients, unlike for other long bone fractures.

One study did focus exclusively on the outcome of patients weighing over 50 kg (110 lb) [21] by exploring clinical and radiological outcomes by reviewing 26 consecutive patients weighing 50 kg (110 lb) or more treated by ESIN for displaced, closed tibia shaft fractures. The factors investigated were weight and age limits of ESIN and the role of nail size/medullary canal diameter ratio. The study showed that patients weighing 50 kg (110 lb) or more had 15.4% overall rate of adverse events, i.e., lower than complication rates reported by Deakin et al. and Sankar et al. [19, 22]. The only major complication involved a patient weighing 64 kg (141 lb). The study only considered the patient's weight, not their body mass index (BMI). It was assumed, as a first approximation, that the patient's height (and therefore their BMI) could be taken as being negligible compared to their weight, which is the main factor influencing deformation forces acting on the elastic nails.

There are many studies that have extensively investigated surgical management and role of ESIN fixation [25, 35–38]. The overall reported rate of adverse events in pediatric tibia shaft fractures treated by ESIN ranges between 5 and 33.3%, but the range is higher, at 27–44.4%, in heavier patients [12, 27]. However, no firm conclusions can be drawn from these figures due to the limited number of studies, low number of patients and heterogeneity of case series [12, 16, 25, 27]. Deakin et al. [19] reviewed 21 patients with displaced tibia shaft fractures, of which 11 (52.4%) had a mean weight of 65.7 kg (range 50–88). In this subgroup of patients, the reported complication rate was 27% compared to 10% adverse effects in patients weighing less than 50 kg (mean weight: 42.2 kg; range 36–49). In particular, Deakin et al. reported two cases of malunion and one case of compartment syndrome in this group of patients. Note that all the complications occurred in patients weighing 60 kg or more [19]. Pandya et al. [39] identified three factors associated with the development of compartmental syndrome after flexible nailing of tibial shaft fractures related to the increased forces needed to perform a fracture reduction and nail fixation: weight > 50 kg, comminuted/complex fracture patterns and presentation with preoperative neurologic deficits in the absence of compartmental swelling. Sankar et al. reviewed 19 patients with displaced tibia shaft fractures treated by ESIN. At the time of index surgery, 9 out of these 19 (47.4%)

patients weighed 50 kg or more (mean weight 54.8 kg; range 50–65). In this group of patients, one major complication (full-thickness skin necrosis) and three minor complications (bursitis at the tip of the nails) were recorded, but the authors found no significant difference in terms of coronal or sagittal plane angulation between patients weighing > 50 and < 50 kg [22].

Overall, femur fractures treated with ESIN tend to have a higher complication rate compared to tibial fractures treated with ESIN in patients weighing 50 kg (110 lb) or more [28–30] (Tables 1, 2; $p < 0.05$). Marengo et al. [21] assert that that complication rate may be higher in femur fractures than tibial fractures due to the bone's anatomy. If we assume that femur and tibia are rigid bodies, then the elastic deformations involved would be negligible. Both bones are constrained at both top (by the hip for the femur and by the knee for the tibia) and bottom (by the knee for the femur and by the ankle for the tibia). The upshot is that the main force acting on both bones is therefore weight. Through the femur, the weight vector actually counts two components: one along the anatomical axis of the femur and the other perpendicular to it, whereas for the tibia, the weight vector runs right through anatomical axis. Note that the femur bone has lateral forces acting on it that could help improve the procurvatum, whereas the tibia does not have to bear lateral forces as the weight vector only acts in one direction, i.e., along the axis of the bone. Gordon et al. reviewed a group of 60 tibia shaft fractures and found that patients with a delayed union averaged out older, i.e., at 14.1 years, than patients with uneventful union, i.e., at 11.7 years [40]. In our group of patients, there were no cases of malunion or delayed union, which were all aged over 11. Marengo et al. [21] did not find any significant correlation between patient age and complication rate. However, remodeling potential of the tibial shaft should be taken into account as it is more significant in patients younger than 8 (girls) and 10 years of age (boys) compared to children older than 9 (girls) and 11 (boys) years, and it becomes very close to zero in patients older than 13 years of age (both genders) [41].

There is controversy over the size of the nail to be used to stabilize such fractures. Nail size is chosen as a function of medullary canal diameter measured in the narrowest part. Some surgeons recommend a nail size/medullary canal diameter (NS/MCD) ratio of 40% and have advised against ESIN in children with MCD > 10 mm [15, 42, 43]. Others support the hypothesis that a weight/nail size ratio of less than 4 kg/mm should be obtained [34, 43], but this appears to be somewhat restrictive, as the largest elastic nail is 4 mm in diameter, which would cap the upper weight limit for the use of ESIN in children and adolescents with displaced tibia shaft fractures at 32 kg [43]. None of the literature to date dealing with surgical management of tibia shaft fractures in children have evaluated the influence of NS/MCD and weight over 50 kg on outcome. In contrast to these previous findings, Marengo et al. [21] found no correlation between NS/MCD and complication rate, and the only factor associated with increased complication rate was weight over 60 kg.

Further controversy concerns how to evaluate patient overweight. Leet et al. [8] defined as obese all patients who exceeded the expected weight for their age, and they did not take into account BMI. They may thus have classified as obese children who were merely tall for their age. Other studies have only considered the patient's weight and not their BMI, based on the first-approximation assumption that the patient's height (and therefore their BMI) could be taken as negligible compared to their weight, which is the main factor influencing deformation forces acting on the elastic nails [20, 21].

There are several potential options to treat tibial and femur shaft fractures in children. In the youngest population, these fractures can be successfully managed with closed reduction and casting, but older or heavy patients and adolescents require operative fixation. The main factors influencing fixation choice are fracture location, age and patient weight [44]. External fixation is indicated in open fractures with substantial disruption of the surrounding soft tissue, multiple trauma, vascular injuries needing revascularization procedures, highly unstable fracture patterns and failure of non-operative treatment [45]. Nevertheless, even in polytrauma and younger patients, ESIN treatment offers lower complication rates and more esthetic scarring compared with external fixator, which is part of the reason why ESIN has become the gold standard for the treatment of displaced tibial and femur shaft fractures in children between 6 and 12 years of age for femur fracture and 15 years of age for tibial fracture [16, 30, 46]. Analysis of the available literature finds no correlation between NS/MCD and complication rate [20]. In contrast to data in tibial shaft fractures, the use of ESIN for displaced femur shaft fractures in children and adolescents weighing 50 kg (110 lb) or more, or older than 11 years of age, is contraindicated due to poorer outcomes [15, 20, 21, 31], which makes it necessary to consider alternative methods of fixation. Submuscular plating is an option for treatment of femur shaft fractures in children older than 11 years, especially when affected by high-energy complex fractures with length-unstable fracture patterns, and fractures involving metaphyseal areas [18, 47]. Rigid intramedullary fixation with trochanteric entry nailing can be a successful method in adolescents nearing or at skeletal maturity.

Whichever technique is chosen, optimal outcome hinges on a proper understanding of the subtleties involved, including the limitations and possible complications of each technique.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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