Complications after operative treatment of femoral shaft fractures in childhood and adolescence

Christiane Kruppa,[1]
Gabriele Wiechert,[1]
Thomas A. Schildhauer,[1]
Marcel Dudda[1,2]

[1]Department of General and Trauma Surgery, University Hospital Bergmannsheil Bochum, Ruhr-University Bochum; [2]Department of Orthopaedics and Trauma Surgery, University Hospital Essen, Germany

Abstract

Purpose of the study was to retrospectively analyze the complication rates after operatively treated femoral shaft fractures in childhood and adolescence. Retrospective evaluation of 42 children with operatively treated femoral shaft fractures between 2000 and 2014. Fractures were classified as 27 A type, 12 B type and 3 C type fractures according the OTA/AO classification. 8 (19.05%) fractures were open. Age averaged 10.2 years (3-16). Fracture treatment was recorded as temporary or definitive external fixation, ESIN, plate fixation or IMN. Complications such as wound infection, re-fractures, nonunion and malunion were analyzed. Six (14.29%) fractures were temporarily stabilized using an external fixator. In 22 (52.38%) children the femoral shaft fracture was stabilized using ESINs. 10 (23.81%) children had a plate fixation and 9 (21.43%) adolescents were treated using an IMN. ESIN treated children were significantly younger (P=0.000) and had less weight (P=0.000) than children treated with both other methods. Complications were two (4.76%) superficial and two deep (4.76%) wound infections, one (2.38%) re-fracture with the ESIN in situ, one (2.38%) nonunion and one (2.38%) malunion. Six (14.29%) children required a reoperation for a complication. Risk factors for complications were temporarily applied external fixators, open fractures, C Type fractures (P=0.031) and an increasing age (P=0.048) and weight (P=0.047) of the child. The majority of children in our study population were successfully treated using ESIN presenting a low complication rate. Complications were observed following open fractures and more complex fracture types. Furthermore we observed an increasing complication rate with increasing ages and weights of the children.

Introduction

Femoral shaft fractures in childhood and adolescence are frequent injuries requiring operative treatment and hospitalization. Although non-operative treatment methods such as spica-casting or traction have their indications in young children, the number of operatively treated femoral shaft fractures have increased within the last 15 years, especially for the age group 5 to 9 years.[1] Fracture treatment is still a controversy and implant choice depends on the age of the child, associated injuries, fracture characteristic and more recently on the weight of the child.[2,3] Therefore different implants may be used for different age groups. Between the age of 3 and 12 years elastic stable intramedullary nailing has become widely accepted. For older children or children with high body mass indices submuscular plate fixation,[4] or intramedullary nailing are alternatives. In polytraumatized children or in open fractures external fixation still has its advantages and safety and effectiveness is reported with staged procedures.[5] But, even in patients with correct indications and procedures complications may occur. Implant failure, nonunion, malunion, infection or delayed wound healing problems may lead to further necessity of care and in rare cases to long time disabilities, even in the pediatric population.

Therefore we only wanted to focus on operatively treated children to retrospectively analyze and evaluate the complications of operatively treated femoral shaft fractures in childhood and adolescence to expose and understand possible reasons for complications to further reduce the rates in the future.

Materials and Methods

The study was approved by the institutional ethic committee. Between February 2000 and March 2014 we retrospectively reviewed all children, who were operatively treated for a femoral shaft fracture at our Department of General and Trauma Surgery at a level one trauma center. Children and adolescent, up to the age of 16 years, with operatively treated diaphyseal femoral shaft fractures were identified. Children (23) with follow up more than 12 months as well as children (19) with radiologically healed fractures and definitive implant removal at our institution were included for further investigation. Therefore the study population consisted of 32 (76.19%) boys and 10 (23.81%) girls with 27 (64.29%) left and 15 (35.71%) right femoral shaft fractures. Demographics were documented. Fracture patterns were analyzed on plain anterior posterior (AP) and lateral radiographic imaging and classified according to the OTA/AO-Classification system (Orthopaedic Trauma Association/ Arbeitsgemeinschaft für Osteosynthesefragen)[6] (Table 1). Eight (19.05%) fractures were open. Open fractures were classified according to the Gustilo and Anderson system.[7] Indications for operative treatment at our Department of General and Trauma Surgery were unstable, open, comminuted, combined or failed conservatively treated fractures, as well as fractures requiring closed reduction under anesthesia. The choice of implant was based on the age of the child, fracture pattern, soft tissue damage and associated injuries. If stable fixation was achievable we used two ESIN of equal diameter in children up to the age of 11 to 13 years, depending on the weight and skeletal maturity. In older and heavier children where loss of reduction after ESIN fixation was dreaded we used a submuscular plate for fracture fixation. When the physes appeared to be closed and the central bony canal was wide enough, we used a rigid intramedullary nail for fracture

Correspondence: Christiane Kruppa, Department of General and Trauma Surgery, BG-University Hospital Bergmannsheil Bochum, Ruhr-University Bochum, Bürkle-de-la-camp Platz 1, 44789 Bochum, Germany.
Tel.: +49.234.3023837 - Fax: +49.234.3026542.
E-mail: christiane.kruppa@ruhr-uni-bochum.de

Key words: pediatric, femoral shaft fractures, ESIN, complications, nonunion, infection.

Contributions: CK: study design, data collection, writing; GW: data collection; TAS: study design, revision; MD: study design, revision.

Conflict of interest: the authors declare no potential conflict of interest.

Received for publication: 12 November 2017.
Accepted for publication: 10 December 2017.

Orthopedic Reviews 2017;9:7493
doi:10.4081/or.2017.7493

fixation in selected adolescents. Depending on associated injuries in polytraumatized children or severe soft tissue damage an external fixator was applied. Surgical excisional debridement and irrigation was performed in all open fractures followed by primary wound closure (4), staged procedures with secondary wound closure (2) or mesh graft (2).

Two children were primarily treated with ESIN (1) and IMN (1) at another department of surgery and referred for further treatment to our Department of General and Trauma Surgery.

Clinical and radiographic follow up was performed after 2, 4 and 12 weeks after surgery. Postoperative mobilization was limited to non-weight bearing for 3-6 weeks, depending on the age of the child, fracture stability and radiographic fracture consolidation.

Neurological complications due to the fracture, apparent at the time of injury, were recorded in three children as sensory and motor deficit of the femoral nerve in one child with an additional compartment syndrome, motor deficit of the peroneal nerve in another child and one child presenting sensory and motor deficits of both nerves.

Complications such as superficial and deep wound infections, re-fractures, nonunion and malunion were evaluated and analyzed concerning different treatment methods. Hip and knee range of motion (ROM) and pain were recorded on final follow up. Descriptive statistics were completed including percent, mean, range and standard deviation using Microsoft Excel, 2010. Nominal variables were evaluated using the chi-square test, unless the sample size was too small, in which case the two-tailed Fisher's Exact test was used. Significance was determined at $P<0.05$. Data were analyzed using SPSS version 22.0 (IBM, Armonk, NY).

Results

Children age averaged 10.2 years (SD=4.4; range 3-16 years). In 19 (45.2%) children the injury was caused by a traffic accident (Figure 1). 38.10% (16) children had associated injuries (Table 2). 11 (26.2%) children were polytraumatized. Operative treatment was performed after an average time of 1 day (range 0-6 days; SD=1.1). Length of hospital stay averaged 12 days (SD=14.7; range 2-74 days). Treatment was definitive (1) or temporarily (6) applied external fixator, for an average time of 16 days (range 1-39 days; SD=16.3), elastic stable intramedullary nailing (22) (ESIN) (Figure 2), open reduction and plate fixation (10) (Figure 3), and rigid intramedullary nailing (9) (IMN) (Figure 4) (Table 3). Children treated with ESIN were significantly younger (P=0.000) compared to children treated with IMN and plate fixation, and had significantly less weight (P=0.000) compared to both other groups.

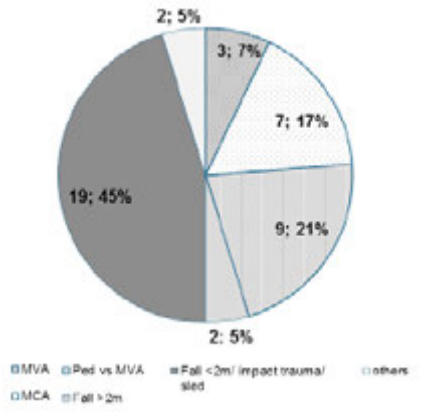

Figure 1. Mechanism of Injury. 19 injuries were caused by a traffic accident. Again, 19 injuries were caused by a fall from a low height, a direct impact or fall from a sled. MVA = motor vehicle accident; MCA = motor cycle accident; Ped vs MVA = Pedestrian versus motor vehicle accident.

Table 1. Fracture classification.

OTA/AO classification6		N (%)	Open fracture,7 n (%)	Average children age (years)
A	27 (64.29)	3 (7.1)		10.2 (3-16)
	A1	9 (21.4)	I	
	A2	4 (9.5)	III	
	A3	14 (33.3)	I	
B	12 (28.6)	4 (9.5)		9.3 (4-15)
	B1	3 (7.1)	III	
	B2	6 (14.3)	II	
	B3	3 (4.4)	II, III	
C	3 (7.1)	1 (2.4)		13.1 (10-16)
	C1	1 (2.4)	-	
	C2	2 (4.8)	III	
	C3	-	-	

Table 2. Associated injuries.

Associated Injury*	N. (%)
Concussion/mild traumatic brain injuries	6 (14.3)
Thoraxtrauma	6 (14.3)
Ipsilateral lower leg fx [both bone fx (5)]	5 (11.9)
Upper extremity fx: humerus (1), forearm (3), hand (1), clavicle (1)	6 (14.3)
Pelvic ring injury	2 (4.8)
Acetabular fx (ipsilateral)	1 (2.4)
Hip dislocation with Pipkin fx (contralateral)	1 (2.4)

*multiple injuries were present; fx=fracture.

Table 3. Treatment, age, weight and fracture classification.

Treatment	N. (%)	Average age (range)	Average weight (kg) (range)	Polytrauma	Fracture Classification6
Ext. fixator temp.	6 (14.3)	13 years (8-16)	59.6kg (22-99)	3	2 A, 3 B, 1 C
Ext. fixator def.	1 (2.4)	6 years	unknown	0	1 B
ESIN	22 (52.4)	7 years (3-13)	29.4kg (15-65)	4	14 A, 7 B, 1 C
Plate fixation	10 (23.8)	12 years (7-16)	46.4kg (24-65)	3 (+ 1 sec.)	7 A, 2 B, 1 C
IMN	9 (21.4)	15 years (14-16)	72.3kg (53-99)	1 (+ 2 sec.)	6 A, 2 B, 1 C

Ext. = external; temp. = temporarily; def. = definitive; ESIN = elastic stable intramedullary nailing; ORIF = open reduction internal fixation; IMN = intramedullary nailing; sec. = plate fixation/intramedullary nailing was performed as secondary treatment after a temporarily stabilization with an external fixator.

Two children (4.8%) with an A-type fracture developed a compartment syndrome pre-operatively and consequently fasciotomy was performed. In one 15 years old child IMN was performed at the time of fasciotomy, in another 16 years old child an external fixator was applied and converted to plate fixation after 18 days.

23 children had follow up >12 months with 41.2 months (range 12-144; SD=38.70) on average. The remaining 19 children showed a healed fracture on radiographs and had an average follow up of 4.4 months (range 1.1-9.8) at the time of their implant removal without further consultation afterwards.

Complications were two (4.8%) superficial and two (4.8%) deep wound infections, one (2.4%) re-fracture with ESIN *in situ*, one nonunion (2.4%) and one (2.4%) malunion. 14.3% (6/42) children required one or more reoperation for a complication (Table 4).

Type A fractures had a complication rate of 14.8% (4/27), B type fractures 8.3% (1/12) and type C fractures showed a complication rate of 33.3% (1/3). This was statistically significant (P=0.031). 28.6% (2/7) fractures requiring an external fixator primarily developed a complication. One of two (50.0%) fractures, which presented a compartment syndrome showed a complication. Open fractures had a complication rate of 37.5% (3/8). This was not statistically significant (P=0.079). Children, who developed a complication were significantly older than children without complications (P=0.048) (13.3 years *vs*. 9.6 years), as well as significantly heavier (P=0.047) (57.67 *vs*. 39.54 kg) than children who developed no complication.

All fractures healed. Neurologic complication due to the fracture completely

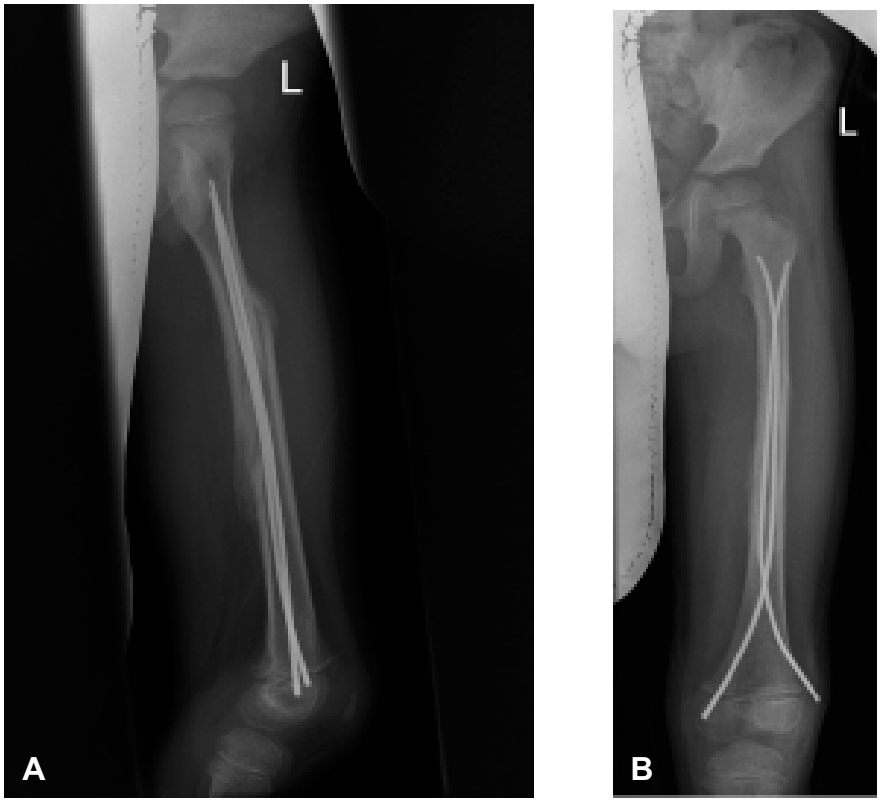

Figure 2. Anterior posterior (AP) and lateral views (A and B) of a left femoral shaft fracture 1 month postoperatively in a 5 years old boy treated with ESINs. The bridging callus is already seen 1 month postoperatively along the fracture.

Table 4. Complications.

ID	Age (years)	Fracture Type OTA/AO	Open?	Ex Fix?	Treatment	Complication	Treatment
1	7	A1	No	No	Plate fixation	Rotational malunion (16° external rotation)	No treatment
2	10	C2	III	Yes	ESIN + Ex Fix + Dermotraction	Local pin and superficial wound infection	Removal Ex Fix, I&D, Secondary Wound Closure
3	12	B1	III	No	ESIN (ex domo), temporarily wound coverage (epigard)	Deep wound infection, osteomyelitis (enterobacter cloacae) + nonunion	Multiple wound revisions with I&D; ESIN Removal + segmental resection + Hybrid external fixateur + Mesh graft
4	13	A3	No	No	ESIN	Refracture with ESIN *in situ* (adequate trauma)	ESIN removal, new ESIN fixation
6	16	A3	No	No	IMN (retrograde)	Nonunion	Additive plate fixation+ bone graft after 9 months
7	16	A2 + Compartment syndrome	No	No	IMN + Fasziotomy	Deep wound infection at fasciotomy wound	Multiple I&D, secondary wound closure
8	16	A3	No	Yes (ex domo)	Removal of ex fix + IMN	Deep wound infection lateral femoral wound after open reduction	Multiple I&D

ESIN = elastic stable intramedullary nailing; ex fix = external fixator; IMN = rigid intramedullary nailing; I&D = irrigation and drainage; ex domo = procedure was performed at another department of surgery

resolved with follow up. Fractures which had developed a nonunion healed after treatment for nonunion. No limitations on hip and knee range of motion were observed. Implant removal was performed in 38 (90.5%) children as ESIN (22), plate (8), IMN (7), definitive external Fixator (1) at our Department of General and Trauma Surgery after an average time of 8.8 months (range 1.1-43.8; SD=8.7). Time to implant removal in ESIN treated children averaged 6.2 months (=SD=9.1; 1.1-43.8months), in children treated with plate fixation 11.5 months (SD=4.5; 6.3-43.8months) and in children treated with IMN 15.5 months (SD=6.5; 4.9-26.5months). Asymptomatic nail prominence of the ESIN was palpable in 7 children. Two children showed skin penetration of the medial ESIN at time of implant removal, one with local skin redness. In this five years old child early ESIN removal after 1.1 months was performed with additional cast application for 2 weeks.

Discussion

An increasing rate of operative treatment in pediatric femoral shaft fractures has been described in the past.[1] To assess the complication rate and identify risk factors in operatively treated children with a femoral shaft fracture we performed a retrospective analysis. The majority of our study population (52.38%) was successfully treated using elastic stable intramedullary nailing (ESIN). They were significantly younger (P=0.000) and had significantly less weight (P=0.000) compared to children treated with plate fixation or IMN. Seven children developed a complication in our study population, of whom six children required a reoperation. Unsurprisingly complex fracture types such as C type fractures had the highest complication rate of 33.3%, which was statistically significant compared to A type fractures and in B type fractures. We further observed a complication rate of 37.5 % in open fractures. Further risk factors for development of complications were an increasing age (P=0.048) and weight (P=0.047) of the children.

Two superficial (4.76%) and two (4.76%) deep wound infections were present in our study population. Two occurred in ESIN treated fractures and two in IMN treated fractures.[7] Fractures which developed a wound infection were either open (2), required fasciotomy (1) for a compartment syndrome or were primarily treated with an external fixator (2). In a univariate and multivariate analysis by Momaya *et al*. open fractures were identified as risk factor for hospital readmission after

Figure 3. Anterior posterior plus lateral view 5 months postoperatively with already united right femoral shaft fracture. The fracture was initially stabilized with an external fixator in this 15years old multiple injured child and converted to plate fixation 19 days later.

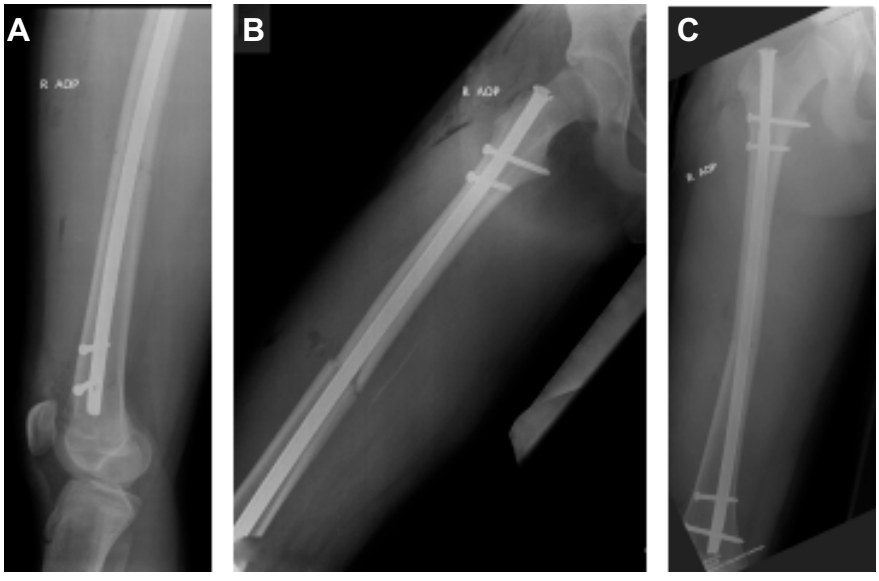

Figure 4. Anterior posterior (AP) and lateral views postoperatively of a right femoral shaft fracture in a 16 years old boy treated with rigid intramedullary nailing. Mechanism of injury was a motor cycle accident. This fracture healed without any complication.

intramedullary nailing of a femoral fracture.[8] Hutchins *et al*. reported in a series of 44 open femoral fractures an infection rate of 50% in grade III open fractures.[9] This is similar to our observation, 2 of 4 III° open fractures developed an infection in our study population. One deep wound infection in a 12 years old child, who was referred with an infectious nonunion after ESIN fixation of a grade III open fracture to our department for further treatment, required multiple revisions with segmental resection, had the potential to cause permanent disability. Although two wound infections in our population were associated with initial external fixator treatment, we would prefer a staged procedure with initial external fixator application until wound coverage in a grade III open fracture rather than in direct intramedullary nailing, especially if the femur isn't sufficiently soft tissue covered. Hutchins reported a 50% risk of osteomyelitis in Grade III open femoral injuries.[9] In adults open fracture wounds are described as predictive factor for the development of a nonunion in femoral shaft fractures by Taitsman *et al*.[10] Acknowledging the fact that pin track irritation or infection is reported as common complication of external fixation in pediatric femoral shaft fractures in up to 72% patients,[11] which may increase the risk of further wound infections after fixator removal and definitive treatment with plates or ESINs as well. Usually those pin track infections are successfully treated with local debridement or antibiotic treatment. Nowotarski *et al.* stated emergent external fixation followed by early intramedullary rodding as a safe procedure in patients with a femoral shaft fracture with only 2% infection rates.[5] Further Hosalkar *et al*. stated the conversions from external fixation to intramedullary nailing within 2 weeks of injury as a save procedure.[12]

One child of our study population sustained a re-fracture with the ESINs in situ because of an adequate trauma one week after initial treatment. The ESINs were removed and closed reduction with new ESIN insertion followed. Flynn *et al*. reported two children with a re-fracture after ESIN treatment for a femoral shaft fracture in 48 children, one after early implant removal and one with the nails in situ. Both underwent repeat treatment with ESINs.[13] With an average time of almost six month until ESIN removal, we did not observe a re-fracture after implant removal. Within the literature complication rates after elastic stable intramedullary nailing for femoral shaft fractures diverge between the absence of serious complications, which was reported by Mazda *et al.*[14] in 34 fractures with an average follow up of 2.5 years and complication rates up to 21%, which was reported by Flynn *et al*. in 48 children. All of them were reported to be minor complications, which were not expected to cause permanent disability.[13] Bhuyan reported excellent results in 82.5% patients after titanium elastic intramedullary nailing of 40 pediatric patients.[15] In a prospective study performed by Karaman *et al.* a complication rate of 10.0% (4/40) was observed. They reported two insufficient reductions, 1 refracture and one leg length discrepancy. All patients regained full range of motion and normal function.[16]

Other studies reported higher complication rates of elastic stable intramedullary nailing in heavier and older children.[17,18] In our population the average children age treated with ESIN was 7 years with an average body weight of 29 kg. Within this group we were not able to show a relationship between age, weight and complication rates. Nail prominence, soft tissue irritation our nail back out are frequently reported as minor complication. In our study population we saw two medial ESINs with perforation of the skin at the time of implant removal, one with local signs for infection with the need for early implant removal and additional cast application for two weeks.

We further observed one other nonunion in a 16 years old patient developed treated with IMN. Especially after plate fixation or intramedullary nailing with fracture distraction delayed union or nonunion is reported.[19] Our patient was successfully treated with additive plate fixation and additional bone grafting. While nonunion in pediatric femoral fractures are rare,[20] it may occur more often in adolescence or adult. The incidence of nonunion in pediatric femoral fractures is reported to be 15%.[2] One third of patients treated with IMN showed the complications in our study population. These patients also were the oldest and heaviest patients with an average body weight of 72 kg and average age of 15 years, respectively. Therefore the complication rate of this group may be more comparable to the adult population as to the pediatric population. This also might be the reason we did not observe femoral head osteonecrosis as one of the most dreaded complications after IMN in skeletally immature patients, which also has been reported in adolescents.[21-23] Crosby *et al.* reported development of asymptomatic coxa valga in two of 246 fractures treated with rigid IMN, no femoral head necrosis was occurred in their population. A total number of 9.8% (24/246) complications were present in their study population. Three fractures showed delayed union requiring dynamization. Further three malunion (>10°) were observed and one deep infection.[24] Garner *et al.* observed in 10 of 15 children treated with rigid locking nails (weight 47-85 kg, average age of 15 years) complications such as unplanned reoperation, compartment syndrome, neurovascular injury and implant-related problems.[25]

One external rotational malunion of 16° was present after plate fixation in a seven years old child, which had no further treatment until final follow up. Controversy exists about rotational remodeling in young children, for adolescents no remodeling is expected.[2] Davids *et al.* reported rotational malunion up to 30° to be well-tolerated in children, if they are not worsening a preexisting deformity.[26] Kregor *et al.* reported good results with plate fixation in multiple injured children without major complications, and anatomical alignment in fourteen of fifteen children. They reported no restriction due to the femoral fracture with follow up.[4] In our study population three polytraumatized children were initially treated using plate fixation and one secondary. Recently, Stoneback *et al.* showed no significant differences in strength between the operative and non-operative limb after submuscular plate fixation.[27]

The present study shows a number of limitations on the one hand because of the inherent problems of a retrospective design. One the other hand different ages, different fracture types and different treatment methods lead to limited comparability in this population. Because we included nineteen children with follow up less than 12 months, but healed fractures and completed removal of the implants, follow up is limited and no conclusions can be made regarding longer-term outcomes.

Conclusions

In conclusion the majority of our study population was successfully treated using either elastic stable intramedullary nailing, plate fixation or rigid intramedullary nailing depending on the age of the child and fractures characteristics. Complications were mainly observed following open fractures, fractures requiring a fasciotomy or primary treatment with external fixation, which were mainly more complex fracture types.

References

1. Naranje SM, Stewart MG, Kelly DM, et al. Changes in the treatment of pediatric

femoral fractures: 15-year trends from united states kids' inpatient database (KID) 1997 to 2012. J Pediatr Orthop 2016;36:e81-5.
2. Flynn JM, Skaggs, D.L. Femoral shaft fractures. In: Beaty JH, Kasser JR, eds. Rockwood and Wilkins' Fractures in Children. 7th ed. Philadelphia: Lippincott Williams & Wilkins; 2010. p. 797pp.
3. Madhuri V, Dutt V, Gahukamble AD, Tharyan P. Interventions for treating femoral shaft fractures in children and adolescents. Cochrane Database Syst Rev 2014:CD009076.
4. Kregor PJ, Song KM, Routt ML Jr., et al. Plate fixation of femoral shaft fractures in multiply injured children. J Bone Joint Surg Am 1993;75:1774-80.
5. Nowotarski PJ, Turen CH, Brumback RJ, Scarboro JM. Conversion of external fixation to intramedullary nailing for fractures of the shaft of the femur in multiply injured patients. J Bone Joint Surg Am 2000;82:781-8.
6. Marsh JL, Slongo TF, Agel J, et al. Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee. J Orthop Trauma 2007;21:S1-133.
7. Gustilo RB, Simpson L, Nixon R, Ruiz A, Indeck W. Analysis of 511 open fractures. Clin Orthop Relat Res 1969;66:148-54.
8. Momaya A, Baker D, Gilbert S, Ponce B. Risk factors for complications and readmission after operative fixation of pediatric femur fractures. J Child Orthop 2015;9:307-11.
9. Hutchins CM, Sponseller PD, Sturm P, Mosquero R. Open femur fractures in children: treatment, complications, and results. J Pediatr Orthop 2000;20:183-8.
10. Taitsman LA, Lynch JR, Agel J, et al. Risk factors for femoral nonunion after femoral shaft fracture. J Trauma 2009;67:1389-92.
11. Miner T, Carroll KL. Outcomes of external fixation of pediatric femoral shaft fractures. J Pediatr Orthop 2000;20:405-10.
12. Hosalkar HS, Pandya NK, Cho RH, et al. Intramedullary nailing of pediatric femoral shaft fracture. J Am Acad Orthop Surg 2011;19:472-81.
13. Flynn JM, Luedtke LM, Ganley TJ, et al. Comparison of titanium elastic nails with traction and a spica cast to treat femoral fractures in children. J Bone Joint Surg Am 2004;86A:770-7.
14. Mazda K, Khairouni A, Pennecot GF, Bensahel H. Closed flexible intramedullary nailing of the femoral shaft fractures in children. J Pediatr Orthop B 1997;6:198-202.
15. Bhuyan BK, Mohan Singh S. Titanium elastic nailing in pediatric femoral diaphyseal fractures in the age group of 5-16 years - A short term study. J Clin Orthop Trauma 2014;5:203-10.
16. Karaman I, Halici M, Kafadar IH, et al. Mid-term results of the elastic intramedullary nailing in paediatric long bone shaft fractures: a prospective study of 102 cases. J Pediatr Orthop B 2014;23:212-20.
17. Moroz LA, Launay F, Kocher MS, Newton PO, Frick SL, Sponseller PD, et al. Titanium elastic nailing of fractures of the femur in children. Predictors of complications and poor outcome. J Bone Joint Surg Br 2006;88:1361-6.
18. Ho CA SD, Tang CW. Use of flexible intramedullary nails in pediatric femur fractures. J Pediatr Orthop 2006;26:497-504.
19. Flynn JM, Schwend RM. Management of pediatric femoral shaft fractures. J Am Acad Orthop Surg 2004;12:347-59.
20. Lewallen RP, Peterson HA. Nonunion of long bone fractures in children: a review of 30 cases. J Pediatr Orthop 1985;5:135-42.
21. Mileski RA, Garvin KL, Crosby LA. Avascular necrosis of the femoral head in an adolescent following intramedullary nailing of the femur. A case report. J Bone Joint Surg Am 1994;76:1706-8.
22. O'Malley DE, Mazur JM, Cummings RJ. Femoral head avascular necrosis associated with intramedullary nailing in an adolescent. J Pediatr Orthop 1995;15:21-3.
23. Thometz JG, Lamdan R. Osteonecrosis of the femoral head after intramedullary nailing of a fracture of the femoral shaft in an adolescent. A case report. J Bone Joint Surg Am 1995;77:1423-6.
24. Crosby SN Jr., Kim EJ, Koehler DM, et al. Twenty-year experience with rigid intramedullary nailing of femoral shaft fractures in skeletally immature patients. J Bone Joint Surg Am 2014;96:1080-9.
25. Garner MR, Bhat SB, Khujanazarov I, et al. Fixation of length-stable femoral shaft fractures in heavier children: flexible nails vs rigid locked nails. J Pediatr Orthop 2011;31:11-6.
26. Davids JR. Rotational deformity and remodeling after fracture of the femur in children. Clin Orthop Relat Res 1994:27-35.
27. Stoneback JW, Carry PM, Flynn K, et al. Clinical and radiographic outcomes after submuscular plating (SMP) of pediatric femoral shaft fractures. J Pediatr Orthop 2016.