The Egyptian Journal of Hospital Medicine (January 2025) Vol. 98, Page 1315- 1320

Combined External Fixator and Flexible Intramedullary Nails in Management of Unstable Long Bone Fractures in Children

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ABSTRACT

Background: Over the last few decades, there have been considerable changes in management of pediatric comminuted long bone fractures (LBF). Flexible intramedullary nails (IMN) were developed to solve the problems of locked IMN in pediatric LBF.

Aim: To assess the efficacy of combined external fixation (EF) and flexible IMN (FIN) in unstable LBF in children.

Patients and Methods: This retrospective study included 23 pediatric patients with unstable long bone fractures who were treated by combined EF and FIN. Patients were assessed and examined regarding whether or not the fracture had united, leg length discrepancy (LLD), angular deformities and rotational deformities, hip and knee motions, the overall result was evaluated according to Flynn score.

Results: All the 11 cases with fractured tibia, had united tibia and 11 out of 12 cases with fractured femur, had united femur. Regarding functional assessment of the studied cases, there were 82.6% have excellent function, 13% satisfactory and only one case (4.3%) poor function. As regards range of motion (ROM); all cases had range of motion grade. Regarding complications, 8.7% had grade I, 4.3% had grade II, and 4.3% had grade III pin tract infection (PTI). There was a significant relationship between age and Flynn criteria. There was insignificant relationship between fracture type, degree of comminution with functional assessment of studied cases (p=0.270 and 0.228, respectively).

Conclusion: Combined use of external fixators and FIN proved to be an effective and reliable approach for managing unstable long bone fractures in children ensuring optimal alignment and stabilization.

Keyword: External Fixator, Flexible Intramedullary Nails, Unstable Long Bone Fractures

INTRODUCTION

Comminuted diaphyseal fracture in children has been considered a challenging condition in orthopedic surgery. It is accompanied by a higher risk of adverse events and poor prognosis because of the instability and difficulty in management. There is no general classification regarding pediatric fractures. Fractures are typically categorized (descriptive classification) based on i) configuration - transverse/spiral/oblique, ii) comminution - comminuted or non-comminuted, and iii) soft tissue coverage around the fracture - open/closed. More than half of the cases are represented by a simple, transverse, non-comminuted diaphyseal fracture, which is the most prevalent type of fracture [1].

The mechanisms of injury of the femoral shaft include high-energy trauma, motor car accidents, falling, sport injuries, and pathologic fractures. In younger children, especially children the pre-walking age, non-accidental traumas have to be taken into consideration [2].

A lot of factors affect the choice of treatment modality either by conservative or surgical interference, including age and weight, the fracture type, and accompanying traumas. Of note, age is the primary predictor of the treatment [3].

The management of comminuted LBF in children has undergone considerable changes in the last few years. Several years ago, the majority of fractures needed prolonged LOS in traction. In recent years, the popularity of flexible elastic nails has increased. The approach was initially developed for cases contraindicated to traction or casting, while nowadays, it has become the first therapeutic line [4].

FINs were developed to solve the problems of locked IMN in pediatric and teenage LBF that couldn't be managed using cast immobilisation. With FIN, a stable but non-rigid fixation is achieved, which permits micromotion at the fracture site under load. This triggers abundant bridging callus development and enhances rapid union [5].

On the other hand, FIN aren't enough in the management of comminuted or spiral tibial and femur fractures in teenagers who are length unstable and rotationally unstable. Combined external fixation (EF) and FIN would be a good alternative for pediatric unstable LBF. It has the benefits of minimal surgical trauma, control of alignment and length of long bones, short operative time, less blood loss, lack of periosteal stripping, and the capability to permit early weight-bearing [6].

AIM OF THE WORK

To assess the efficacy of combined EF and FIN in unstable LBF in children, retrospectively.

PATIENTS AND METHODS

This retrospective study included 23 children with unstable LBF and was treated by combined EF and FIN and it was held at Mansoura Emergency Hospital and was performed over one year from July 2023 to august 2024. This study included children above 6 years old with spiral and comminuted long bone fractures. This study excluded cases younger than 6 years and older than 18 years of age, patients with transverse fracture, pathologic fracture, open Gustilo type III fractures and with intra-articular fractures.

Received: 22/10/2024
Accepted:23/12/2024

METHODS

All patients were subjected to full history (Age, gender, etc.), past medical and surgical history. Physical examination included vital signs. Investigations included full radiographic data of X-ray anteroposterior and lateral and CT for assessment of union of the bone. We also collected data about the time from trauma to operation, duration of operation, radiation exposure and length of postsurgical immobilisation. We followed up the patients for more than 6 months.

Radiographic Evaluation

Fractures were categorized as oblique, transverse, spiral, or comminuted based on the association between the fracture line and the femoral shaft axis and the degree of fragmentation. The degree of comminution was categorized based on the **Winquist and Hansen** classification [7].

Surgical Technique

A radiolucent fracture table was used for all surgical procedures. Two flexible nails were placed through the fracture: retrograde from distal to proximal in the femur and anterograde from proximal to distal in the tibia.

Fracture reduction was conducted by closed reduction in entire patients with closed fractures. It was established that the diameter of the single nail occupies less than half of the medullary canal at both the narrowest points of the femur and tibia (the isthmus of the femur). The length and rotation were adjusted to neutral and a uniplanar EF (2-3 pins proximal and 2-3 pins distal) was after that applied to keep this proper position. The foot and patella were utilized to manage the rotation, while the contralateral limb was utilized to adjust the length. The management of open fracture was conducted by wound debridement and rapid fixation by the flexible nails and an EF.

Postsurgical Care

No further immobilisation of the affected limb was needed following operation. Hip and knee functional exercises were initiated on the 1st postsurgical day. Weight bearing was permitted four days following the initial operation (according to the patient's tolerance). The EF was removed five weeks following the initial surgery according to the existence of callus formation. The elastic nails were removed six to twelve months following fracture consolidation.

In the postsurgical period, parenteral antibiotics were administered for four days, followed by oral antibiotics for 10 days in cases with open fractures. In cases with closed fractures, parenteral antibiotics were administered for 2 days only. Full weight bearing was allowed when the radiograph indicated callus formation. Patients were evaluated clinically and radiologically every 2 weeks for the first 2 months and at 4-week intervals after that. When a proper bridging callus was noticed on radiograph, the EF was removed. A union was regarded as complete when the patient could fully weight the operated leg without assistance and without pain.

Frequent clinical and radiological assessments every 14 days for the initial two months and at two-month intervals were conducted. The hip and knee ROM of the affected side were assessed at each follow-up visit and compared to the unaffected side. Radiological evaluation was utilized to evaluate the clinical functional outcome.

Patients were assessed and analysed for union of the fracture, LLD, angular and rotational deformities, hip and knee motions, nail adverse events and any epiphyseal injuries in the proximal or distal ends of the femur and tibia, the overall result were evaluated according to Flynn score [8].

The most common complication of post-operative was PTI, which was described as manifestations of infection around a pin or wire that needed increasing the rate of local cleansing, protecting the pin site with dressing, using antibiotics, removal of the pin or wire, or conducting surgical debridement. Based on Paley, it may be classified into grade I, inflamed soft tissue; grade II, soft tissue infections; and grade III, bone infections[8].

Ethical considerations

The study protocol was submitted to the Institutional Review Board in the Faculty of Medicine, Mansoura University for approval (Code number: MS.23.12.2638) and according to the Declaration of Helsinki. As recorded in the files, before admission to hospital, informed verbal consent was obtained from each caregiver of each patient in the study after assuring confidentiality.

Statistical analysis:

Data were analyzed using SPSS version 22. Qualitative data were presented as numbers and percent. Quantitative data were assessed for normality by the Shapiro-Wilk test and then were defined as mean±SD and range. P value < 0.05 was considered significant.

RESULTS

The present study was retrospective study that was carried out at Mansoura Emergency Hospital to assess efficiency of combined EF and FIN in unstable long bone fracture of both lower limbs in children. Table **(1)** shows that mean age of the studied cases was 10.30±2.49 years ranging from 6 to 17 years and most of them (65.2%) were males. 52.2% of the studied cases were injured through RTA and 34.8% through fall from height. 73.9% of the studied cases had closed fracture. Patten of fracture was mainly (82.6%) comminution. Degree of comminution among studied cases was mostly (57.9%) type IV.

Table (1): Demographic characteristics, mechanism of injury, fracture types, degree of comminution, average time of surgery and time of external fixation of the studied cases

	N=23	**%**
Age / years Mean ±SD (min-max)	 10.30±2.49 (6-18)	
Sex Male Female	 15 8	 65.2 34.8
Mechanism of injury FFH RTA Sport injury	 8 12 3	 34.8 52.2 13.0
Type of fracture Open Close	 6 17	 26.1 73.9
Pattern of fracture Oblique Spiral Comminution	 2 2 19	 8.7 8.7 82.6
Degree of comminution III IV	N=19 8 11	 42.1 57.9
Average time of surgery (min) Mean ±SD (min-max)	 82.17±3.94 75-85	
Average time of removal of external fixation of tibia (months) Mean ±SD (min-max)	 1.67±0.58 (1.0-2.5)	
Frequency of cases regarding time of removal external fixation of femur 1 month 2 months	N=12 5 7	 41.7 58.3

Figure **(1)** demonstrates that 43.5% of the studied cases have average time of injury and fixation one day. Mean duration between injury and fixation was 1.74±0.75 days ranging from 1 to 3 days.

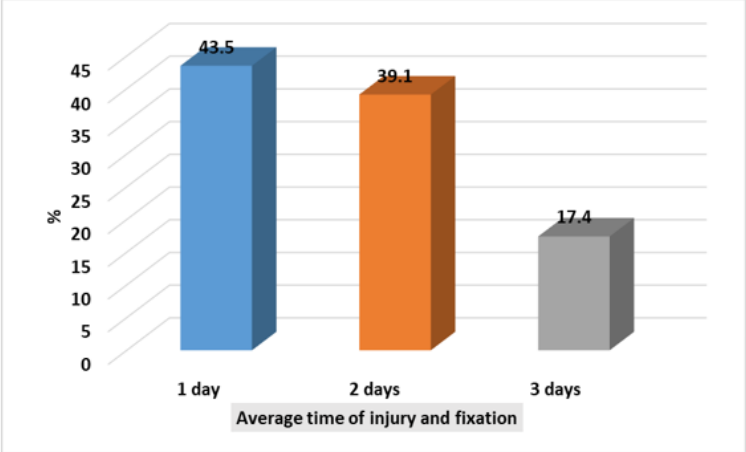

Figure (1): Average time of injury and fixation.

Table **(2)** demonstrates that mean time of tibia union was 2.56±0.46 months ranging from 2 to 3 months. All the 11 cases that had fractured tibia, had united tibia and 11 out of 12 (91.7%) cases that had fractured femur, had united femur. Regarding functional assessment of the studied cases, most of cases (82.6%) had excellent function. Regarding complications, 8.7% had grade I pin tract infection, 13% had irritation, 4.3% had lower limb discrepancy, and 4.3% had mal alignment.

Table (2): Time of union of tibia and femur, union type, functional assessment and Complications among studied cases

	N=23	%
Time of union for tibia (months)		
Mean ±SD	2.56±0.46	
(min-max)	2-3	
Time of union for femur(months)		
Mean ±SD	2.17±0.24	
(min-max)	2-2.5	
Fracture site		
Tibia	11	47.8
Femur	12	52.2
United tibia	11	100.0
United femur		
Not united	1	8.3
United	11	91.7
Flynn criteria (functional Assessment)		
Poor	1	4.3
Satisfactory	3	13.0
Excellent	19	82.6
ROM		
Score	23	100.0
Complications		
Pin tract infection (according to Paley)		
No	19	82.6
Grade I	2	8.7
Grade II	1	4.3
Grade III	1	4.3
LLD	1	4.3
Irritation		
No	20	87.0
Yes	3	13.0
Mal alignment		
No	22	95.7
Yes	1	4.3

Table **(3)** illustrates a statistically significant association between age and Flynn criteria. No statistically significant association was detected between sex of the studied cases with functional assessment by Flynn criteria of the studied cases. There was no statistically significant association between average time of injury and fixation and functional assessment of the studied cases. There was no statistically significant association between type of fracture, degree of comminution with functional assessment of the studied cases.

Table (3): Relation between Flynn criteria for functional assessment and demographic characteristics, average time of injury and fixation, type of fracture and degree of comminution among the studied cases

	Flynn criteria (Functional Assessment)		**Test of significance**
	Poor to Satisfactory N=4	Excellent N=19	
Age / years Mean ±SD	13±2.74	9.74±2.10	t=2.69 P=0.014*
Sex N (%)			
Male	2(50)	13(68.4)	FET=0.494
Female	2(50)	6(31.6)	P=0.589
Average time of injury and fixation			
1 day	2(50)	8(42.1)	MC=0.456
2 days	1(25)	8(42.1)	P=0.796
3 days	1(25)	3(15.8)	
Type of fracture			
Open	2(50)	4(21.1)	FET=1.44
Close	2(50)	15(78.9)	P=0.270
Pattern of fracture			
Oblique	1(25)	1(5.3)	MC=4.33
Spiral	0	2(10.5)	P=0.228
Comminution	0	8(42.1)	
III	3(75)	8(42.1)	
IV			

FET: Fisher exact test, t: Student t test, MC: Monte Carlo test

DISCUSSION

The proper management of pediatric comminuted diaphyseal fractures has been considered a challenging problem. The primary objective of surgery is to restore the length, alignment, and rotation [9]. The optimum device for the management of those pediatric fractures could be simple load sharing that allows mobilisation, while keeping limb length and alignment until bridging callus develops. Titanium elastic nails offer these features; on the other hand, they aren't free from complications. With regard to comminuted or unstable fracture patterns, elastic IMN (EIN) has an indefinite management of rotation and length, and improper management of proximal or distal fractures in large children [10].

Submuscular plating has been considered a promising therapeutic approach for the management of comminuted LBF in pediatrics. It offers a high degree of stability and allows the treatment of proximal and distal fractures that aren't adequate for nailing; on the other hand it carries the risk of particular drawbacks such as LLD, deep infections, and re-fractures following plate removal. In addition, it has a learning curve, and major operation might be needed to remove the plate [11].

Although not specific to long bones, FIN has gained popularity for treating long-bone fractures in children [12]. In addition, EF is a rapid and minimally invasive approach used to manage LBF. On the other hand, the use of an EF is accompanied by adverse events, which include PTI, delay in union may take more than 4 months, malalignment, non-union, and patient anxiety because of the extended duration of EF. In addition, EF permits early hospital discharge, is less burdensome than the hip spica cast, and may effectively control fracture alignment, hypothetically causing diminished frequency of malunion. Short-term immobilisation, returning joint ROM, lack of any stiff joint, reduction in the length of hospital stay (LOS), and low charges are considered as benefit of the FIN [13].

In our study we evaluated the efficacy of combined EF and FIN in unstable long bone fractures of lower limbs in children to accomplish the benefits of both approaches and decrease the adverse events of each.

These fixators are semi-rigid and permit micromotion at the fractured area, which is advantageous to bone healing. Additionally, they don't totally occupy the medullary cavity; as a result, endosteal callus development isn't suppressed. The EF, on the other hand, keeps the length and manages the rotation [14].

The mean time of union in our study was 2.56±0.46 months for tibia, while was 2.17±0.24 months for the femur. The range of time for removal of EF for tibia was 1-1.5 months while from 1 to 1.5 months for that of the femur.

In our investigation, according to Fynn criteria, functional assessment of the studied cases illustrates that 82.6% had excellent function, 13% satisfactory and only one case (4.3%) had poor function. Our results here are in accordance with **Lu *et al.*** [6] where functional outcomes were excellent in 24 out of 28 patients based on Flynn's criteria. In general, complications were minimal (14.3%).

Also, a retrospective study evaluated 42 pediatric patients with unstable tibial shaft fractures. The used combined approach involved elastic stable IMN (ESIN) and temporary EF. Functional outcomes were excellent in 38 out of 42 patients based on Flynn's criteria. Complications were minimal (11.9%). This study supports the effectiveness of the combined technique for tibial shaft fractures [15].

El-Alfy *et al.* [16] highlighted the synergistic effect of the EF and the FIN in the management of unstable pediatric LBF. The two approaches are minimally invasive and consider the biological aspect of fracture healing. The combined use of the two approaches offers adequate stability, which permits partial weight-bearing early in the therapeutic course.

In our study we revealed that most common complications were superficial infection caused by irritation of EIN on skin (13%). In preceding researches in which RF was utilized as conclusive treatment, there were increased frequencies of PTI, malalignment, and refractures as compared to intramedullary nails [13].

In addition, **Sink *et al.*** [17] displayed a complication rate of 57%, and most of their cases (71%) were treated by elastic stable intramedullary nailing. The investigators recorded that approaches excluding elastic stable intermedullary nails (ESIN) have to be utilized in children with unstable femur shaft fractures (UFSF).

In our study we revealed 2 cases of 8.7% grade I, 1 case (4.3%) of grade II, (treated with antibiotics) and 1 case (4.3%) of Grade III (PTI which treated by early removal of external fixator), 13% of irritation and one case (4.3%) of lower limb discrepancy, and 4.3% of malalignment. The relatively low rate of complications could be attributed to rapid removal of the EF, which could decrease the risk of PTI. Correspondingly, the introduction of the IMN might reduce the weight-bearing forces at the pin–bone interface, which can predispose PTI.

El-Alfy *et al.* [16] also found in their study fewer cases of PTI. On other hand, it's well-known for cases of external fixation alone to have high rate of PTI as recorded before [18]. Another study by **Moroni *et al.*** [19] displayed that callus bending stiffness rises between the 3rd and the 7th week. In addition, they recorded that pin loosening began following the 8th week. So, they suggested removal of the fixator prior to pin loosening.

LIMITATIONS

The small sample size, the absence of a control group, the absence of comparison with different therapeutic options, and the relatively short period of follow-up have been considered the main limitations. Future research should focus on long-term follow-up and comparative studies with alternative treatment methods to further validate the efficacy and safety of this combined approach.

CONCLUSION

The combined use of external fixators and FIN proves to be an effective and reliable approach for managing unstable long bone fractures in children. This method offers several advantages, including enhanced fracture stability, minimal soft tissue disruption, and a reduction in the incidence of complications commonly associated with single modality treatments. The dual approach not only facilitates early mobilization and rehabilitation but also demonstrates favorable outcomes in terms of bone healing and functional recovery. Our study confirmed that this hybrid technique is

particularly beneficial in complex pediatric fractures, ensuring optimal alignment and stabilization.

Conflict of interest: None.
Funding: None.

REFERENCES

1. **Herman M, Martinek M, Abzug J (2014):** Complications of tibial eminence and diaphyseal fractures in children: prevention and treatment. *JAAOS-Journal of the American Academy of Orthopaedic Surgeons*, 22(11): 730-41.
2. **Khoriati A, Jones C, Gelfer Y *et al.* (2016):** The management of paediatric diaphyseal femoral fractures: a modern approach. *Strategies in trauma and limb reconstruction*, 11: 87-97.
3. **Kocher M, Sink E, Blasier R *et al.* (2010):** American Academy of Orthopaedic Surgeons clinical practice guideline on treatment of pediatric diaphyseal femur fracture. *JBJS.*, 92(8): 1790-2.
4. **Lieber J, Schmittenbecher P (2013):** Developments in the treatment of pediatric long bone shaft fractures. *European Journal of Pediatric Surgery*, 23(06): 427-33.
5. **Frumberg D, Van Lanen-Wanek D, Jauregui J *et al.* (2019):** Can flexible intramedullary nails provide proper fixation of long bone fractures in patients weighing over 100 pounds? *Journal of Orthopaedics, Trauma and Rehabilitation*, 26(1): 9-13.
6. **Lu Y, Canavese F, Lin R *et al.* (2022):** Elastic stable intramedullary nailing and temporary external fixation for the treatment of unstable femoral shaft fractures in children aged 5-11 years old: a retrospective study of 28 cases. *Frontiers in Pediatrics*, 10: 914834.
7. **Winquist R, Hansen S (1980):** Comminuted fractures of the femoral shaft treated by intramedullary nailing. *Orthopedic Clinics of North America*, 11(3): 633-48.
8. **Flynn J, Hresko T, Reynolds R *et al.* (2001):** Titanium elastic nails for pediatric femur fractures: a multicenter study of early results with analysis of complications. *Journal of Pediatric Orthopaedics*, 21(1): 4-8.
9. **Rickert K, Hosseinzadeh P, Edmonds E (2018):** What's new in pediatric orthopaedic trauma: the lower extremity. *Journal of Pediatric Orthopaedics*, 38(8): e434-e9.
10. **Ricci W, Bellabarba C, Lewis R *et al.* (2001):** Angular malalignment after intramedullary nailing of femoral shaft fractures. *Journal of orthopaedic trauma*, 15(2): 90-5.
11. **Kanlic E, Anglen J, Smith D *et al.* (2004):** Advantages of submuscular bridge plating for complex pediatric femur fractures. *Clinical Orthopaedics and Related Research*, 426: 244-51.
12. **Carter T, Oliver W, Bell K *et al.* (2024):** Operative vs nonoperative management of unstable medial malleolus fractures: a randomized clinical trial. *JAMA network open*, 7(1): e2351308-e.
13. **Albushtra A, Mohsen A, Alnozaili K *et al.* (2024):** External fixation as a primary and definitive treatment for Complex Tibial Diaphyseal fractures: an underutilized and Efficacious Approach. *Orthopedic research and reviews*: 75:84.
14. **Radke H, Aron D, Applewhite A *et al.* (2006):** Biomechanical analysis of unilateral external skeletal fixators combined with IM-pin and without IM-pin using finite-element method. *Veterinary surgery*, 35(1): 15-23.
15. **Govindasamy R, Gnanasundaram R, Kasirajan S *et al.* (2018):** Elastic stable intramedullary nailing of femoral shaft fracture-experience in 48 children. *Archives of Bone and Joint Surgery*, 6(1): 39.
16. **El-Alfy B, Ali A, Fawzy S (2016):** Comminuted long bone fractures in children. Could combined fixation improve the results? *Journal of Pediatric Orthopaedics B.*, 25(5): 478-83.
17. **Sink E, Gralla J, Repine M (2005):** Complications of pediatric femur fractures treated with titanium elastic nails: a comparison of fracture types. *Journal of Pediatric Orthopaedics*, 25(5): 577-80.
18. **Parameswaran A, Roberts C, Seligson D *et al.* (2003):** Pin tract infection with contemporary external fixation: how much of a problem? *Journal of orthopaedic trauma*, 17(7): 503-7.
19. **Moroni A, Vannini F, Mosca M *et al.* (2002):** State of the art review: techniques to avoid pin loosening and infection in external fixation. *Journal of orthopaedic trauma*, 16(3): 189-95.