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Brief Communication

Augmentation of elastic stable intramedullary nail with external fixator in the management of comminuted shaft femur fracture in adolescents

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Abstract: Background: The management of adolescent femur fractures continues to evolve and remains controversial. Currently, operative fixation methods are favoured, offering options such as external fixator, flexible and locked intramedullary nailing, compression and locked plating. Our study aims to introduce a novel approach for treating adolescent femoral shaft fractures by combining an external fixator with an elastic stable intramedullary nail. Material and methods: We included 32 patients aged 11-16 years with femoral shaft fractures treated using an external fixator augmented elastic intramedullary nail at our institution from August 2015 to January 2019. Results: All patients achieved bony union. We analysed patient's results both clinically and radiologically. On average, the surgery took 77.34 minutes to complete with an average time to union of 13.9 weeks. External fixator and elastic nail removal took an average of 3.59 months and 26.5 months, respectively. At the final follow-up, knee range of motion averaged 131.88 degrees. According to the Flynn criteria, functional outcomes were excellent in 18 patients, satisfactory in 11 patients and poor in 3 patients. Pin site infection occurred in 3 patients, malunion in 4 patients, limb length shortening < 1 cm in 3 patients, distal nail tip prominence and knee stiffness in 3 patients. Conclusion: The management of femur fractures in adolescents using an elastic nail augmented with an external fixator is a minimally invasive procedure that provide secure fracture stabilization and predictable outcomes.

Keywords: Fracture shaft femur, adolescents, elastic stable nail, external fixator

Introduction

Femoral shaft fractures account for 1.6% of all bony injuries in children and adolescents [1, 3]. Comminuted shaft femur fractures in adolescents are problematic to manage because of inherent stability and minimal cortical contact leading to shortening and rotational deformity. Motor vehicle collision being the most common mode of injury causing these fractures in this age groups [11]. Other causes include sports injuries and fall from height. These fractures if not properly managed may lead to shortening, overgrowth, leg length discrepancy, malunion (angular and rotational) and non-union [16]. Various treatment options exist for these fractures in children including early spica casting, traction followed by casting, external fixation, open reduction internal fixation with plating, and elastic stable intramedullary nails (ESIN) [1]. In contrast, adult femoral shaft fractures are typically managed with intramedullary fixation [7]. However, adolescents fall into a unique category not fitting neatly into either age group. There is still ongoing debate regarding the treatment of femoral shaft fractures in adolescents. They are too young for adult-style treatment but too old for methods like hip spica and flexible nails [7]. Rigid intramedullary nail fixation has been recommended for adolescent patients with head injuries and polytrauma [4] and for those nearing skeletal maturity [8]. However, multiple studies cited the risk of avascular necrosis of femur head, coxa valga and growth arrest of greater trochanter associated with rigid intramedullary nail [11, 15, 23]. Other implant options described in the literature for managing femoral shaft fractures in adolescents include compression plating, flexible nails, and external fixators [24, 25]. The optimal treatment approach should aim for adequate stability, preservation of fracture biology, minimal scarring, prevention of adverse outcomes, all while being cost-effective [9].

Our study presents our experience in managing comminuted shaft femur fractures in adolescent patients using a combination of ESIN and an external fixator. The principle behind using this combo approach was to provide sufficient stability at fracture site which the ESIN alone will not dispense. Using ESIN with external fixator also prevent shortening and rotational malalignment. Our primary objective was to evaluate the clinical and radiological performance of this unique approach. Additionally, we aim to identify any technical challenges or issues associated with this method.

Material and methods

Study design

This prospective study included 36 adolescent patients with a diagnosis of comminuted fracture shaft of femur. The duration of study was from August 2015 to January 2019. Fractures were classified using Winquist and Hansen classification system [27]. The study was approved by institutional ethical committee. Informed consent was obtained from all the patients. The study was performed according to the ethical standards of the 1964 declaration of Helsinki as revised in 2000.

Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) confirmed diagnosis of comminuted shaft femur fracture; (2) closed or open Gustilo [26] type I and II injury; (3) age between 11 and 16 years irrespective of body weight; (4) treatment by ESIN and EF in combination; (5) treatment within 2 weeks from the date of injury; (6) complete clinical and radiographic data; (7) follow-up of more than 1 year. The exclusion criteria were: (1) fracture not involving diaphysis (fracture located within 5 cm of proximal and distal articular surface); (2) intra-articular fractures of femur; (3) transverse and oblique fractures; (4) pathological and Gustilo type III fractures; (5) patient less than 11 years or more than 16 years; (6) incomplete clinical and radiographic data; (7) follow-up less than 1 year.

Surgical technique

The surgical procedure was performed on a fracture table under spinal anaesthesia, with the patient in the supine position. The level of entry point for the nail was determined to be 2.5-3 cm proximal to the distal femoral physes in both the AP and lateral views. Two independent skin incisions measuring 2-3 cm were made at the desired spots for nail insertion on the medial and lateral aspects of the distal thigh. Soft tissues were carefully cleared, allowing visualization of both sides of the bone. The entry point was created with a hand-held awl initially kept perpendicular to the bone and then turned 45 degrees cephalad after entering the intramedullary canal. Two flexible titanium elastic rods pre-contoured into a 'C' shape were inserted from both the medial and lateral entry sites into the femoral canal. The fracture site was reached. Longitudinal traction and manipulation (closed/open) were employed to achieve reduction and the flexible rods were advanced proximally. One end of the nail was inserted into the greater trochanter while the other end was driven into the neck of the proximal femoral metaphysis. Fluoroscopy was used to assess the reduction and ensure an ideal nail position. The distal ends of the rods were left exposed by about 1 cm to facilitate removal.

After nailing, the fracture was further stabilized with an external fixator. Two Schanz pins (3.5/4.5 mm) proximal and two pins distal to the fracture site were placed posterior to the flexible nail. These pins were connected with two bars spanning across the fracture site, and pin sites were covered with dry sterile gauze. Patients and their families were instructed to perform daily dressing for the pin sites. After 10-14 days post-surgery, patients were allowed to wash and clean the pins and fixator with soapy water.

Data collection and radiographic evaluation

After the injured limb stabilisation on Thomas splint, all patients underwent full length anteroposterior (AP) and lateral radiograph of the injured thigh. The femur shaft was defined as area just distal to neck of femur and proximal to supracondylar ridge. All X-rays were assessed to check for inclusion criteria. The magnitude of comminution was classified as per the Winquist

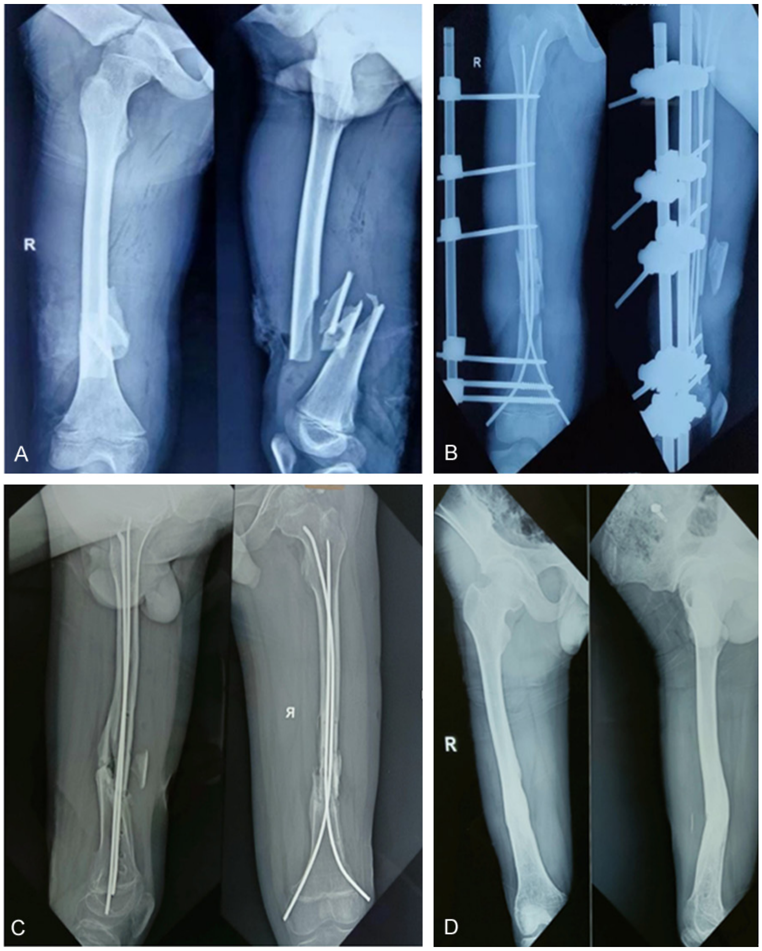

Figure 1. Pre- and post-operative Radiograph of 12 y/M patient showing: (A) Comminuted fracture shaft right femur; (B) Immediate post-operative X-ray with ESIN and external fixator in-situ; (C) X-ray at 3 months after fixator removal; (D) X-ray at final follow-up.

and Hansen classification and is divided into four types based on the percentage of fragmentation of the femoral diaphysis width. Type 1: fragmentation < 25%; Type 2: fragmentation between 25-50%; Type 3: fragmentation between 50-75%; Type 4: fragmentation > 75% or segmental.

Clinical evaluation and follow-up

Baseline characteristics and outcome measures were collected from clinical examination, serial follow-up evaluation, pre- and post-operative radiographs. Gentle progressive hip and knee range of motion (ROM) exercises and quadriceps building exercises were started from the first day post-surgery. The patients were allowed to walk without bearing weight on the affected limb 3 to 5 days after surgery. Partial weight bearing walk commenced at 6 to 8 weeks and full weight bearing (FWB) walk at 4 to 6 months post-surgery. Immediate post-operative radiographs were assessed for the quality of reduction. All patients underwent clinico-radiological evaluation at 2 weeks, 6 weeks, 3 months and then every 3 months until the fracture healed for a minimum of 1 year to check for any angulation, displacement and progress of union (**Figure 1**). The hip and knee ROM were evaluated at each visit and compared with uninjured side. Union was defined as bridging callus on at least three of four cortices on antero-posterior and lateral radiographs. Following visualisation of sufficient callus on X-rays, the fixator was removed 3 to 5 months after the surgery while the patient was sedated. After complete fracture healing, often after 2 years following surgery, flexible nails were removed. Functional outcomes were assessed using Flynn's criteria based on limb length discrepancy, malalignment, pain and complications.

Statistical analysis

Categorical variables are expressed as frequencies and percentages. Qualitative data are expressed as the means and standard deviations (SD). All statistical analysis was performed using Microsoft office 2010. Unpaired t test was used for continuous variables whereas for categorical variables, Fisher's exact test was used. The statistical significance was set to a p value < 0.05.

Results

Study population and demographic characteristics

After four patients were lost to follow-up, a total of 32 patients were included in our study.

Table 1. Demography and pre-operative parameters

Demography	Mean (SD)
Age (Years)	13.8 (2.2)
Sex (male:female)	21:11
Side of injury (R/L)	17/15
Mode of injury (RTA/FFH/GS)	19/10/3
Time of presentation (hours)	16.2 (10.2)
Closed/open fracture (grade I/II)	34.5 (16.4)
Closed/open fracture (grade I/II)	15/(10/7)
Fracture pattern (AO/OTA)	26/6
Fracture pattern (Winquist and Hansen)	
Type 1	6
Type 2	4
Type 3	10
Type 4	6

Table 2. Perioperative parameters, follow up and outcome measures

Peri-operative evaluation and functional outcome	Mean (SD)
Duration of surgery (minutes)	77.34 (10.7)
Follow up (months)	28.31 (3.07)
Radiological union (weeks)	13.9 (5.91)
Time of implant removal	
External fixator (months)	3.59 (0.76)
Elastic nail (months)	26.5 (1.97)
Knee range of motion (degree)	
6 weeks	60.3 (13.67)
6 months	105.16 (9.8)
Final follow up	131 (10.38)
Functional results (Flynn's criteria)	
Excellent	18
Satisfactory	11
Poor	3
Return to sporting activities (months)	10.06 (2.75)

Patient demographic data is presented in **Table 1**. The mean age of the patients was 13.8 years consisting of 11 girls and 21 boys. Among the cases, 17 involved injuries to the right thigh while 15 affected the left thigh. The most common mode of injury was road traffic accidents (RTA) occurring in 19 patients followed by falls from heights (FFH) in 10 patients and gunshots (GS) in 3 patients. Fifteen patients sustained closed injuries while 10 had grade I open injuries and 7 had grade II open injuries.

According to the Winquist and Hansen classification of femoral fractures, there were 2 patients with type 1 fractures, 6 with type 2 fractures, 6 with type 3 fractures and 18 patients with type 4 fractures. On an average, patients arrived at the hospital 16.2 hours after sustaining the injury and underwent surgery at an average of 34.5 hours post-injury. Fracture reduction was performed closed in 26 patients and open in 6 patients. The mean time for radiological union was 13.9 weeks.

Peri-operative and clinico-radiological outcome evaluation

The average duration of surgery was 77.34 minutes (**Table 2**). The average follow-up period extended to 28.3 months with an average time for bearing full weight at 5.76 months. Sporting activities resumed after an average of 10.06 months. The mean time for external fixator and ESIN removal was 3.59 months and 26.5 months respectively. Knee flexion at 6 weeks averaged 60.30 degrees. Notably, knee range of motion (ROM) showed significant improvement after external fixator removal with an average knee ROM of 105.16 degrees at 6 months and 131.8 degrees at the final follow-up (**Figure 2**). Functional results were assessed according to the criteria of Flynn et al. [17], resulting in excellent outcome for 18 patients, satisfactory outcome for 11 patients and poor outcome for 3 patients.

Complications

Infections were the most common complications observed in our study as detailed in **Table 3**. Three patients developed pin site infections with two of them successfully treated through local debridement. In one patient with a resistant infection, early fixator removal was performed at 6 weeks to resolve the issue. Additionally, two patients developed entry site infections which healed with daily dressing and intravenous antibiotics. Four fractures exhibited malunion with one patient experiencing varus angulation, two patients showing valgus

Figure 2. Clinical picture of 12 y/M patient showing range of motion of right knee at final follow-up (2 years). A. Flexion; B. Extension; C. Cross leg; D. Squat position.

Table 3. Complications

Complications	Number of patients
Infection (pin tract/entry site)	3/2
Malunion (Varus/Valgus/Posterior angulation)	1/2/1
Limb length (Shortening/lengthening)	3/0
Distal nail tip prominence	3
Knee stiffness	3

angulation and one patient presenting posterior angulation. It's worth noting that all malunions remained within acceptable limits and no cases of non-union were observed. Minimal shortening of the operated limb was noted in three patients (0.5-1 cm) but none of them exhibited clinical symptoms. We did not identify any cases of limb lengthening. Furthermore, distal nail tip prominence was found in three patients. This prominence was evident immediately after surgery and was not due to nail backout or fracture collapse. These three patients developed knee stiffness and required early nail removal although knee range of motion improved marginally as a result. Importantly, no cases of refracture were observed after implant removal.

Discussion

Orthopaedic surgeons still face challenges in treating femoral shaft fractures in adolescents due to the relative diameters of the femur and the open physes [11]. Despite extensive research in this field, these fractures remain common in our hospital's emergency room with no established treatment standards. Historically, nonoperative methods were employed [4] but in recent years, treatment options for these fractures have expanded from conservative to surgical approaches [2]. Over the past 25 years, there has been significant progress in the development of implants and surgical techniques for managing these fractures [10]. Operative fixation methods described in the literature include rigid interlocking nails, flexible intramedullary nails, open reduction internal fixation (ORIF) using plates, external fixators, and minimally invasive plate osteosynthesis (MIPO) [12-15], each with its advantages and disadvantages. In our study, we utilized a novel combination of implants consisting of ESIN supplemented with an external fixator to manage femoral fractures in the 11 to 16-year age group. Although this combination has been described in the paediatric age group [3, 5, 6], it has not been extensively studied in adolescents making direct comparisons challenging.

Our study predominantly had male patients with road traffic accidents (RTAs) being the

Table 4. Complications according to gender, age, mode of injury and fracture characteristics

	No complications	Complications	*p*-value
Gender			
Male	7	14	0.89
Female	10	1	
Age			
11-13 years	9	3	0.845
14-16 years	8	12	
Fracture type			
Closed	13	4	0.876
Open	4	11	
Mode of Injury			
RTA	7	12	0.874
FFH	8	2	
GS	2	1	

most common cause of injury. This reflects the higher exposure of males to trauma. On average, patients presented to the hospital 16.2 hours after injury and surgical intervention occurred approximately 34.5 hours post-injury aligning with findings by Dey S et al. [3]. Open fractures were more common than closed ones attributed to the prevalence of RTAs. Closed reduction was successful in 26 patients while open reduction was necessary in 6 patients primarily due to comminuted fracture morphology in four cases and soft tissue interposition between fracture fragments in two cases. Comparing to the findings of Park KC et al. [9], our mean surgical duration of 77.34 minutes was notably shorter. This may be attributed to the ease of using this implant and the shorter learning curve required to master the technique. Time to bony union in our study was comparable with results from Shivashankarappa A et al. [10] and Ramseier LE et al. [16]. We removed the external fixator when bridging callus was observed in three of the four cortices. Nail removal was performed on average two years after the initial injury. Knee flexion was satisfactory at six weeks likely due to soft tissue tethering by external fixator pins. Subsequently, knee range of motion significantly improved after fixator removal reaching full range of motion at final follow-up. Three patients had poor functional results according to Flynn criteria [17] primarily due to distal nail tip prominence leading to pain and limited range of motion.

One common adverse consequence of using an external fixator is pin tract infection [18, 19]. Most cases respond to debridement and local antibiotics [20, 21]. In our series, three patients experienced pin site infections. One patient with early fixator removal due to infection and loosening ultimately healed well and the fracture union was satisfactory. Two patients had superficial entry site infections which healed with intravenous antibiotics and daily dressing. Four patients experienced malunion which resolved adequately within acceptable limits due to good bone remodelling at the fracture site. We did not observe any cases of nonunion or delayed union in our series. Limb shortening was noted in three cases (range 0.5-1 cm) but none of these patients exhibited clinical symptoms and none experienced limb lengthening. Distal nail tip prominence was found in three cases. This issue was minimized by cutting the nail just outside the bone. Notably, none of the patients in our group experienced nail back-out or intramedullary nail sinking possibly due to the external fixator's role in preventing collapse at the fracture site. All the complications mentioned above were common and inherent to external fixator and comminuted femur fractures. Our rate of complication was much lower than the complications reported in previous studies on the use of external fixator and ESIN alone [16, 17]. None of our complications required second operation. Our data revealed that these complications were unrelated to sex, age, mode of injury and location of fractures (**Table 4**).

Various treatment options exist for femoral fractures in teenagers including compression plating, rigid IM nailing, external fixators and flexible nails each with its advantages and disadvantages [22]. However, our combination of ESIN and an external fixator offers a minimally invasive approach that provides adequate fracture stability with appropriate angular and rotational alignment, minimal limb length discrepancy (LLD) and avoidance of significant complications [5]. The technique broadens the indications for flexible nailing when the stability offered by ESIN alone is uncertain. Nevertheless, using an external fixator and performing closed flexible nailing required increased radiation exposure and posed challenges when navigating the elastic nail across comminuted areas. Careful planning is necessary to ensure the fixator pin and nail entry point are adequately spaced to prevent refracture. It is important to note some limitations in our study. We did not consider patient weight which can significantly impact implant selection in patients over 11 years with a weight of over 49 kg. Polytrauma patients were excluded from our study, as multiple systemic involvements can alter the treatment approach. Lastly, our study has a small sample size and a relatively short follow-up duration. Further research comparing this approach with alternative modalities is needed to confirm its efficacy.

Conclusion

Indeed, the combination of elastic stable intramedullary nails (ESIN) with an external fixator proves to be a successful and low-risk procedure for managing adolescent femoral shaft fractures. This method offers excellent functional outcomes while minimizing complications. It promotes early independent ambulation reducing hospital stays and sparing patients from prolonged bedrest ultimately lowering morbidity. Surgeons can rely on the stability and predictability provided by this adjuvant therapy when dealing with femoral shaft fractures in teenagers aged 11 to 16. It represents a safe and effective approach to their treatment.

Disclosure of conflict of interest

None.

Abbreviations

ESIN, Elastic stable intramedullary nail; EF, External fixator; ROM, Range of motion.

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