Results of quadruple elastic nailing for length unstable fracture femur in pediatrics

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Background
Length-unstable shaft femur fractures including spiral, long oblique, and comminuted fractures are mechanically unstable under axial, bending, and rotational forces. The risk of shortening, rotation, and malalignment increases substantially with the standard technique using only two nails. Our study was the first to report the results of quadruple elastic nailing for length-unstable femoral fractures on a prospective basis. Moreover, our study was the first to correlate this technique to the operative time and to the radiation exposure time.

Patients and methods
In all, 26 patients with simple length-unstable pediatric shaft fracture femur were included from October 2020 to October 2022. We used four elastic stable intramedullary nails (ESINs) for fracture fixation. Operative time and radiation exposure time were calculated for each patient. Follow-up of union was judged by radiograph at 1, 2, 3, and 6 months postoperatively. The Flynn score was used for evaluation at the 6th month postoperatively.

Results
Most of the studied cases were associated with excellent outcomes (84.6%) with four cases being associated with satisfactory outcomes (15.4%). Entire cases were associated with full ROM with no recorded angular deformity or rotational deformity. The mean operative time, radiation exposure time, and full union duration were 1.23 ± 0.31 h, 1.26 ± 0.27 min, and 9.08 ± 2.78 weeks, respectively.

Conclusion
Our case series supports the use of ESIN in length-unstable diaphyseal femur fractures with 26 patients treated with a quartet of ESINs.

Keywords:
elastic nail, femur, length unstable, quadruple

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Background

The incidence of femoral shaft fractures is less than 2% of all fractures in children. However, the most common pediatric fractures leading to hospitalization are the femoral fractures [1]. They are accompanied by prolonged hospital stays and prolonged immobility and put a huge load on the healthcare system [2].

Elastic stable intramedullary nails (ESINs) represent one of the most popular methods of fracture fixation for femoral shaft fractures in children aged 6–12 years. It is a simple, effective, minimally invasive technique, which preserves the fracture hematoma. ESINs are load-sharing devices, which provide relative stability and subsequent fracture healing by indirect bone healing [3]. However, complications including pain and skin irritation secondary to nail prominence were reported. Moreover, higher rates of malunion (10% to 50%) have been reported with the management of length-unstable femur fractures [4].

Length-unstable femur fractures including spiral, long oblique, and comminuted fractures are mechanically unstable under axial, bending, and rotational forces. The risk of shortening, rotation, and malalignment increases substantially with the standard technique using only two nails [5,6]. The addition of a third nail for double elastic nailing (for the sake of increasing the fracture stiffness and resistance to axial, bending, and rotational forces) has been biomechanically and clinically tested [5,6]. Furthermore, the addition of a 4th nail has been tested biomechanically. It was concluded that adding two more nails for stability of the fracture treated with double elastic nailing is a good alternative [7]. Clinical evaluation of this technique has been reported only once and on a retrospective basis [8]. Our study was the first to

report the results of quadruple elastic nailing for length-unstable femoral fractures on a prospective basis. Moreover, our study was the first to correlate this technique to the operative time and the radiation exposure.

Patients and methods

The current prospective study was conducted at the author's institute after approval of the Ethics and Scientific Committee of the related medical school. In all, 26 patients with simple length-unstable fracture femur were included. The inclusion criteria were being skeletally immature and having a length-unstable femur fracture including all fractures of the shaft of the femur with spiral, long oblique, and multi-fragmentary fractures. Open fractures, pathological fractures, and fractures near the physeal plate along with polytraumatized patients were excluded from our study [8]. All patients were admitted to the authors' hospital from October 2020 to October 2022. All cases completed follow-up for at least a year. All procedures were performed by the same senior trauma surgeon in a period of 1–2 days of the initial trauma.

Preoperatively, the length of the normal femur was measured under fluoroscopy using a metal ruler. This length was used intraoperatively as a reference for length adjustment of the fractured side to adjust the length.

After being anesthetized, the patient was positioned supine on a traction table to allow for manual traction of the injured limb as needed and the other side was abducted at 45°. The entire lower extremity was draped, and C-arm fluoroscopy was brought in from the contralateral side. This allowed the surgeon and assistant to have complete access to the operative extremity. ESINs were contoured with a 45° bent at the insertional end and a gentle, even curve over the whole length of the nail.

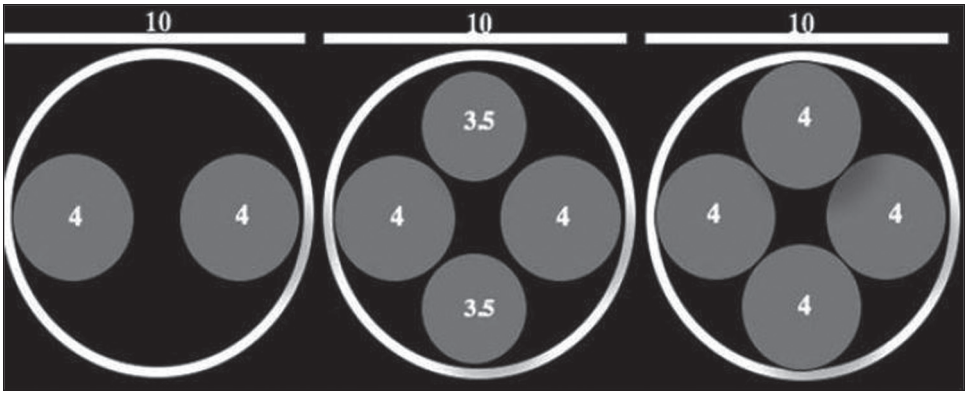
The diameter of each ESIN was determined by measuring the diameter of the femoral canal at the isthmus on an AP radiograph and then selecting the nail sizes that were ~40% of that measurement to obtain at least 80% canal fill (Fig. 1). For example, if the isthmus diameter was 10 mm, we used a nail with a diameter of 4 mm. Prebending of nails was performed in the coronal plane to allow passage through the femoral canal. No prebending of the nails was performed in the sagittal plane.

For the nail entry, a 1 cm-long skin incision was made in the supracondylar area medially and laterally about 2 cm proximal to the distal femoral physics. At the entry point, we introduced an awl to open the near cortex and direct it proximally. This created an oval entry opening that facilitated retrograde advancement of the flexible nail. This elliptical-shaped entry hole also facilitated the entry of the second nail. After reducing the fracture and establishing the entry holes, one medial and one lateral ESIN were introduced into the canal, advanced through the fracture, and pushed to the proximal metaphysis.

The first two nails had been inserted just proximal to the fracture site before the next two nails were inserted. The incompletely inserted nail was retracted away from the skin allowing the next nail to be inserted between the distal end of the elliptical entry hole and the rod, paying attention not to plastically deform the rod being retracted (Fig. 2). If the space is not enough to insert the tip of the next nail, the entry can be enlarged using a drill.

The third and fourth nails were typically either the same size or 0.5 mm smaller than the first two nails. Once they had been advanced beyond the fracture, all nails were fully inserted and cut to sit flush leaving about

Figure 1



An 80% filling of the coronal plane while allowing for the insertion of the two additional nails in the sagittal plane.

0.5–1 cm outside the bone to facilitate removal but not more to avoid soft tissue irritation followed by wound closure. The proximal tips of the rods were typically fanned out from each other, often obtaining purchase in the femoral neck and the greater trochanter.

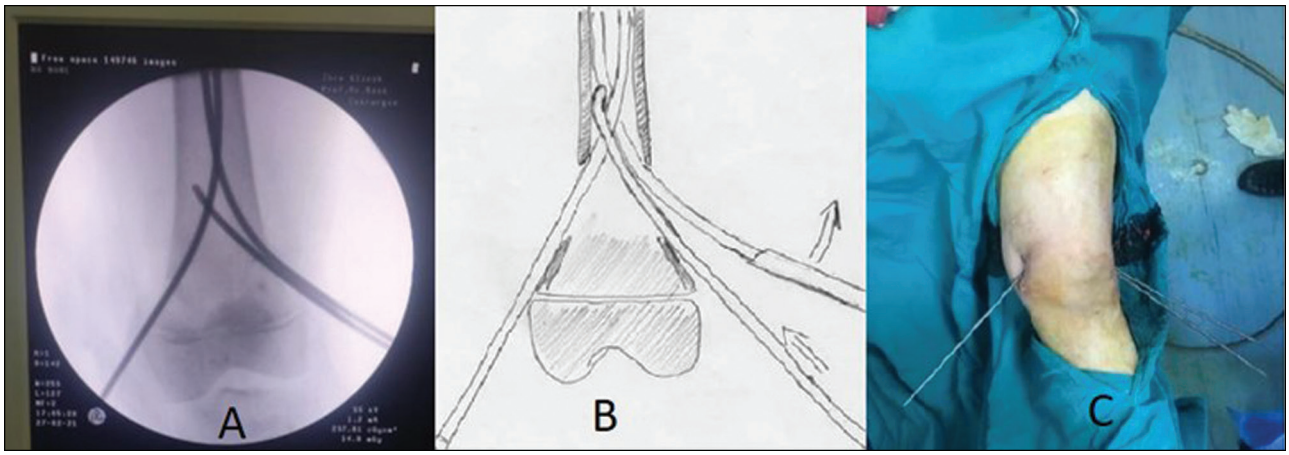
Operative time and radiation exposure time were calculated for each patient. Follow-up of union was judged by a radiograph at 1, 2, 3, and 6 months postoperatively (Figs. 3–5). The Flynn score was used for the evaluation at the 6th month postoperatively [9] (Table 1).

Data were fed to the computer and analyzed using IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp. Qualitative data were described using number and percentage. Quantitative data were described using mean and standard deviation for parametric data after testing normality using Kolmogrov–Smirnov test. The significance of the obtained results was judged at the (0.05) level.

Results

The age of most of the studied cases was more than 8 years (69.2%), while only 30.8% of them have an age of less than or equal to eight. The percentage of male-to-female (M/F) ratio was 76.9/23.1. The most common mode of trauma was FFH (30.8%), followed by falling downstairs (23.1%), direct trauma (23.1%), and lastly road traffic accident (7.7%), motor vehicle accident (7.7%) and

Figure 2



The incompletely inserted nail was retracted away from the shaft allowing the next rod to be inserted: A: radiology image, B: drawing depiction, and C: live image.

Figure 3

Preoperative AP and lateral radiograph.

Figure 4

Immediate postoperative AP and lateral radiograph.

Figure 5

AP and lateral radiograph taken 6 months postoperatively.

bicycle crash (7.7%). Multi-fragmentary was the most common fracture pattern (53.8%), followed by spiral (23.1%) and long oblique (23.1%). Concerning diaphyseal location, proximal was recorded in 46.2% of cases, while the middle was recorded in 53.8%.

The mean weight was 33.08 kg. The mean nail sizes were 3.46 ± 0.43 and 3.19 ± 0.43 for the conventional and additional nails, respectively. The mean operative time, radiation exposure time, and full union duration were 1.23 ± 0.31 h, 1.26 ± 0.27 min, and 9.08 ± 2.78 weeks, respectively.

Table 1: The Flynn score

	Excellent results	Satisfactory results	Poor results
Limb length inequality	< 1 cm	< 2 cm	>2 cm
Malalignment	5 degrees	10 degrees	>10 degrees
Pain	None	None	Present
Complications	None	Minor and resolved	Major and lasting morbidity

Most of the studied cases were associated with excellent outcomes (84.6%) with four cases being associated with satisfactory outcomes (15.4%). Entire cases were associated with full ROM with no recorded angular deformity or rotational deformity. In addition, there were no recorded complications among the studied cases with the exception of two cases being associated with prominent nails. (Table 2).

There were no statistically significant differences among demographic characteristics (age and sex) and the Flynn score at 6 months (P>0.05).

There were no statistically significant differences among all fracture characters (mode of trauma, side, fracture

Table 2: Outcome distribution among studied cases

	N=26 [n (%)]
Flynn score at 6 months:	
Satisfactory	4 (15.4)
Excellent	22 (84.6)
Knee and hip full range of motion	26 (100.0)
LLD<1 CM	26 (100.0)
Angular deformity	0
Rotational deformity	0
Complications:	
No	24 (92.3)
Prominent nail	2 (7.7)

pattern, and diaphyseal location) and the Flynn score at 6 months (P>0.05) (Table 3).

Discussion

Matching with our hypothesis, we found that quadruple ESIN achieved good to excellent results in the management of length unstable femur shaft fracture. In our present series, the radiological union was achieved in a mean time of 9.08 ± 2.78 weeks. No cases showed nonunion or delayed union. No patients had clinical evidence for leg length discrepancy coronal or sagittal malalignment. At the final follow-up, all patients had full hip and knee range of motion. No child required additional surgery other than the routine removal of hardware. There were two minor complications; two patients presented with implant prominence and skin ulceration that were treated with early implant removal after 4 months.

In 2001, Flynn JM *et al.* published an important analysis of the early results, describing the scoring outcome criteria and complications of ESINS, which were trialed in several major pediatric centers of trauma located in North America before they were released widespread [9] (Flynn *et al.*, 2001a). According to Flynn's scoring classification, our present series results were excellent in 11 (84.6%) patients and satisfactory in two (15.4%) patients, while no patients had a poor score.

We are aware that the Flynn score was not initially developed for the specific type of length-unstable femur fracture. However, there are two reasons why we utilized it; first, there is no specific score in the literature for the follow-up of the length-unstable femur fracture. Second, 25% of the score marks depend on the limb length inequality, which is the main expected complication of such fracture.

The reason that encouraged us to conduct this study was the reported high complication rate of using 2 ESINs in the management of length-unstable femur shaft fractures. A retrospective review published in 2005 by Sink *et al*. reported a 40% reoperation rate in length unstable femur fractures treated with two ESINs. They concluded that ESIN is not a suitable treatment for length-unstable femur fractures [4] (Sink *et al.*, 2005).

In 2020, Siddiqui *et al*. published a retrospective study on 58 patients with femoral shaft fractures, which were fixed by two ESINs with the recommendation to achieve an intramedullary canal fill greater than 80%. The study concluded that there was no significant difference in outcomes or complications between length stable and length-unstable femoral shaft fractures treated with two ESINs [10] (Siddiqui *et al.*, 2020). However, we could justify these results by noting that the mean age was only 5 years, and 33% of the patients were aged under 5 years. The study also excluded any patient aged 11 years or over.

The only clinical trial that can be compared with our study was published in 2019 by Busch *et al.* It was a retrospective study carried out on 12 children with an average age of 9.3 years and weight of 47.7 kg with length-unstable femur fractures fixed with a quartet of ESINs. They reported good to excellent outcomes [8]. Compared with ours, this study lacks the quantification of the operative time and radiation dose, which would be very helpful in future review articles and comparative studies. Moreover, it was performed on a retrospective basis.

Literature about radiation exposure in lower extremity ESIN is rare. Kraus *et al*. reviewed operative records of 57 children and adolescents with diaphyseal femoral fractures who were treated operatively with two ESINs with regard to operation time and intraoperative radiation time. They found that the mean incision-suture time was 41.8 min, and the mean image intensifier time was 70.3 s in all cases of femoral shaft fractures treated with two ESINs [11] (Kraus *et al.*, 2008).

Ours is the only study that quantified the radiation exposure while using the quadruple ESIN. We found increased total operation times and increased image intensifier times in comparison with the previous study which included only two nails. The mean incision-suture time was 73.8 min, while the mean image intensifier time was 75.6 s. However, this higher demand for time and radiation is logical due to the need for additional operative steps.

Our case series supports the use of ESIN in length-unstable diaphyseal femur fractures with 26 patients treated with a quartet of ESINs. Successful union occurred in all patients. With this technique, no specific

Table 3: Relationship between fracture characters and Flynn Score at 6 months among studied cases

	Flynn Score at 6 months		Test of significance
	Satisfactory *N*=4	Excellent *N*=22	
Mode of trauma:			
RTA	0	2 (9.1)	MC *P*=0.737
MVC	0	2 (9.1)	
FFH	0	8 (36.4)	
Falling down	2 (50)	4 (18.2)	
Direct trauma	2 (50)	4 (18.20	
Bicycle crash	0	2 (9.1)	
Side			
Right left	0	12 (54.5)	^{2}=2.03
	4 (100)	10 (45.5)	*P*=0.155
Fracture pattern:			
Spiral	2 (50)	4 (18.2)	^{2MC}=1.29 *P*=0.524
Multi-fragmentary	2 (50)	12 (54.5)	
Long oblique	0	6 (27.3)	
Diaphyseal location			
Proximal	2 (50)	10 (45.5)	FET=0.014 *P*=1.0
Middle	2 (50)	12 (54.5)	

^{2}, Chi-square test; FET, Fischer's exact test, Monte Carlo test.

complications related to the extra two nails could be reported. Even the presumed excessive rigidity was not a problem as all the cases achieved full secondary healing with a bridging callus.

The greatest limitation of our study is the relatively small sample size of 26 patients. This is most likely because the majority of femur fractures in children are of stable patterns that are successfully treated with the traditional two-nail techniques. In light of this, all the reported larger sample sizes for this technique were reported on a retrospective basis. Furthermore, our study was not a comparative study..

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Conflicts of interest
No conflict of interests to be declared: Results of quadruple elastic nailing for pediatric length-unstable femur shaft fractures.
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