Retrograde flexible intramedullary fixation of pediatric femur diaphyseal fractures: all-lateral entry versus medial and lateral entry point techniques

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Background
Femur fractures are the most common orthopedic injury requiring hospitalization in children(1). Fixation using flexible intramedullary nailing (FIMN) for the treatment of children aged 5–11 years having diaphyseal femur fractures is recommended by The American Academy of Orthopedic Surgeons (Level of Evidence: III, Grade of Recommendation: C). Antegrade placement of 'C'-shaped and 'S'-shaped nails, retrograde placement of two 'C'-shaped nails (CC) through medial and lateral approaches, and retrograde placement of 'C'-shaped and 'S'-shaped nails (CS) through a single lateral approach are all nail configurations for FIMN.(2)
Objectives
This study aimed to assess and contrast the clinical and radiological outcomes of fixation of pediatric femoral shaft fractures using paired CC-shaped versus paired CS-shaped flexible nails placed in a retrograde manner.
Patients and methods
In this study, 40 children aged from 5 to 12 years with diaphyseal fracture femur were treated by FIMN in Helwan University and Sheikh Zayed Specialized Hospitals. According to the surgical approach, patients were classified into two equal groups: group (1): retrograde placement of 'C'- shaped through medial and lateral (ML) approaches (CC) and group (2): 20 patients with 'C'-shaped and 'S'-shaped nails (CS) through a single lateral approach (AL). At the end of follow–up, the results were assessed clinically using Flynn's score and radiographically by plain radiographs.
Results
Among the children included in the study, there were 12 (30%) females and 28 (70%) males. Their ages ranged from 6 to 12 years in group (1) with a mean of 8±1.12 years and in group (2) had a mean of 7.67±2.34 years with a range from 6 to 10 years. The two groups were matched in age and sex (*P*>0.05). The duration of anesthesia was longer in group (1), 52.78 min as against 45 min in group (2), with a 12 min difference, which recorded a significant difference of *P*=0.034. Complications were less in the CS group than the CC group. In this study, postoperatively, 40% of the CC group had no pain, while 14% of the CS group had no pain [visual analog scale (VAS = 0)]; 45% of the CC group had mild pain (VAS = 1–3) and 30% of the CS group had mild pain; 5% of the CC group had moderate pain (VAS = 4) and 10% had severe pain (VAS = 5), while the CS group did not show moderate or severe pain.
Conclusion
Both techniques for retrograde flexible intramedullary fixation (CC and CS) provide excellent clinical, and radiological outcomes and a low incidence of complication rate for the treatment of pediatric femur fractures. The CS technique can be a faster operation, but proper technique is critical to reduce the risk of shortening and malunion of pediatric femoral fractures.

Keywords:
diaphyseal, femur fracture, flexible intramedullary fixation, pediatric

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Introduction

Femur fractures are the most common orthopedic injury requiring hospitalization in children [1,2]. In pediatrics, femoral shaft fractures occur for ~1.6% of all fractures [3].

High-energy trauma is the most common cause of femoral shaft fractures in children over the age of 6 years, with motor vehicle incidents accounting for more than 90% of injuries in this age group.

Pediatric orthopedic surgeons prefer to surgically fix femur fractures in children over 5 years old, while opting for conservative treatment for femur fractures in younger children [3]. Conservative treatment consisting of closed reduction and spica casting could be the option used to treat patients under the age of 5 years; however, teenagers with a closed proximal femoral physis should be fixed with rigid intramedullary nailing [4].

Flexible intramedullary nailing (FIMN) for the fixation of femoral shaft fractures in children and young adolescents has increased in popularity during the last 15 years.

In comparison to nonsurgical treatment options for juvenile femoral shaft fractures, flexible nailing has several advantages over typical, including shorter hospital stays, quicker patient movement, and lessening the psychosocial effects of protracted immobilization [5]. Furthermore, when compared with external fixation, this approach seems to offer distinct advantages over other surgical treatment options because it does not seem to have the same refracture risk [6], requires less exposure than plate fixation [7], and avoids the risk of femoral head osteonecrosis and premature greater trochanteric epiphysiodesis associated with rigid intramedullary devices [8].

The American Academy of Orthopedic Surgeons recommends that clinicians consider using FIMN for the treatment of children aged from 5 to 11 years having diaphyseal femur fractures (Level of Evidence: III, Grade of Recommendation: C).

Antegrade insertion of ‘C’-shaped and ‘S’-shaped nails, retrograde insertion of two ‘C’-shaped nails (CC) through medial and lateral (ML) approaches, and retrograde insertion of ‘C’-shaped and ‘S’-shaped nails (CS) through a single lateral approach (AL) are all nail configurations for FIMN [9]. The type of construct used depends on the surgeon’s preference and the location of the fracture. Although the single-incision technique seems to require substantially shorter anesthesia time, current evidence suggests that there is no significant difference in fracture alignment at union between both CS and CC retrograde fixation techniques [10].

Patients and methods

Patients

In all, 40 children aged from 6 to 12 years with diaphyseal fracture femur were treated by FIMN. Patients were classified into two equal groups according to the surgical approach: group (1): underwent retrograde insertion of ‘C’-shaped nails through ML approaches CC and group (2): 20 patients with ‘CS through AL.

Methods

Diagnosis

(1) History taking.
(2) Clinical examination.
(3) Routine preoperative laboratory investigations.
(4) Radiograph of the affected femur including hip and knee joints.

Treatment

Intraoperative:

(1) General anesthesia.
(2) A prophylactic dose of IV antibiotic.
    (a) Position: supine position on a radiolucent table so we could see the whole femur from hip to knee by the fluoroscopy Fig. 1.

(1) Sterilization: from above hip joint to the ankle.
(2) Draping: from hip joint to below knee joint Fig. 2.

Surgical technique

All lateral entry technique: With the guidance of fluoroscopy, the physis was identified. A 1-cm skin incision on the lateral aspect was, ~ 2 cm above the physis Fig. 3.

Figure 1

Position of the patient and image intensifier.

The skin and subcutaneous tissue were sharply incised, and then blunt dissection through the muscles was done to reach the underlying bone.

Under fluoroscopic guidance, a 4.5 mm drill bit was used to drill the near cortex; first perpendicularly and then gradually aiming superiorly reaching an angle of 45°.

Figure 2

Sterilization and draping.

An awl was used to widen the opening as both flexible nails were placed through the same cortical opening.

Flexible nail size was then assessed by the patient with the assistance of fluoroscopy, aiming for an 80% fill of the canal Fig. 5.

One of the nails was contoured to an 'S' shape, whereas the other one was contoured to a 'C' shape.

The nails were then placed through the cortical openings and passed till just proximal to the fracture site Figs 7 and 8.

The fracture was reduced, the nails were passed across the fracture, and the nails were impacted into their final position. One nail was directed medially to the neck and the other laterally to the greater trochanter Fig. 9.

The position of the nails was checked using the C-arm and they were then withdrawn by 0.5 cm. The nails were pulled away from the bone and cut flush with its surface, leaving behind a small stump that was pushed in for 0.5 cm Fig. 10.

Wound closure in layers Fig. 11.

Medial and lateral entry technique

With the guidance of fluoroscopy, the physis was identified. A 1 cm skin incision in the lateral aspect was made ~ 2 cm above the physis.

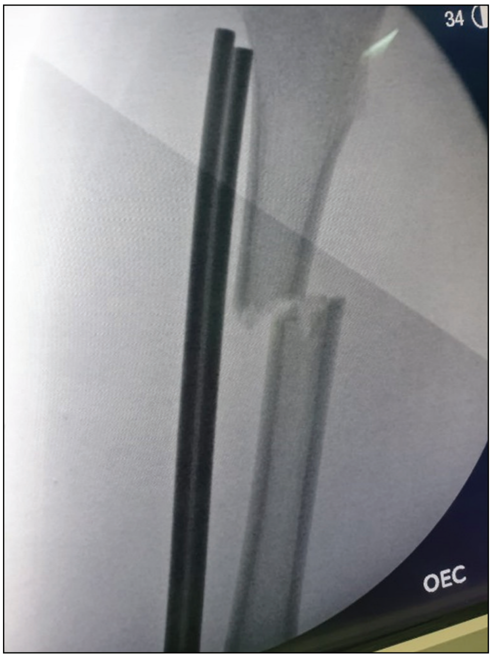
Figure 3

With guidance of the fluoroscopy, the physis was identified.

Figure 4

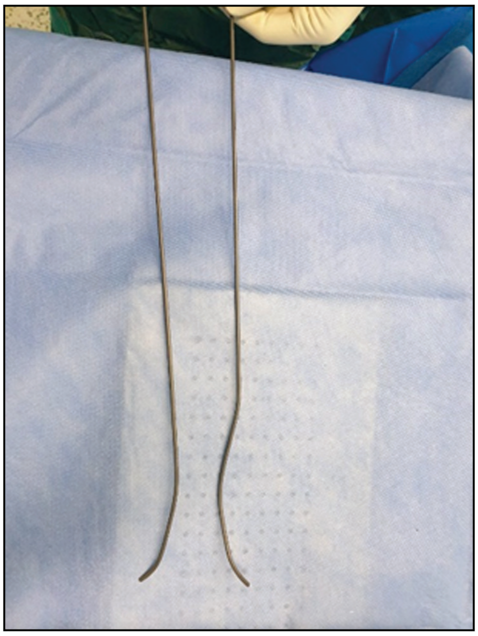
Awl was used to widen the opening.

Figure 5



Identification of the size of nails used with the help of an image intensifier.

Figure 6

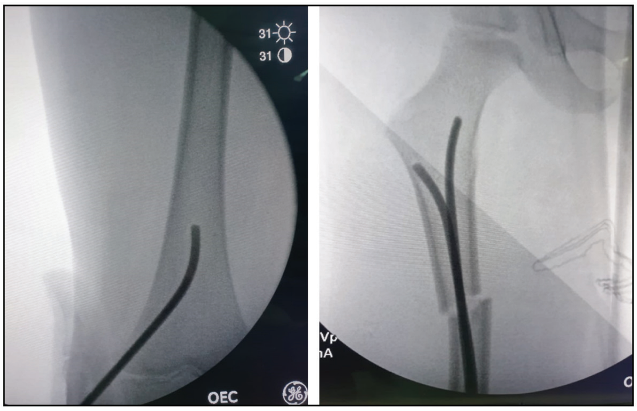


Contouring of nails.

The skin and subcutaneous tissue were sharply incised, and then blunt dissection through the muscles was done to reach the underlying bone.

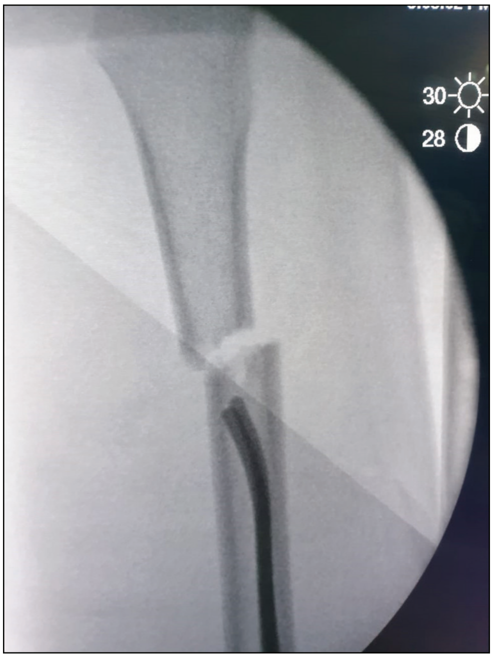
Under fluoroscopic guidance, a 4.5 mm drill bit was used to drill the near cortex, first perpendicularly and then gradually aiming superiorly reaching an angle of 45°. An awl was used to widen the opening Fig. 12.

Figure 7



Insertion of the first nail with the help of an image intensifier.

Figure 8



Both nails were introduced to the fracture site.

Flexible nail size was then assessed by the patient with the assistance of fluoroscopy, with a goal of both nails filling 80% of the canal diameter.

2 ‘C’-shaped rods were contoured. The first nail was then placed through the lateral cortical opening and passed to the fracture site Fig. 13.

With the guidance of fluoroscopy, the physis was identified. A 1 cm skin incision on the medial aspect (nearly on the same level of the lateral entry) was made ~ 2 cm above the physis.

The skin and subcutaneous tissue were sharply incised, and then blunt dissection through the muscles was done to reach the underlying bone.

Figure 9

Nails were passed across the fracture.

Figure 10

The nails were pulled away from the bone and cut flush with its surface; leaving behind a small stump that was pushed in for 0.5 cm.

Figure 11

Wound closure in layers.

Figure 12

An awl was used to widen the opening.

The 4.5 drill bit was used to make the entry, and the awl was used to widen the entry and open the medullary canal.

The other nail was then inserted through the cortical opening and passed to the fracture site.

The fracture was reduced, the nails were passed across the fracture, and the implants were impacted into their final position Figs 14 and 15.

The medial nail was directed to the neck and the lateral one was directed to the greater trochanter Fig. 16.

The position of the nails was checked using the C-arm; they were then withdrawn by 0.5 cm. The nails were

Figure 13

The first rod was then passed through the lateral cortical opening.

Figure 14

The second rod was then inserted through the cortical opening and passed to the fracture site.

Figure 15

The fracture was reduced; the nails were passed across the fracture.

pulled away from the bone and cut flush with its surface, leaving behind a small stump that was pushed in for 0.5 cm Figs 17 and 18.

Wound closure in layers

Postoperative management

Immediately postoperatively all the patients had their femur radiographed in anteroposterior and lateral views to check the position, size, and length of the nails, the position of the fracture, any angulation, or rotational deformity.

The patients were all admitted to the ward for 1–2 days, where they received analgesic, anti-edematous medication, and IV antibiotics

All patients were allowed a full range of motion for the knee but strict nonweight bearing.

All patients were discharged within 48 h where they received IV antibiotics after obtaining postoperative radiographs and measuring their sound limb length and the fractured side with a tape measure.

They were followed up at 2 weeks postoperatively for suture removal, then at 6 weeks postoperatively for follow-up

Figure 16

The medial nail was directed to the neck and the lateral one was directed to the greater trochanter.

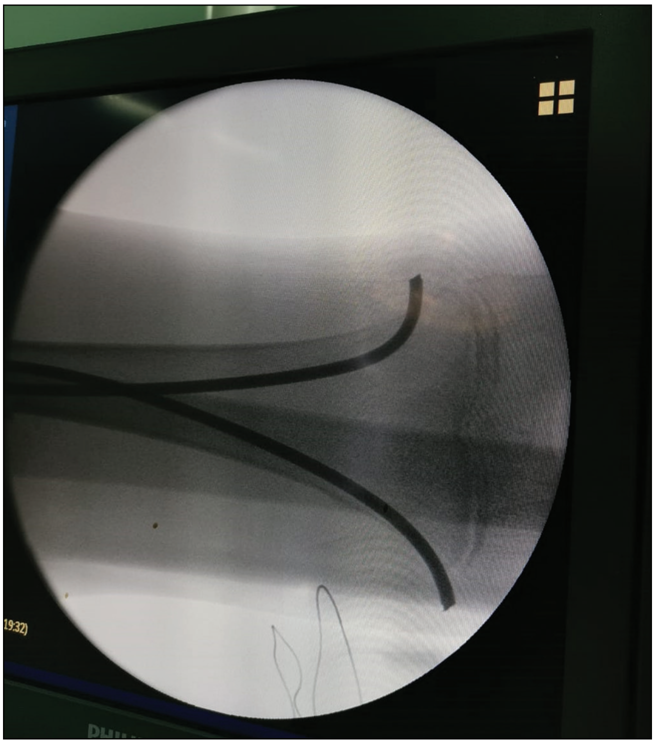
Figure 17

The nails were pulled away from the bone and cut flush with its surface, leaving behind a small stump that was pushed in for 0.5 cm.

radiographs and assessment of union. At 3 months limb leg length discrepancy (LLD), knee range of motion, and knee pain were assessed for each patient (Table 1).

Full weight-bearing was allowed once union was achieved. At 6 months follow-up, Flynn's score was applied.

Figure 18



Check the final position of the nail under the image intensifier.

Table 1 Flynn's Score

Score	Excellent	Satisfactory	Poor
Limb length discrepancy	≤1.0 cm	<2.0 cm	>2.0 cm
Sequence disorder	≤5°	6-10°	>10°
Pain	Absent	Absent	Present
Complication	Absent	Mild	Major complication

Statistical methods

Data were collected in a master sheet, coded, entered, and analyzed using both SPSS version 22 Medical Statistics Software and Microsoft Excel v. 2019.

The phase of analysis of data

(1) Data were presented as mean±standard deviation for quantitative variables and number and percentage for qualitative variables.
(2) Data were coded, entered, and analyzed by computer package (version 10).
(3) Categorical data were compared using χ^2 and calculated.
(4) The significance level was set at a P value less than 0.05 for χ^2 and when the confidence interval of odds ratio (CI of OR) did not include 1 in its range.

Descriptive statistics

Arithmetic mean: as an average describing the central tendency of observations:

$$\text{Mean}(\overline{X})=\frac{\sum X}{n}$$

where ΣX is the sum of individual data and n is the number of individual data.

$$\sqrt{\frac{\sum(\overline{X}\text{-}X)^2}{n\text{-}1}}$$

Analytical analysis:

Chi-squared χ^2 test:

It is a test of significance for the difference between more than two proportions, i.e., to assess whether the observed frequency (O) of an event departs significantly from that expected (E) based on the null hypothesis. It can be calculated from the following equation:

$$\chi^2=\frac{\sum(o\text{-}E)^2}{E}$$

where O is the observed value.

E is the expected value.

The expected value was calculated as follows:

$$E=\frac{(\text{row total})(\text{column total})}{\text{Grand total}}$$

Level of significance

For all the above-mentioned tests, the threshold of significance was fixed at the 5% level using Student's *t*-test (t) and the probability (*P* value) calculated:

(1) A *P* value of greater than 0.05 indicates nonsignificant results.
(2) A *P* value of less than 0.05 indicates significant results.

Results

This is a prospective cross-sectional, randomized, and comparative study involving 40 patients with pediatric femur fractures treated by FIMN classified into two equal groups according to the surgical approach: group (1): 20 patients underwent retrograde placement of 'C'-shaped through ML approaches CC and group (2): 20 patients with 'CS through AL approach. They were six (30%) females and 14 (70%) males. Their ages ranged between 5 and 12 years. Both age and sex were matched between the two groups (P>0.05) as illustrated in the next table and figures.

Males composed 80% (16) in medial and lateral entry, while females composed 90% (18) in all lateral entry techniques. The mean age was about 8 years in patients treated by medial and lateral entry techniques and about 7.5 years in patients treated by all lateral entry techniques.

In both groups, the body mass index (BMI) was about 17, the weight was about 31 kg, and the time till surgery was about 1 day. So there was an insignificant difference between the two groups as regards BMI, weight, time till surgery, and fracture type (P >0.05).

In the medial and lateral entry technique groups, the fracture was simple diaphyseal in 70% (14) and comminuted in 30% (12) of patients, while in all lateral entry technique groups fracture was simple diaphyseal in 65% (13) and comminuted diaphyseal in 35% (7) of patients.

Preoperative and postoperative findings of the studied groups.

There was an insignificant difference between both groups regarding preoperative hemoglobin and postoperative hemoglobin.

There was a significant difference between both groups regarding the duration of anesthesia, duration of surgery, number of soaked surgical gauzes (blood loss), and number of radiation shots during surgery (P <0.05).

There was shorter anesthesia and surgical duration in all lateral entry technique groups than in medial and lateral entry technique groups with statistically significant differences.

The comparison of the two studied groups regarding soaked surgical gauze and C-arm radiological shots during surgery revealed a statistically significant difference.

Regarding postoperative complications of the two studied groups, CS showed fewer complications than the CC group.

There was a significant difference between both groups regarding infection. No infection was reported in all lateral entry technique groups, while there was one case of infection in the medial and lateral entry groups.

There was an insignificant difference between both groups regarding inflammation and weight bearing. There was no reported cases of neurological injury or refracture.

The findings indicate that all lateral entry technique groups showed fewer pain complaints compared with the medial and lateral entry technique groups with statistically significant differences ($P<0.05$): 40% of the CC group had no pain, while 14% of the CS group had no pain [visual analog scale (VAS = 0)]; 45% of the CC group had mild pain (VAS = 1–-3) and 30% of the CS group had mild pain; 5% of the CC group had moderate pain (VAS = 4) and 10% had severe pain (VAS = 5), while the CS group did not show moderate or severe pain.

Figure 19

Preoperative radiograph.

There was a statistically significant difference between both groups regarding the range of motion. Within the first week postoperatively, 90% (18) of patients in the all-lateral entry technique group gained 90° knee flexion, while only 20% (4) of patients in the all-lateral entry technique group attained the same degree of flexion.

All patients treated with all-lateral entry techniques showed excellent Flynn scores, while in the medial and the lateral entry group technique, 80% (16) were excellent and 20% (4) were satisfactory. No cases reported poor Flynn scores in both the groups.

Patient 1

Figures 19–22

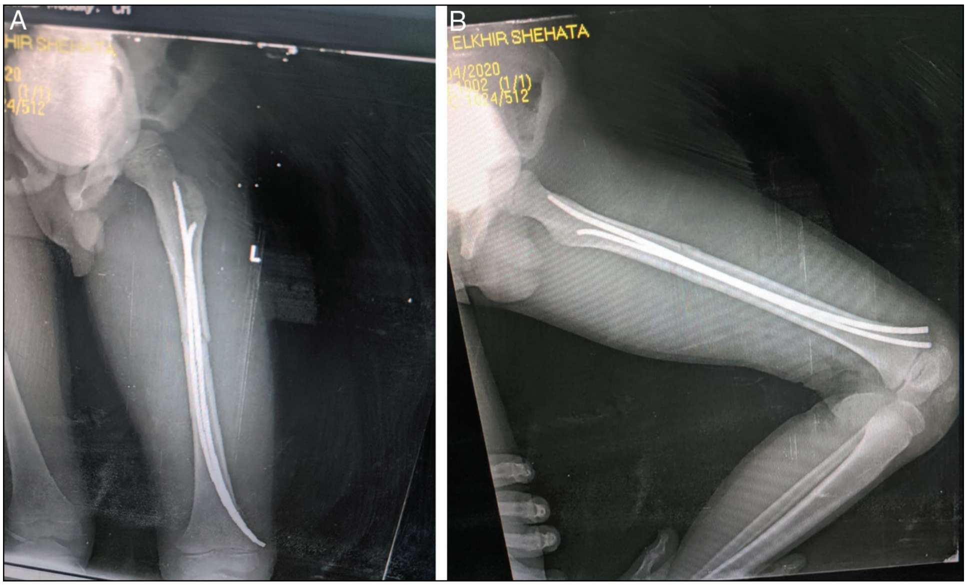
Patient 2

Figures 23–27

Discussion

Conservative treatment inevitably causes prolonged immobilization with negative effects on the child's social development, schooling, and family. As the demand for hospital beds grows, management methods

Figure 20

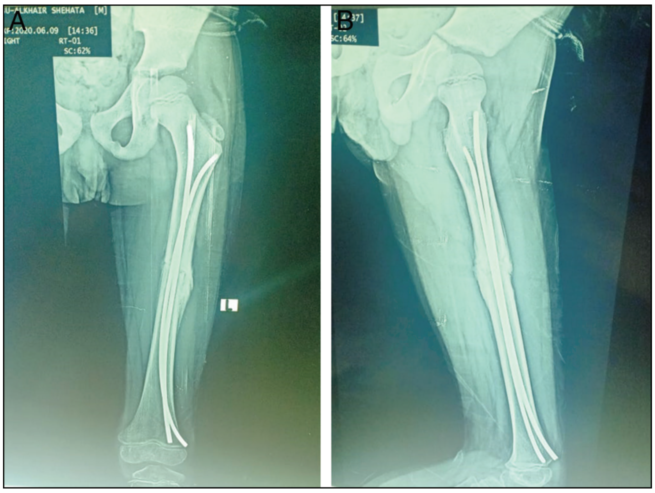


(A, B): Immediate postoperative radiograph: (A) anteroposterior view and (B) lateral.

that promote early mobilization and discharge gain traction [1].

Although there are a variety of treatment methods for femoral shaft fractures in children aged from 5 to 12 years, flexible intramedullary fixation is considered the gold standard of care. Over the past 2 decades, the indications and popularity of these implants have expanded as good clinical results and lower complication rates have been reported.

Figure 21



(A): Follow-up radiograph (6 weeks postoperatively): anteroposterior view.

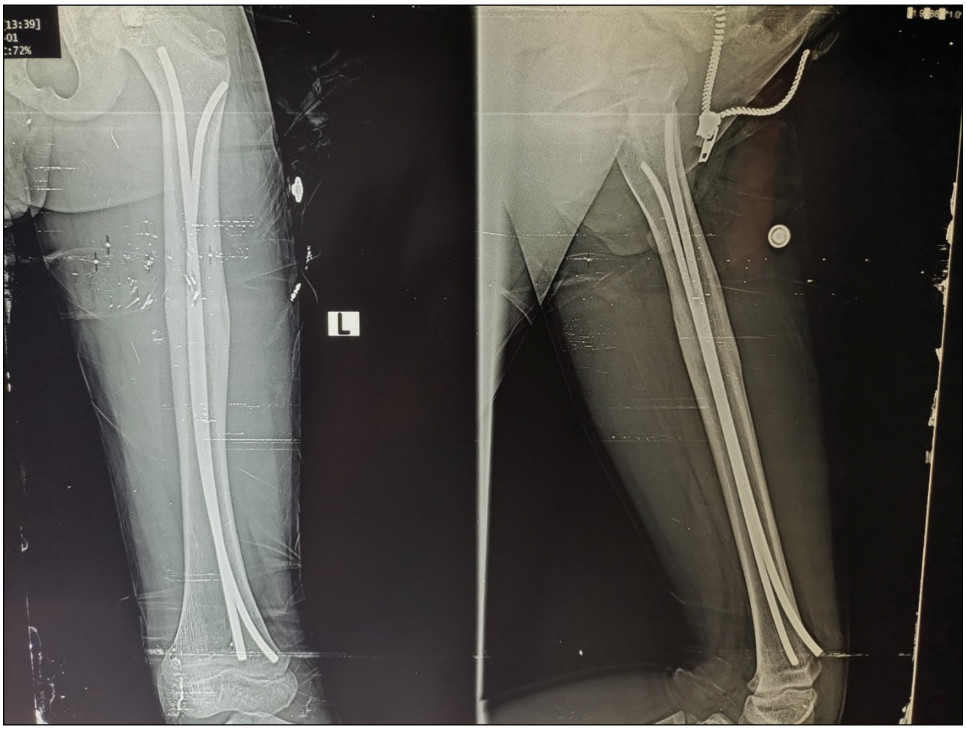
Many authors prefer FIMN over other techniques of fixation due to its advantages including shorter length of hospitalization, less refracture risk, earlier mobilization, less risk of femoral head avascular necrosis, and less blood loss [2–4].

There are two nail configuration possibilities when using an all-retrograde technique: medial and lateral (ML) distal entrance nails and all-lateral (AL) distal entry nails. Both techniques have been reported to have positive clinical outcomes [11].

In this prospective cross-sectional study involving 40 patients with pediatric femur shaft fractures treated by FIMN, who were classified into two equal groups according to the surgical approach: group (1): 20 patients who underwent retrograde placement of ‘C’-shaped through ML approaches CC and group (2): 20 patients with ‘C’-shaped and ‘S’-shaped nails (CS) through AL approach. They were six (30%) females and 14 (70%) males. Their ages ranged between 6 and 12 years in group (1) with a mean of 8±1.12 years and group (2) had a mean of 7.67 ±2.34 years with a range of 6–10 years. Both age and sex were matched between the two groups (*P*>0.05).

Perhaps operative indications for femoral shaft fractures can be expanded to include children of all ages with femoral shaft fractures and open physis [3].

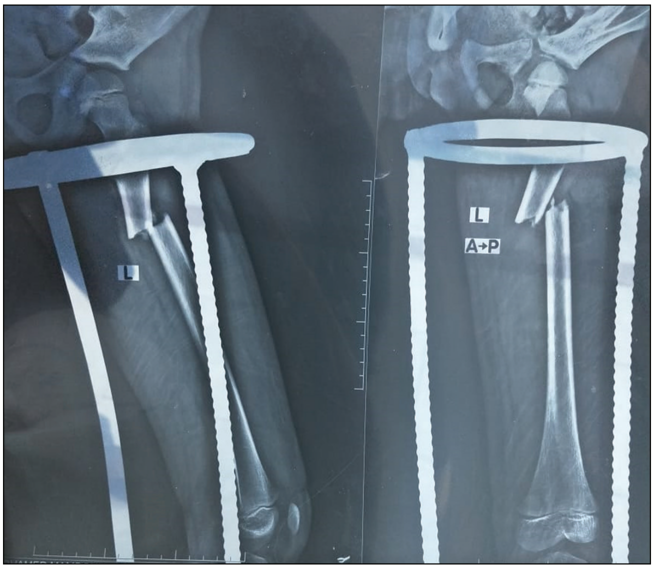
Figure 22



(A, B): Follow-up radiograph (6 months postoperatively): (A) anteroposterior view and (B) lateral view.

In comparison between this study and the Cage *et al.* [11] study, there was no difference in age and sex (74% vs. 82% males, *P*=0.15). Both had an age range of 3.7–14 years and a mean of 8 years in group (1) and a range of 2.2–17 years with a mean of 8.6 years in group (2).

Figure 23



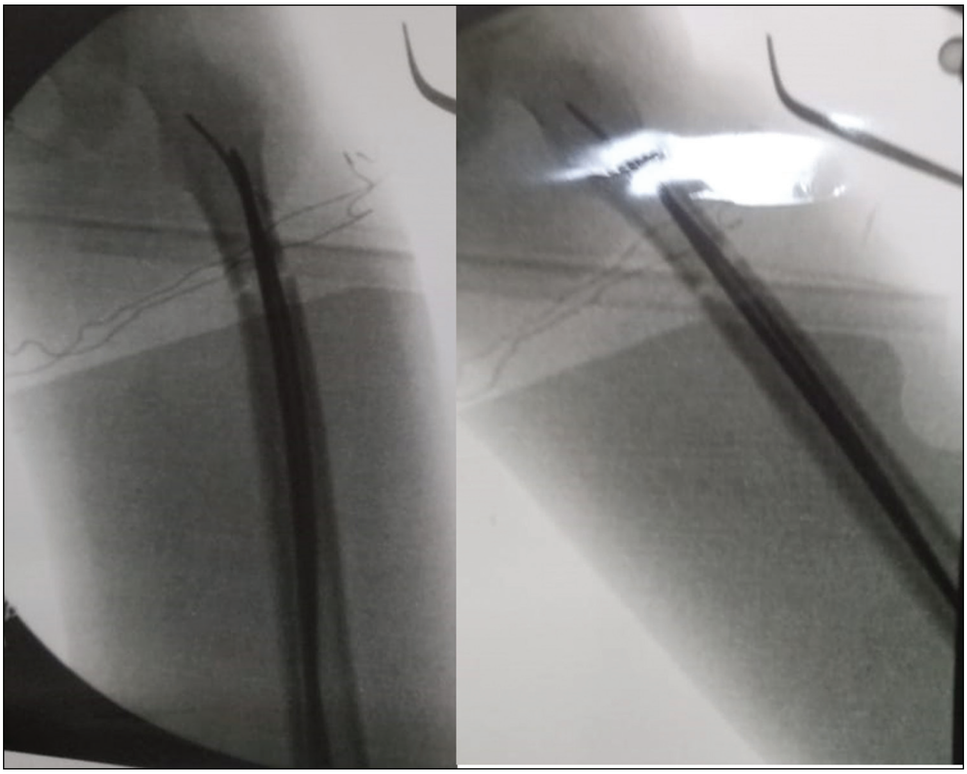
(A, B): Preoperative radiograph: (A) anteroposterior view and (B) lateral view.

Both studies showed statistically insignificant differences in average BMI. The average BMI in this study was 16.9 and 17.1 kg/m^2 in group (1) and (2) and was 17.2 and 17.4 in group (1) and (2), respectively in the Cage *et al.* [11] study. Also, it was similar in weight which was on average 31.4 kg and 30.9 kg in group (1) and (2), respectively,in this study it was 29.4 kg and 31.2 kg in both groups, respectively, in the Cage *et al.* [11] study.

There were insignificant differences between fracture patterns between both studies. Cage *et al.* [11] found that fractures of the proximal third of the femur were present in 46 (29.5%) patients in the CC technique group and 32 (36.4%) patients in the CS technique group (*P*=0.44). Fractures of the middle third were present in 96 (61.5%) patients in the CC technique group and 52 (.1%) patients in the CS technique group (*P*=0.61). Fractures of the distal third of the femur were present in 14 (8.97%) patients in the CC technique group and four (4.55%) patients in the CS technique group (*P*=0.09).

The duration of anesthesia in this study was longer in group (1), 52.78 min compared with 45 min in group (2), with a 12 min difference, which recorded a significant difference of *P*=0.034. In the Cage *et al.* [11] study, there was a longer difference (30 min) between the two groups and a very high significance

Figure 24

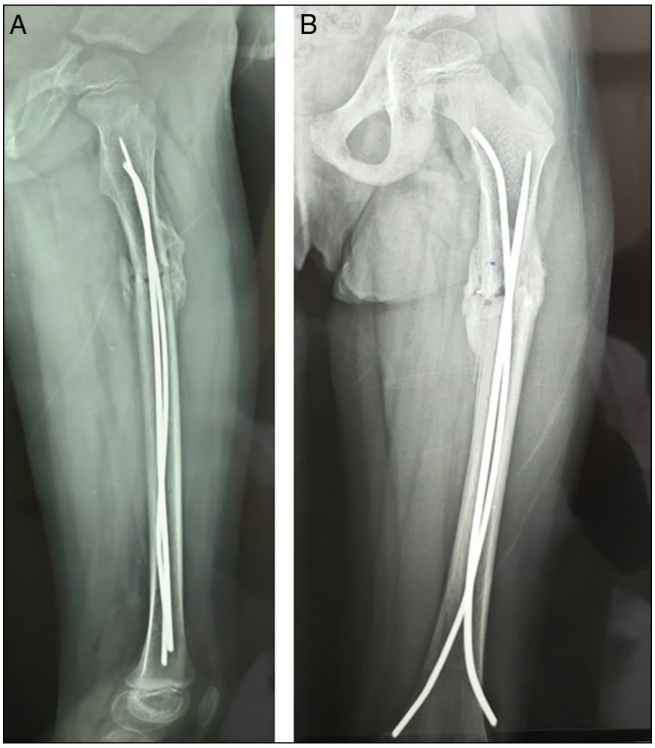


(A, B): Immediate postoperative radiograph: (A) anteroposterior view and (B) lateral view.

Figure 25

(A, B): follow-up postoperative (6 weeks) radiograph: (A) anteroposterior view and (B) lateral.

Figure 26



(A, B): Follow-up postoperative (12 weeks) radiograph: (A) anteroposterior view and (B) lateral view

Figure 27

(A, B): Follow-up postoperative (6 months) rdiograph: (A) anteroposterior view and (B) lateral view.

of P=0.0001. Also, the duration of surgery was longer in group (1) than group (2), which was similar to their study (P <0.001). There was no difference in blood loss between both techniques (P=0.0). The Cage *et al.* [11] study found no difference in blood loss in both groups (46 mL CC vs. 38 mL CS, P=0.32).

This study showed that CS had fewer complications than the CC group. CC group had infection in 1 (5%), inflammation in 4 (20%), while CS had only inflammation in 2 (10%) cases. In both groups, none of them had nonunion; however, malunion was minimal compared with previous studies with a high rate of fracture union and a low number of complications.

Similarly, Cage *et al.* [11] recorded one infection case that occurred in the CC technique group in the setting of an open fracture. One patient in the CC technique group had a revision of his hardware before union for symptomatic implants. There were no infections in the CS technique group. While many other studies have shown flexible intramedullary fixation of pediatric femur fractures is a successful treatment option, none have directly compared differing retrograde nail techniques [2,6,9].

Cage *et al.* [11] found that the CS technique group had 3.0 mm (range, 0–21°) of average shortening, 2.6° (range, 0–17°) of average absolute coronal angulation, and 2.7° (range, 0–12°) of average absolute sagittal angulation.

There was no statistical difference in shortening, absolute sagittal angulation, or absolute coronal angulation between the two groups (*P* >0.05). They supposed that both techniques have good radiographic outcomes.

LLD was a frequent but clinically insignificant complication as most fractured limbs were within 1 cm in length of the contralateral normal limb. However, shortening of greater than 1 cm was observed in some patients having grade III or IV commination in their study. Although the lesser degree of limb length discrepancy is fairly common, most published articles have reported infrequent occurrences of clinically significant discrepancy [12].

It has been previously claimed that a CS retrograde flexible intramedullary fixation method in distal fracture patterns tends to cause a varus deformity. However, in reviewing all distal fractures in our patient population, we found no difference in coronal or sagittal angulation. Cage *et al.* [11] demonstrated that all femur fractures that united with greater than 10° of valgus angulation (N=3) were in the CS technique group. The presence of a valgus deformity greater than 10° did not correlate to fracture location. Although it is difficult to conclude only three patients, it is notable that all patients with clinically significant valgus were from the CS technique group.

Comparison between this study and the Shabab *et al.* [12] study.

Shabab *et al*. [12] studied 95 (79.17%) males and 25 (20.83%) females with a male-to-female ratio (M: F) of 3.8: 1. In this study, males were more predominant than females, this was approved by many studies.

In this study, postoperatively, 40% of the CC group had no pain, while 14% of the CS group had no pain (VAS = 0); 45% of the CC group had mild pain (VAS = 1–3) and 30% of CS group had mild pain; 5% of CC group had moderate pain (VAS = 4) and 10% had severe pain (VAS = 5), while the CS group did not show moderate or severe pain.

These results were comparable to the results of Shabab *et al.* [12], who used a retrograde flexible intramedullary nail for the treatment of pediatric femoral shaft fractures and found that 54 (45%) patients had no pain, 43 (35.83%) patients had mild pain, 16 (13.33%) patients had moderate pain, and seven (5.83%) patients had severe pain.

Shabab *et al*. [12] reported poor outcomes and had 30.8% excellent results and only 14.1% had successful results. All these (54 patients, 45%) patients had no postoperative pain, and lower LLD was less than 2 cm. Poor results in their study were not allocated to any patient because no patient was found to have an LLD of more than 2 cm.

Limitations

It is crucial to note that our study has a number of limitations.

The very low number of patients was not enough to achieve accurate results, it was recommended that the next study be performed on a large number of cases to achieve more reliable statistical results.

The study does not take into account the configuration of fracture during treatment decision-making because it may affect postoperative LLD and VAS scores.

It is important to understand that all lateral entry techniques can be more a technically demanding operation and that one must be aware of its nuances to achieve similar results even though it was shown to be an average of 12 min faster than medial and lateral entry point techniques.

Conclusion

Both the all-lateral entry and medial and lateral retrograde fixation techniques for flexible nails provide excellent clinical, and radiological outcomes and a low complication rate for the treatment of pediatric femur fractures. The all-lateral entry technique can be a faster operation, but proper technique is critical to minimize the shortening and malunion of pediatric femoral fractures Figure 4 and 6.

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Author contribution

Authors contributed equally to the study.

Ethical consent

Approval of the study was obtained from the Helwan University Academic and Ethics Committee. Every parent signed an informed written consent for acceptance of participation in the study. This work has been carried out following The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans.

Financial support and sponsorship
Nil.

Conflicts of interest
The authors declare no conflict of interest.

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