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Management of Length Unstable Femur Fractures in Children by Flexible Intramedullary Nails: A Systematic Review

Léčba délkově nestabilních zlomenin femuru u dětí flexibilními nitrodřeňovými hřeby: systematický přehled

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ABSTRACT

PURPOSE OF THE STUDY

Surgical options for paediatric femoral fractures include flexible intramedullary nailing (FIN), plating, and external fixators. Length unstable fractures are usually spiral, long oblique, or comminuted and are often associated with > 2 cm of shortening. The purpose of this study was to see whether FIN is effective for managing unstable femur fractures in children.

MATERIAL AND METHODS

An electronic literature search was performed up to 25 February 2022 in Cochrane Library, PubMed, and Embase databases using a combination of MeSH search terms and keywords related to the population (e.g., "child" AND "diaphyses" AND "femur"), and intervention (e.g., "nail" OR "ESIN"). The data extracted included the study details, Demographic data, surgical details, postoperative immobilization, complications, and outcome.

RESULTS

Eight studies with a total sample size of 369 patients were reviewed. The mean operative time, blood loss, and length of stay in the hospital were 67.62±12.32 minutes, 33.82±16.82 ml, and 4.9±1.27 days, respectively. The results were excellent in 61.92% of the patients, satisfactory in 32.61%, and poor in 5.43%. 4.54% of patients had major complications requiring reoperation and 32.46% of patients had minor complications. the most common complication was nail prominence seen in 26.30% of patients. Locked Ender's nail was associated with the least reoperation, malunion, and LLD rate compared to other types of FIN.

CONCLUSIONS

FIN along with a single walking spica cast is a good choice in all forms of paediatric femoral fracture patterns allowing proper alignment and rotation. Locked Ender's nail is safe and effective for managing unstable paediatric femur fracture.

Key words: pediatric femur fracture, length unstable, flexible intramedullary nailing, submuscular plating, Flynn criterion.

INTRODUCTION

Pediatric femoral fracture accounts for about 1.6% of all bony injuries in children (3). The incidence of fractures of these injuries has been reported at 5.82 per 100,000 children (27). The mechanism of injury is usually high-energy trauma, such as a fall or motor vehicle collision (4). Surgical options for diaphyseal femur fractures in children between 5–11 years, include flexible intramedullary nailing (FIN), plating, and external fixation (EF) (11). Infection, leg length discrepancy, malunion, non-union, refracture, and skin irritation are various complications associated with these surgical methods (18, 25).

In 2016, the National Institute for Health and Care Excellence (NICE) and the American Academy of Orthopaedic Surgeons (AAOS) recommended using FIN in children aged 5 to 11 with stable pattern fractures (7). Length unstable fractures are usually spiral, long oblique or comminuted and are often associated with > 2 cm of shortening, with authors recommending the use of EF and submuscular plating for these fracture configurations in children between 5–11 years of age. However, more recently, some authors have recommended the use of FIN's for the management of these fractures (9, 11, 22, 23).

Previous literature is not clear on the ideal management of length unstable fractures. Given the recent trend that recommends the use of FIN, we ana-

lyze the current literature regarding the use of FIN in the management of pediatric length unstable femur fractures.

MATERIAL AND METHODS

Search strategy

The study was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses format (PRISMA) using Cochrane Review methods. An electronic literature search was performed up to 25 February 2022 in Cochrane Library, PubMed, and Embase databases using a combination of MeSH search terms and keywords related to the population (e.g., "child" AND "diaphyses" AND "femur"), and intervention (e.g., "NAIL" OR "ESIN" OR "FIN"). Various combinations, including Boolean operators, were used to maximize the search results. The search was supplemented by manually checking the bibliographies of the retrieved papers. Additional articles were identified through the "related articles" feature. One reviewer initially screened the titles and abstracts and removed any duplicates to provide a list of potentially relevant articles (AR). Full-text articles were obtained after the screening of the title and abstract.

Eligibility criteria

The studies included were:

1. original articles,
2. children with femur fractures,
3. closed and Gustilo grade I open fractures,
4. treated with FINs, and
5. written in the English language.

Exclusion criteria

1. case reports,
2. case series of fewer than three patients,
3. letters to the editor,
4. reviews,
5. cadaveric studies,
6. animal studies,
7. biomechanical studies, and
8. any other treatment other than FIN.

It was performed independently by two reviewers (AG, AR). In the presence of a disagreement about the inclusion or exclusion of a particular study, the senior author's opinion was sought (VG).

Data extraction

Two investigators (VG, AG) independently extracted data related to the outcomes from the cohorts/groups. The data was collected on an Excel spreadsheet (Microsoft, USA). A second reviewer independently repeated the process to verify the extracted data (AG). The data extracted for the review: study details, level of evidence, patient demographics, fracture characteristics, FIN used, postoperative protocol, duration of follow-up, and complications. The level of evidence of the studies was noted according to the Oxford Centre for Evidence-based Medicine guidelines. If reoperation was necessary before the bony union, complications were categorized as major, whereas reoperation was not required for minor complications. Coronal and sagittal angulation and limb length discrepancy at final follow-up were noted. LLD was defined as a discrepancy of at least 1cm between limbs. The significant angular deformity was defined as a coronal angulation of more than 10 degrees and a sagittal angulation of more than 15 degrees. The surgical time, blood loss, and duration of hospital stay were all recorded if data was provided. Any outcome measure used to assess the function at final follow-up was also noted. In the event of any conflicts, the senior author made the final choice on the data extraction (VG).

Risk of bias assessment

We used the methodological index for Non-Randomized Studies (MINORS) to judge the quality of study conclusions (ideal maximum score of 16 for non-comparative and 24 for comparative studies) by two investigators independently. In case of disagreement, a consensus was sought between both authors (VG, AG).

Statistical analysis

Categorical variables were presented in number and percentage (%), and continuous variables were presented as mean±SD. All continuous data were pooled and a descriptive analysis was performed.

RESULTS

Literature search

The initial literature search yielded 313 articles for consideration. 246 articles were screened after removing the duplicates. 11 articles were selected from among these after reading the title and abstract. Of these, 3 articles were excluded because of inadequate data in the study. Finally, 8 articles were considered for qualitative review (2, 5, 14, 15, 19, 20, 25). (Fig. 1).

Study characteristics

All the studies were retrospective in nature. There were six-level III studies and two-level IV studies. Among the studies involved, there were seven comparative studies (5, 14, 15, 19, 20, 25). In the studies that were considered, unstable femur fractures were either classified as comminuted, long oblique, or spiral fractures. In one study by Attasi et al., both proximal, distal fractures and fracture instability ratio of > 2 were also classified as unstable (2). In their study, they used the method used by Murphy et al. to measure the fracture instability ratio (17). Patients with pathological fractures were excluded from all the studies except one study (5). One non-comparative study had a score of 9 on the MINORS score (2). Three studies had a score of 18 (15, 20, 25), while four studies had a score of 17 (5, 14, 19, 24). (Table 1).

Demographic data

The total sample size of all the studies included in this review was 369 patients. Two studies provided details of fracture patterns, with 73.61% (106/140) of the fractures being long oblique or spiral and 23.61% (34/140) being comminuted (5, 19). The mean age of the patients at the time of surgery was 8.53±0.38 years. There was a male predominance, with 65.79% (75/114) being male. The mean weight of the patients included in this review was 29.35±3.32 kg. All the patients included in this review were followed up at least till radiological and clinical evidence of bone union. (Table 1).

Surgical details and postoperative immobilization

All the studies included in this study employed FIN to fix the fractures. The Ender's nail was the most commonly utilized implant in 44.40% (107/241) of the patients, followed by ESIN in 39% (94/241) and steel FIN in 40 patients. The locked Enders nail was utilized to treat these fractures in 37 (15.3%) patients, while the unlocked Ender's nail was used in 70 (29.05%) patients (Table1). The mean operative time, blood loss, and length of stay in the hospital were 67.62±12.32 minutes, 33.82±16.82 ml, and 4.9±1.27 days, respectively (Table 2). Spica casting was the most often utilized method of postoperative immobilization in 47.37% (89/171) of patients, followed by knee immobilizer in 30.99% (53/171) and long leg cast or single-leg spica cast in 16.96% (29/171).

Outcomes

One research provided data on the duration of bony unions (15). In their study, the average union duration

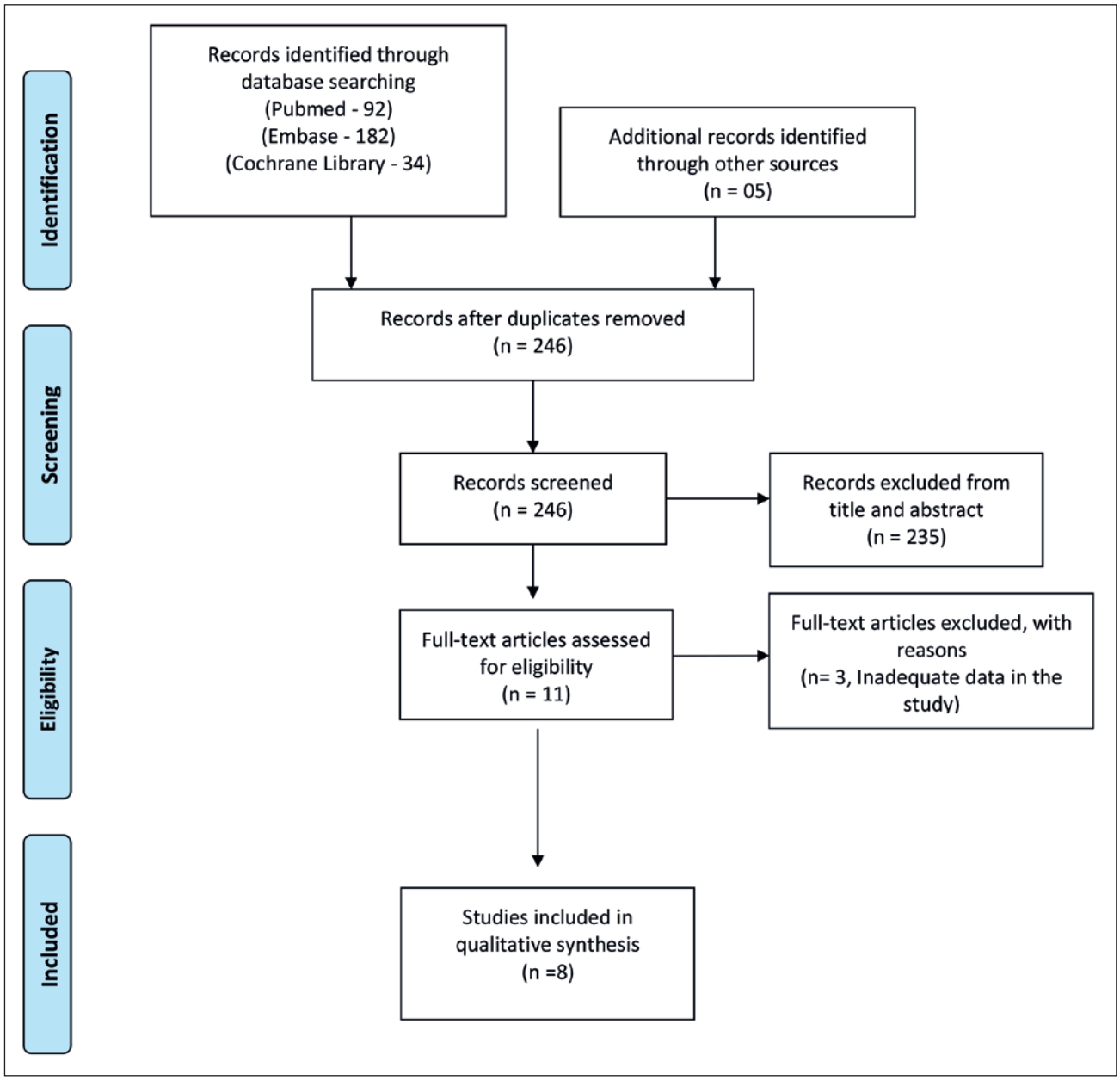

Fig. 1. PRISMA flow diagram unstable length femur fracture operated with FIN.

Table 1. Showing study and patient details

Author	Year	Level of evidence	Study design	MINORS score	Number	Sex	Mean age (years)	Mean weight (kg)	Follow-up	Unstable fracture pattern included	Implant
Siddiqui et al. (24)	2019	3	Retrospective	17	32	–	–	–	6 months	Spiral, comminuted, or long oblique fracture	ESIN
Sink et al. (25)	2005	3	Retrospective	18	15	–	–	–	Bone union	Comminuted or long oblique fracture	ESIN
Luo et al. (15)	2019	3	Retrospective	18	10	–	–	–	At least 2 years	Comminuted or oblique fracture	ESIN
Rathgen et al. (2)	2007	3	Retrospective	18	40	–	–	–	Bone union	Spiral or comminuted fracture	Steel FIN
Ouillette et al. (19)	2022	4	Retrospective	17	37	30 M 7 F	8.7±1.9	31.7±11.6	16.6±15.3 months	Comminuted or long oblique/spiral fracture	ESIN
Atassi et al. (2)	2020	4	Retrospective	9	51	–	–	–	Bone union or implant removal	Proximal/distal, spiral fractures, butterfly segments, fracture ratio 2.0 or greater, or comminution	FIN
Li et al. (14)	2020	3	Retrospective	17	77	45 M 32 F	8.1±1.9	27.0±5.4	Bone union or implant removal	Spiral, comminuted, or long oblique fracture	FIN
Ellis et al. (5)	2011	3	Retrospective	17	107	–	8.6	–	Bone union	Comminuted fracture or spiral fracture	Ender's Nail

was 2.30±1.34 months. Flynn criterion was used to report the outcome in the studies included in this review (5, 14). The results were excellent in 61.92% (114/184) of the patients, satisfactory in 32.61% (60/184), and poor in 5.43% (10/184).

Complications

Complications were noted in 32.79% (101/308) of the patients reviewed, with 4.54% (14/308) patients having major complications and 32.46% (100/308) patients having minor complications. The most common reason for reoperation in the studies included in this reason was prominent nail (5 patients) requiring early nail removal followed by loss of reduction (4 patients), infection (2 patients), re-fracture (1 patient), and non-union (1 patient). The reason for reoperation was not given to one patient. Overall, the most complication seen was prominent nail causing skin irritation in 26.30% (81/308) of patients. Other uncommon complications were malrotation (3 patients), knee stiffness (3 patients), and knee effusion (1 patient) (Table 4).

Table 2. Showing surgical details

Study	Operative time (min)	Blood loss (ml)	Hospital stay (days)
Luo et al. (15)	69.40±33.98	18.30±29.74	5.8±2.62
Li et al. (14)	54.5±8.1	51.7±18.9	4.0±0.9
Ellis et al. (5)	78.95	31.46	–

Table 3. Showing patient's outcome according to Flynn criteria

Study	Excellent	Satisfactory	Poor
Li et al. (14)	42	34	1
Ellis et al. (5)	72	26	9

ESIN was responsible for major complications in 10.71% (9/84) patients followed by unlocked Ender's nail in 5.71% (4/70) patients. Minor complications were seen in 41.66% (35/84), 42.5% (17/40), 32.85% (23/70) and 8.1% (3/37) patients with ESIN, Steel FIN, unlocked Ender's nail and locked Ender's nail respectively (Table 5).

Three percent (8/267) of patients had an LLD of more than 1 cm at the final follow-up in this review. Luo et al. reported an average LLD of 1.44 cm at the final follow-up (15). They reported an LLD of more than 2.5 cm to be significant in their study. LLD was seen in 7.5% (3/40) and 7.14% (5/70) patients with Steel and unlocked Ender's nail respectively. No LLD was seen with locked Ender's nail in this review. Luo et al. used ESIN in their study. 2.52% (3/119) of patients had coronal angulation > 10^0 at final follow-up. Titanium and steel FIN was responsible for coronal angulation in 2.53% (2/79) and 2.5% (1/40) patients respectively. No patient reported having a sagittal angulation > 15^0 in this review (Table 4).

DISCUSSION

Table 4. Showing complications in various studies

Study	Major complication	Minor complication	LLD (>1 cm)	Coronal angulation (>100)	Sagittal angulation (>150)	Prominent nail	Other
Siddiqui et al. (24)	2	14	0	0	0	14	Loss of reduction-1 Refracture-1
Sink et al. (25)	6	6	–	–	0	10	–
Luo et al. (15)	–	–	1.40±3.66 cm*	0	0	–	–
Rathgen et al. (20)	0	15	3	1	0	13	–
Ouillette et al. (19)	1	5	0	2	0	3	Malrotation-1
Atassi et al. (2)	–	–	0	–	0	–	–
Li et al. (14)	1	34	–	–	0	31	Loss of reduction-1
Ellis et al. (5)	4	26	5	–	0	10	Loss of reduction-2, Malrotation-2, Infection-2 Stiffness-2

*gave mean value of LLD at final follow-up

The appropriate management of length-unstable femoral fractures in the pediatric age group has been a long-debated topic. Historically, skeletal traction followed by spica casting, although a practical procedure, was largely abandoned because of excessive hospital stay and unfavorable quality of life (13). Such fracture pattern can be managed by external fixation to maintain anatomic alignment for a femur fracture but is associated with a high risk of refracture, increased time to union, and pin tract infections (6, 8). In the past two decades, techniques like FIN and submuscular plating have gained pivotal importance depending on the age, fracture location, and pattern (1, 16). Back in 2005, Sink et al. (25) stated there were higher chances of complications when children with unstable fracture patterns were treated using FIN. On the contrary, the recent literature advocates the use of FIN as a suitable option in treating unstable fractures (11, 22). The purpose of this study was to see the efficacy of FIN in the management of length unstable fractures.

Table 5. Showing complications with different type of implant used

	ESIN n(N)	Steel FIN n(N)	Unlocked Ender's nail n(N)	Locked Ender's nail n(N)
Major complication	9(84)	0(40)	4(70)	0(37)
Minor complication	35(84)	17(40)	23(70)	3(37)
Prominent nail	27(84)	13(40)	8(70)	2(37)
LLD	0(69)	3(40)	5(70)	0(37)
Coronal angulation	2(79)	1(40)	–	–

Luo et al. and Li et al. (14, 15) in their retrospective comparative study of length unstable fracture, found that FIN is associated with statistically significant less blood loss, decreased operative time and lower hospitalization stay compared to the plating. Li et al. (14) also reported that the number of intraoperative fluoroscopy shoots in their study was not statistically different from submuscular plating. In this study, the mean operative time, blood loss, and length of stay in the hospital were 67.62±12.32 minutes, 33.82±16.82 ml, and 4.9±1.27 days, respectively. Ellis et al. (5) used Enders rods with locking end caps to fix unstable femur fractures in 37 patients while unlocked nails in 70 patients. The duration of surgery for locked and unlocked nails in their study was 85.3 min and 75.6 min respectively. (p-value > 0.05).

According to Lascombes et al., FIN is recommended in all femoral diaphyseal fractures in children over the age of six until the epiphysis is closed (12). However, postoperative immobilization should be used till radiological sign of healing is present, as it does not prevent shortening or control rotation in unstable fractures. However, Kalnic et al. (10) and Stuphen et al. (26) reported that no postoperative immobilization was necessary with submuscular platings. The outcome in this review were similar to that of stable femur fractures managed with FIN's. 61.92% had excellent outcomes, satisfactory in 32.61%, and poor in 5.43% of patients in this review. Saikia et al. (21) reported excellent outcomes in 59%, satisfactory in 27.2%, and poor in 13.6% of patients while treating a stable femoral diaphyseal fracture in children with FIN.

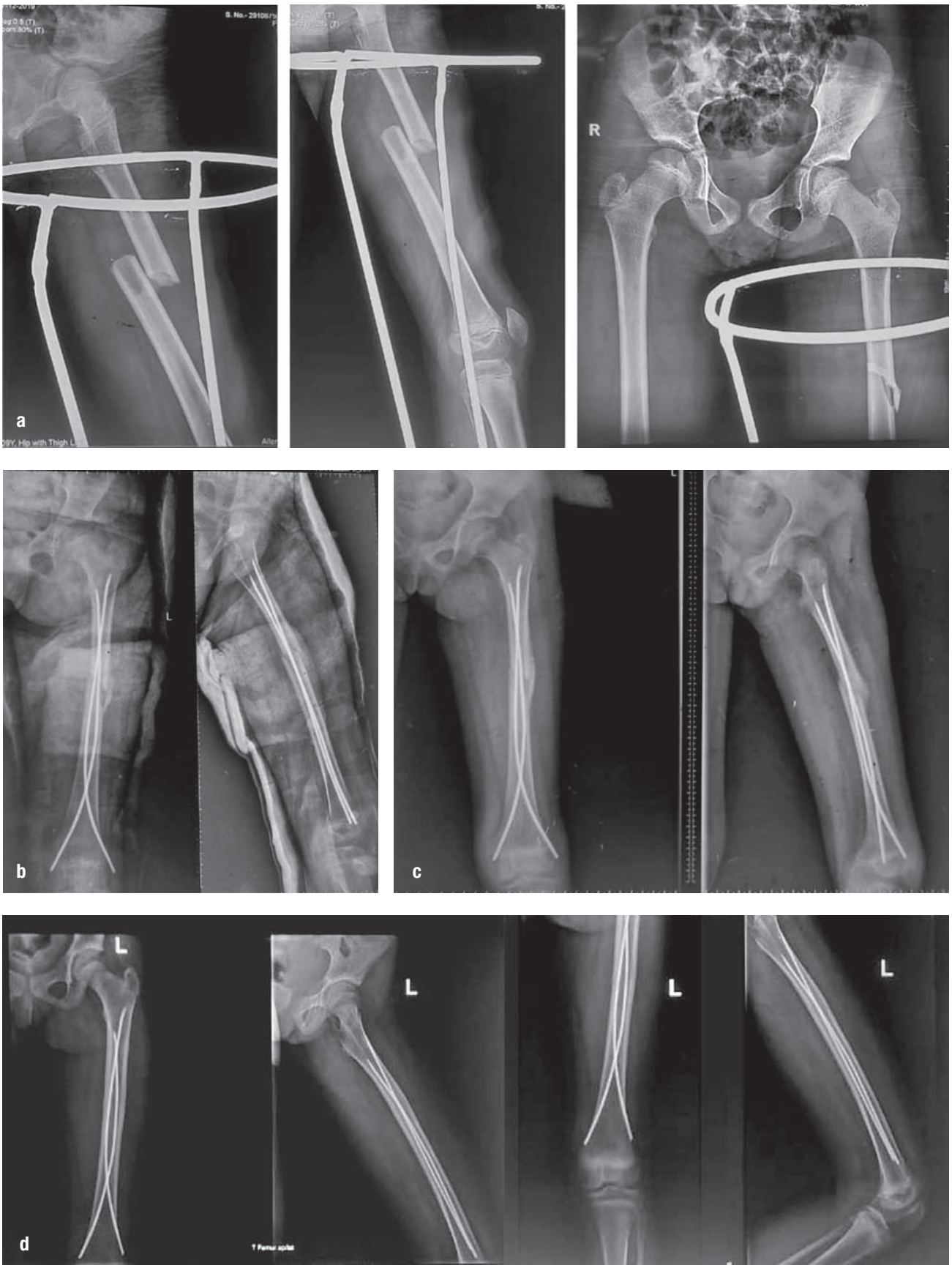

Fig. 2. Case example. a – 12-year-old female presented with left side shaft of femur fracture; b – 2 weeks post-op radiographs; c – follow-up at 6 weeks; d – follow-up at 6 months.

According to Sink et al. (25), 66% of "length unstable" fractures treated with FIN needed unplanned surgery. With comminuted fractures, Narayanan et al. (18) found a higher rate of unplanned operations when managed by FIN. In this review, the reoperation rate was 4.54%. Li et al. (14) evaluated unstable femur fracture treated with FIN against the submuscular plate and found that there was no statistically significant difference in unplanned surgery rate between both the techniques. They also reported that the FIN group had a 48% total complication rate versus 14% in the submuscular plate group. On the contrary, Attasi et al. (2), showed that when unstable femur fractures were treated with FIN, it was associated with fewer complications when canal fit was >80%, and the patient's weight was less than 49 kg. However, Shaha et al. (22) showed that there was no significant difference in malunion, malalignment, or shortening in patients over 100 pounds compared to a lighter group when Ender's nail was used for managing femur fracture in children. We could not calculate any correlation between the patient's weight and canal fit with complication because of inadequate data in the studies. The most common cause for reoperation in our study was the prominent nail. According to Ellis et al. (5), this could be prevented by using a locked Ender's nail. Previous studies have also failed to show any benefit of locking in providing axial stability in biomechanical analysis (5). Multiple reports suggest that titanium nails are associated with a higher rate of reoperation rate, malunion, and LLD as compared to steel and Ender's nail. In our study, locked Ender's nail was associated with the least reoperation, malunion and LLD rate compared to other nails.

Other advantages of using FIN are reduced operating time, blood loss, and hospital stay as compared to SMP for implant removal. Li et al. (14) reported nail removal is associated with significantly less operative time (21.1±5.6 min v/s 49.3±6.3 min), reduced blood loss (19.6±6.6 ml v/s 50.9±6.9 ml), and decreased length of hospital stay (2.9±0.9 days v/s 3.8±0.8 days) compared to plate removal.

Selection bias due to non-randomization is an inherent drawback of the studies included in this review. Heterogeneity of the fracture pattern used for defining fracture instability, weight and age of the child, implant used, and postoperative rehabilitation could have potentially created a bias in this review. Another limitation of this review is a short follow-up of the included studies.

CONCLUSIONS

FIN along with a single walking spica cast for length unstable pediatric femoral fractures is a very efficient method with high satisfactory outcomes and a low complication rate. Steel and Ender's nail are associated with a low complication rate compared to ESIN. Locking seems to reduce the complication rate in unstable fractures.

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