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ORIGINAL CLINICAL ARTICLE

Treatment of femoral fractures in children: is titanium elastic nailing an improvement over hip spica casting?

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Abstract
Purpose The purpose of the study was to assess the validity of surgical interference with elastic nailing in treating pediatric femur fractures in comparison with the traditional treatment method—hip spica casting.
Methods Sixteen consecutive femur fractures in children 5–15 years of age were recruited prospectively over 13 months. An equal number of age-matched children treated by spica casting were recruited retrospectively. Subtrochanteric, supracondylar femur fractures were excluded.
Results Fracture union occurred earlier in the surgical group (6 weeks) than in the spica group (8 weeks) ($P = 0.001$). Spica casting caused higher coronal plane angulation ($P = 0.001$), higher rotational malalignment ($P < 0.001$), higher limb length discrepancy at 1-year follow-up ($P < 0.001$), longer duration of immobilization ($P < 0.001$), later full weight-bearing ($P < 0.001$), and greater absence from school ($P < 0.001$). Flynn outcome scores were better with titanium elastic nailing than with hip spica casting.
Conclusion Titanium elastic nailing led to better outcomes compared to hip spica casting in terms of earlier union, lower rates of malunion, shorter rehabilitation milestones, and better functional outcome scores.

Keywords Titanium elastic nailing · Pediatric femur fracture · Hip spica casting

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Introduction

Femoral shaft fractures are among the most common major pediatric injuries treated by orthopedic surgeons [1] and result in high direct and indirect medical costs [2]. The treatment of such fractures has ranged from closed reduction with hip spica casting with or without traction to surgical stabilization with intramedullary devices, plates and screws, and external fixators [3–6].

While spica casting is effective for most children less than 6 years of age and the skeletally mature teenager is best managed with an antegrade interlocked intramedullary nail, the best treatment for children between 6 and 16 years of age is a matter of much debate [3–6].

Traditionally, this age group had been managed by spica casting after a period of traction. However, this method of treatment is fraught with many complications and, in addition, causes psychological, social, educational, and economic difficulties [7].

Over the past two decades, the advantages of fixation and early mobilization have been increasingly recognized [5, 8]. These surgical methods included external fixation, plating, and solid intramedullary nailing. Though the long-term results of the majority of children treated by these methods have been excellent, the risk of certain significant complications remain. A search for a solution to these intricacies led to the development of the elastic stable intramedullary nail in Nancy, France, by Metaizeau, Prévot, Ligier, and others in the 1980s. Thereafter, these elastic stable intramedullary nails (ESINs) have been refined in many ways.

The present study attempts to validate the use of one of the recent advances in the treatment of pediatric femur fractures, i.e., titanium elastic nailing (TEN). Though there are recent studies describing the outcome of treatment with

TEN and complications associated with the treatment, there are few studies comparing the flexible intramedullary nailing with the common treatment modality, i.e., hip spica casting. Also, the usefulness of such a change of trend to operative treatment of pediatric femoral fractures in developing countries like India is not known. The purpose of this study is to compare the outcome of fractures treated by this relatively new method, i.e., TEN, with the conservative treatment method, i.e., hip spica casting.

Patients and methods

The study was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki and was approved by the Ethics Committee of our institution. Sixteen consecutive children of ages 5 to 15 years with closed or Gustilo Anderson type I compound fractures of the femoral shaft presenting to the Emergency Department of our institute between January 2008 and February 2009 were recruited for elastic nailing. They underwent retrograde elastic nailing with a pair of equal-sized titanium nails. An equal number of age-matched (within 2 years) children with similar inclusion criteria treated with hip spica casting were randomly selected retrospectively from hospital records and the patients were reviewed (Spica group). Segmental, Winquist type III and IV comminuted and pathological fractures were excluded from both groups. The standard method for retrograde elastic nailing of the femur [8] was used. The distal ends of the nails were not bent and were allowed to lie flush with the metaphyseal flare (Fig. 1). Stable fracture fixations underwent external support with plaster-of-Paris thigh corset, while fixations with doubtful stability were put on a walking long-leg cast until 1 month postoperatively. Quadriceps strengthening exercises and non-weight-bearing with axillary crutches were started immediate postoperatively when tolerated. Partial weight-bearing was started at around 4 weeks and progressed to full weight-bearing after 2 weeks.

In the retrospective group, one-and-half hip spica was applied under general anesthesia, with the hips at 20 to 30° of flexion and the limb in 10°–15° external rotation under fluoroscopy. Spica was continued until union. Full weight-bearing was started 1–2 weeks following spica removal.

Data collected included details of the patient (age, gender), description of the fracture (type, location, pattern), surgery (open/closed), presence of fracture angulation or rotational malalignment, details of fracture union and rehabilitation milestones (non-weight-bearing, partial and full weight-bearing, return to school), and the presence of complications.

Measurements of angulation in the sagittal and coronal planes were done on anteroposterior and lateral radiographs immediately following surgery and during subsequent visits. Rotational malalignment was assessed by comparison of the available rotations of the hip with the normal side. Fracture union was defined as the ability to fully bear weight on the limb without pain in the presence of bridging callus in at least three cortices. Major complications were defined as those leading to unscheduled operative treatment or malunion, delayed union, or nonunion. Delayed union was defined as the persistence of bone pain and tenderness 3 months after the fracture without complete radiological union. Nonunion was defined as the absence of osseous union more than 6 months after the injury. Angular malalignment was defined as an angulation of $>10°$ in the coronal plane or $>15°$ in the sagittal plane [9]. Rotational malalignment was termed 'excessive' if it was more than 10°. Minor complications were defined as those that did not require operative treatment and would not cause future disability. The details of minor complications were not available for the retrospective hip spica group. Limb length was measured clinically by the tape method. Final outcome was graded *excellent*, *satisfactory*, or *poor* based on criteria described by Flynn et al. [5].

Nonparametric unpaired Student's t test and test of proportions were used for comparison. A P value < 0.05 was considered as significant.

Results

Among the 16 patients managed with titanium elastic nails, there were 12 boys and 4 girls. The mean age was 10 years and the median body weight was 25.5 kg (range 15–47 kg) (Table 1).

Of the sixteen patients in the spica group, there were 13 boys and three girls, with a mean age of 9.25 years. The distribution of gender, site of fracture, type of fracture (open/closed), mode of injury, and pattern of fracture were not significantly different between the groups as tested by test of proportions. In the surgical group, follow-up ranged from 12 to 18 months. All patients in the spica group had a follow-up of more than 1 year.

There was no significant difference in the delay of definitive treatment between the nailing group (range 4–16 days; mean 8.25 days) and the spica group (range 1–20 days; mean 6.62 days) ($P = 0.295$).

The duration of hospital stay was significantly higher in the elastic nailing group (range 12–41 days; mean 21.19 days) than in the spica group (range 5–36 days; mean 11.62 days) ($P = 0.002$).

In the nailing group, angulation in the coronal plane ranged from 10° varus to 4° valgus, while that in the sagittal plane ranged from 24° anterior (major

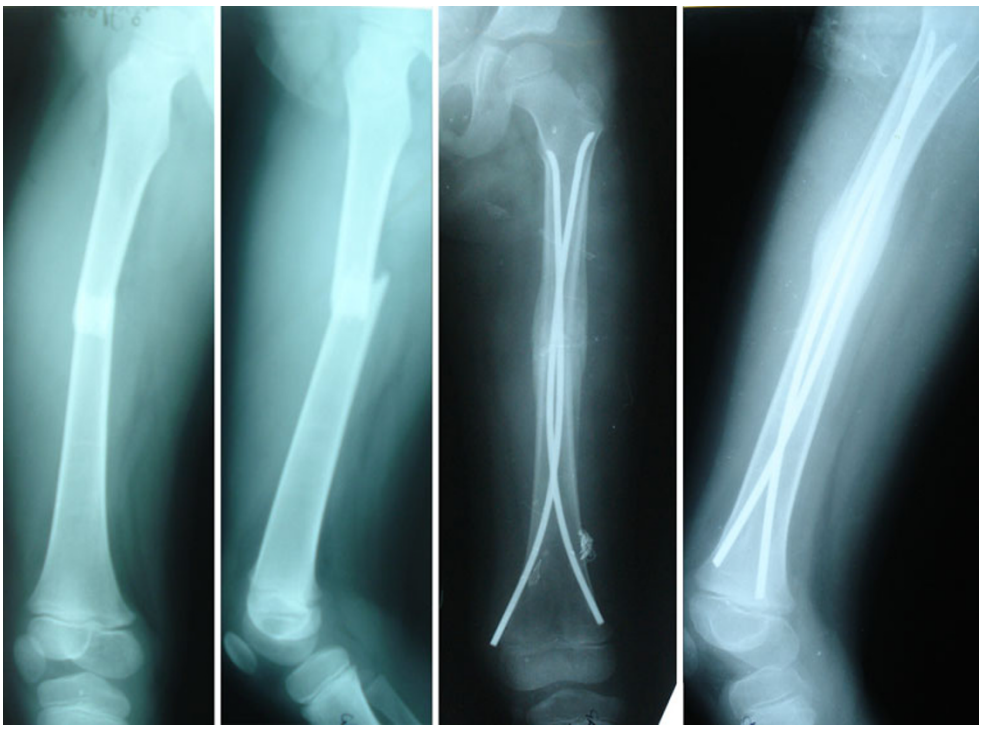

Fig. 1 Preoperative and 2 months postoperative radiographs of a 6-year-old child showing good union

Table 1 Clinical and radiological details of patients treated with titanium elastic nailing (TEN)

Subject no.	Age/ sex	Site of fracture	Pattern of fracture	Coronal angulation	Sagittal angulation	Malrotation	LLD	Flynn score	Complication
1	8/M	Middle 1/3	Short oblique	2° varus	0°	0°	0.0	Poor	Postoperative fall , fracture angulation, and implant exposure
2	12/F	Prox-mid jn	Transverse	10° varus	10° anterior	10° ER	0.0	Satisfactory	Asymptomatic nail migration
3	14/M	Middle 1/3	Transverse	0°	4° anterior	0°	0.0	Excellent	Nil
4	8/M	Middle 1/3	Transverse	5° varus	0°	0°	1.0	Excellent	Nil
5	13/M	Mid-dist jn	Winquist II	4° valgus	5° anterior	10° ER	0.0	Excellent	Nil
6	6/F	Middle 1/3	Transverse	0°	2° anterior	0°	0.5	Excellent	Nil
7	6/M	Middle 1/3	Spiral	0°	5° anterior	10° IR	0.5	Excellent	Nil
8	10/M	Middle 1/3	Short oblique	10° varus	24° anterior	10° ER	−1.0	Poor	Fracture angulation following delayed fixation
9	8/M	Middle 1/3	Short oblique	5° varus	0°	10° ER	1.0	Excellent	Nil
10	5/M	Mid-dist jn	Short oblique	0°	5° anterior	10° ER	1.0	Excellent	Nil
11	15/M	Middle 1/3	Winquist II	0°	5° anterior	10° ER	0.5	Excellent	Nil
12	12/M	Prox-mid jn	Long oblique	0°	4° anterior	0°	1.0	Excellent	Nil
13	8/F	Middle 1/3	Short oblique	4° varus	5° anterior	0°	1.0	Excellent	Nil
14	15/M	Prox-mid jn	Short oblique	2° varus	4° posterior	10° ER	0.5	Excellent	Nil
15	12/M	Middle 1/3	Short oblique	4° varus	15° anterior	0°	0.0	Poor	Subclinical 15° anterior angulation
16	10/F	Prox-mid jn	Long oblique	5° varus	4° anterior	10° ER	1.0	Excellent	Nil

ER external rotation; *IR* internal rotation; *LLD* limb length discrepancy in cm

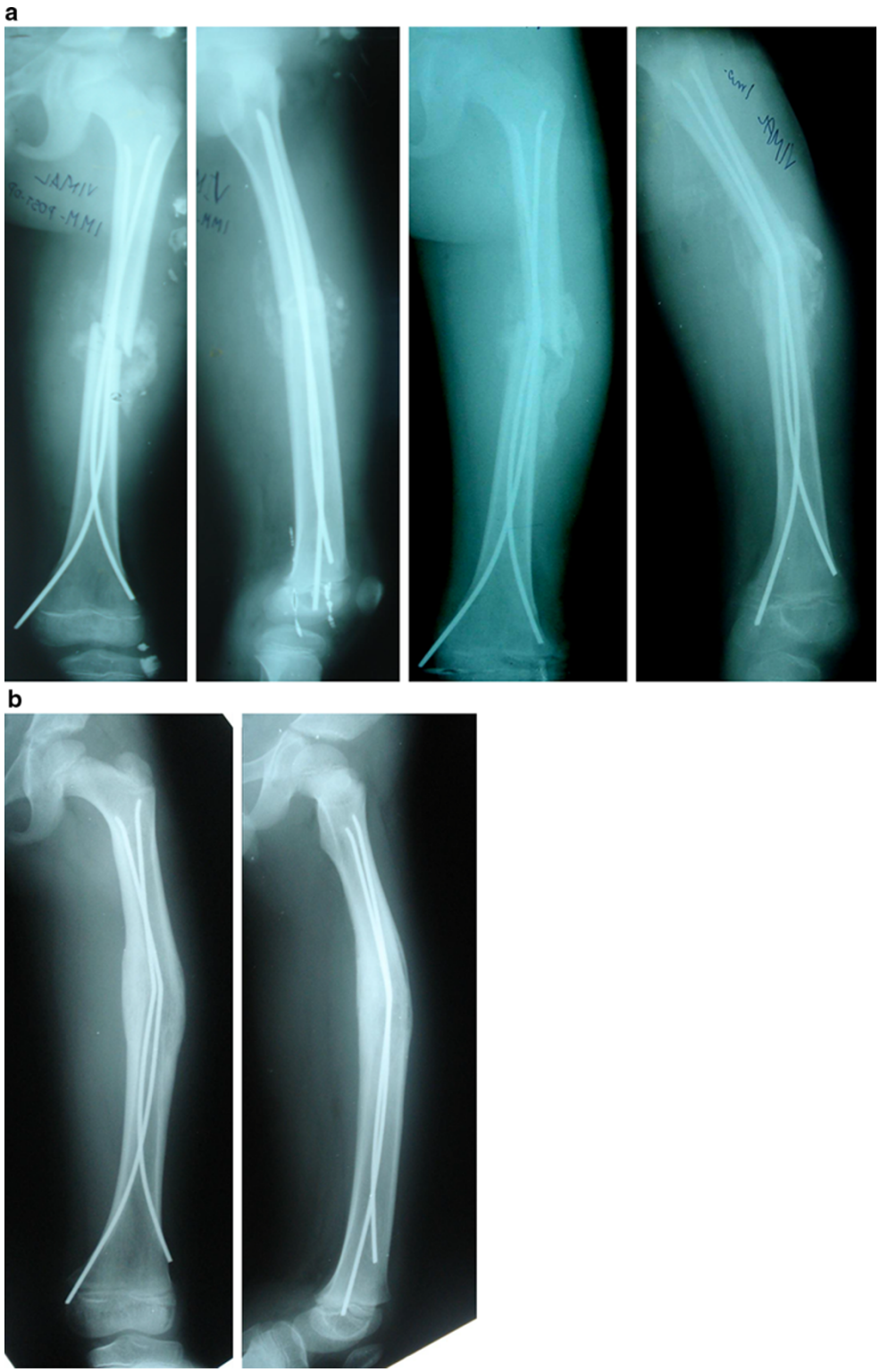

Fig. 2 **a** Immediate postoperative and 4 weeks postoperative radiographs of a 10-year-old child who underwent closed elastic nailing at 16 days post-trauma. The child developed angulation of the fracture due to the deforming force of the strong callus towards the preoperative shortened position. **b** One year follow-up radiograph

complication; Fig. 2) to 4° posterior angulation. Angulation in the coronal plane (varus or valgus) was significantly higher in the spica group (mean 9.6°) than in the nailing group (mean 3.2°) ($P = 0.001$). However, such a difference was not noted with sagittal plane angulation (Table 2). The lack of difference is likely to be due to an

Table 2 Comparison of the outcomes of TEN and spica casting

Parameter	Group	Range	Mean	Standard deviation	Significance (P value, two-tailed)
Coronal plane angulation (°)	TEN	10° varus to 4° valgus	3.19	3.351	0.001
	Spica	22° varus to 8° valgus	9.57	5.612	
Sagittal plane angulation (°)	TEN	24° anterior to 4° posterior	5.75	6.137	0.349
	Spica	20° anterior to 8° posterior	7.79	5.466	
Rotational malalignment (°)	TEN	10° IR to 10° ER	5.62	5.123	0.000
	Spica	25° IR to 20° ER	14.69	5.907	
LLD at 1 year follow-up (cm)	TEN	−1 cm to +1 cm	0.56	0.443	0.000
	Spica	−0.5 cm to −2 cm	1.25	0.408	
Union (weeks)	TEN	5–8 weeks	6.47	0.990	0.001
	Spica	6–12 weeks	8.25	1.483	
Non-weight-bearing (weeks)	TEN	4–8 weeks	5.33	1.447	0.000
	Spica	6–9 weeks	7.38	1.025	
Full weight-bearing (weeks)	TEN	5–8 weeks	6.87	1.125	0.000
	Spica	8–12 weeks	10.00	1.155	
Schooling lost (weeks)	TEN	5–12 weeks	7.13	1.767	0.000
	Spica	8–14 weeks	11.44	1.632	

extreme value (24° anterior angulation) in one patient in the surgical group.

Rotational malalignment ranged from 10° internal rotation to 10° external rotation in the surgical group and from 25° internal rotation to 20° external rotation in the spica group. The presence of rotational malalignment (internal or external rotation) was significantly higher in the spica group (mean 14.69°) than in the nailing group (mean 5.62°) ($P < 0.001$) (Table 2). Parents complained of in-toe gait in 7 of 16 children (43.75%) in the spica group, while none of the children had in-toeing in the surgical group.

At 1 year follow-up, the limb length discrepancy (LLD) in the surgical group ranged from 1 cm shortening (in the child with angulation) to 1 cm lengthening. In the spica group, LLD at 1 year ranged from 0.5 cm shortening to 2 cm shortening. Length inequality (lengthening or shortening) at 1 year was significantly higher in the spica group (median = 1.25 cm) than in the surgical group (median = 0.56 cm) ($P < 0.001$) (Table 2). Parents noticed length inequality in 8 of 16 children (50%) in the spica group and in none of the children in the nailing group.

Union occurred at a median of 6.47 weeks (range 5–8 weeks) in the nailing group and at a median of 8.25 weeks (range 6–12 weeks) in the spica group. It was significantly earlier in the nailing group ($P = 0.001$) (Table 2).

The duration of non-weight-bearing ($P < 0.001$), postoperative duration at full weight-bearing ($P < 0.001$), and the duration of schooling lost ($P < 0.001$) were all significantly higher in the spica group in comparison with the TEN group (Table 2).

Two patients (12.5%) had major complications. The first patient of the series who had corkscrewing of the nails sustained a fall postoperatively and angulated the fracture. He underwent closed reduction and spica casting with nails in situ. The other major complication occurred in a 10-year-old child, who had an oblique fracture of the midshaft femur and underwent closed elastic nailing at 16 days post-trauma in the presence of fracture callus. Follow-up radiographs revealed fracture angulation (Fig. 2). The deforming force of the strong callus towards the preoperative shortened position in an oblique fracture had resulted in fracture angulation.

There were no cases of skin 'irritation' due to nails. There was no incidence of infection, either superficial or deep. In the spica group, 12 children (75%) had major complications ('excessive' rotational malalignment in 11 and redo closed reduction for unacceptable angulation in one). The proportion of patients with major complications was significantly higher in the spica group ($P < 0.001$).

In the surgical group, the Flynn score was 'excellent' in 12 (75%), 'satisfactory' in 1 (6.2%), and 'poor' in 3 (18.8%), while the scores for the spica group were 'excellent' in 1 (6.2%), 'satisfactory' in 2 (12.5%), and 'poor' in 13 (81.3%).

Discussion

Femoral fractures in children have been traditionally treated with either early spica casting or traction followed by spica casting. Though this is an accepted standard of care

in younger children, such treatment in older children has commonly resulted in complications like malunion, joint stiffness, and delay in functional recovery [10–14]. The psychological, social, educational, and economic difficulties resulting from such treatment has also been of much concern recently [5, 7, 15].

An ideal device for treating pediatric femur fractures would be a simple load-sharing internal splint, allowing the mobilization and maintenance of alignment until bridging callus forms. The device would exploit the rapid healing and ability to remodel without risking the physes or blood supply to the femoral head [5]. TEN fulfills these qualities.

The duration of hospital stay in the present study was significantly higher in the surgical group than in the control group. This is in contrast to other reports [4, 16–18], most of which have reported shorter hospital stay with TEN. This difference was because the surgical patients were discharged only after suture removal in order to have a closer follow-up for the presence of early postoperative complications, if any. The spica patients were usually discharged a day or two following spica casting after observation for the presence of plaster-of-Paris-related complications. The longer hospital stay in the surgical group was, however, not related to the development of any postoperative complications.

The present study demonstrates higher coronal angulation and rotational malalignment in patients treated with spica casts. High incidence of loss of reduction and malunion in children treated with spica casting has been reported earlier [4, 11, 19]. However, no literature exists comparing the rotational alignment of fractures treated by the two modalities.

Angulation following titanium elastic nails have been reported by other authors and followed the use of mismatched nail diameters or comminution at the fracture site [6, 8]. Both cases of fracture angulation in the present study occurred early in the series and could be avoided by strictly adhering to the principles of the procedure.

Children in the spica casting group had a significantly higher limb length inequality than those treated with elastic nailing at 1 year postoperatively.

High risk of shortening with spica casting has also been reported by other authors [10, 19, 20]. Flynn et al. [4] reported a higher incidence of shortening and unacceptable angulation with spica casting than with elastic nailing.

Earlier union and return to weight-bearing and school was observed in the surgical group compared to the spica casting group. This could be a result of greater contact of the fracture surfaces and anatomical reduction in the operated patients. Earlier fracture union and earlier mobilization in turn led to earlier return to the normal routine in these patients. Such earlier recovery milestones have also been shown by Greisberg et al. [17] and Flynn et al. [4].

The Flynn scores were better in the surgical group than in the spica group. The most common cause of poor score in the control group was ‘excessive’ rotational malalignment. Such comparison of the final outcome score has not been done in other studies.

The study has certain limitations. As this was a single-center study, the results should be generalized with caution. Other surgeons may find different results or complication rates with the two treatment methods. We did not attempt to estimate the cost of treatment in the two groups and, hence, the difference in the cost of treatment. As with any other new procedure, TEN has a steep learning curve and a small sample size in such a situation could lead to erroneously high complication rates. The study attempts to assess the short-term outcome of the treatment methods. We did not attempt to determine the long-term results of treatment.

In conclusion, the present study supports the treatment of femoral shaft fractures in children aged 5–15 years with TEN, as it hastens fracture union, reduces the rate of malunion and amount of shortening, and allows earlier rehabilitation and return to school.

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