Pediatric Femoral Shaft Fractures Treated With Titanium Elastic Nailing

Liao-Jun Sun, MD; Jie Yang, MD; Nai-Feng Tian, MD; Yao-Sen Wu, MD; Xian-Bin Yu, MD; Wei Hu, MD; Xiao-Shan Guo, MD; Hua Chen, MD

abstract

The objective of this study was to prospectively compare intraoperative fluoroscopy time and clinical and radiological results in pediatric femoral shaft fractures treated with titanium elastic nailing (TEN) using a small-incision, blind-hand reduction vs closed reduction. From February 2008 to December 2009, sixty-eight children were enrolled in the study. Patients were divided into 2 groups: group A comprised 34 patients treated with a small-incision, blind-hand reduction technique and group B comprised 34 patients treated with a closed reduction technique. Operative time, intraoperative fluoroscopy time, fracture union time, and complications were recorded in both groups. Clinical and radiological results were assessed using the TEN scoring system. Mean operative time was 30.5±8.5 in group A and 53.0±15.0 minutes in group B, and mean fluoroscopy time was 28.4±18.5 seconds in group A and 65.0±28.5 seconds in group B. Operative time and fluoroscopy time were significantly longer in group B (P<.001). According to the TEN scoring system, the results were excellent in 31 patients and good in 3 patients in group A and excellent in 29 patients and good in 5 patients in group B. There was no significant difference between the 2 groups in terms of clinical and radiological results. There was also no significant difference in terms of fracture healing time, weight-bearing time, and complications. The small-incision, blind-hand reduction technique provided similar clinical results as closed reduction. This technique could be an alternative to closed reduction because it significantly reduced intraoperative radiation exposure and operative time.
Titanium elastic nailing (TEN) has become an increasingly popular method for pediatric femoral fractures.1-6 This technique, adapted from existing flexible rodding techniques, was developed in France. Satisfactory results have been reported using this technique.1,3,6 The perceived advantages include early mobilization, fewer complications, and minor dissection.1,3,6 The generally accepted technical option is closed reduction and intramedullary nailing under fluoroscopy control, which may increase the intraoperative radiation to both patients and surgeons. Furthermore, closed reduction may not be successful in some cases. The blind-hand technique, with a mini-skin incision at the fracture level, has been used in several studies.3,4 Through this technique, fracture reduction is achieved with 1 or 2 fingers without visualization of the fracture site. Nevertheless, its effectiveness with regard to clinical and radiological results has not yet been determined.

The purpose of this study was to prospectively assess the intraoperative fluoroscopy time and clinical and radiological results in pediatric femoral shaft fractures treated with TEN using a small-incision, blind-hand technique vs closed reduction. The authors hypothesized that the small-incision, blind-hand technique would not adversely affect the clinical and radiological results and would decrease fluoroscopy time and operative time compared with closed reduction.

**Materials and Methods**

After approval from the institutional review board of the authors’ institution, 68 consecutive children with femoral shaft fractures treated with TEN between February 2008 and December 2009 were enrolled in the study. The inclusion criteria were (1) age between 4 and 15 years; (2) fresh closed fractures (within 7 days from injury); (3) unilateral femoral fractures; and (4) using 2 elastic nails during TEN. The exclusion criteria were (1) ipsilateral or contralateral lower limb fractures and/or dislocation; (2) pathological fractures, open fractures, or comminuted fractures; (3) nerve or vascular injury; and (4) metabolic bone disease, previous ipsilateral lower limb surgery, or mental illness. In addition, the reduction method was chosen at random by drawing from a box containing envelopes holding the same number of both methods. Informed consent was obtained from each child’s parents preoperatively.

Group A comprised 34 patients (22 boys and 12 girls) with an average age of 8.2±2.5 years. Mean body weight was 27.2±11.5 kg. The left leg was involved in 10 cases and the right leg in 24. Group A comprised 18 cases of transverse fracture, 12 cases of oblique fracture, and 4 cases of spiral fracture. Mechanism of injury was a road traffic accident in 30 patients and a fall in 4. Three patients had associated injuries, including a pelvic fracture that did not require operative treatment, an ipsilateral distal radial fracture treated by open reduction and internal fixation with pins, and a lung contusion. Average time from injury to surgery was 4.0±3.0 days.

Group B comprised 34 patients (18 boys and 16 girls) with an average age of 8.6±2.6 years. Mean body weight was 28.0±10.2 kg. The left leg was involved in 14 cases and the right leg in 20. Group B comprised 15 cases of transverse fracture, 14 cases of oblique fracture, and 5 cases of spiral fracture. Mechanism of injury was a road traffic accident in 28 patients and a fall in 6. One patient had an associated lung contusion and rib fractures, and another had an associated brain injury. Average time from injury to surgery was 4.5±2.5 days.

**Surgical Technique**

The surgical techniques used in both groups were similar to those previously described in the literature.4 All surgeries were performed by the same group of surgeons (L.-J.S., J.Y., H.C.). Each patient was in a supine position on a standard radiolucent table, and all TENs were placed in a retrograde fashion through the distal part of the femur. Two nails were used. Nail diameter was measured as 40% of the narrowest diameter of the diaphysis. Nails were contoured with a long, gentle bend such that the apex of the convexity was at the level of the fracture. The cortex at the point approximately 2.5 cm proximal to the distal femoral metaphysis was opened with a drill. The drill was then inclined so that it made a 10° angle with the distal metaphyseal cortex. This steeply angled drill channel greatly facilitated passage of the nail through the dense pediatric metaphyseal bone so that it glanced off the far cortex as it was advanced toward the fracture site.

In group A, after the fracture site was determined using fluoroscopy, a 2- to 3-cm mini-lateral incision was performed at the level of the fracture. Using the blind-hand technique, reduction was achieved with 1 or 2 fingers, without visualization of the fracture site, and TENs were advanced proximally. In group B, closed reduction by manipulative traction was performed under fluoroscopic control in all cases. The second nail was advanced, rotating as necessary to enter the proximal fragment. The tip of the nail that entered the lateral distal cortex came to rest just distal to the trochanteric apophysis. The opposite nail stopped at the same level, but the tip pointed toward the calcaneus region of the femoral neck. Distally, the nail was cut to keep 1 to 2 cm remaining outside the cortex. The extraosseous portion of the nail was bent slightly away from the bone.

Postoperative treatments in both groups were the same. In all cases, a one-and-a-half-hip spica cast was applied for 4 weeks after injury to control pain and prevent weight bearing. After the cast was removed, patients were referred to physical therapy for initial gait training. More active exercises were started when the callus appeared.

At each postoperative follow-up visit, anteroposterior and lateral radiographs were specifically analyzed by the operat-
ing surgeon and a radiologist (Y.-S.W.). For data collection, operative time was defined as the time from skin incision to skin closure. Fluoroscopy time was obtained from the fluoroscopy logger. The authors also recorded fracture union time, perioperative complications, late complications, and the time of partial and full weight bearing. Union was defined as the absence of pain and the presence of bridging callus in 3 of the 4 cortices seen on anteroposterior and lateral radiographic views of the femur. Limb-length discrepancy, limb alignment and rotation, implant status, range of motion of the hip and knee, condition of the wound and skin, and any pain or other symptoms were noted at each follow-up visit. Limb-length discrepancy was determined by radiological examination at final follow-up visit. Nails were removed when the fracture line was no longer visible radiographically, which was typically 6 to 8 months postoperatively. Refracture occurring after removal of the TENs was recorded. A patient satisfaction questionnaire was completed at final follow-up (1=dissatisfied, 2=moderate, 3=good, 4=satisfied). Satisfied and good were considered to be successful. The clinical and radiological results were assessed using the TEN scoring system, including limb-length discrepancy, alignment, pain, and complications. Statistical analysis was performed using SPSS version 11.0 statistical software (SPSS, Inc, Chicago, Illinois). Patient demographics (sex, injured side, cause of injuries, associated injuries, postoperative complications, and TEN score) and fracture characteristics were compared between the 2 groups using Pearson’s chi-square test or Fisher’s exact test for nonparametric categorical variables. Independent-samples t test was used to compare patients’ age, body weight, time from injury to surgery, operative time, fluoroscopy time, duration of follow-up, bone-healing time, and time of partial and full weight bearing. A P value less than .05 was considered significant.

**RESULTS**

There was no significant difference in mean age (t=0.647, P=.520), sex (chi-square=0.971, P=.324), body weight (t=-0.303, P=.762), injured side (chi-square=1.030, P=.310), type of the fracture (chi-square=0.538, P=.764), cause of injuries (chi-square=0.469, P=.493), associated injuries (P=1.0), and time from injury to surgery (t=0.747, P=.458) between the 2 groups. Mean operative time was 30.5±8.5 minutes in group A and 53.0±15.0 minutes in group B. There was significantly increased operative time in group B (t=7.610, P<.001). Mean intraoperative fluoroscopy time was 28.4±18.5 seconds (less than 1 minute in 30 cases and 1 to 2 minutes in 4 cases) in group A and 65.0±28.5 seconds (less than 1 minute in 5 cases, 1 to 2 minutes in 23 cases, and more than 2 minutes in 6 cases) in group B. Statistical analysis showed a significant difference between the 2 groups (t=6.281, P<.001). Patients’ baseline characteristics are shown in Table 1.

**Table 1**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group A</th>
<th>Group B</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age, y</td>
<td>8.2±2.5</td>
<td>8.6±2.6</td>
<td>.520</td>
</tr>
<tr>
<td>No. of M/F</td>
<td>22/12</td>
<td>18/16</td>
<td>.324</td>
</tr>
<tr>
<td>Mean weight, kg</td>
<td>27.2±11.5</td>
<td>28.0±10.2</td>
<td>.762</td>
</tr>
<tr>
<td>No. of L/R fractures</td>
<td>10/24</td>
<td>14/20</td>
<td>.310</td>
</tr>
<tr>
<td>No. of transverse/oblique/spiral fractures</td>
<td>18/12/4</td>
<td>15/14/5</td>
<td>.764</td>
</tr>
<tr>
<td>No. of road accident/fall mechanism of injury</td>
<td>30:4</td>
<td>28:6</td>
<td>.493</td>
</tr>
<tr>
<td>No. of combined/noncombined injuries</td>
<td>3/31</td>
<td>2/32</td>
<td>1.000</td>
</tr>
<tr>
<td>Mean time from injury to surgery, d</td>
<td>4.0±3.0</td>
<td>4.5±2.5</td>
<td>.458</td>
</tr>
</tbody>
</table>

Abbreviations: F, female; L, left; M, male; R, right.

Mean fracture union time was 5.8±1.3 weeks in group A and 5.7±1.4 weeks in group B, with no statistically significant difference between the 2 groups (t=0.305, P=.761). Mean time to partial and full weight bearing did not differ significantly between the 2 groups (6.0±1.5 vs 6.2±1.3 weeks and 10.5±2.5 vs 9.8±2.4 weeks, respectively; P>0.05).

There were 2 pin-tract infections in each group, both of which resolved with wound dressing and antibiotic therapy. Deep infection or osteomyelitis did not occur in any case. There were no intraoperative complications, wound-healing problems, instances of hip or knee stiffness, or delayed or nonunion. Neither reduction loss nor implant failure was noted. No patient had more than 10° angulation or rotational malalignment. Two patients in each group developed a sagittal plane angulation between 5° to 10°, and a patient in group B had a coronal plane angulation of 6°. The minor complications were nail-tip irritations (2 cases in group A and 3 cases in group B), which resolved without intervention or early hardware removal. Thirteen patients in group A had limb-length discrepancy, including 12 patients with limb lengthening and 1 with limb shortening less than 2 cm. In group B, 10 patients had leg-length discrepancy, including 8 patients with limb lengthening and 2 patients with limb shortening. Leg-length discrepancy at final follow-up ranged from -1 to 1.7 cm. All nails were routinely removed 6 to 8 months postop-
When rating surgical results, 94% of patients in group A and 91% in group B were good or satisfied, and no patient was dissatisfied with the outcome. There was no significant difference between the groups (P=1.0). Using the TEN scoring system described by Flynn et al, there were 31 excellent and 3 satisfactory results in group A and 29 excellent and 5 satisfactory results in group B. There was no significant difference between the groups (P=.709) (Table 3).

**DISCUSSION**

Usually used with a closed reduction technique, the benefits of TEN include early patient mobilization, minimally invasive fixation, and improved alignment with good reported results. Nevertheless, like other intramedullary nails, TEN requires an increased amount of intraoperative fluoroscopy time. Mastrotrangelo et al suggested that surgeons need to be aware of the increased cancer risk under the long-term exposure to radiation in an orthopedic hospital. Several studies propose that when the surgical procedure is prolonged, surgeons should shift their surgical technique from closed to open reduction to protect both surgeons and patients from unnecessary intraoperative radiation exposure. However, open reduction may increase the incidence of wound infection and slow down the speed of fracture healing. For some significant displaced transverse or short oblique fractures with much overlapping, some fractures whose displacement is caused by stronger muscle strength, or certain fractures whose fracture gap is embedded with soft tissue, implementation of closed reduction by manipulative traction may not succeed. Repeated closed reduction can cause damage to the soft tissue, blood vessels, and nerves near the fracture and may ultimately influence the speed of fracture healing. To date, the ideal reduction method for the TEN technique remains controversial.

In the current study, in neither the closed reduction nor the small-incision, blind-hand groups was the blood supply to the fracture site or the environment of the fracture site significantly damaged in any objective way. This minimal iatrogenic damage did not appear to interfere with callus growth. Therefore, mean fracture healing time and weight-bearing time between the 2 groups were not significantly different. In addition, the small-incision technique for fracture reduction provided the same satisfactory clinical and radiologic results as did the closed reduction. Interestingly, operative time and fluoroscopy time in the small-incision, blind-hand group was significantly shorter due to the fact that small-incision reduction can achieve reduction easily, making the nailing process more smooth.

Surgeon experience is important in reducing the radiation dose. Several studies have shown that the presence of a senior surgeon resulted in a 36% to 40% decrease in the amount of radiation and radiation exposure time during surgical procedures. Madan and Blakeway found that the participation of trainees and middle-grade surgeons was associated with higher radiation exposure during proximal screening of the long bones to identify the insertion site of the guide pin. They compared the fluoroscopic screening time between middle-grade surgeons and consultants, and the former required significantly more time. In the current study, all patients displayed similar fracture types, and all surgeries were performed by the same experienced surgeons. The authors found a significantly longer operative time and extended intraoperative fluoroscopy time in group B compared with group A.

There was no significant difference between the 2 groups in terms of overall incidence of complications (P=.808)
There were no patients with implant failure, delayed or nonunion, or refracture. The majority of TEN-related complications were irritation at the nail insertion site. The incidence of nail-tip irritation in published reports ranges from 7% to 29%.2,4 Narayanan et al5 recommended that nail ends be trimmed short and further advanced with a hollow tamp so that the unblunt nail end lies in close apposition to the supracondylar flare of the distal femoral metaphysis. This will prevent tethering of the adjacent soft tissues and minimize the rate of symptoms at the entry site and may allow earlier return of functional range of knee motion. Following incision closure, the nail ends should not be palpable and the knee should have a full range of unrestricted motion. The nail ends are not buried within the bone but remain 1.0 to 1.5 cm outside the actual cortical entry site. Luhmann et al2 found that the nail-tip problems may be lessened by using the largest possible nail diameter and leaving the nail protruding less than 2.5 cm from the bone.

Removing the TENs may be difficult when using the method recommended by Narayanan et al.5 In the current study, for nail diameter sizing, the narrowest diameter of the femoral diaphysis was measured, and nails that were 40% of this narrowest diameter in size were used. Afterward, the authors cut the extraosseous portion of the nails so that 1 to 2 cm was kept outside the cortex. The nail tip was bent slightly away from the bone to prevent soft tissue irritation and to facilitate nail removal. The authors encountered nail-tip irritations in 2 patients in group A and 3 patients in group B, and the incidence rate was 7.4%, which was significantly lower than the data reported in previous literature.2,4 The authors did not need to perform early removal of the TENs before the fracture healed. Two patients experienced pin-tract infection at the lateral entry side of the TENs. They did not progress to deep infection or osteomyelitis.

Limb-length discrepancy is the most frequent complication of femoral shaft fracture treatment in childhood,3,5,15-18 although it gradually decreased in the current study, and limb-length symmetry was restored in the majority of children. The incidence of limb-length discrepancy of more than 10 mm following flexible intramedullary nailing ranges from 8% to 20%.15 In the current study, 9 (13%) patients had clinically significant limb-length discrepancy of more than 10 mm. On further analysis of the data using the radiological leg-length measurements, the authors found that patients were lengthened by a mean of 6.0 mm (range, -1.0 to 1.6) in group A and 6.4 mm (range, -0.5 to 1.7) in group B. The incidence of leg-length discrepancy and mean lengthening were not significantly different between the 2 groups (P>.05 for both). One year after nail removal, all patients had equal limb lengths.

The incidence of limb-length discrepancy may be either shortening at the fracture site or overgrowth through stimulation of the physis.15-17 Some authors have suggested that cerebral dominance may play a role.16,17 Reynolds17 demonstrated that fractures of the femur and tibia resulted in accelerated growth of those bones for up to 2 years, peaking at 3 months with a growth rate of 38% more than the unaffected limb. Several studies15-17 have shown that accelerated growth may follow fracture of the femoral shaft in childhood and that this creates a limb-length discrepancy that persists into adolescence and early adulthood.

In clinical practice, the current authors found that limb lengthening following elastic nailing in children was a more common phenomenon than shortening. However, it should be noted that shortening was much more important than lengthening and corrected slowly. The exact cause is unclear. The authors also found that this overgrowth phenomenon occurred predominantly in children younger than 10 years. Older children had a more angular deformity and limb-shortening phenomenon. This may be due to the stronger growth potential of the epiphysis in younger children. There were no patients with angulation greater than 10°, and the incidence of angulation and rotational deformity were not significantly different between the 2 groups. The authors used retrograde nailing, which they believe gained more advantages over antegrade nailing in controlling angulation and rotational deformity, especially for distal femur fractures, which has been proven by a biomechanical study.19

The current study has several limitations. First, it was a single-center study that enrolled only a small number of patients. To confirm these results, high-quality randomized, controlled trials with a larger sample size are needed. Second, although patients were allocated randomly to 1 of 2 surgical groups, it was impossible to ensure that the surgeons and patients were blinded, which may have influenced the results. Third, the surgeons who opened the fracture site could have been subconsciously motivated to operate more quickly, using less fluoroscopy. Although this factor could not explain the significantly decreased operative time and fluoroscopy time, it should be further explored in future studies.

CONCLUSION

This prospective comparative study found that pediatric femoral shaft fractures can be effectively treated with TEN using the small-incision, blind-hand technique. The technique provided the same satisfactory clinical and radiologic results as does closed reduction. The authors suggest the small-incision, blind-hand technique as an alternative to closed reduction to avoid extensive intraoperative radiation exposure and decrease operative time.

REFERENCES


