Pediatric Diaphyseal Femur Fractures: Submuscular Plating Compared With Intramedullary Nailing

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abstract

This study compared the radiographic and clinical outcomes of pediatric diaphyseal femur fractures treated by submuscular plating, flexible retrograde intramedullary nailing, or rigid antegrade intramedullary nailing with a trochanteric entry point in skeletally immature patients who were 8 years and older. A retrospective review was conducted of skeletally immature patients 8 years and older who were treated for femur fracture with submuscular plating, flexible intramedullary nailing, or rigid intramedullary nailing from 2001 to 2014 with a minimum 12-week follow-up. Treatment outcomes were compared for statistical significance, including time to union, malunion, nonunion, heterotopic ossification, avascular necrosis, time to full weight bearing, limb length discrepancy, residual limp, painful hardware, and infection. The study identified 198 femur fractures in 196 patients (mean age, 11.9 years). Each femur fracture was treated with submuscular plating (35), flexible intramedullary nailing (61), or rigid intramedullary nailing (102). Mean follow-up across the cohort was 48 weeks, ranging from 12 to 225 weeks. Flexible nailing was associated with an increased incidence of malunion ($P < .0001$) and hardware irritation ($P = .0204$) and longer time to full weight bearing ($P = .0018$). Rigid nailing was associated with an increased incidence of limp at 12-week follow-up ($P = .0412$). Additionally, 23.5% of patients who were treated with rigid nailing had heterotopic ossification. Of all surgical methods, submuscular plating allowed for the most rapid return to full weight bearing (mean, 7 weeks) and offered the fastest healing rate (mean, 6 weeks). Submuscular plating resulted in faster times to union and full weight bearing, with minimal complication rates. Rigid intramedullary nailing with trochanteric entry resulted in a lower incidence of malunion and hardware-related complications; however, these patients had an increased incidence of heterotopic ossification and residual limp postoperatively. Flexible retrograde intramedullary nailing resulted in the highest rates of malunion and hardware irritation and the longest time to full weight bearing. [Orthopedics. 2016; 39(6):353-358.]

Pediatric diaphyseal femur fractures account for 1.7% of all pediatric fractures, with the annual incidence estimated at 19 per 100,000. Fracture management is affected by associated injuries, patient age, fracture characteristics, body weight, and cost. During the past decade, surgical stabilization has gained favor in the management of femoral shaft fractures in skeletally immature patients. Options for surgical stabilization include open or submuscular plate fixation, flexible intramedullary nailing, and rigid intramedullary nailing. Each method has advantages and disadvantages, with the ideal technique largely debated.

Submuscular plating is an established operative treatment for femur fractures, acting as an internal splint, providing
stable fixation, and allowing for maximum biologic healing. Alternatively, flexible intramedullary nailing has become a popular method of treatment, with good clinical outcomes and low complication rates. However, recent studies showed an increased risk of complications when flexible nails are used in heavier children and those with fractures of unstable length. Femoral shaft fractures treated with rigid antegrade intramedullary nailing have shown promising results, but this treatment is generally reserved for older children and adolescents. This technique affords stable internal fixation and allows for early mobilization. Previously, a piriformis entry point was used, but this technique has been associated with avascular necrosis of the femoral head. Trochanteric entry has reduced the risk of avascular necrosis, with only 2 reported cases.

This study compared early radiographic and clinical outcomes of pediatric diaphyseal femur fractures treated with submuscular plating, flexible retrograde intramedullary nailing, or rigid antegrade intramedullary nailing with a trochanteric entry point in skeletally immature patients 8 years and older. The study hypothesis was that pediatric femur fractures treated with submuscular plating would have faster times to union and full weight bearing, with minimal complication rates compared with flexible and rigid nailing.

**MATERIALS AND METHODS**

After institutional review board approval was obtained, the authors performed a retrospective review of all pediatric diaphyseal femur fractures treated at their level 1 pediatric trauma center from January 2001 to October 2014. A total of 344 children with femoral shaft fractures were treated by 13 different pediatric orthopedic surgeons. Each surgeon used all 3 techniques, including submuscular plating, retrograde flexible intramedullary nailing, and rigid intramedullary nailing. Anterior bowed femoral locking plates (Synthes, West Chester, Pennsylvania; Smith & Nephew, Andover, Massachusetts; and OrthoPediatrics, Warsaw, Indiana) measuring 3.5 and 4.5 mm were used, and the procedure was performed with the 2-incision technique described by Samora et al. The surgical techniques for flexible and rigid trochanteric entry and antegrade nailing were described previously. All flexible nail procedures were performed with a retrograde technique with titanium elastic nails (Synthes) (30 procedures) or flexible stainless steel Enders rods (Smith & Nephew, Memphis, Tennessee) (31 procedures) (Figure 1).

The study included skeletally immature children who were at least 8 years old and had a minimum follow-up of 12 weeks. Children were excluded if they were younger than 8 years, if they had a closed physis, if they had inadequate follow-up, or if they had inadequate medical records or radiographs. After the inclusion and exclusion criteria were met, the cohort included 198 fractures in 196 children. Submuscular plating was performed in 35 children, a flexible rod procedure was performed in 61 children, and rigid trochanteric nailing was performed in 100 children (102 fractures). The surgical treatment was dictated by the surgeon and was based on fracture location, fracture characteristics, patient age, and patient weight.

All clinical, surgical, and radiographic reports were retrospectively reviewed, and comorbidities, associated injuries, and pertinent demographic data were recorded. Each patient had preoperative radiographs (anteroposterior and lateral views) that visualized the diaphyseal fracture. The fracture pattern was characterized as comminuted, spiral, oblique, or transverse, and the fracture location was characterized as proximal, middle, or distal third shaft. Angulation of the fracture was measured as the angle between fracture fragments in the sagittal and coronal planes.

Patients were followed at regular intervals postoperatively with radiographic and clinical assessments. Radiographic

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**Figure 1:** Anteroposterior radiographs showing pediatric diaphyseal femur fractures treated with submuscular plating (A), flexible intramedullary nailing (B), and rigid intramedullary nailing (C).
evaluation included time to union as well as the incidence of malunion, delayed union, nonunion, and heterotopic ossification. Radiographic evidence of union was defined as callus bridging at least 3 of the 4 cortices seen on 2 orthogonal views of the femur. Delayed union and nonunion were defined as lack of complete healing at 12 weeks and 6 months, respectively. Malunion was defined as greater than 10° angulation in the sagittal plane (flexion or extension) or greater than 5° angulation in the coronal plane (varus or valgus). Clinical outcome measures reviewed from outpatient records included time to full weight bearing and the incidence of clinically detectable limb length discrepancy, presence of residual limp (after >12 weeks of follow-up), infection, and painful implants. Patients were considered full weight bearing when they resumed ambulation without the use of an assistive device. Finally, the rates of refracture and reoperation were recorded. Reoperation was defined as any fracture-related surgery other than routine implant removal after the initial procedure.

Statistical Analysis

Descriptive analyses were used to describe the demographic and clinical characteristics of pediatric patients with diaphyseal femur fractures treated with submuscular plating, flexible intramedullary nailing, or rigid antegrade intramedullary nailing. Differences were compared across the 3 treatment groups in radiographic outcomes (eg, time to union and incidence of malunion, delayed union, nonunion, heterotopic ossification, and avascular necrosis of the femoral head) and clinical outcomes (eg, time to full weight bearing and incidence of clinically detectable limb length discrepancy, residual limp, infection, and painful implants) with analysis of variance, chi-square test, or Fisher’s exact test, as appropriate. Statistical significance was set at alpha=.05. All analyses were conducted with SAS version 9.3 software (SAS Institute Inc, Cary, North Carolina).

RESULTS

A total of 198 fractures in 196 patients met the study inclusion criteria. Mean patient age at injury was 11.9 years (range, 8-17 years). There was a broad distribution of ages in all 3 treatment groups. Patients who were treated with elastic nailing (mean, 10.6 years) or submuscular plating (mean, 10.6 years) were considerably younger than those treated with rigid nailing (mean, 13.9 years). A total of 35 patients (27 boys and 8 girls) were treated with submuscular plating, 61 patients (45 boys and 16 girls) were treated with flexible intramedullary nailing (31 stainless steel Enders rods and 30 titanium nails), and 100 patients (78 boys and 22 girls) were treated with rigid intramedullary nailing (Table 1). No significant sex difference was found (P=.791).

Of the 198 fractures, 103 involved the right femur and 95 involved the left femur. In addition, 2 patients had bilateral femur fractures and 2 patients had open fractures. Of the fractures, 134 (68%) involved the mid-part of the femur diaphysis, 40 (20%) involved the proximal third of the diaphysis, and 24 (12%) involved the distal third of the femur diaphysis. In addition, 83% of patients in the flexible nail group and 68% of patients in the rigid nail group had fractures that occurred in the mid-part of the diaphysis. Of the submuscular treatment group, 28% of fractures involved the proximal third of the diaphysis and 34% of fractures involved the distal third of the femur diaphysis, respectively. Distribution of the fracture site was significantly different among the treatment groups (P<.0001).

Fracture patterns included 93 (47%) transverse, 46 (23%) comminuted, 43 (22%) oblique, and 16 (8%) spiral fractures. Fracture type had a variable distribution among the 3 treatment groups (Figure 2). A significant association was found between treatment type and fracture pattern (P<.0001). A higher proportion of spiral fractures and fewer transverse fractures were found in the submuscular plate group. In 72% of the comminuted fractures, treatment was with rigid nailing.

No intraoperative complications occurred. Average C-arm fluoroscopy time for the 3 groups was 161.13 seconds. Mean fluoroscopy time was 85 seconds (range, 8-197 seconds) in the submuscular plating group, 108 seconds (range, 34-509 seconds) in the flexible nailing group, and 218 seconds (range, 46-540 seconds) in the rigid nailing group. Adjusting for surgeon variability, significantly lower fluoroscopy times were found in the submuscular plate and flexible nail groups compared with the rigid nail group (P<.0001).

Average follow-up time was 48 weeks (range, 12-225 weeks). Mean time to
union for all fractures was 9 weeks (range, 3-37 weeks). Mean time to union was 6 weeks in the submuscular plate group, 8 weeks in the flexible nail group, and 11 weeks in the rigid nail group (Table 2). When time to union was compared, the submuscular plate group had a significantly shorter time to union than the rigid nail group and the flexible nail group (P<.0001). No delayed union or nonunion occurred in the submuscular plate group.

In the flexible nail group, delayed union occurred in 4 patients. In the rigid nail group, 28 delayed unions (27%) healed uneventfully.

Malunion was noted in 2 (2%) fractures in the rigid nail group, 4 (12%) in the submuscular plate group, and 13 (22%) in the flexible nail group. Flexible nailing was associated with significantly higher rates of malunion vs rigid nailing (P=.0001). Deformities varied from 12° procurvatum to 10° recurvatum and from 15° valgus to 9° varus in the flexible nailing group.

Mean time to full weight bearing was 7 weeks (range, 3-13 weeks) in the submuscular plate group, 12 weeks (range, 4-26 weeks) in the elastic nail group, and 9 weeks (range, 4-31 weeks) in the rigid nail group. When adjusted for sex, age, and surgeon, the submuscular plate group had a significantly shorter time to full weight bearing (P<.0001) compared with the other 2 treatment groups.

At the time of fracture union, 9 patients (1 in the submuscular plate group, 3 in the flexible nail group, and 5 in the rigid nail group) showed clinical limb length discrepancy (P=.8827). In addition, 36 patients (2 in the submuscular plate group, 10 in the flexible nail group, and 24 in the rigid nail group) had residual limp at 12-week follow-up. Rigid nailing was associated with a significantly higher incidence of residual limp (P=.0412).

Heterotopic ossification did not occur in the flexible nail group; however, 2 (5.9%) patients in the submuscular plate group and 24 (24%) patients in the rigid nail group had heterotopic ossification. A significantly greater incidence of heterotopic ossification was found in the rigid nail group (P<.0001). In all affected patients, heterotopic ossification was characterized as class I. No clinical restriction of range of motion was noted in patients with heterotopic ossification.

In the flexible nail group, 14 (23%) patients had implant irritation, all occurring at the nail tip insertion sites. Flexible nailing was associated with a higher rate of implant irritation (P=.0204) compared with rigid nailing (n=13, 13%) and submuscular plating (n=1, 3%).

No cases of avascular necrosis were identified. A postoperative wound infection occurred in the rigid nailing group and was successfully treated with irrigation and debridement in addition to antibiotics. One patient who was treated with rigid nailing had refracture approximately 2 years after the primary surgery. In the

<p>| Table 2 |</p>
<table>
<thead>
<tr>
<th>Outcome Variable</th>
<th>Rigid Nail</th>
<th>Flexible Nail</th>
<th>Submuscular Plate</th>
<th>P</th>
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<tr>
<td>Total (N=198), No.</td>
<td>102</td>
<td>61</td>
<td>35</td>
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<td>Time to union, mean, wk</td>
<td>11.1</td>
<td>8.1</td>
<td>6.2</td>
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<tr>
<td>Time to full weight bearing, mean, wk</td>
<td>9.5</td>
<td>12.1</td>
<td>7</td>
<td>&lt;.0001</td>
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<tr>
<td>Fluoroscopy time, mean, s</td>
<td>218</td>
<td>108</td>
<td>85</td>
<td>&lt;.0001</td>
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<td>Limp at 12 wk, No.</td>
<td>24 (23.5%)</td>
<td>10 (16.7%)</td>
<td>2 (5.9%)</td>
<td>.0534</td>
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<tr>
<td>Hardware irritation, No.</td>
<td>13 (12.8%)</td>
<td>14 (23.3%)</td>
<td>1 (2.9%)</td>
<td>.0204</td>
</tr>
<tr>
<td>Hardware removal, No.</td>
<td>20 (19.6%)</td>
<td>30 (49.2%)</td>
<td>20 (57.1%)</td>
<td>&lt;.0001</td>
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<tr>
<td>Limb length discrepancy, No.</td>
<td>5 (4.9%)</td>
<td>3 (4.9%)</td>
<td>1 (2.9%)</td>
<td>.8827</td>
</tr>
<tr>
<td>Malunion, No.</td>
<td>2 (2.0%)</td>
<td>13 (22.4%)</td>
<td>4 (11.8%)</td>
<td>&lt;.0001</td>
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<td>Heterotopic ossification, No.</td>
<td>24 (23.5%)</td>
<td>0 (0.0%)</td>
<td>2 (5.9%)</td>
<td>&lt;.0001</td>
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submuscular plate group, 1 implant failure occurred and required formal open reduction and replating.

**Discussion**

The literature has compared operative outcomes in femoral shaft fractures in the skeletally immature child. However, these studies have largely focused on the adolescent population, and few data are available on younger cohorts. The current study compared 3 surgical methods of fixation in skeletally immature children 8 years and older. A minimum age of 8 years was chosen because patients 8 years and older may be treated with any of these 3 treatment options.

Children treated with flexible nailing had a significantly higher incidence of malunion and implant irritation compared with those treated with other surgical methods. Implant irritation is common after placement of elastic nails, and it is typically the result of skin irritation at the nail tip. Previous studies showed an incidence of implant irritation after flexible nailing of as high as 52%. Each of these children underwent implant removal that resulted in complete symptomatic relief. Additionally, the current results showed an increased risk of malunion with flexible nailing (22.4%) compared with rigid nailing (2%). Moroz et al found a 7.7% incidence of malunion in 234 patients treated with elastic nailing. Factors associated with poor outcomes and increased risk of malunion included fractures of unstable length and increased patient weight. Correspondingly, 2 malunions occurred in children weighing more than 45 kg, 1 malunion occurred in a patient with a fracture of unstable length, and 1 malunion occurred in a child with increased weight (>45 kg) and a fracture of unstable length.

With larger patients and fractures of unstable length, rigid intramedullary nailing with a trochanteric starting point allows for rapid mobilization, high rates of union, and early weight bearing. This finding was consistent with the current study because rigid nailing was associated with a significantly shorter time to full weight bearing compared with elastic nailing, although rigid nailing was associated with an increased incidence of limp 12 weeks postoperatively compared with submuscular plating and elastic nailing.

Proximal femoral avascular necrosis is a well-recognized consequence of using a piriformis entry point for intramedullary nailing. The use of an entry point at the tip of the greater trochanter or lateral to the tip of the greater trochanter can decrease the risk of this complication because the pericapsular vasculature is avoided. The current study included only children who had a trochanteric entry point and found no evidence of avascular necrosis at the latest follow-up. Trochanteric entry is not without risks, and growth disturbance of the proximal femoral apophysis may occur in skeletally immature patients. However, Gage and Cary found that arrest of the greater trochanter apophysis after 8 years had no effect on trochanteric growth.

The study also found an increased incidence of heterotopic ossification in the rigid intramedullary nailing group. Approximately 24% of patients had heterotopic ossification, but all were asymptomatic and required no further intervention. To the authors’ knowledge, no previous studies have evaluated the incidence of heterotopic ossification after intramedullary nailing of femur fractures in the pediatric population.

Operative stabilization of pediatric femur fractures with a submuscular bridge plate has become increasingly popular. This option offers decreased risk of infection, shorter operative time, and minimal blood loss compared with traditional open plating. This technique optimizes biologic healing by providing a stable internal construct. The current study found that submuscular plating provided the shortest time to full weight bearing among all surgical methods as well as the fastest time to union. Studies showed that submuscular plating is an effective alternative for the treatment of fractures of unstable length. Samora et al found that submuscular plating produced excellent healing rates, low complication rates, and early return to weight bearing, with mean time to full weight bearing of 7.8 weeks. Similar results were shown in previous series.

**Limitations**

The current study had several limitations. This study was a retrospective review performed at a single pediatric center with data from 13 different surgeons. The data were subject to variation by surgeon preference in the perioperative and postoperative periods. A large prospective multicenter study would control for this variation. In addition, there was considerable variation in patient follow-up. To account for this variation, the study included only patients with at least 12 weeks of follow-up. The 12-week follow-up period reflected the time needed for most patients to return to the preoperative state.

**Conclusion**

This study showed 100% healing rates for femoral shaft fractures in skeletally immature children 8 years and older who were treated with 1 of the 3 studied techniques. Submuscular plating produces the fastest times to union and full weight bearing, with minimal complication rates. In addition, intramedullary nailing with rigid trochanteric entry results in a lower incidence of malunion and fewer implant-related complications compared with flexible nailing as well as minimal risk of avascular necrosis.

**References**


