Management of pediatric diaphyseal femur fractures

Benton E. Heyworth · Catherine A. Suppan ·
Dennis E. Kramer · Yi-Meng Yen

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Abstract A variety of strategies are utilized for management of pediatric diaphyseal femur fractures, depending chiefly on the age of the patient. Other factors that can influence the selection of a technique—which range from skeletal traction with spica casting to immediate spica casting, flexible intramedullary nailing, rigid intramedullary rodding, or plate fixation—are weight, fracture severity, associated injuries, and underlying medical or musculoskeletal conditions. The available evidence regarding technique, outcomes, and complications of the aforementioned treatment options remains largely insufficient, and, at times, conflicting, which contributes to the challenges in management decisions. Considerable controversy has arisen over several topics, particularly the optimal treatment for patients aged 5 to 12 years and accepted standards of treatment. This review is designed to provide perspective for some of the most recent influential literature on pediatric diaphyseal femur fracture treatment in light of established evidence and evolving controversies.

Keywords Pediatric femur fracture · Diaphyseal femur fracture · Hip spica casting · Intramedullary nailing · Submuscular plating

Introduction

Pediatric orthopedic trauma remains a leading cause of morbidity and results in high direct and indirect costs in the United States each year. Femoral shaft fractures rank among the most common traumatic musculoskeletal injuries requiring inpatient care in children [1, 2] with an incidence of hospitalization for femoral fracture estimated at 27.2 per 10,000 children in the United States, which accounts for nearly 22% of hospitalized traumatic orthopaedic conditions [2]. Most femur fractures in the pediatric population are attributable to falls and motor vehicle accidents, with bicycle accidents, abuse, and non-traumatic events also identified as leading causes of fracture [3]. Despite the frequency and impact, treatment of pediatric diaphyseal femur fractures continues to evolve as an area of controversy, particularly in the middle age group of patients aged approximately 5 to 12 years.

Several factors fuel the controversy over the appropriate method of treatment, including the growing variety of treatments available and a lack of high-level comparative evidence regarding outcomes of these options. Comparisons across existing studies are further confounded by differences in age groupings of patient cohorts, institutional preferences, and varying severity or complexity of the fractures studied. Furthermore, some treatment methods for diaphyseal fractures in children have seen a relatively rapid evolution of understanding, leaving the topic in somewhat continual flux. For example, while the 1990s saw the increasing use of elastic nails for operative stabilization of patients aged 5 to 12 years [1, 4–7], an increasing number of reports over the past two decades have highlighted technical challenges and complications, somewhat narrowing the indications for their use, while parallel evidence supporting submuscular plating has emerged [7–16]. Though complications associated with submuscular plating are also well-reported, including minor

B. E. Heyworth (✉) · C. A. Suppan · D. E. Kramer · Y.-M. Yen
Department of Orthopaedics, Children's Hospital Boston,
300 Longwood Avenue,
Boston, MA 02115, USA
e-mail: Benton.Heyworth@childrens.harvard.edu

C. A. Suppan
e-mail: Catherine.Suppan@childrens.harvard.edu

D. E. Kramer
e-mail: Dennis.Kramer@childrens.harvard.edu

Y.-M. Yen
e-mail: Yi-Meng.Yen@childrens.harvard.edu

leg length discrepancies [11], plate fracture [11], re-fracture following plate removal [11], and fracture malalignment [15], the reports on this technique remain in their infancy and more long-term and higher-volume studies are needed before an exhaustive safety profile is understood. Even relatively established methods for certain populations, such as spica casting in younger pediatric patients, have been subject to scrutiny, in light of better understanding of complications and outcomes of treatments, and technical innovation surrounding these treatments.

While the American Academy of Orthopaedic Surgeons has attempted to formulate clinical practice guidelines (CPG) for the management of femoral shaft fractures in children, only one of the 14 recommendations formulated in the CPG was substantiated by “good-quality evidence”. The remaining 13 are based on either “fair”, “poor”, or “inconclusive” evidence [14•]. This review aims to discuss the recent contributions to the literature that may enhance our understanding of pediatric diaphyseal femur fracture treatment methods and their outcomes.

Traction

Pediatric patients may be placed in either skeletal or skin traction temporarily before definitive treatment of femoral shaft fractures in some instances or somewhat routinely in some countries or institutions. Vanlaningham et al. recently compared the use of narcotics in the first 24 h of both types of traction in a group of 75 pediatric patients with isolated femoral shaft fractures, aged 4 to 14 years, and found no significant difference in narcotic use between the groups [17]. These results lend further support to the notion that invasive skeletal traction may offer no benefit over simple skin traction in the pediatric population with femur fractures for initial pain management prior to definitive treatment. While the study did not involve a control group who did not receive traction, there remains a general trend away from its use in the U.S., in part because it has been associated with longer hospital stays and higher overall costs with comparable clinical results to other existing options [18, 19].

Spica casting

Hip spica cast treatment of femur fractures remains the standard of care in younger patients, ages 6 months to 5 years, with the Pavlik harness usually being employed for newborns and patients under 6 months old. A recent long-term follow-up study from Switzerland demonstrated the efficacy of spica casting in the young age group by analyzing its use in a cohort of patients with a mean age of 22 months (range, 0–53 months) and an average follow-

up of 7.5 years [20]. Of the 22 patients with long term follow-up, several developed complications, including one patient with a leg discrepancy greater than 2 cm, one patient with a minor valgus and rotational deformity, and two patients with a limp, but without impediment to their daily activities. Despite the demonstrated efficacy of spica casting in this age group, there are increasing reports of children in preschool ages receiving various other forms of fixation [21–23].

For older children, an important study in 2010 by Shemshaki et al. compared the use of titanium elastic nailing (TEN) to hip spica casting in 46 patients, aged 6 to 12 years, with simple femur fractures [24]. Compared to patients treated with a spica cast, those treated with TEN had shorter hospital stays, took a shorter time to start walking, returned to school sooner, had a lower rate of malunion, and had higher parent satisfaction. Saseendar et al. found similar results among a group of 16 patients aged 5 to 15 years treated with TEN when compared to a group of retrospectively age-matched children treated by spica casting [25]. They reported shorter times of immobilization and time to fracture union, lower rates of malalignment and time leg length discrepancy, and better functional outcome. These results serve to further substantiate the growing preference of non-casting options in the middle age group.

Elastic intramedullary nailing

Intramedullary elastic nails have become a widely used option for pediatric diaphyseal femur fracture treatment, particularly in patients 6 to 12 years. Typically they have been most successfully utilized in length stable fracture patterns such as transverse or short oblique fractures in patients less than 100 lbs. While the relatively low risk of complications and quick return to mobility reported in studies in the 1990s and 2000s have made elastic nails appealing to both surgeons and patients, patients treated with elastic nails often undergo another surgery for hardware removal, and more recent reports have revealed several technical challenges and complications that may serve to limit the use of intramedullary nails in certain populations.

Anastasopoulos et al. recently analyzed 36 patients aged 7 to 13.5 years [26]. At mean follow-up of 25.5 months, successful fracture union was observed in all patients. Follow-up reports indicated return to a full range of motion for all patients with the exception of one who experienced a 10° extension lag. However, radiographic review revealed 44% of the children had a malalignment at the fracture site and 50% had a leg length discrepancy, though these patients did not present with clinical misalignment or report pain or inconvenience. In another cohort of 70 patients aged 4 to 15 years, Sagan et al. found malunion—defined as greater

than a 15° of angulation on the lateral radiograph or 10° angulation on the anteroposterior radiograph—in 16 patients, mostly older children [22•]. They additionally found that weight was a significant predictor of anterior bow formation, with mean weight in patients treated with elastic nailing who experienced anterior bowing greater than 15° was $46.5 \text{ kg} \pm 13.5$, whereas the mean weight of those who did not experience bowing was $36.8 \text{ kg} \pm 18.5$ [22•]. Additionally, the authors revealed that 47% of their patients experienced torsional malalignment following elastic nail treatment. Previous biomechanical data also cautions against the use of elastic nails in heavier patients. Li et al. [27] evaluated 4-point bending load to failure following fracture fixation in a cadaveric model. The authors noted that weight greater than 40–45 kgs provides a load at which permanent sagittal and coronal deformation of the nail can occur [27]. Salem et al. [21] reported similarly high rates of torsional differences $>15^\circ$ in 50% of 68 children who underwent elastic nailing of femur fractures. This group included 31 patients with external torsion but only four cases of clinical out-toeing.

Conversely, Garner et al. found that compared to a weight matched cohort that underwent rigid locking nail treatment, heavier patients (defined as those weighing 47–85 kgs) who underwent elastic nail treatment had less blood loss, a shortened time in the operating room, fewer complications, and were observed to have no increased risk of malunion or leg length discrepancy [28•]. Despite these intra-operative benefits, six of the 15 patients in the elastic nail treated cohort still experienced a complication.

Altay et al. investigated the effect of the use of an open versus a closed reduction technique during TEN [23]. Of 87 children, 42 were treated with a mini-open technique by which a 2–3 cm lateral incision is made at the point of fracture to achieve reduction, while 45 were treated with a closed technique where fluoroscopic control is used to insert the nail. Duration of surgery and intraoperative fluoroscopy time were significantly higher in the closed reduction group, while similar union and complication rates for both procedures were seen at an average of almost 2 years follow-up.

Jencikova-Celerin et al. recently reported on outcomes following use of a flexible interlocking nailing system, which incorporates a nail less rigid than an external fixator but more rigid than an elastic nail, as well as an interlocking screw [29]. Of the 58 patients who received the interlocking fixation, only 19% experienced complications compared to the 30.4% of the 70 patients in the study treated with other fixation methods. The authors found that patients who weighed under 45.5 kg who were treated with standard elastic nails had 8.1 times the complication rate of those treated with the interlocking nails; however, the patients treated with interlocking nails were 1.7 times more likely to develop trochanteric heterotopic ossification than those

treated with other fixation procedures. While technical modifications of traditional intramedullary nailing such as these may improve results, other types of fixation have also begun to be used for this middle age group.

Plate fixation

While there has long been a role for open reduction internal plate fixation in rare, select cases of pediatric femur fracture, newer techniques of less invasive submuscular plating for unstable femur fractures, primarily described in the 2000's, have since increased in popularity [12, 16]. In a retrospective study comparing two different periods of fracture treatment at a single institution—in which use of submuscular plating for unstable fractures increased from 19% to 71% of cases—Sink et al. observed a significantly decreased rate of complications [8•]. The authors suggested that this decrease resulted from limiting the use of elastic nails for unstable fractures. Unpublished analysis from our institution revealed that amongst 85 skeletally immature femur fracture patients treated with submuscular plating, there was an 8% rate of major complications (i.e. those that required unplanned surgery) and a 4% rate of minor complications (i.e. those that did not require operative intervention). Major complications included screw prominence, wound infections, development of distal femoral valgus deformity, and leg length discrepancy. These occurred at a later time point (mean: 27.5 months) than did the minor complications (mean: 2.6 months), which included delayed union, superficial wound infection, and valgus malunion. There were no intraoperative complications, no reports of knee stiffness, shortening, or reoperations to address fracture stability.

In 2008 Hedequist et al. [12] reported on 32 patients, aged 6 to 15 years, whose proximal, mid-shaft, or distal fractures were treated with submuscular locking plates. Indications for plate usage were fracture comminution (13 cases), pathologic fractures (non-malignant, 9 cases), atypical fracture location (either too proximal or too distal for typical elastic nailing, 7 cases), and osteopenia (3 cases). All fractures healed, there were no intraoperative complications, and only one patient displayed a valgus malalignment (12°), but required no intervention. The authors proposed that screw purchase in a minimum of three cortices per fragment was necessary for stable fixation. Eidelman et al. reported similar outcomes with the use of pre-contoured submuscular plates fitted to cadaver adolescent femurs in 11 patients [11]. All treated fractures healed with good alignment with no major complications. The authors reported the use of such pre-contouring was more precise and easier to perform than pre-contouring accomplished by molding the plate to the unfractured femur based on preoperative X-rays or through fluoroscopy.

While elastic nails are usually removed once fracture healing is achieved, little consistency in practice or evidence in the literature exists with regard to removal of submuscular plates. However, in one study, Pate et al. described a series of 22 patients aged 5 to 15 years treated with submuscular plating who later underwent plate removal [30•]. Seven of the patients required a more extensive procedure to remove the plate than was required to insert it, due chiefly to the presence of bony overgrown at the leading edge of the plates. No patients experienced refracture, or fracture at the site of a screw hole. Similarly, in the previously mentioned unpublished analysis at our institution, 52 of the 85 patients (61%) underwent removal of hardware with no instances of complications related to the removal.

The primary advantages of submuscular plating—rigid fixation for unstable fractures and for heavier patients who potentially represent poor candidates for elastic nailing—have led to an increase in their use at select centers. However, more research into the complication rates and the implications of growth and removal of hardware is warranted before such techniques earn widespread appeal.

External fixation

As several reports have emerged detailing relatively high complication rates associated with external fixation of femur fractures [7, 31] there has been an overall decrease in the frequency of its use, and recommendations *against* its use for some patient groups [14••] have even emerged. Among the unfavorable sequellae associated with external fixation use in the femur in children includes a significantly higher refracture rate and skin and soft tissue scarring. However, external fixation may still represent a viable option in certain clinical situations, such as in the multiply injured child, or for use as a temporizing stabilization approach when traction cannot be utilized.

Rigid intramedullary nailing

While rigid nailing has long represented the preferred approach for the treatment of adult and adolescent diaphyseal femur fractures [32], its role in pediatric fractures is less certain, chiefly due to concerns over femoral head osteonecrosis, particularly with techniques involving nail entry in the piriformis fossa [33]. However, implant design has evolved to include trochanteric entry and lateral trochanteric entry, in which the critical vasculature to the femoral head is theoretically avoided. A recent study comparing lateral trochanteric versus piriformis fossa entry reported effective treatment outcomes in the former group with limited complications. In this study of 78 patients with a mean age of 12.9 years (range, 8–

18 years), no nonunions, delayed unions, or malunions were observed, and no patient had evidence of osteonecrosis of the femoral head at a mean follow up of 8 years [34]. There was no significant difference in neck-shaft angle, articulo-trochanteric distance, or femoral diameter when compared with the nonsurgical, normal side in these patients. These results indicate a possibility for increasing the use of rigid nailing in treating pediatric diaphyseal femur fractures in the future, and in some institutions, trochanteric or lateral entry nailing may already represent the technique of choice for those fractures that would otherwise be treated with submuscular plating. Studies with longer term follow-up and larger sample sizes over a broader age range will more clearly elucidate the true rates and risks of the catastrophic complication of femoral head avascular necrosis and provide comparative evidence related to rigid nailing versus plating.

Conclusion

The reported advantages and disadvantages of the variety of femur fracture management techniques described and their associated complications further demonstrate the challenges in treating pediatric femur fractures and the need for more concrete practice guidelines. Registries of pediatric femur fracture incidence, injury pattern, and treatment type, such as that compiled in Sweden [35], can contribute to the body of knowledge needed to make such decisions on best treatment. Heideken et al. was able to demonstrate that over an 18 year period, Sweden experienced a 42% decrease in fracture incidence, children aged 4 to 12 were most often injured in sports, and there was a shift in treatment modality away from widespread casting towards increased use of external fixation and elastic intramedullary nailing, based on the registry [35].

The emerging clinical literature demonstrates that while fracture management decisions continue to evolve, the younger age group of children under 6 years still benefits most from spica casting, with or without skin traction. The middle age group of children 5 to 12 years are most commonly be treated with elastic nailing, though newer techniques such as submuscular plating and lateral entry rigid nails may have a select, or even primary role, depending on the fracture pattern and patient factors, such as weight and bone quality. Children older than 12 and adolescents are best treated with rigid nailing in most cases, with attention towards the factors that allow for avoidance of femoral head osteonecrosis. As the implications of intervention for pediatric femur fractures undergoes an accelerated period of development and understanding, awareness and critical analysis of published studies such as those contained in this review remains essential.

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