Femoral Fractures in Adolescents: A Comparison of Four Methods of Fixation

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Background: The optimal management of femoral fractures in adolescents is controversial. This study was performed to compare the results and complications of four methods of fixation and to determine the factors related to those complications.

Methods: We conducted a retrospective cohort study of 194 diaphyseal femoral fractures in 189 children and adolescents treated with elastic stable intramedullary nail fixation, external fixation, rigid intramedullary nail fixation, or plate fixation. After adjustment for age, weight, energy of the injury, polytrauma, fracture level and pattern, and extent of comminution, treatment outcomes were compared in terms of the length of the hospital stay, time to union, and complication rates, including loss of reduction requiringa reoperation, malunion, nonunion, refracture, infection, and the need for a reoperation other than routine hardware removal.

Results: The mean age of the patients was 13.2 years, and their mean weight was 49.5 kg. There was a loss of reduction of two of 105 fractures treated with elastic nail fixation and ten of thirty-three treated with external fixation ($p < 0.001$). At the time of final follow-up, five patients (two treated with external fixation and one in each of the other groups) had >2.0 cm of shortening. Eight of the 104 patients (105 fractures) treated with elastic nail fixation underwent a reoperation (two each because of loss of reduction, refracture, the need fortrimming or advancement of the nail, and delayed union or nonunion). Sixteen patients treated with external fixation required a reoperation (ten because of loss of reduction, one for replacement of a pin complicated by infection, onefordebridementof the site of a deep infection, three because of refracture, and one for lengthening). One patient treated with a rigid intramedullary nail required debridement at the site of a deep infection, and one underwent removal of a prominent distal interlocking screw. One fracture treated with plate fixation required refixation following refractures. A multivariate analysis with adjustment for baseline differences showed external fixation to be associated with a 12.41-times (95% confidence interval = 2.26 to 68.31) greater risk of loss of reduction and/or malunion than elastic stable intramedullary nail fixation.

Conclusions: External fixation was associated with the highest rate of complications in our series of adolescents treated for a femoral fracture. Although the other three methods yielded comparable outcomes, we cannot currently recommend one method of fixation for all adolescents with a femoral fracture. The choice of fixation will remain influenced by surgeon preference based on expertise and experience, patient and fracture characteristics, and patient and family preferences.

Level of Evidence: Therapeutic Level III. See Instructions to Authors for a complete description of levels of evidence.

Fractures of the femur are the most common major musculoskeletal injury in adolescents[1]. Femoral fractures in younger children are generally thought to heal satisfactorily irrespective of the form of treatment[2], but the management of femoral fractures in adolescents presents specific challenges. As the body weight and the size of skeletally immature adolescents approach those of adults, there are greater demands on the stability afforded by implants used to treat these fractures. The ideal treatment method should provide adequate stability to permit early mobilization, preserve or optimize fracture biology, minimize scarring, avoid serious complications, and achieve these goals in a cost-effective manner. Currently, there are a number of surgical options, including rigid and flexible intramedullary nailing[3,4], external fixation[5], and compression or bridge plate fixation[6,7] (Fig. 1). With each of these methods, there are trade-offs among these

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various goals. Consequently, the optimal method of treatment is unclear. The purpose of this study was to compare the results and complications of four different methods of fixation of femoral fractures in adolescents and to determine the factors related to these complications.

Materials and Methods

We conducted a retrospective cohort study of traumatic diaphyseal femoral fractures in children eleven to eighteen years of age who had been treated between 1995 and 2005 at The Hospital for Sick Children, Toronto, a level-I pediatric trauma center. Approval was obtained from the research ethics board of The Hospital for Sick Children. Patients were identified with use of the institution's surgical database. A review of the medical records and radiographs of all eligible patients was conducted, and pathological fractures were excluded. To be included in the study, patients had to have been followed at least until radiographic or clinical union of the fracture and/or until they had regained their usual physical function. of 210 diaphyseal femoral fractures identified during this period, 194 in 189 patients met these criteria for inclusion. The majority of the patients had open physes. The patients were characterized according to age, sex, weight, mechanism and energy of injury, whether they had sustained multiple injuries or an isolated injury, fracture level and pattern, percentage comminution (according to a modification of the classification system of Winquist and Hansen[8]), and method of fixation. The four fracture fixation methods were elastic stable intramedullary nail fixation (105 fractures; 104 patients), external fixation (thirty-three fractures; thirty-two patients), rigid intramedullary nail fixation (thirty-seven fractures; thirty-seven patients), and plate fixation (nineteen fractures; seventeen patients). (one girl with a bilateral fracture was treated with a different fixation method on each side.)

Age, Sex, and Body Weight (see Table E-1 in Appendix) The mean age of the patients was 13.2 years (range, eleven to 17.6 years). There was a wide distribution of ages in all four treatment groups. Patients in the rigid nail group were significantly older (14.5 years) than those in the elastic nail and external fixation groups (12.9 years each) and those in the plate group (13.3 years) ($p < 0.001$). There were 145 boys (148 fractures) and forty-four girls (forty-six fractures), and the sex distribution was similar across all four groups.

The patients had a mean weight of 49.5 kg (range, 23 to 84 kg), with a wide distribution of body weights across all four groups. The patients in the rigid nail group were, on the average, significantly heavier (55.2 kg) than those in the plate group (54.4 kg), those in the elastic nail group (47.6 kg), and those in the external fixation group (46.8 kg) ($p = 0.001$).

Mechanism of Injury and Associated Trauma (see Table E-2 in Appendix)

Various injury mechanisms were responsible for these fractures across all treatment groups. Thirty-six percent (sixty-nine) of the 194 fractures were associated with multiple injuries, including other fractures, visceral injuries, and head injuries. The proportion of fractures associated with polytrauma did not differ significantly among the four treatment groups ($p = 0.24$). One hundred and three (53%) of the fractures were caused by high-energy trauma, which was characterized on the basis of the mechanism of injury (a pedestrian or bicyclist struck by a motor vehicle or a motor-vehicle accident) and/or the presence of other injuries. The

Fig. 1
Comminuted diaphyseal fractures treated with each of the four methods. a and b: Elastic stable intramedullary nail fixation. c: External fixation. d: Rigid intramedullary nail fixation. e: Bridge plate fixation.

rates of high-energy trauma were comparable across the four treatment groups.

Fracture Level, Pattern, and Percent Comminution (see Table E-3 in Appendix)

There were 112 fractures involving the right femur and eighty-two involving the left femur. Five patients had a bilateral fracture. one hundred and twelve fractures (58%) involved the midpart of the femoral diaphysis, sixty-one (31%) involved the proximal third of the diaphysis, and twenty-one (11%) involved the distal third. The distribution of fracture levels did not differ significantly among the treatment groups.

Ninety-seven (50%) of the fractures were transverse, forty-seven (24%) were oblique, and fifty (26%) were spiral. The distribution of fracture patterns varied among the four treatment groups. There was a significantly higher proportion of spiral fractures and fewer transverse and oblique fractures in the external fixation group than in the other treatment groups
($p = 0.001$).

The magnitude of comminution was graded according to the percentage ofthe shaft width that was fragmented, a method adapted from the classification system described by Winquist and Hansen[8]. There was no fragmentation (grade 0) at the fracture site in seventy-four femora (38%), whereas there was some degree of comminution in 120 (62%). Grade-i fragmentation (<25% of the shaft width) was noted in sixty-two femora (32%); grade II (25% to <50%), in twenty-one (11%); grade III (50% to <75%), in fourteen (7%); and grade IV (75% to 100% or segmental), in twenty-three (12%). The distribution of fracture comminution varied significantly among the four treatment groups. The external fixation group and rigid nail group had a significantly higher proportion of more comminuted fractures than did the elastic nail group ($p < 0.001$).

There were thirteen open fractures, and a significantly higher rate of open fractures in the external fixation group (eight) than in the elastic nail group (two), rigid nail group (two), or plate group (one) ($p < 0.001$).

Outcomes

The length of the hospital stay, time to union, and complications associated with each of the treatment methods are presented in Tables I and II. The time to union was defined as the number of weeks until there was radiographic and clinical evidence of union. Radiographic evidence of union was defined as remodeling (mature) callus bridging at least three of the four cortices seen on two orthogonal views of the femur. Clinical union was inferred from the absence of tenderness at the fracture site along with full weight-bearing without pain. Complications of interest included loss of reduction, malunion, nonunion, refracture, infection, and the need for a reoperation. Malunion was defined as one or more of the following: >10° of angulation in the coronal plane (varus or valgus), >20° of angulation in the sagittal plane (apex-anterior or apex-posterior angulation), clinically obvious malrotation (an asymmetric foot progression angle with corresponding asymmetry of internal or external rotation of the hip), or a limb-length discrepancy of >2.0 cm. A clinically relevant loss of reduction was defined as any change in the postoperative alignment that prompted operative intervention or resulted in malunion as defined by the criteria described above. A reoperation was defined as any fracture-related procedure, other than routine hardware removal, performed after the initial fixation.

Statistical Methods

Means and standard deviations of interval data are reported. The baseline characteristics in the four treatment groups were compared by using analysis of variance for continuous data and Pearson chi-square statistics for proportions. Analysis of variance was used to compare the mean lengths of the hospital stay and the time to union among the four treatment methods. When a significant difference was found, pairwise comparisons of the four different treatment groups were performed with levels of significance adjusted by Bonferroni correction to account for multiple comparisons. Medians are reported for skewed data. Complications are reported as rates. We hypothesized that malunion and/or loss of reduction requiring a reoperation would be associated with age, sex, body weight, high-energy trauma, polytrauma, increased comminution, fracture level and pattern, an open fracture, and the method of fixation. Univariate analyses were performed with use of Pearson chi-square statistics. Multiple logistic regression was utilized to test jointly the explanatory variables that were significant up to the 0.1 level in the univariate analyses. The adjusted odds ratios are presented with their respective 95% confidence intervals. Significance was set at a two-tailed level of 0.05.

Source ofFunding

There was no external funding for this study.

Results

T ean follow-up time was 14.6 months.

Length ofHospital Stay (Table I)

The median hospital stay in the series (all treatment groups) was five days. The median hospital stay, which did not vary significantly among the treatment groups, was five days in the elastic nail group, seven days in the external fixation group, six days in the rigid nail group, and six days in the plate group.

Time to Union (Table I)

All fractures united, in a mean of twelve weeks (range, five to seventy-two weeks). An increased time to union was significantly associated with the fixation type ($p = 0.003$), high-energy fracture ($p = 0.007$), polytrauma ($p < 0.001$), and open fracture ($p = 0.006$). The mean time to union (and standard deviation) was 11.2 ± 7.6 weeks in the elastic nail group, 16.1 ± 8.9 weeks in the external fixation group, 10.1 ± 4.8 weeks in the rigid nail group, and 13.1 ± 7.0 weeks in the plate group. The pairwise comparison of the time to union between the groups (adjusted

TABLE I Results

	Total (N = 194 Fractures, 189 Patients)	Elastic Nail (N = 105 Fractures, 104 Patients)	External Fixation (N = 37 Fractures, Patients)	Rigid Nail (N = 33 Fractures, 32 37 Patients)	Plate (N = 19 Fractures, 17 Patients)	P Value
Length of hospital stay (days)						0.062
Median	5	5	7	6	6	
Mean (stand. dev.)	7.8 (9.0)	6.8 (10.1)	9 (5.5)	7.3 (4.5)	12.9 (12.7)	
Mean time to union (stand. dev.) (wk)	12.01 (7.6)	11.2 (7.6)	16.1* (8.9)	10.1 (4.8)	13.1 (7.0)	0.003 (0.016f)

*The time to union was shown to be significantly longer in the external fixation group in pairwise comparisons with the elastic nail group (Bonferroni adjusted p = 0.005) and the rigid nail group (Bonferroni adjusted p = 0.005). fAdjusted for other baseline factors in multivariate analysis.

for multiple comparisons) showed that the external fixation group had a significantly longer time to union than the elastic nail group ($p = 0.005$) and the rigid nail group ($p = 0.005$). In the multivariate model, only the fixation type ($p = 0.016$) and polytrauma ($p = 0.023$) remained significantly associated with an increased time to union. This was found to be true evenwhen we adjusted for baseline differences in risk factors for delayed healing.

Complications (Table II)

There was a loss of reduction of two (2%) of the 105 fractures in the elastic nail group, ten (30%) of the thirty-three in the external fixation group, and none of those in the rigid nail or plate group ($p < 0.001$). At the time of final follow-up, malunion was noted in seven of the 105 femora in the elastic nail group, three of the thirty-three in the external fixation group, one of the thirty-seven in the rigid nail group, and one of the nineteen in the plate group ($p = 0.73$). The deformities ranged from 14° of varus to 13° of valgus and from 22° of procur-vatum (apex-anterior) to 20° of recurvatum (apex-posterior). Five patients (one in the elastic nail group, two in the external fixation group, one in the rigid nail group, and one in the plate group) had a limb-length discrepancy of between 2.0 and2.5 cm at thetimeoffractureunion.Noneofthese patients had an externally visible deformity or functional limitations secondary to the malalignment or shortening, and consequently they had not received any treatment by the time of this report.

TABLE II Clinically Relevant Loss of Reduction and/or Malunion

	Total (N = 194 Fractures, 189 Patients)	Elastic Nail (N = 105 Fractures, 104 Patients)	External Fixation (N = 33 Fractures, 32 Patients)	Rigid Nail (N = 37 Fractures, 37 Patients)	Plate (N = 19 Fractures, 17 Patients)	P Value
Loss of reduction (resulting in reoperation and/or malunion)	12 (6%)	2 (2%)	10 (30%)*	0	0	<0.001 (0.039f)
Malunion	12 (6%)	7 (7%)	3 (9%)	1 (3%)	1 (5%)	0.73
Limb-length discrepancy of	5 (3%)	1 (1%)	2 (6%)	1 (3%)	1 (5%)	0.36

>2cm						
Total (loss of reduction 1 malunion 1 limb-length discrepancy)	25 (13%)	10 (10%)	11 (33%)f	2 (5%)	2 (11%)	0.004 (0.01f)

*In the pairwise comparisons, the rate of clinically relevant loss of reduction was significantly higher only in the external fixation group compared with the three other fixation groups (Bonferroni adjusted p < 0.001 in all three comparisons). fAdjusted for other baseline factors in multivariate analysis. fThe rate of clinically relevant loss of reduction and/or malunion and/or limb-length discrepancy was shown to be significantly higher in the external fixation group in pairwise comparisons with the elastic nail group (p = 0.002) and the rigid nail group (p = 0.003) but not in the pairwise comparison with the plate group (p = 0.09). (All p values are Bonferroni adjusted for multiple comparisons.) No significant difference was found between the elastic nail group and the rigid nail (p = 0.41) or plate (p = 0.95) group.

In the univariate analyses, the type of fixation (p < 0.001), fracture pattern (specifically, spiral fractures) (p = 0.027), and polytrauma (p = 0.09) were associated with a clinically relevant loss of reduction. in the multivariate analysis, only the fixation type (external fixation) remained significantly associated with loss of reduction (p = 0.039). Compared with elastic nail fixation, external fixation was associated with a 12.41-times (adjusted odds ratio) (95% confidence interval = 2.26 to 68.31) greater risk of loss of reduction and/or malunion (p = 0.004). Rigid nail and plate fixation were not significantly different from elastic nail fixation with regard to subsequent loss of reduction (p = 0.99). Polytrauma was associated with a 3.34-times (95% confidence interval = 0.69 to 16.31) greater risk of loss of reduction, but this association did not reach significance (p = 0.14).

Reoperations (Table III)

Eight of the 105 fractures in the elastic nail group required a reoperation. There were two instances of loss of reduction. In a fourteen-year-old boy with a bilateral femoral fracture, varus angulation of the right femur was noted one week postopera-tively. This deformity was treated with plate fixation (see Appendix). in the second case, involving a fourteen-year-old girl, inadequate intraoperative imaging led to a failure to recognize that one nail had failed to engage the proximal segment; this led to varus angulation and shortening. This deformity was managed with lengthening over a nail, resulting in full correction as well as restoration of the length of the femur (Fig. 2). Two fractures with delayed union after elastic nail fixation were stabilized with rigid intramedullary nailing at seven and ten months after the initial operation. in addition, there were two refractures in patients who had been treated initially with elastic nail fixation. One occurred five months after the initial fixation and was treated with another elastic nail procedure. The other occurred at one month and was treated with closed manipulation to straighten the bent nail and restore fracture angulation. Two additional patients needed trimming or advancement of the nails because of symptomatic prominence prior to fracture union.

sixteen of the thirty-three fractures treated with an external fixator required a total of seventeen reoperations. Loss of reduction in ten cases required a total of eleven readjustments of the external fixator with the patient under general anesthesia. There were three refractures (at six, seven, and eight months after the initial treatment), which were treated with elastic intramedullary nail, plate, and rigid intramedullary nail fixation, respectively. One patient required replacement of a pin because of an infection, and one required debridement of the site of a late-onset deep infection. one patient was taken back to the operating room for an attempt to achieve acute lengthening of a shortened fracture through immature callus; however, he had a persistent 2.5-cm limb-length discrepancy.

A deep infection developed, two months after the injury, at the site of a Grade-IIIA (Gustilo and Anderson system[9]) open femoral fracture that had been treated with rigid nailing; the infection required debridement and antibiotic therapy. One patient treated with plate fixation had two separate re-fractures through the fracture site, at two and five months, along with plate and screw pull-out. Both episodes were addressed with repeat plate fixation.

Major Complications

A major complication was defined as a clinically relevant loss of reduction, a malunion or shortening, and/or a reoperation for any reason other than routine hardware removal. In the multivariate model, the factors that remained significantly associated with a major complication were fixation type (p = 0.002), polytrauma (p = 0.014), and an open fracture (p = 0.048). After adjustment for all other factors, the risk of a major complication was 6.4 times greater with external fixation than it was with elastic nail fixation (p = 0.001). The risk of a major complication did not differ significantly among the elastic nail, rigid nail, and plate fixation groups. The risk of a major complication associated with polytrauma was 3.2 times

TABLE III Reoperations

Reason for Reoperation	Total (N = 194 Fractures, 189 Patients)	Elastic Nail (N = 105 Fractures, 104 Patients)	External Fixation (N = 33 Fractures, 32 Patients)	Rigid Nail (N = 19 Fractures, 17 Patients)	Plate (N = 37 Fractures, 37 Patients)	P Value
Loss of reduction*	12 (13)	2	10 (11)	—	—	
Malunion/shortening*	1		1	—	—	
Delayed union*	2	2	—	—	—	
Refracture*	6 (7)	2	3	—	1 (2)	
Infection*	3		2	1	—	
Advancement/trimming nails*	2	2	—	—	—	
All reoperations *(no.[%])*	28 (14%)	8 (8%)	17 (52%)f	1 (3%)	2 (11%)	0.013f

*Number of patients (number of reoperations). fOnly the external fixation group had a significantly higher reoperation rate than the other groups.