Malunion following flexible intramedullary nails for tibial and femoral fractures in adolescents

D. E. Deakin · H. Winter · P. Jain ·
C. E. Bache

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Abstract

Purpose Flexible intramedullary nails (FIN) are increasingly used in the management of paediatric tibial and femoral fractures. Concerns have recently been raised regarding the use of FIN in older children. The aim of this study was to determine how effective FIN is in treating tibial and femoral fractures in adolescents.

Methods Patients aged 11 years or older undergoing FIN for tibial and femoral fractures between 2003 and 2009 were identified. Radiographs and case notes were reviewed to identify complications.

Results Thirty-five consecutive adolescent patients underwent FIN for tibial ($n = 21$) and femoral fractures ($n = 15$), with a mean age of 12.9 years. The mean radiographic follow up was 29 weeks. Sixty percent (60%, $n = 9$) and 38% ($n = 9$) of femoral and tibial fractures, respectively, malunited. Fracture severity was associated with increased malunion for both tibial and femoral fractures ($P = 0.046$ and $P = 0.044$, respectively). Two femoral fractures took longer than 20 weeks to unite and seven tibial fractures took longer than 16 weeks to unite.

Conclusion The higher than expected rates of malunion and delayed union in this study suggest that other treatments should be considered when treating adolescents with unstable tibial or femoral fractures.

Keywords Femoral fracture · Tibial fracture · Femur · Tibia · Flexible intramedullary nail · Elastic nail

Introduction

Flexible intramedullary nails (FIN) have been used increasingly since the 1980s for the management of paediatric tibial and femoral fractures [1]. The advantages of rapid mobilisation and avoiding prolonged periods of traction are well documented [2–4]. Excellent results have been reported for FIN in the treatment of both tibial and femoral fractures in the general paediatric population [5–8]. Malunion rates have been reported in the region of 0–10%, with good or excellent outcomes in the majority of patients [3, 9]. However, concerns have recently been raised regarding the use of FIN in older, heavier children and in unstable fracture configurations. Moroz et al. reported a series of 234 femoral fractures treated with FIN from six separate institutions and demonstrated poorer outcomes for older children and for heavier children [10]. A recent biomechanical study demonstrated that patients weighing more than 45 kg are at increased risk of loss of fracture reduction [11]. The use of FIN has also recently been questioned for unstable fracture configurations, with comminution of greater than 25% being associated with malunion [12]. Length-unstable fractures, defined as long oblique fractures or fractures with comminution, have also been shown to have increased complications compared to length-stable fractures [13]. The aim of this study was to determine the complication rate of FIN used for the treatment of unstable tibial and femoral fractures in adolescents. In particular, we wanted to determine which factors were most important in predicting outcome.

Patients and methods

Hospital records were used to identify all children aged 11 years or older who were admitted to our regional

D. E. Deakin (✉) · H. Winter · P. Jain · C. E. Bache
Department of Trauma and Orthopaedics,
Birmingham Children's Hospital, Steelhouse Lane,
Birmingham B4 6NH, United Kingdom
e-mail: dandeakin@doctors.org.uk

children's hospital with a tibial or femoral fracture between 2003 and 2009. Radiographs, theatre records and case notes were used to identify those undergoing FIN for tibial or femoral fractures. Children aged 11 years or older who were treated with FIN for a tibial or femoral fracture were included. Children aged less than 11 years were excluded, as were children with pathological fractures. During the study period, children with minimally displaced stable tibial fractures were managed conservatively and did not receive FIN. Our indication for FIN for tibial fractures were displaced unstable fractures. All femoral fractures in children aged over 11 years were managed with FIN. Case notes and radiographs were reviewed to identify demographic and injury details, surgical technique and complications. All operations were performed either by, or under the direct supervision of, a Consultant Paediatric Orthopaedic Surgeon. Standard surgical techniques, as described by the implant manufacturer were used (Strawberry Medical, Buckinghamshire, UK). All femoral nails were inserted retrograde and tibial nails were inserted antegrade. A traction table was used to aid fracture reduction at the discretion of the Consultant Surgeon. The elastic nails were sized so that both nails occupied no less than 70% of the medullary diameter at the isthmus. Both nails were of the same diameter and only titanium elastic nails were used. Antibiotic prophylaxis was given at the induction of anaesthesia. Post-operatively, all patients had anterior-posterior (AP) and lateral radiographs prior to discharge from hospital and patients were followed up in the clinic with serial radiographs until fracture union. Our department protocol required that all patients were kept non-weight-bearing until there was radiographic evidence of callus formation. All tibial fractures were put in a long leg plaster initially, as were the distal femoral fractures. The duration of plaster immobilisation was also determined by radiographic evidence of fracture union, with a mean duration of 4 weeks in plaster. All FINs were routinely removed 6–12 months after fracture union. Open fractures were classified by the Gustilo and Anderson classification [14]. Radiographs were examined independently by two of the authors separate to the case notes to prevent bias. Fractures were classified by the AO classification (Table 1) [15]. Femoral malunion was defined as shortening at the fracture of greater than 20 mm or malalignment of greater than 10° in any plane at the time of final follow up. Tibial malunion was defined in the same way, with the exception of varus malalignment of greater than 5°. Shortening was determined from both the radiographs and documented clinical findings. Rotational malalignment was determined from the documented clinical findings. Length-unstable fractures were defined as by Sink et al.—fractures with comminution or oblique fractures where the length of the fracture was more than twice the diameter of the bone at

the level of the fracture [13]. Fracture union was defined radiographically as the earliest time post-operatively that three or more cortices showed union on AP and lateral radiographs. Where two authors' interpretations differed, a third author's opinion was sought and the majority verdict taken. Data was recorded in a database and the Chi-squared test was used to determine significant differences between groups.

Results

Thirty-five consecutive adolescent patients underwent FIN for 21 tibial and 15 femoral fractures (one patient having ipsilateral tibial and femoral FIN). Of the patients with femoral fractures, 67% ($n = 10$) were male and of the patients with tibial fractures, 95% ($n = 20$) were male. The mean age was 12.9 years (range 11–16) and the mean weight was 53.4 kg (range 32–88 kg). Case notes and radiographs were available for all patients, with a mean radiographic follow up of 29 weeks. Eight patients sustained multiple injuries. Two femoral fractures were open (one grade 1, one grade 2) and eight tibial fractures were open (five grade 1, one grade 2, two grade 3b). Fifteen of the 21 tibial fractures had associated ipsilateral fibular fractures.

Malunion

Of those with femoral fractures, 60% ($n = 9/15$) malunited (Table 2). Two of these patients had shortening of over 20 mm and two had deformity of over 10° on the AP radiograph. All patients with femoral malunion had deformity of over 10° in the sagittal plane. Length-unstable femoral fractures were more likely to malunite than length-stable femoral fractures ($P = 0.044$). Every length-unstable femoral fracture went on to malunite. Every femoral fracture classified as “B” or “C” by the AO classification (Wedge or Complex) went on to malunite. One patient was

Table 1 AO classification of tibial and femoral diaphyseal fractures

Femoral fracture	Tibial fracture	Description
32-A1	42-A1	Simple spiral
32-A2	42-A2	Simple oblique
32-A3	42-A3	Simple transverse
32-B1	42-B1	Spiral wedge
32-B2	42-B2	Bending wedge
32-B3	42-B3	Fragmented wedge
32-C1	42-C1	Complex spiral
32-C2	42-C2	Complex segmental
32-C3	42-C3	Complex irregular

offered surgical correction of his femoral malunion but they declined. The mean weight of patients who went on to malunion was 56 kg (range 38–70 kg), whereas those who did not had a mean weight of 45 kg (range 32–60 kg).

Of those with tibial fractures, 38% ($n = 8/21$) malunited (Table 3). Length-unstable tibial fractures were more likely to malunion than length-stable tibial fractures ($P = 0.046$). There was a higher rate of malunion in AO “B” fractures when compared to AO “A” fractures; 62.5% ($n = 5/8$) and 23.1% ($n = 3/13$), respectively. The average weight of patients with tibial fractures who malunited was 50 kg (range 36–70 kg) compared to 57 kg (range 38–88 kg) for those who did not malunion. One patient underwent osteotomy and plate fixation of his malunited tibial fracture. Another patient was offered surgical correction of his tibial malunion but they declined.

Other complications

There were no cases of non-union. The mean time to radiographic tibial union was 13 weeks and to femoral union, it was 17 weeks. Two femoral fractures took longer than 20 weeks to unite and seven tibial fractures took longer than 16 weeks to unite. One patient developed compartment syndrome after tibial FIN and required fasciotomy. One patient with shortening at his tibial fracture required the early removal of FIN due to prominence at the

nail insertion site, resulting in malunion (Fig. 1). One patient developed deep infection of their tibial fracture requiring early removal of the nails, resulting in malunion. One patient required manipulation under anaesthesia of their tibial fracture and remoulding of the plaster, which did not result in malunion. One patient was treated with 6 weeks of traction after femoral FIN for the progressive loss of fracture position and went on to malunion. One patient who had a malunited femoral fracture sustained a broken nail during attempted nail removal. The nail was left in situ. There were no cases of re-fracture following FIN removal.

Discussion

FIN was initially described for the treatment of paediatric femoral fractures and the indications have been expanded to the management of unstable tibial fractures. Numerous publications, including from our own institution, have demonstrated that FIN is a safe and effective treatment for both tibial and femoral fractures in the general paediatric population [7]. Malunion rates have been reported to be in the region of 0–10% [3–9]. Definitions of malunion vary in these studies, with some authors not stating their definition. The majority of authors, however, have defined malunion as being an angular deformity of over 10° or a shortening of

Table 2 Outcome of femoral fractures

Sex	Age (years)	Weight (kg)	Open fractures	Level of # (third of diaphysis)	AO classification	Length-unstable	Sagittal alignment at union (°)	Coronal alignment at union (°)	Shortening (mm)	Malunion	Complications—other
F	11	70	Open (g1)	Distal	32A1	Yes	15 aa	1 valgus		Yes	Prolonged traction
F	13	60		Middle	32A2	No	10 aa	5 varus		Yes	
M	14	45		Middle	32A3	No	16 aa	4 varus		Yes	
F	15	70		Proximal	32A3	No	15 aa	0		Yes	FIN broke on removal
M	11	50	Open (g2)	Proximal	32A3	No	18 aa	12 varus		Yes	
M	13	38		Proximal	32B2	Yes	12 aa	3 varus		Yes	
M	14	70		Middle	32B3	Yes	13 ap	4 varus	20	Yes	
M	12	32		Middle	32B3	Yes	33 aa	14 valgus		Yes	Prolonged traction
M	15	70		Distal	32C2	Yes	17 aa	0	20	Yes	Offered osteotomy
M	13	34		Middle	32A2	No	8 aa	4 varus		No	
F	12	50		Proximal	32A3	No	0	4 valgus		No	
F	13	55		Middle	32A3	No	5 aa	2 valgus		No	
M	11	40		Middle	32A3	No	3 aa	4 varus		No	
M	12	32		Proximal	32A3	No	8 aa	2 valgus		No	
M	11	60		Middle	32A3	No	0	5 valgus		No	

Patients in **bold** indicate malunion

aa apex anterior; ap apex posterior

Table 3 Outcome of tibial fractures

Sex	Age (years)	Weight (kg)	Open or closed	Level of # (third of diaphysis)	AO classification	Length-unstable	Fibular fracture	Sagittal alignment at union (°)	Coronal alignment at union (°)	Shortening (mm)	Malunion	Complications—other
M	14	45		Distal	42A1	Yes	Y	11 ap	5 valgus	20	Y	Prominent nail, FIN removed early, malunion
M	13	60		Distal	42A1	Yes	N	2 ap	0	20	Y	Deep infection, FIN removed early, malunion
M	13	50		Distal	42A2	Yes	N	5 ap	7 varus	10	Y	
M	11	36		Distal	42B3	Yes	N	15 ap	16 valgus		Y	Osteotomy
M	12	50		Middle	42B2	Yes	N	12 ap	3 valgus		Y	
M	11	40		Middle	42B2	Yes	N	4 aa	8 varus	9	Y	
M	14	47	Open g3b	Middle	42B2	Yes	Y	20 ap	12 valgus	10	Y	
M	15	70		Distal	42B3	Yes	Y	17 aa	15 varus	20	Y	Offered osteotomy
M	12	49	Open g3b	Distal	42B2	Yes	Y	8 ap	3 valgus	9	N	Compartment syndrome
M	14	70	Open g1	Middle	42B2	Yes	Y	4 ap	0		N	
M	12	57		Middle	42B3	Yes	Y	5 ap	5 valgus		N	
F	11	45		Middle	42A1	Yes	Y	0	0		N	
M	12	78		Distal	42A1	Yes	Y	0	3 varus		N	
M	15	70	Open g1	Middle	42A2	No	Y	1 ap	6 valgus		N	
M	15	80		Distal	42A2	Yes	Y	4 aa	3 varus	15	N	
M	16	88		Middle	42A2	Yes	Y	0	2 valgus	10	N	
M	14	50	Open g1	Distal	42A2	No	N	4 ap	1 valgus	8	N	
M	11	37	Open g2	Middle	42A2	No	N	4 ap	4 valgus		N	
M	13	38	Open g1	Middle	42A2	No	Y	5 ap	3 valgus		N	
M	14	40		Distal	42A2	No	Y	5 aa	6 valgus	11	N	MUA and moulding of POP, no malunion
F	11	45	Open g1	Middle	42A2	No	Y	0	2 valgus		N	

Patients in **bold** indicate malunion

aa apex anterior; ap apex posterior

Fig. 1 **a** Anterior-posterior (AP) radiograph of a 14-year-old boy showing a closed, length-unstable fracture of the tibia with associated fibular fracture. **b** Two weeks post-operatively showing varus alignment with shortening and proximal wire migration. **c** Ten weeks post-

operatively with further shortening and prominent medial wire proximally, necessitating early removal of the flexible intramedullary nails (FIN). **d** Eleven weeks post-operatively showing malunion

over 20 mm. A recent multi-centre review of 234 femoral fractures treated with FIN reported shortening or unacceptable angulation in 22 patients (9%) [10]. Further sub-group analysis demonstrated that children aged 11 years or older had poorer outcomes than those under 11 years of age. A poor outcome was also five times more likely in children who weighed more than 49 kg. Another recent biomechanical study investigated the effect of patient weight on simulated transverse midshaft femoral fractures [11]. They concluded that patients weighing more than 40–45 kg were at risk of loss of fracture reduction, despite using the maximum sized titanium nails of 4 mm.

Our study is the first series to look specifically at older children undergoing FIN for both tibial and femoral fractures. We have demonstrated 60 and 38% of femoral and tibial fractures, respectively, go on to malunion in adolescents undergoing FIN. The reasons for this are unclear. Subsequent review of the malunited patients' case notes and radiographs did not demonstrate any significant deviations from the implant manufacturer's recommended technique. When proximal or distal 1/3rd fractures are managed using this technique, it may be difficult to avoid crossing of the nails near to the level of the fracture. We did not find that fracture

location was associated with malunion. Mismatched nail sizes have previously been shown to be associated with malunion, although there were no cases of different sized FIN used in this series [12]. All cases were performed by, or under the direct supervision of, a number of Consultant Paediatric Orthopaedic Surgeons experienced in the surgical technique. We use nails that are designed not to be cut, with nail lengths in increments of 20 mm. As a result, it is possible that there may be a tendency to use slightly shorter nails. This could be overcome by utilising nails that are designed to be cut at the optimum length at the time of insertion. Our institution has been using FIN for the treatment of tibial and femoral fractures for over 12 years and has previously published excellent results [7].

It is possible that the weight of older children is one factor as to why older children appear to be at increased risk of malunion. However, whilst increased weight seemed to be associated with higher risk of malunion in femoral fractures, the same did not seem to be true for tibial fractures.

Another possibility is that older children's fractures heal more slowly than younger children's fractures, thus, allowing more time for the loss of fracture reduction. The mean time to radiographic union in this series was 13 and

17 weeks for tibial and femoral fractures, respectively. Subsequent review of radiographs of those children with malunion suggested that the loss of reduction occurred progressively in the weeks after surgery. The initial post-operative radiographs on the first post-operative day usually demonstrated the same fracture position as the intra-operative fluoroscopy images. Malunion appeared to develop in the first few weeks after surgery. This was during the time that all patients were non-weight-bearing and that all tibial fractures and distal femoral fractures were protected in plaster.

A recent paper compared steel elastic femoral nails to titanium elastic femoral nails used for paediatric femoral fractures [16]. The authors demonstrated a 23% malunion rate when titanium nails were used compared to a 6% malunion rate when steel nails were used ($P = 0.017$). They conclude that steel elastic nails are superior. The nails used in the series were titanium and this is another possible explanation for the higher than expected rates of malunion seen here in older heavier patients.

Fracture stability has also been demonstrated to influence malunion. A previous study demonstrated increased malunion when FIN is used to treat comminuted femoral fractures [12]. Another study reported a series of 39 children of all ages treated with FIN for femoral fractures [13]. They classified fractures as “length-stable” or “length-unstable”, as previously described. Some 66% ($n = 10/15$) of the length-unstable femoral fractures malunited compared to only 13% ($n = 3/24$) of length-stable femoral fractures. Our study also demonstrates that length-unstable fractures were more likely to malunite than length-stable fractures for both femoral and tibial fractures. We found that fracture configuration was the most powerful predictor of malunion for both femoral and tibial fractures.

The clinical significance of our results is difficult to quantify. The overgrowth of long bones following fracture is well reported and may compensate for minor limb length discrepancy. However, we would suggest that a shortening of more than 2 cm will certainly have long-term sequelae, particularly in adolescents. The potential for bone remodelling reduces as patients approach skeletal maturity and while an angular deformity of 10° – 15° may remodel in a younger child, it probably will not in a teenager.

The alternatives to FIN for the management of femoral fractures in older children include prolonged traction, external fixation, reamed intramedullary nailing and plating. Conservative management of femoral fractures in adolescents would require prolonged periods of immobilisation, with implications for the adolescent's education. Reamed intramedullary nailing has been associated with the devastating complication of avascular necrosis (AVN) and its use has been discouraged [17]. More recent designs have included trochanteric entry point nails. Townsend and

Hoffinger describe a series of 20 children with open proximal femoral physes undergoing trochanteric entry point reamed intramedullary nailing for femoral fractures [18]. With a minimum of 2 years radiographic follow up, they report no cases of AVN and recommend this technique for the treatment of paediatric femoral fractures. However, there is at least one case report in the literature of AVN following reamed intramedullary nailing using a trochanteric entry point nail and it should be used with caution in the paediatric population [19]. Plating femoral fractures traditionally involved extensive surgical exposures. More recent sub-muscular percutaneous plates avoid this and some authors have adopted this as their preferred technique for managing length-unstable femoral fractures [13]. Newer designs of FIN have used end caps to attempt to reduce the risk of the fracture shortening and the FIN backing out. No end caps were used in this study. Further research is required to investigate whether they reduce the incidence of malunion in length-unstable fractures.

The same alternatives exist for managing tibial fractures in older children. External fixation or fine-wire circular frames are frequently used in lower limb deformity correction and would be an alternative to FIN. Reamed intramedullary nailing of paediatric tibial fractures has also been shown to be a safe and effective treatment. Court-Brown et al. reported a series of 36 adolescents with tibial fractures, all of whom had open proximal tibial physes [20]. All underwent reamed intramedullary nailing with no long-term complications associated with injury to their proximal tibial physes. There were no cases of malunion. Conservative management with functional bracing is another alternative with low published rates of malunion [21].

We conclude from our study that the high levels of malunion following tibial and femoral FIN should be carefully considered when deciding how to manage older children with these injuries. Adolescents undergoing FIN should be closely monitored in the weeks following surgery to identify progressive loss of fracture reduction. Alternative treatments should be considered in this age group, particularly for heavier patients with length-unstable fractures or those approaching skeletal maturity.

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