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ORIGINAL CLINICAL ARTICLE

Elastic intramedullary nailing in unstable fractures of the paediatric tibial diaphysis: a systematic review

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Abstract
Purpose The majority of paediatric tibial fractures can be managed conservatively. However, there is a small but significant group of patients that require surgical intervention for several indications, most notably, unstable fractures. There are various surgical options, each with its own advantages and risks. This review establishes the current available evidence for the use of elastic intramedullary nails in this group.
Methods A systematic review of the currently available literature was performed. The relevant studies were then critically appraised.
Results Seven applicable retrospective case series were identified, with the outcomes from a total of 210 (range 16–60) patients considered. The mean time to union ranged from 7 to 21 weeks. Reported complications included small numbers each of delayed union, non-union, malunion, leg length discrepancy and infection.
Conclusions There is only a small body of evidence currently published on this topic. The evidence published so far concludes that elastic intramedullary nailing represents an effective and reliable method to treat an unstable fracture of the tibial diaphysis in the paediatric patient, where conservative management is not appropriate.

Keywords Paediatric · Fracture · Tibia · Elastic · Intramedullary nail

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Introduction

An adult patient with an unstable tibial diaphyseal fracture can be treated with a rigid intramedullary nail. This treatment may also be appropriate in the adolescent patient with fused growth plates. However, in the younger paediatric patient, this is not acceptable, due to the potential damage to the physes and subsequent growth impairment. Alternative surgical options include plating, external fixation and elastic stable intramedullary nails (ESIN) [1, 2].

The advantages of ESIN include minimal soft tissue disturbance with small scars, early mobilisation, low infection rates and shorter hospital stays [3]. Possible complications such as malunion and refracture remain as they would with conservative treatment. The nails can be removed once the fracture has united, depending on the patient and surgeon preference.

This study aims to review the currently available evidence for the use of ESIN in the skeletally immature paediatric patient with an unstable fracture of the tibial diaphysis.

Methods

The Medline and PubMed databases were searched using the strategy shown in Table 1.

The search keywords were derived from the clinical question and the two databases. The dates of the search were not limited.

The bibliographies of the eligible articles were also reviewed in order to discover any other relevant papers.

The abstracts of the identified studies were then reviewed and excluded according to the following criteria:

Table 1 Search strategy

1	(tibia* and fracture and (shaft* or diaph*)).mp. [mp = title, abstract, full text, caption text]
2	(nail and (flexible or elastic)).mp. [mp = title, abstract, full text, caption text]
3	(child* or paediat* or pediat*).mp. [mp = title, abstract, full text, caption text]
4	union.mp. [mp = title, abstract, full text, caption text]
5	1 and 2 and 3 and 4
	This search strategy was used for both the PubMed and Medline databases. Medline was searched using OVID and PubMed was searched using the clinical questions tool for a broad search.

- Non-human studies
- Studies solely of other bones, e.g. femur, forearm
- Biomechanical studies
- Nailing for other reasons, e.g. limb lengthening, non-union
- Not published in English
- Not using union as an outcome measure
- Studies with less than ten patients (limited due to the learning curve of the surgical technique)

The results from these studies were then analysed and critically appraised using a Critical Appraisal Skills Programme (CASP) tool from the NHS Public Health Resource Unit (PHRU), UK [4]. Critical appraisal of the literature has recently become more rigorous, with various bodies such as the Centre for Evidence Based Medicine (CEBM), Oxford, UK, developing to promote meticulous research [5].

The CASP tool is freely available on the PHRU website, as long as it is used for non-profit-making activity [4]. The CASP tool consists of a checklist of criteria that can be used to assess any study. These help to ascertain the study's precision when answering the research question. The checklist is a guide of important questions to apply to each study in order to assess thoroughness, validity and applicability.

Results

The search strategy revealed seven studies, all retrospective case series [6–12]. Three other studies were excluded due to their small patient numbers: Berger et al. [13] reported results from nine patients, Salem et al. [14] included five and Huber et al. had one [15]. Tibial ESIN has a significant learning curve and small studies could, therefore, be subject to error.

The seven studies vary in size from 16 to 60 patients who had ESIN for a tibial diaphyseal fracture [6–12]. In total, these studies report the outcomes of 210 patients. These studies are summarised in Table 2 and are then critically appraised.

It was not possible to perform a formal meta-analysis of this topic from these papers because of the variation in practice and reporting. In addition to this, all of the identified studies were retrospective case series. A meta-analysis is not usually performed on this type of study due to their uncontrolled observational nature.

The seven studies recorded outcomes from a total of 210 fractures treated with ESIN. The authors describe a range of indications for using this technique, but several state that it was used because the fracture was unstable. However, instability is never clearly defined and it is, therefore, not clear in exactly what situation ESIN was used. Some of the papers suggest that, if the fracture cannot be reduced and maintained with a cast, then it is unstable and would require fixation.

Many of the fractures were open and, therefore, the fracture could be reduced directly if necessary in many cases. None of the papers detail the proportion of closed fractures that had to be opened to facilitate a reduction.

A variety of outcome measures were used throughout the seven studies. They all include time to union, although not all defined union. The majority assessed it radiographically and some described it as tricortical bridging. Definitions for delayed union and non-union were not clear or universal throughout the studies. Malalignment was also defined differently in each study. Some recorded it as greater than 5° angulation, whereas others used a measurement of greater than 10° or 20°.

The shortest mean time to union was 7 weeks, reported by Kubiak et al. [8], and the longest was 20.7 weeks, reported by Srivastava et al. [11].

Reported complication rates were similar in all of the studies. It is not possible to pool the rate of reported complications due to the variation in practice. Complications included delayed union, malunion, non-union, leg length discrepancy (most asymptomatic) and infection (superficial and deep).

Critical appraisal

All of the relevant studies were retrospective case series reviews. They are, thus, subject to selection bias, with the consequence that the results may not be applicable to all patients. However, this type of study is reasonable in view of the relatively small numbers of procedures undertaken and the difficulties of ethics with performing randomised studies on children.

Goodwin et al. [6]

This paper reviews the results of 19 patients who had tibial fractures stabilised with elastic nails between 1997 and 2004 at a single centre. The operative procedure is clearly

Table 2 Summary of key studies

Study	Design	Size	Patient demographics		Technique	Reason for flexible nailing	Outcome measures	Results
			Mean age (range)	M:F ratio				
Goodwin et al. [6]	Retrospective case series	19	12 years (9–15)	16:3	Ti Elastic (17) or Ender (2) × 2 (×4 if tibia large)	Unstable # (11), open # (8)	Radiographic union, complications	3 delayed unions, 2 malunions, 1 premature physeal closure
Gordon et al. [7]	Retrospective case series	60	11.9 years (5–17)	35:15	Flexible Ti × 2 (1 pt × 1)	Unstable (34), open (26)	Radiographic union, alignment, leg length, complications	45 unions 8 weeks (4–18), 5 delayed unions (31–51 weeks), 1 malunion, 7 LLD, 1 infection
Kubiak et al. [8]	Retrospective case series	16	11 years (7–14)	11:5	Elastic × 2	Surgeon choice	Union, alignment, complications	Union 7 weeks (5–12), 1 bony overgrowth secondary to nail, no malunion, no infections
O'Brien et al. [9]	Retrospective case series	16	10 years 4 months	12:2	Flexible Ti × 2	Failed closed reduction (11), open # (3), multiple injuries (2)	Radiographic union, infection, knee pain, knee/ankle range of motion	Union 9 weeks, no infection or knee pain, K&A ROM normal
Sankar et al. [10]	Retrospective case series	19	12.2 years (7.2–16)	14:5	Ti Elastic × 2	Unstable (12), open # (5), impending compartment syndrome (2)	Radiographic union, leg length, malalignment, pain, complications	Union 11 weeks (6–18), 4 malunions, no LLD, no infections, 2 repeat MUA
Srivastava et al. [11]	Retrospective case series	24	11 years (4 years 6 months–16 years 4 months)	21:3	Nancy nails	Open (16), unstable (8)	Radiographic union, leg length, complications	Union 20.7 weeks, 2 non-unions, 2 infections, 2 malunions, 2 LLD
Vallamshetla et al. [12]	Retrospective case series	56	12 years (4–16)	43:11	Flexible Ti × 2	Polytrauma (23), failed closed reduction (20), open (13)	Clinical & radiographic union, leg length, complications	Union 10 weeks (7–18), 3 infections (all open), 2 malunions, 2 LLD

LLD limb length discrepancy; *ROM* range of motion, *MUA* manipulation under anaesthetic

described, together with a method of biomechanical analysis. The primary outcome measure, union, was not clearly defined.

Three different constructs were employed, pre-bending the elastic nails in different ways. Ten patients had a double-C method, seven had medial C and S, and two had a four-nail stacking technique. This variability does limit the applicability of this paper and the power of the results. The four-nail stacking technique is not standard practice, but was justified by the authors in two cases due to the unusually large size of the tibia. The use of any additional stabilisation or immobilisation was not described.

There were several complications, with three patients having a delayed union (defined) and two having a malunion of more than 10°. Both malunions occurred in the medial C and S group, although the significance of this is not assessable due to the small numbers in each treatment group. As the authors acknowledge, there may have been selection bias due to the retrospective nature of the study and the fact that eight of the fractures were open.

Although this paper is systematic and clearly written, it suffers from having a small number of included patients. The power of the results is further reduced by splitting the patients into three groups, each with a different operative technique.

Gordon et al. [7]

This review of 59 patients with 60 fractures was performed over a 4-year period (1st January 1999 to 31st December 2003). The primary outcome measure was radiographic union (defined as bridged callous on three cortices). Alignment was also assessed from the radiographs. Leg length was reported, although it was not clear how this was measured. There was no blinding of the assessor and no description of possible confounding factors that may have affected the study.

All fractures were stabilised with antegrade nailing through the proximal tibial metaphysis. In 50 of the 51 cases, two nails were used; the remaining case had one nail. Twenty-one had closed nailing and 30 had open reduction, although this was usually through a traumatic wound. The nail size was clearly described, as was the post-operative follow-up regime. A short leg splint was used for 2–3 weeks and the patient was mobilised at between 2 and 6 weeks, at the surgeon's discretion. The nails were removed after solid fracture union.

The results show that 45 fractures united at a mean time of 8 weeks (range 4–18 weeks) and five unions were delayed, with a mean of 41 weeks (range 31–55 weeks). Two of the delayed union group were described as non-unions because they required further surgery. The mean age of the patients with a delayed union was older at 14.1 years compared with 11.7 years for the uneventful union group. One patient had a malunion requiring a corrective osteotomy. Three patients had an asymptomatically long tibia (6–11 mm) and four patients had a shorter tibia (7–24 mm). Three of these were asymptomatic and one had unrelated early physeal closure.

The results from this larger study are consistent with the other studies. However, the patient population, their fracture conformation and the reason they were selected for elastic intramedullary nailing are not described.

Kubiak et al. [8]

This was a comparative review performed between April 1997 and June 2004 of 16 patients who had elastic nailing and 15 who had unilateral external fixation. The indication for nailing was not clearly described. Union was not well defined, although delayed union (callous progression but greater than 6 months to unite) and non-union (pain, motion and radiolucency at greater than 6 months with not callous progression) were well described. Malunion was defined as more than 10° varus/valgus angulation or more than 20° anterior/posterior angulation. None of the patients were immobilised in a cast post-operatively.

The results show a shorter time to union in the elastic nail group (7 weeks) compared with 18 weeks for the ex-fix group. There was also a better functional outcome and fewer complications in the elastic nailing group. The fixation method had been chosen at the time by the senior surgeon and, as a result, this study is subject to selection bias. For example, in the nailing group, there were five open fractures, whereas in the ex-fix group, there were eight.

This paper supports the use of elastic nails, stating that the outcomes are better than an external fixation method. However, it is a small study and, as with the other studies, suffers by being retrospective.

O'Brien et al. [9]

This paper discusses the outcomes of 16 unstable tibial fractures in 14 patients who had elastic nail stabilisation during a 5-year period. The operative technique was clearly described, with two pre-bent 2–4-mm elastic nails used in each patient. They were then placed into a below-knee cast and allowed to weight-bear when the fracture had begun uniting.

Three of the fractures were open and these were slower to unite, at an average of 15 weeks compared with 8 weeks for the closed fractures. The exact follow-up regime is not clear, although patients were followed-up for an average of 1 year and 5 months. Union was described as tricortical bridging callous. The results were generally good, with no

significant angulation or leg length discrepancy and no infections.

This paper advocates elastic nailing as a safe and effective technique to treat unstable tibial fractures. Nonetheless, it is a small retrospective study with similar problems to the other papers, such as selection bias and technique variability.

Sankar et al. [10]

This paper reports the outcomes of 19 consecutive patients who underwent titanium elastic tibial nailing between 1998 and 2005 in a tertiary children's hospital. It is a thorough review, with the inclusion of patient demographics and a good description of the surgical technique. Union was defined clearly as three bridging cortices. There was no loss to follow-up and 15 patients were followed up for at least 1 year. The indications for surgery are also clearly defined. Other outcome measures were described, including malalignment, leg length discrepancy and complications.

Following surgery, all patients were immobilised, most commonly in a long leg cast. This was usually left on for 6 weeks. Irritation at the nail entry point was the most common complication. Two patients required repeat manipulation due to the loss of reduction. The mean time to union was 11 weeks (range 6–18 weeks), with closed fractures healing more rapidly than open fractures. The tibia of one patient had not united at 12 weeks and was commenced on a bone stimulant. They went on to unite at 18 weeks. Four patients had a malunion with malalignment greater than 5°, one in the sagittal plane and three in the coronal plane.

This study again suggests that this method of stabilisation of a paediatric tibial fracture is acceptable. Its limitations are similar to the other case series in that it is retrospective and includes only a small number of patients over a long time span.

Srivastava et al. [11]

Between 1997 and 2005, 24 patients with 24 tibial fractures were treated operatively with elastic intramedullary nails in one centre. Eight of the fractures were closed and the other 16 were open. The time to union and complications were reported. The inclusion criteria were strict and it is, therefore, possible that some patients were excluded from this study, for example, if they were not followed up for a year post-operatively. The demographics of the patients were comprehensively described, although the operative technique and post-operative regime were not. Some patients were immobilised in a cast (either short or long), depending on the surgeon preference.

This study reports a longer time to union than the other studies at 20.7 weeks (range 8–42 weeks). However, union was described as "painless full weight bearing with radiographic evidence of tricortical callous formation." This is in contrast to the other studies that solely considered radiographic union.

A number of complications were described, with two non-unions, two malunions, two infections and two leg length discrepancies. Nevertheless, the authors do conclude that elastic nailing is a reasonable option for the treatment of paediatric tibial fractures that cannot be managed conservatively.

Vallamshetla et al. [12]

This case series assesses 56 unstable tibial fractures in 54 children treated during an 8-year period from March 1997 to May 2005. This study clearly defines the population with outcome measures of union, time to weight-bearing and function. The authors' indications for flexible nails are clearly described (polytrauma, open fracture or failed closed reduction).

The same operative technique was used for all patients. Post-operatively, all patients had a short leg cast and were mobilised non-weight-bearing for 4–6 weeks. When adequate callous was seen at the fracture site, the patient was allowed to commence weight-bearing.

The outcomes are stated and recorded comprehensively. Union was assessed from radiographs, although with no stated blinding of the assessor. The definition of delayed union is not clear, nor is the method to assess leg length. Malunion was defined as more than 10° angulation in any plane. Confounding factors such as diabetes or parent smoking were not addressed. The mean follow-up was 11 months, with a range from 8 to 17 months. There was no loss to follow-up.

The results demonstrate a mean time to union of 10 weeks (range 7–18 weeks). One reported delayed union required no intervention, although it is not clear when this united. There were two malunions; both were asymptomatic. There was one superficial infection that settled with antibiotics and two deep infections requiring removal of the nails. Two patients, both with oblique fractures, needed the nails revised to a plate after failed fixation at the one-week review. Two patients had significant leg length discrepancies of 1.5 and 2 cm and both had epiphysiodesis of the contralateral leg.

This larger study supports the conclusion of the other studies and is clearer on the indications for using flexible intramedullary nails. The complication rate is consistent with the other studies.

Discussion

Fractures of the tibial diaphysis are a common injury in the paediatric patient. The majority have traditionally been treated conservatively with satisfactory outcomes [16–18]. Closed reduction and immobilisation in a cast enables the fracture to unite successfully in most cases, with few complications [17–20]. Conservative management is appropriate particularly in stable closed fractures of the tibial diaphysis, whether the fibula is intact or not [16–20].

Similar to other paediatric fractures, the tibia has significant capacity to heal and remodel, but has the characteristic that it can overgrow and lead to leg length discrepancy [19, 20]. There are a number of other complications that can result following a tibial fracture, such as malunion with angulation in one or more planes, as well as non-union and refracture.

If the tibial fracture is open, a surgical procedure may be required to enable optimum healing. Certainly, open fractures have a poorer prognosis, but there is no consensus on the optimum treatment for paediatric patients [21]. Other indications for surgery include instability, polytrauma and neurovascular impairment.

For over 20 years, ESIN has provided satisfactory outcomes in paediatric fractures [2, 22]. Some studies advocate the use of straight intramedullary Kirschner wires to stabilise the fracture [23]. However, if two pre-bent elastic nails (usually titanium or stainless steel) are inserted into the tibia with opposing curves, they provide three-point fixation of the fracture. The elasticity of the nail enables micro-movement at the fracture site to encourage callous formation.

This review presents a critical appraisal of the available evidence for the outcomes of skeletally immature paediatric patients who have suffered an unstable fracture of the tibial diaphysis and undergo stabilisation with ESIN. The main limitation of this review is that the included studies differ in significant areas. Definitions of union, delayed union and malunion vary widely. In addition, surgical techniques are different, with contrasting views on post-operative immobilisation.

The existing evidence is limited, with retrospective case series being the only study types currently published. There are several reasons for why this may be the case. The majority of paediatric tibial fractures can be successfully treated conservatively in a cast. Therefore, only small numbers of patients are eligible to be included in studies of elastic nailing. Randomising children to significantly different surgical interventions such as ESIN versus external fixation has considerable ethical implications. These two interventions vary hugely, both in their application and, most notably, in their post-operative regime.

The outcomes reported in the seven studies presented here are largely positive. The studies here all conclude that ESIN represents an effective and reliable method to treat an unstable fracture of the tibial diaphysis in the paediatric patient.

Complications are an inevitable problem with any treatment, particularly surgical. The rate of complications reported in the appraised studies is not high, especially taking into account the number of open fractures. Surgeon training is important and may be more of an influence on outcome than technique per se [3]. The small risk of potentially significant complications should be taken into account and relayed pre-operatively to the patient and their guardians.

Conclusion

The vast majority of paediatric tibial fractures can be successfully treated conservatively with immobilisation in a cast. Unstable or open fractures, polytrauma and neurovascular compromise may each necessitate a surgical procedure. Elastic stable intramedullary nailing (ESIN) provides an acceptable option where surgery is unavoidable.

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