# Flexible Intramedullary Nailing (FIN) in Diaphyseal Fractures in Children

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## Contents



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**Abstract**

More than 30 years after its introduction, the flexible intramedullary nailing (FIN) method has now become a universal way of treating many diaphyseal fractures in children. Children can benefit from a low-morbidity functional surgery which does not interfere with the growth process. Because FIN looks quite easy, many complications have been reported in the literature. Performing a FIN is more than just building a construct, and requires a perfect understanding of biomechanics and skill.

The purpose of this chapter is to guide the surgeon, and to help him perform a perfect surgical technique. In the first part, the basic principles are clearly described. They include the type of nailing according with bones and fractures (antegrade versus retrograde), the implants selection, and the dedicated instruments. Then, technique is detailed for diaphyseal fracture of femurs, forearms, tibias, and humerus. For each bone, post-operative cares and indications of FIN are exposed. A final chapter concerns the complications and how to avoid them.

Some examples are given by cases reports; the surgical approach is represented by many drawings. Many references are cited.

**Keywords**

Children • Complications • Flexible Intramedullary Nailing indications • Fractures of diaphysis • Surgical Techniques-upper limb and lower limb

## General Introduction

There is a wealth of published literature on intramedullary nailing. With current locking designs, intramedullary nailing indications have been expanded to include a large number of diaphyseal and even metaphyseal fractures in adult patients. Küntscher was the one who pioneered the concept [1], but extensive work had been previously carried out on nailing or pinning techniques in which the nails/pins did not fill the entire transverse section of the diaphysis. The so called alignment nailing technique was widely used by Rush [2] after World War II. These bulky devices were used in forearm fractures where they allowed maintaining a precarious reduction without any control of the rotatory stability, which made it necessary to use external immobilization. With the Ender's nailing [3], the notion of "elastic" osteosynthesis was retained and was used for fixation of certain types of fractures such as tibial fractures [4]. Actually, it was even incorporated into the concept of the Ilizarov external fixator, as Ilizarov had fully demonstrated that when traction-compression forces are applied to bone with intact periosteum and blood vessels, healing occurs regardless of the circumstances [5].

In the late 1970s, Jean-Paul Métaizeau, Jean-Noël Ligier, and Prof. Prévot were working out a way to stabilize femoral fractures in children. They took up the idea and tailored the system to children's specific needs.

As early as 1980, flexible intramedullary nailing (FIN) indications expanded dramatically. It was first used in diaphyseal fractures: femur [6], and then both bones of the forearm [7], tibia, and humerus. Our total number of cases has kept increasing over the years and also the FIN method has gradually spread worldwide.

The FIN method, also termed Métaizeau technique [8, 9], Nancy technique [10, 11], or elastic stable intramedullary nailing (ESIN) technique (mainly in Europe) [12] was introduced in the 1980s through instructional course lectures. In addition, K. Parsch published in the 1990s a detailed history of this method in the treatment of femoral fractures in childhood [13], and drew attention to a publication by Moroté Jurado in 1977 in Spain [14].

More than 30 years after its introduction, the FIN method has now become a universal way of treating many diaphyseal fractures in children. Now, children can benefit from a low-morbidity functional surgery which does not interfere with the growth process. The outstanding advantages of FIN over other fixation systems such as intramedullary locked nails, screw-plates, and external fixators have long been recognized although there are still specific indications for each of these systems. Training of the new generation remains a priority.

## Surgical Technique: Basic Principles

The FIN technique is based on well-established biomechanical principles. Ideally, at the end of the procedure, one should have two nails with opposing curves. The concavities should face each other and the apexes of the curves should be located at the fracture site. Thus, both nails cross each other proximal and distal to the fracture. This can be performed using an *antegrade* technique: both nails inserted through the proximal metaphysis and directed toward the distal metaphysis, or using a *retrograde* (ascending) technique: through the distal metaphysis. In certain situations, it may be desirable to perform a *combined antegrade/retrograde* FIN.

An ideal, well-balanced construct should use two nails (*bi-polar* construct) inserted through two metaphyseal incisions (one medial, one lateral). However, depending on the position of the bone relative to the skin surface and on the adjacent neurovascular structures, one single incision is made for both nails. It is recommended to create two distinct entry holes (one for each nail), one above the other to avoid weakening the bone and minimize the potential for secondary fracture. This procedure is called *uni-polar* FIN. The first nail follows a direct route with its concavity and leading end turned toward the entry hole side. The second nail must be rotated 180° as soon as it enters the medullary canal so that its concavity and leading end are turned opposite to the first nail.

Basically, the more distant the fracture is from the entry holes, the easier it is to achieve a perfect construct. But two additional factors are to be considered: easy access to the affected bone, and perfect balance of the opposing curves.

This explains why the vast majority of femoral fractures are managed with bi-polar retrograde FIN whereas distal femoral fractures are best managed with uni-polar antegrade FIN using a sub-trochanteric approach (Fig. 1). Most tibial fractures are managed with bi-polar antegrade FIN bi-polar retrograde FIN should be reserved for some fractures of the proximal one-fourth of the tibia (Fig. 2). Humeral fractures are preferably treated by uni-polar retrograde FIN using a lateral supra-epicondylar approach (Fig. 3). As regards both-bone forearm fractures, a combined antegrade (ulnar)/retrograde (radial) FIN with one nail in each bone is unquestionably the easiest method (Fig. 4). The methods we are recommending have the advantage of being simple and reproducible, but of course, each surgeon is free to use the method he/she is most familiar with.

### Implant Selection

Many types of nails are available made of Titanium or stainless steel.

A curved tip is effective in preventing jamming in the bone trabeculae opposite the entry hole and facilitating advancement of the nail within the medullary canal. The length of the curved tip should not exceed the length of the orthogonal projection of the isthmus of the medullary canal, otherwise the nail will get stuck in the bone (Fig. 5).

It is during the contouring procedure that the personal skill of a paediatric traumatologist makes the difference. Performing a FIN is not just achieving correct alignment through nailing; the real goal of FIN is to generate corrective forces. To achieve this goal, the apex of the curve must be located at the fracture site. Both concavities face each other and nails intersect proximal and distal to the fracture site. Therefore, the surgeon performs contouring manually. The radius of curvature must be about 50–60 times greater than the diameter of the nail, and location of the bend on the nail depends on the anatomic location of the fracture (Fig. 6).

For the lower extremities, the diameter of the nail must be *at least* 40 % [15] of that of the medullary canal. For the upper extremities, a nail diameter, which is 33 % of the intrameduallary canal diameter, suffices for the humerus. It is rare to utilize a nail bigger than 3.0 mm for the humerus. For the radius and the

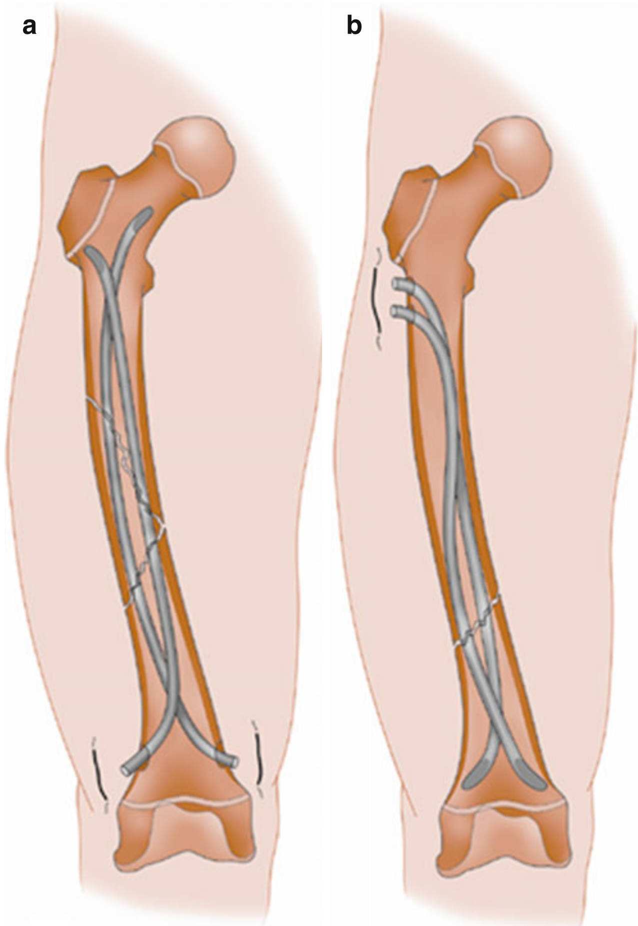


**Fig. 1** (**a**) Femoral bi-polar retrograde FIN; (**b**) Femoral uni-polar antegrade FIN

ulna, the nail diameter may reach 50 % or more of the medullary canal. However, it is seldom necessary to use a nail bigger than 2.5 mm for the radius or the ulna.

## Dedicated Instruments

FIN should be performed with simple though specially designed instruments, particularly if 3.5 mm or 4.0 mm diameter nails are used. As usual, the surgical technique begins with a skin incision that is made over the planned entry point and dissection is carried down to the bone surface.

The following instruments are required:

- Bending iron – hand contouring is possible but the use of a specially designed instrument is most helpful.
- Awl – it is used to create the entry hole into the cortical bone of the metaphysis. It should be slightly larger than the diameter of the selected nails;
- Drill bit with a tissue protection sleeve – in hard cortical bone, it may be necessary to drill the entry hole using a drill bit with a diameter slightly larger than that of the selected nail;
- T-handle or inserter – they provide a firm hold on the nail, allowing the surgeon to apply oscillatory rotary motions, advance the nail into the medullary canal, and complete reduction. They should also have a strong metal surface that withstands firm hammering;
- Hammer – once the nail tip is properly oriented, the nail is pushed across the fracture site with the help of the hammer. At the end of the

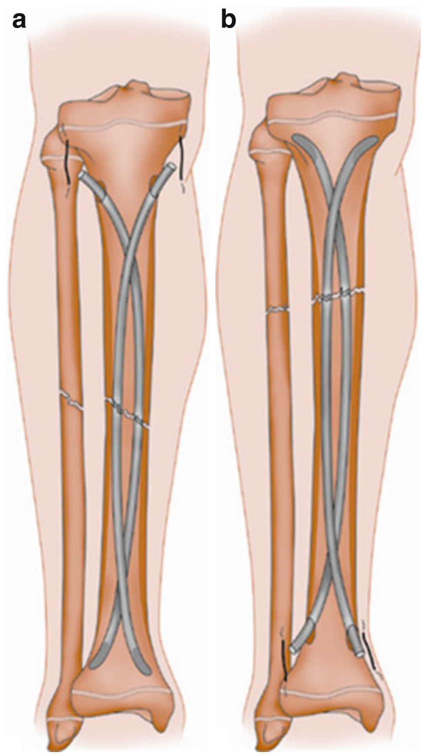


**Fig. 2** (**a**) Tibial bi-polar antegrade FIN (**b**) Tibial bi-polar retrograde FIN

procedure, impaction of the fracture site is also performed using the hammer;

- Nail cutter – the ideal instrument is a guillotine-style cutter that provides a smooth clean cut;
- Cannulated impactor – it is aimed to push the nail forward and leave sufficient length proud of the bone surface to facilitate later removal while not causing skin irritation.

Some additional instruments are particularly helpful for removal of hardware including locking forceps which must have a good holding power.

## Surgical Technique

Patient positioning depends on the location of the fracture. The affected limb is sterilised by careful preparation. An attempt at closed reduction with external manoeuvres is initially performed using the image intensifier to check for reducibility.

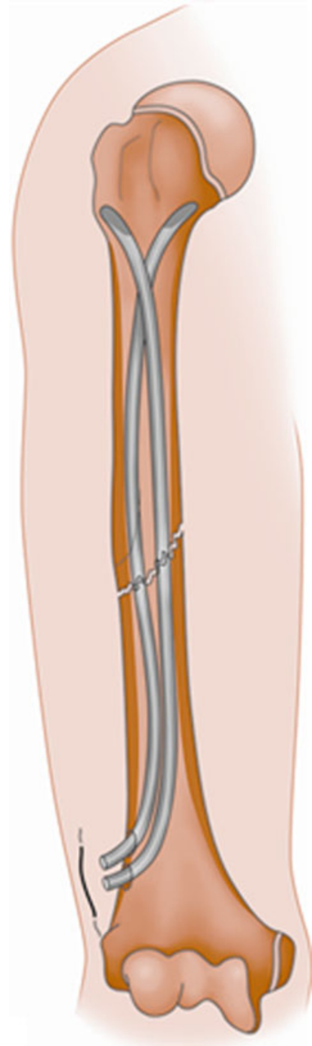

**Fig. 3** Humeral uni-polar retrograde FIN

It is advisable to make a 15–30 mm incision (for radius and femur respectively). Then, two retractors are enough to allow good visualization of the bone. The same incision will be used for nails removal if any.

The entry hole into cortical bone is made with an awl or a drill (Fig. 7). The instrument is initially positioned perpendicular to the bone surface and then directed toward the fracture site. The nail is attached to the T-handle (or the inserter) and inserted into the bone through the entry hole with its curved tip properly oriented. The nail tip should be positioned perpendicular to

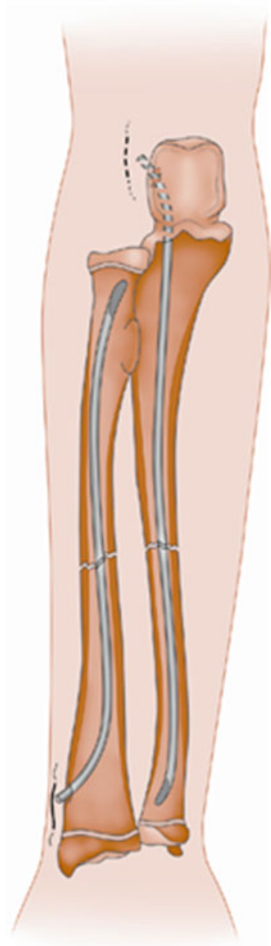

**Fig. 4** Forearm antegrade/retrograde FIN: retrograde for radius, antegrade for ulna

the bone surface, and as soon as it has passed the cortex it is directed toward the fracture line. Then, the nail smoothly glides along the inner wall of the medullary canal with the aid of slight rotary movement of the inserter. When the fracture site is reached, the tip must be oriented so that it sits right in front of the opposite fragment (AP and lateral). The fracture is reduced and reduction is checked using fluoroscopy. Then, the nail is pushed across the fracture site using a slotted hammer, and advanced by hand into the opposite fragment (Fig. 8).

The second nail is inserted in the same manner. Then, both nails are advanced until they reach the metaphysis where they may be rotated to achieve perfect reduction of the fracture. A varus angulation can be corrected by directing the nail tip laterally whereas a valgus angulation can be corrected by directing the nail tip medially (Fig. 9). Once the position and orientation of both nails are satisfactory, they are impacted into the cancellous bone of the metaphysis while maintaining reduction. Attention should be paid to the horizontal plane at all times during this reduction step so as to prevent rotational mal-union.

The last step, but not the least, is final impaction of the fracture site (Fig. 10). Furthermore, impacted nails are trimmed to the proper length. Routine closure is performed using a few subcutaneous sutures and intradermal running sutures.

In short, there are altogether four reduction steps:

1. Before surgery to memorize the appropriate reduction manoeuvres and check for reducibility of the fracture by closed means;
2. Intra-operatively, to allow the nails to cross the fracture site;
3. At the end of the procedure, to complete reduction by properly rotating and orienting the nails;
4. Lastly, final impaction of the fracture site is performed prior to nail trimming.

## Femoral Fractures

The second most common location of diaphyseal fractures in children is the femur with prevalence in boys (sex ratio is M2.5:F1). Femoral fractures in children have varying aetiologies: birth trauma; child abuse: Silverman syndrome; road traffic accident; fall from a height; sports accident; pathological fracture (tumour, osteogenesis imperfecta, cerebral palsy).

### Retrograde FIN for Mid-Shaft Fractures

In children, the procedure is always performed under general anaesthesia associated or not with femoral nerve block.

The use of a fracture table which would seem logical in the majority of cases is not an absolute

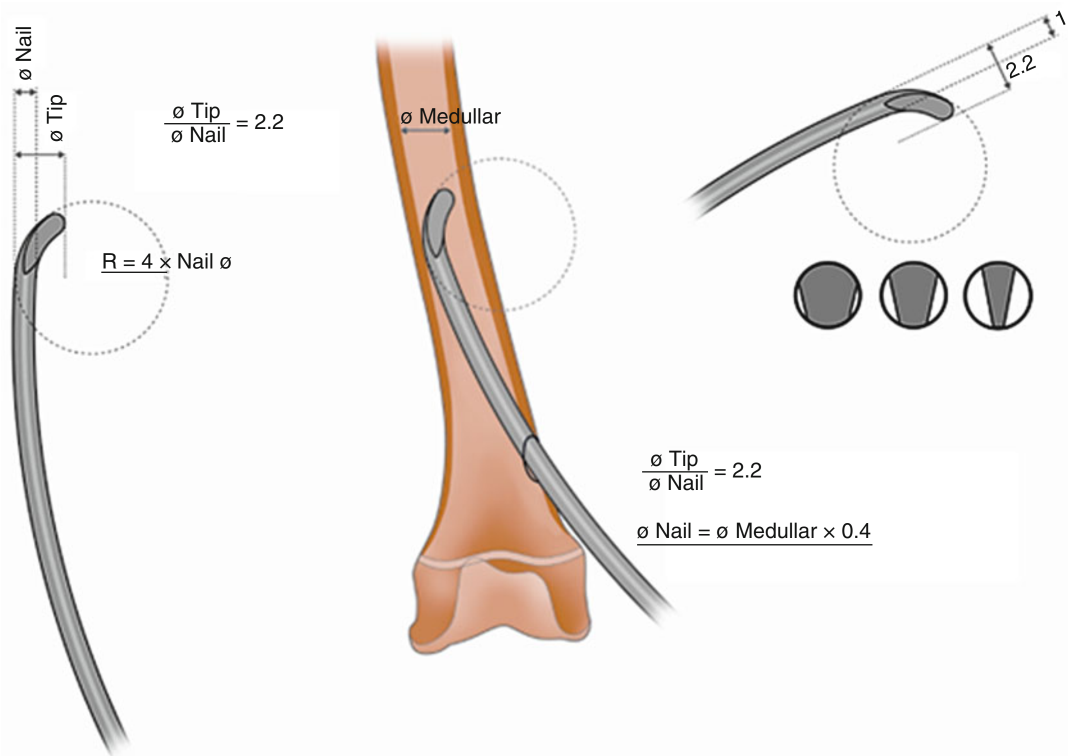


**Fig. 5** The ideal nail. Tip shows a perfect curve with a diameter four times that of the nail, an outer curve and a tapered end. The projected length of the curved tip is about 2.2 times greater than the diameter of the nail (85–90 % of canal diameter)

requirement in some children who may be simply positioned supine on a standard operating table.

Although the use of two image intensifiers is not mandatory, it is highly recommended as it dramatically reduces operative time and radiation exposure.

The operative field should include the nail entry points, the fracture area, in case an open approach should be required either for reducing the fracture if not possible by closed means or for driving the nails across the fracture site. Additionally, the surgeon must provide for a sub-trochanteric access in case antegrade or combined antegrade/retrograde FIN is decided.

Nail diameter is related to the age of the child and the size of the bone:

- 3 mm in a child aged between 6 and 8 years;
- 3.5 mm in a child aged between 8 and 10 years;
- 4 mm in a child older than age 11.

Nails are contoured according to the type and location of the fracture.

For retrograde FIN, two incisions are made (medially and laterally) in the distal metaphysis immediately below the hard cortical bone area, at some distance from the physis (Fig. 11). The skin incisions begin at the planned entry points and extend 20–30 mm distally to avoid skin impingement during insertion of the nails. The medial entry point is located midway between the anterior and posterior border of the femur, approximately 20–40 mm above the distal physis. It is positioned anterior to the adductor tubercle and anterior to the femoral artery. The lateral entry point is symmetrically located on the lateral aspect of the femur. Therefore, both entry points are away from the physis and positioned deep enough to the skin surface to avoid prominence of the nail ends. Blunt scissor dissection is performed down to the bone surface, taking care

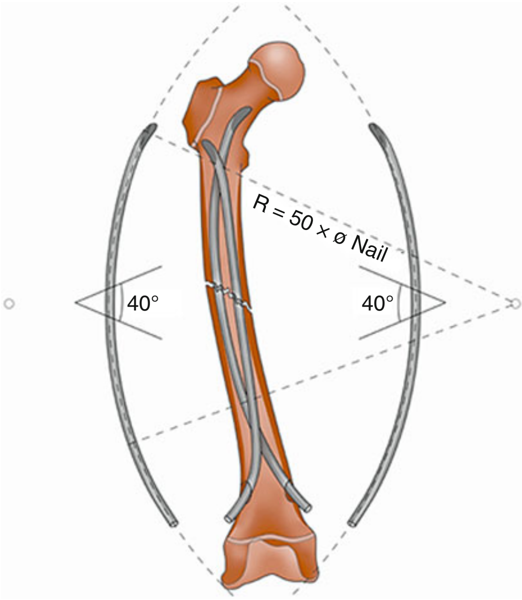


**Fig. 6** Nail contouring. The two nails have opposing curves. The radius of curvature must be about 50–60 times greater than the diameter of the nail. The apex of the curve must be located at the fracture site, here, in the middle-third of the bone

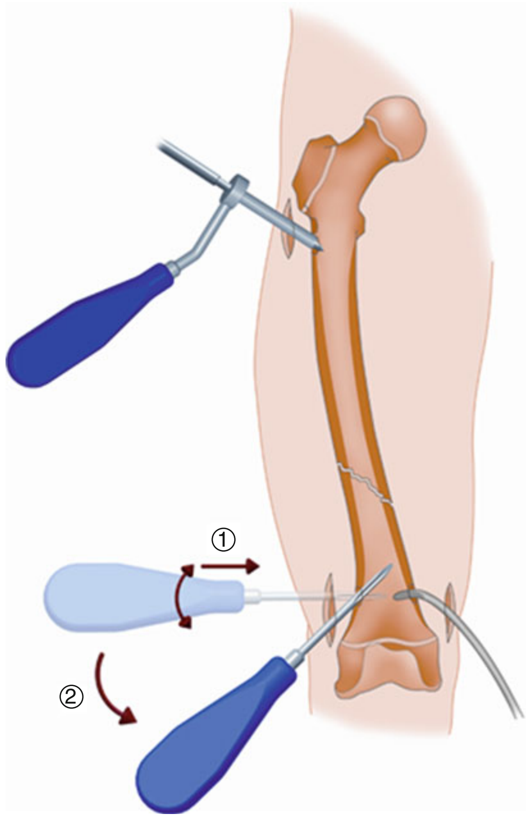


**Fig. 7** Entry hole can be created with an awl or a drill bit. Diameter of the twist drill is 1–2 mm larger than that of the nail. Note the position of the entry hole relative to the skin incision, and the direction of the awl (toward the diaphysis)

to avoid damage to the great saphenous vein that runs medially. After preliminary bone scraping, a hole is created in the mid-line (in the sagittal plane).

Then, the surgeon will follow the general technique as described above.

At the end of the procedure, all transverse fractures must be impacted to minimize the potential for later leg- length discrepancy. In oblique and spiral fractures and even fractures with a third fragment, impaction provides stabilization of the fracture site at the expense of slight shortening (5–10 mm) which is readily compensated for by post-operative overgrowth.

## Types of Femoral Fractures

Proximal and middle-third fractures are managed with standard bi-polar retrograde FIN.

Two options are available to treat distal-third fractures, depending on the type of fracture:

- Retrograde FIN – A technically difficult procedure for two reasons: distal position of the entry points with the nail ends lying beneath the skin; difficulty in getting the nails to cross each other distal to the fracture site. The surgeon should not hesitate to force them against the cortical wall as they progress upwards to achieve an adequate curvature.
- Antegrade FIN – Proximally, the entry point is located below the lesser trochanter, approximately 20 mm distal to the growth-plate (Fig. 12). In this dense cortical bone, it is recommended to drill two holes, one above the other.

In transverse or short oblique fractures, the surgeon will not have difficulty in pushing the curved tip of the nail across the fracture site.

Long spiral or comminuted fractures are a little more challenging. FIN is best performed with the

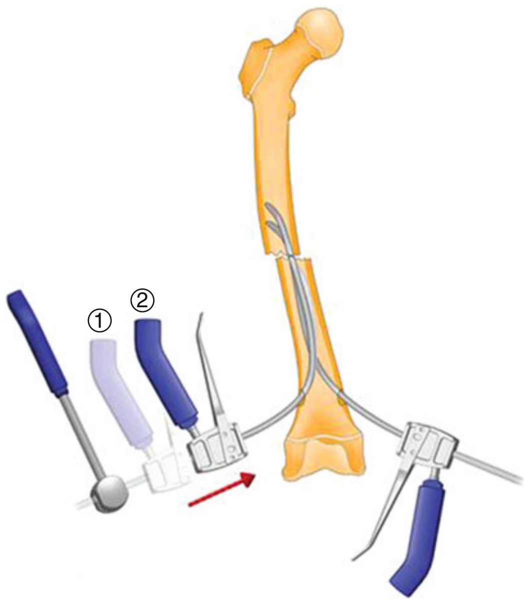


**Fig. 8** Taking advantage of the reduction force exerted by the first nail, the second nail is advanced up to the fracture site, and pushed into the opposite fragment using a slotted hammer

use of two image intensifiers which allow full control of nail advancement and gradual rotation to follow the spiral path, or progression through the comminution zone. A perfect construct is mandatory to stabilize these fractures.

## Post-Operative Care

AP and lateral X-rays are required. The lower limb is elevated, a pillow is placed under the thigh for a few days, and a sandbag may be used to stabilize the foot and prevent external rotation. A simple dressing is applied and replaced on the second post-operative day.

Physical therapy helps hasten recovery of the quadriceps strength and active contraction. The child is instructed and encouraged to lift the leg off the bed. As soon as he/she can, the child gets out of bed and begins to walk with two crutches, being careful to put no weight on the injured leg. Once the child has regained a certain level of functional independence, he/she is discharged from hospital and returns home walking with two crutches.

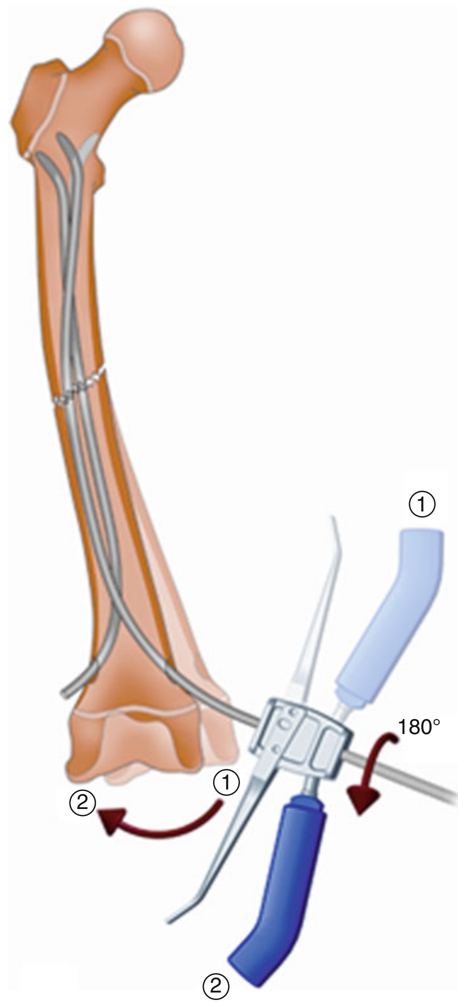


**Fig. 9** If a slight varus angulation exists with the final construct in place, it can be corrected by rotating the medial nail 180°

Both the child and the family are informed that subcutaneous prominence of the nails is absolutely normal and will disappear as soon as the nails are removed.

The child returns to school within 1–2 weeks after discharge, as long as he/she is able to walk with two crutches. Time to weight-bearing is approximately 2–3 weeks for transverse fractures, and around the 6th week for long spiral and oblique fractures and comminuted fractures.

At 2 months, the child should have a good ambulatory status and is able to evaluate his/her ability to resume gentle physical activities like

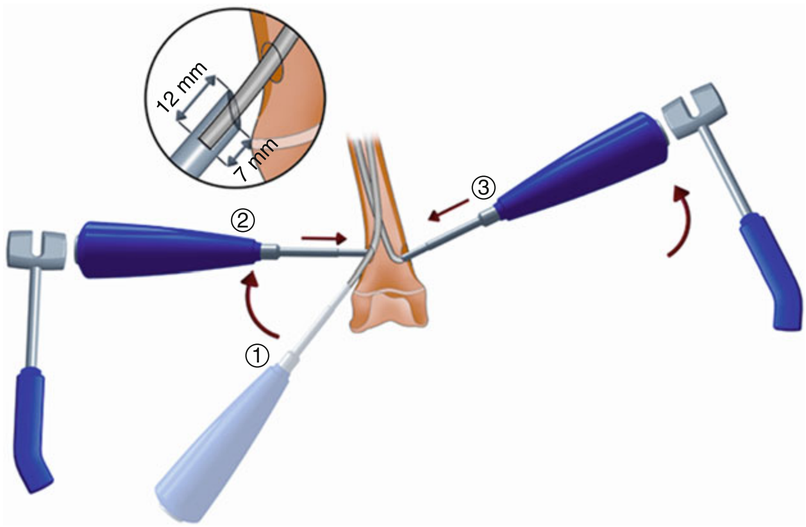


**Fig. 10** Impaction and optional bending of the nails. (1) One option is to simply push the nails and let them lie against the distal cortex. (2) A second option is to bend the nails to about 30°–60° flush to the metaphyseal cortex. (3) A third one is to overbend them and recess the bend into the bone; the aim is to get a strong anchorage distally to avoid any risk of migration

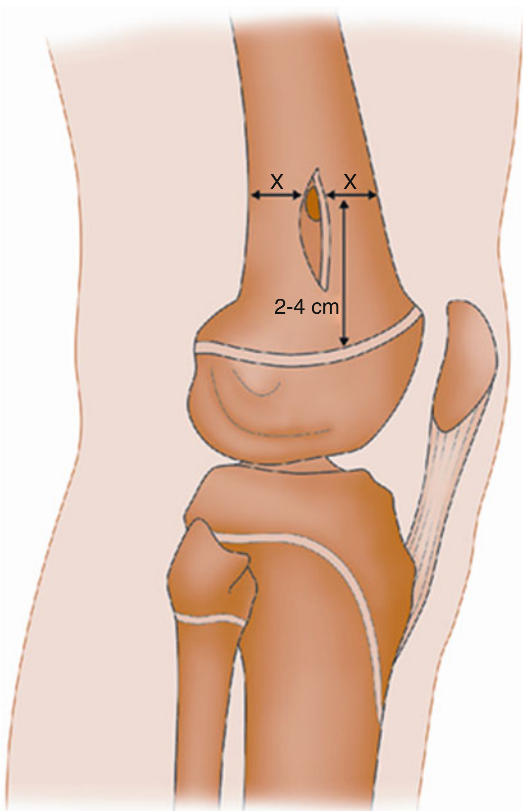


**Fig. 11** Lateral approach to the distal femur: the hole is made 20–40 mm proximal to the physis

swimming. At 4 months, the child can return to individual sports. Clinical and radiological follow-ups are scheduled at 6 weeks and 3 months postoperatively. Once union is complete, hardware removal can be considered. After removal, immediate weight-bearing is allowed but the child is requested to refrain from high impact and collective sports for 2 months to reduce the risk of fracture at the hole sites.

Depending on the age of the child and the presence or absence of residual angulation or other complications, a radiographic assessment is routinely performed at 1 year and at 2 years, based on full-length X-rays of the lower limbs in the standing position to check for correct alignment and leg-length equality.

## Indications

FIN in femoral fractures is recommended in children age 5–11 or below 50 kg body weight (Fig. 13) [16–33]. In younger children, FIN could be justified in fractures with associated traumatic injuries (multiply-injured and polytrauma patients). In children above 11 years old or 50 kg, FIN is in competition with other types of

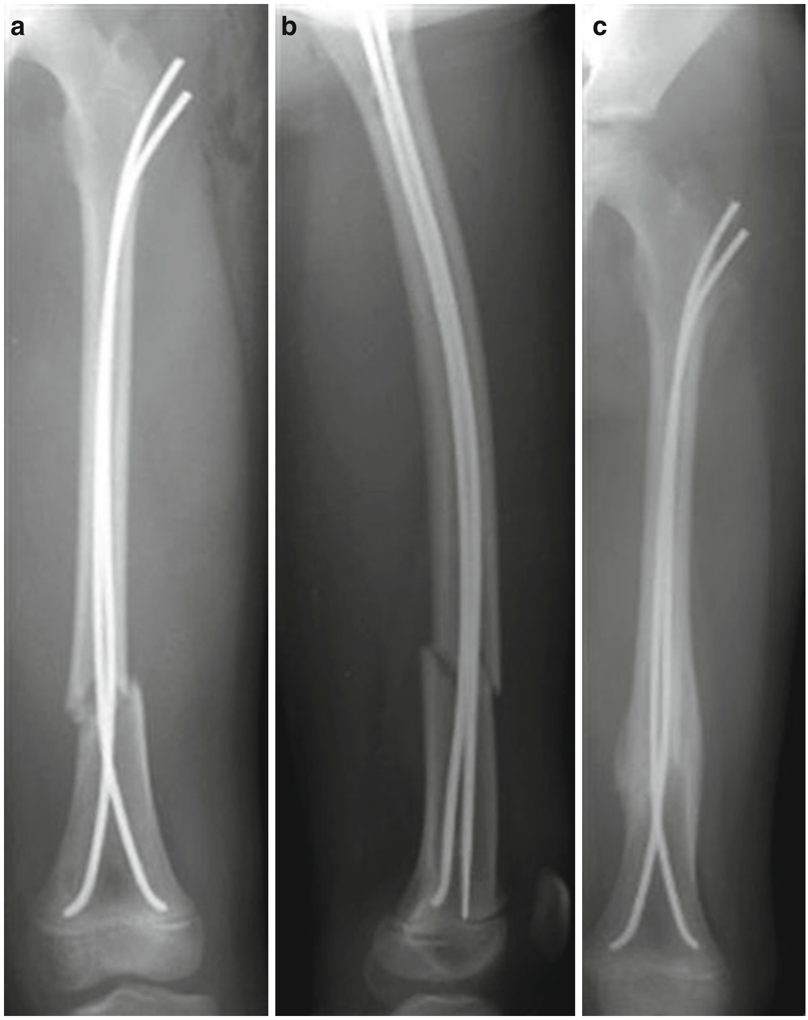


**Fig. 12** A 7 year-old girl run over by a car sustained a distal-third fracture of the femur. She was treated with antegrade FIN using two 3.5 mm titanium nails. Postoperative X-ray (**a, b**). Bone union achieved at 3 months (**c**)

osteosynthesis. FIN remains indicated as far as the stability of the frame is feasible such in many non- comminuted fractures, and is related to the expertise of the surgeon.

## Both-Bone Forearm Fractures

Both-bone forearm fractures account for 5 % of all children's fractures and usually occur at a mean age of 8.5 years. The sex ratio is M 2.5: F 1. Most often, a both-bone forearm fracture is an indirect injury resulting from a fall on an outstretched hand, with the forearm supinated. Both bones are involved in the vast majority of cases (85.7 %), radius only: in 6.5 %, ulna only: in 2.5 %. The Monteggia fracture/dislocation rate is 4.7 % and the Galeazzi fracture rate is 0.6 %. Anatomic location is the middle-third of the both bones in two-thirds, distal-third in 20 %, and proximal-third in 13 %.

Skin wounds have been reported in 7.5 % of Gustilo Type I fractures, seldom in Type II and III. Vascular complications are rare, whereas initial nerve lesions are seen in 3.4 % of patients. However, they have a very good prognosis.

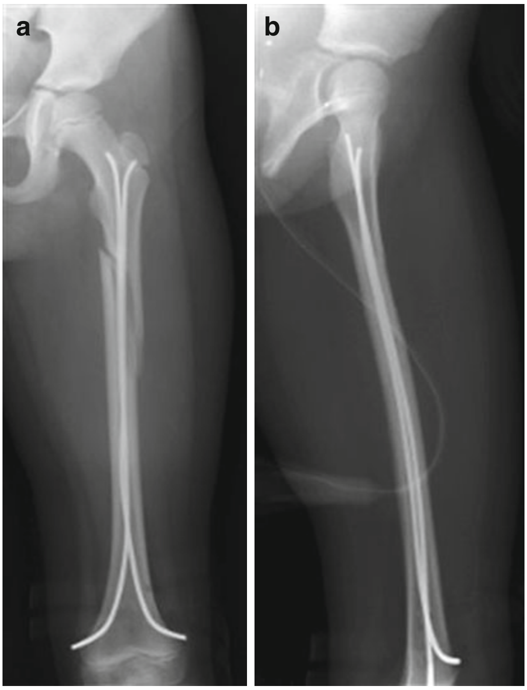


**Fig. 13** A 7 year-old girl who suffered multiple injuries during a car accident. The spiral fracture of the left femur is located at the middle-proximal third junction. The young girl was treated with retrograde FIN using two 2.5 mm stainless steel nails (**a, b**)

## Combined Antegrade/Retrograde FIN (Retrograde for Radius, Antegrade for Ulna)

General anaesthesia should always be employed [34, 35]. The child is positioned supine on the operating table with the injured upper limb placed on an arm table. The image intensifier is placed parallel to the patient's body.

The nail diameter may reach 50 % or more of the IM canal. There is one nail each bone. Therefore, depending on bone size, the average nail diameter is:

- 1.5–1.75 mm for a child aged 6–9 years;
- 2–2.25 mm for a child aged 9–12 years;
- 2.5 mm for a child more than 12 years old.

In 80 % of the cases, the radial fracture is managed first; because the radius lies in a depression, which may make reduction more difficult to perform after the ulna has been nailed. In only 20 % of the cases is the ulna managed first: the ulnar fracture is less displaced, or the surgeon finds it easier to do it this way.

## Retrograde FIN for Radius

The entry hole for the nail is made on the lateral aspect of the distal metaphysis, 10–20 mm above the distal physis (which is preserved), that is, 30 mm above the tip of the radial styloid, preferably on the volar subcutaneous border of the distal radius.

Therefore, a 20 mm longitudinal skin incision is made anterior to the intermediate antebrachial vein so that its proximal end is right over the planned entry hole (Fig. 14).

Then the surgeon follows the main technique described above. After crossing the fracture, the nail is advanced further, with its concave side facing the ulna (in order to restore the radial bow), until its tip reaches the radial neck.

## Antegrade FIN for Ulnar Fractures

The entry point for the ulnar nail is located on the posterolateral aspect of the olecranon. Insertion of the nail through the top of the olecranon is avoided because it inevitably results in painful prominence of the nail tip and even protrusion through the skin every time the elbow flexes. A 20 mm longitudinal incision is made 30 mm below the tip of the olecranon on the posterolateral aspect of the bone, so that its distal end is right over the planned entry hole (Fig. 15).

As for the radius, once proper orientation has been achieved, the nail is carefully advanced across the fracture site, using light hammer blows. With the curved tip directed laterally, the concave side of the nail faces the radius.

A perfect construct is achieved when the curved tip of the radial nail points medially and that of the ulnar nail points laterally.

At the end of the procedure, one critically important step is to move the forearm through its full range of pronation and supination to confirm adequate reduction of the fracture in the horizontal plane, which is further checked on AP and lateral radiographs (Fig. 16).

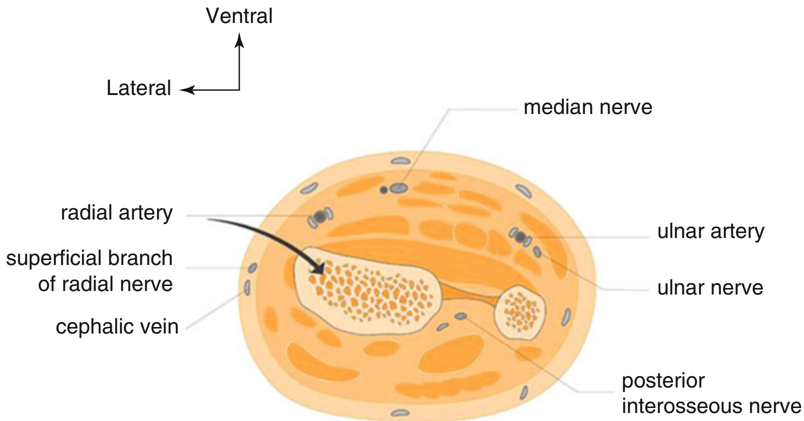


**Fig. 14** Surgical approach to the radius. A 15–20 mm longitudinal incision is made anterior to the intermediate antebrachial vein and sensory branch of the radial nerve. Anatomic section of the distal one-fourth of the forearm: anterolateral approach, and anterior to the extensor pollicis tendons

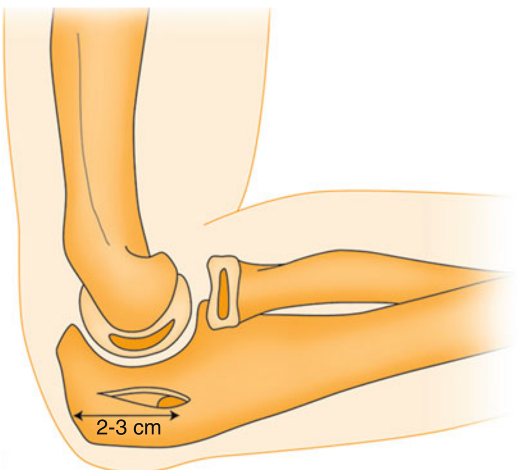


**Fig. 15** Surgical approach to the ulna: entry point is located 20–30 mm distal to the tip of the olecranon on the posterolateral aspect of the bone

## Post-Operative Care

AP and lateral x-rays are taken and the forearm is elevated. A light dressing is applied and replaced on the second post-operative day. If everything is fine, the child is discharged from the hospital, wearing a simple protective sling.

The child is just encouraged to actively mobilize the elbow and the wrist and perform gentle, slow pronation-supination movements.

Stability is such that cast immobilization is unnecessary. As a rule, the child will wear a simple sling for about 3 weeks provided that both bones have been treated concomitantly, as recommended. The child is able to return to school as soon as he/she is back home or after 1–2 weeks (at the most). Even when the dominant limb is involved, handwriting can be resumed within a few weeks. Some children even told us that they had returned to certain sports (e.g. swimming and other individual sports) only 1 month after the injury. Young musicians are able to practice again very rapidly.

The implants are removed later than in other fractures, after the sixth post-operative month in order to decrease the risk of recurrent fracture. The child is requested to refrain from high-impact and group sports for 2 months, to reduce the risk of fracture at the entry hole sites.

## Indications

- Severely displaced fractures above 10 years which are non-accessible to a conservative treatment because of no reducibility [36–45];
- In adolescents, because bone remodelling capacity will be poor, an anatomical reduction is mandatory and cast immobilization undesirable;
- Secondary displacement with plaster support;
- Types I and II open fractures, which allows regular monitoring of skin condition post-operatively;
- Recurrent fractures [46, 47]


**Fig. 16** A 10 year-old girl with a complete unstable fracture at the junction of the middle and proximal third of both bones of the forearm (**a**). FIN was performed in both bones, using two 2.2 mm stainless steel nails. Note the perfect orientation of the nails, with the radial nail directed to the ulna and vice versa (**b**). Six months later, anatomic axes have been restored and function is normal. (**c, d**) Bone union has been achieved

## Tibial Shaft Fractures

The tibia is the third most common location of diaphyseal fractures in children after the forearm and femur, with a high prevalence (75 %) in young boys around the age of 8. Their increasing incidence rate is attributable to road traffic accidents and, above all, to injuries at sport (mountain bike, rollers, ski, snowboard etc.).

Isolated tibial fractures represent 70 % of the cases. Isolated fibular shaft fractures will not be discussed in this chapter.

Oblique fractures (35 %) and spiral fractures (15 %) in the small child result from a twisting type injury. Complete fractures are much more frequent than greenstick fractures. In spiral fractures, it is not uncommon to have an isolated fracture of the tibial shaft with an intact fibula. Transverse fractures (15 %) rarely occur; they are due to a direct impact and may be associated with a third so-called "butterfly fragment". Comminuted fractures (30 %) are often severely displaced and associated with a fracture of the fibula.

Unstable fractures include complete fractures of both bones of the leg, whether oblique, spiral or comminuted with a third fragment which promote development of shortening or rotational mal-union.

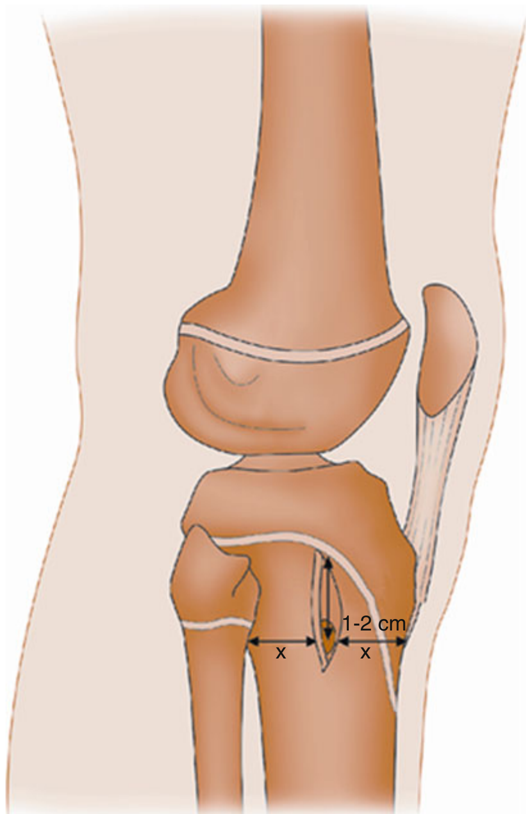


**Fig. 17** Lateral approach to the proximal tibia: the entry hole is located in the mid-section of the bone, anterior to the interosseous border of the tibia, 20–30 mm distal to the proximal physis

## Antegrade FIN

It is preferable to use general anaesthesia as with nerve block a compartment syndrome might go undetected. The child is positioned supine on an operating table with a radiolucent foot section. An image intensifier is placed at the foot of the table. Anterior-posterior views are easy to obtain.

Nail diameter should meet the fundamental rule of FIN: nail diameter = 0.4× diameter of the medullary canal [15]. Therefore the average diameter of the nail should be (depending on bone size):

- 2.5 mm for a child aged between 6 and 8 years;
- 3 mm for a child aged between 8 and 10 years;
- 3.5 mm for a child older than 11;
- 4 mm for a skeletally-immature adolescent.

Two longitudinal incisions about 20 mm long are made in the medial and lateral aspects of the leg, approximately 20–30 mm distal to the proximal physis which is easily palpable at the flare of the proximal tibia (Fig. 17). These incisions should not be placed too anteriorly to remain at some distance from the anterior tibial tubercle. A midline incision is made over the medial aspect of the tibia, and a lateral incision is made midway between the tibial crest and the head of the fibula. Medially, blunt scissor dissection is performed down to the cortical surface of the tibia, posterior to the midsection of the medial proximal metaphysis, close to the posteromedial border, 20–30 mm distal to the physis. Laterally, blunt scissor dissection is carried along the superficial fascia which is retracted posteriorly together with the anterior compartment muscles.

The technique is as described above. During the last step, orientation of the nails is fine-tuned so that the medial nail points medially and the lateral nail laterally. Final construct is technically perfect when two nails with opposing curves which apexes are located at the fracture site.

Should mild displacement persist after both nails have entered the distal fragment, the surgeon can still use contouring to complete the reduction. A slight valgus angulation can be corrected by rotating the lateral nail 180° with its tip pointing medially. A slight flexion angulation can be corrected by directing both nail tips anteriorly without changing their respective medial and lateral orientations: this is achieved by rotating the nails only 90°.

## Other Types of Tibial Fractures

Fractures of the distal fourth of the tibia often have a transverse pattern resulting from a bending force to the tibia, or an oblique pattern. Many of them are classified as Type I or II open fractures. The surgical technique is that of antegrade FIN as used for treatment of a diaphyseal fracture. However, contouring requires skill even with pre-bent nails. The reason is the apexes of the curves must be eventually located at the fracture site, which is difficult to achieve because the nails tend to straighten within the medullary canal. Nevertheless, with final orientation of the nails and firm anchoring in the metaphysis, anatomic reduction can be obtained. Should this not be the case, the surgeon still has the option to apply a resin cast after a few days to correct alignment.

Antegrade access to very proximal fractures of the tibia may be a real challenge. This is why retrograde FIN is the rule (Fig. 2b). The technique itself is the same except that skin incisions are made in the distal tibia.

**Fig. 18** A 13 year-old boy with fracture at the middle distal third junction. Addition of a retrograde fibular nail

## Nailing of the Fibula

In some circumstances, the surgeon may decide to nail the fibula, mainly to enhance the stability and the quality of tibial reduction. Usually, a supramalleolar retrograde technique is used and a single 1.5–2.0 mm diameter nail is inserted. The entry point is located 20 mm proximal to the distal growth-plate of the fibula on the posterolateral aspect of the bone. This decreases the risk of skin lesion at the cut end of the nail as skin coverage on the anterior aspect of the fibula is too thin. The concavity of the nail must be oriented toward the tibia (Fig. 18).

## Post-Operative Care

As soon as he/she can, the child is instructed and encouraged to lift his/her leg off the bed, mobilize both the ankle and the foot, and work on knee locking in extension. Then, the child is allowed to get out of bed and ambulate with two crutches, being careful to put no weight on the injured leg.

Gradual weight-bearing is begun after 2–4 weeks depending on the fracture type: it ranges from a couple of weeks for a transverse fracture to one full month for a long oblique or spiral fracture with one or several fragments.

## Indications

- Multiply-injured patients and polytrauma [26, 48–50];
- Open fractures-Gustilo types I and II [51];
- Immediately unstable fractures and secondary displacements with plaster support.

## Humeral Shaft Fractures

Humeral shaft fractures are very infrequent in children (only 2–5 % of all paediatric fractures). Due to their aetiology, they are predominantly seen in children aged less than 3 years or more than 12 years.

The simplest classification of humeral shaft fractures is based on location of the fracture site in the humeral diaphysis (proximal, middle, and distal), alignment of fragments, and appearance of the fracture line. As to the mechanism of injury, it varies significantly according to age. Adolescents will have transverse fractures due to direct impact, fall from a height, sport, or road traffic accidents.

Radial nerve injury is the most commonly associated lesion due to the close proximity of this nerve, particularly in middle-third fractures.

### Retrograde FIN Technique

General anaesthesia is mandatory as regional anaesthesia would require mobilization of the upper limb, which is almost impossible and could jeopardize neural structures, in particular the radial nerve [52]. The child is positioned supine on the operating table with the affected upper limb placed on a radiolucent arm table. Image intensification is used to control passage of the nails across the fracture site.

The appropriate nail diameter is around one third (33 %) of IM canal diameter. The most commonly-used diameters in adolescent humeral diaphyseal fractures range from 2.5 to 3.0 mm.

In a middle-third fracture, the incision is made just proximal to the lateral epicondyle and extends distally past the points of entry for the nails to facilitate oblique insertion. It is recommended to create two distinct entry points, one above the other (Fig. 19). Following incision of the superficial fascia, the epicondylar muscles are separated longitudinally from one another by blunt dissection which is continued down to bone. The entry holes in the distal portion of the lateral column are made with an awl, 20 mm above the lateral epicondyle. The two nails are then successively inserted into the medullary canal using a T-handle.

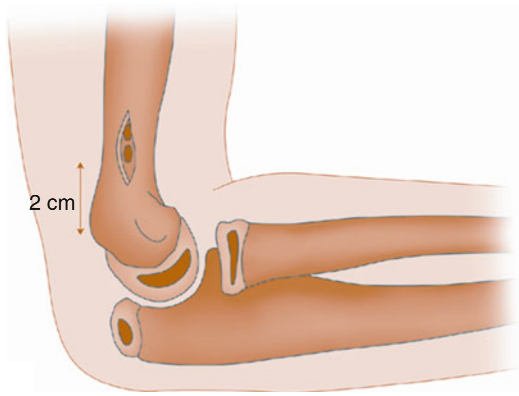


**Fig. 19** Lateral supra-epicondylar incision: both holes are made in the distal part of the lateral supracondylar ridge, approximately 20 mm from the physis

Particular attention should be paid to the direction of the nails in the lateral projection. Under no circumstances should the nails be directed toward posterior soft tissues in order to avoid damage to the radial nerve, which would result in post-operative radial nerve palsy. When the nails are high enough in the medullary canal or cross the fracture site, one nail is rotated 180° so that it lies in the position of a medial nail. Thus, at the end of the procedure, both concavities will face each other with their apexes located at the fracture site.

### Other Types of Humeral Shaft Fractures

The fractures of the proximal third are perfectly amenable to the retrograde FIN technique

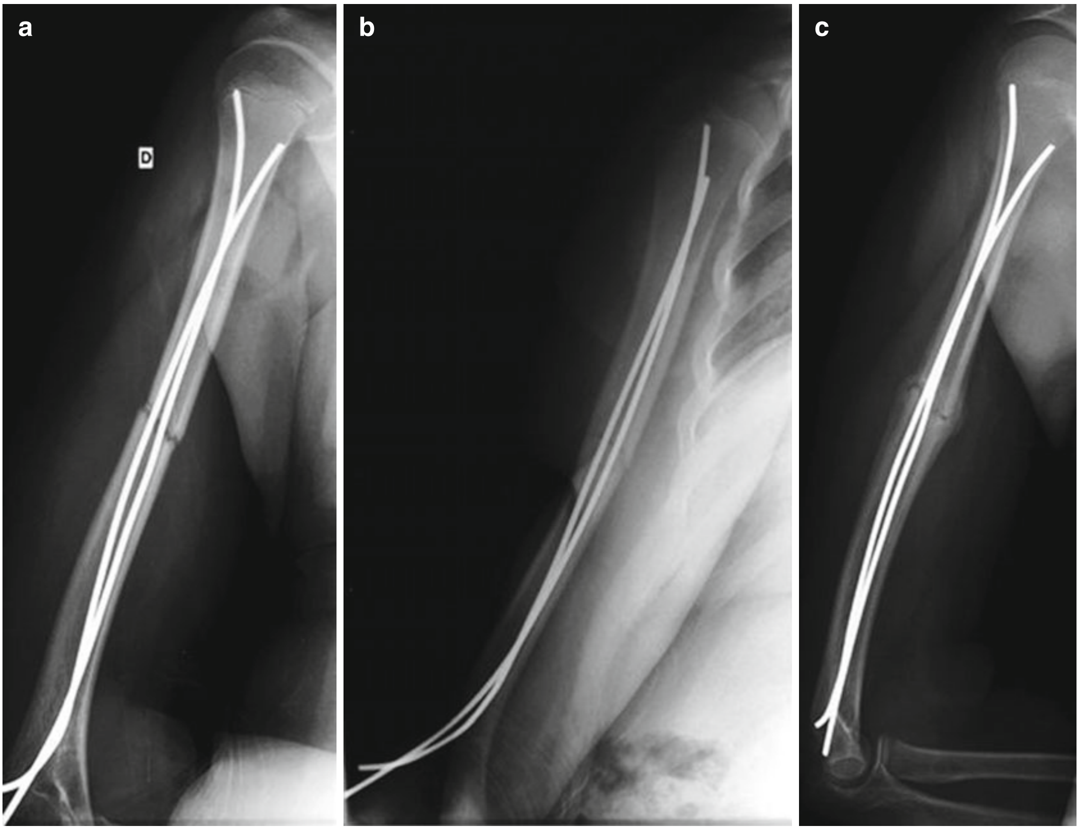


**Fig. 20** A 12 year-old girl presented with a transverse fracture of the middle-third of the humerus sustained in a fall on ice, with no neurovascular complications; uni-polar retrograde FIN using two 2.5 mm stainless steel nails (**a, b**); distinct external callus and evidence of union at 6 weeks (**c**)

(as described above) (Fig. 20). In fractures of the distal third, it may not be possible to use the retrograde FIN technique. An unipolar antegrade FIN may be considered.

## Post-Operative Care

Good stability of the construct generally makes complete immobilization unnecessary. A simple sling is worn for a few days, beginning the day of surgery. During the immediate post-operative period, it is worn permanently to relieve pain, and then occasionally for 2–3 weeks.

The child is encouraged rapidly to gently mobilize his/her elbow and shoulder for a few minutes, everyday. After 2–3 weeks, the child can do without the sling and starts self-rehabilitation by performing activities of daily living and pendulum exercises for the shoulder.

## Indications

Indications for FIN in humeral diaphyseal fractures are [27, 53–55]:

- Older children with difficulties with conservative treatment like a hanging cast;
- Multiple injuries or fractures.

## Complications

Difficult or impossible reduction can occur. In these cases, a short incision is sufficient to reduce the fracture with two clamps; this allows the nail's crossing of the fracture site under visual control [56–62]. Alternatively, percutaneous reduction can be achieved using a punch to push the bone. About 15 % of the forearm fractures require an open approach.

The most common implant-related problem is skin impingement. In a retrograde femoral FIN, nail tips that are in a very distal position should not be bent. Very often, they must be recessed using the impactor and left only 7–12 mm proud of the bone surface.

There are a few important points to remember to avoid instability:

1. Implants: always use the largest diameter that can be accommodated.
2. Technique: nail contouring is a critical step. Achieving the ideal curvature is a matter of experience. In case of problem, do not hesitate to remove the nail and insert a new one;
3. Fracture pattern: comminuted or long spiral fractures are more unstable and require a perfect construct. Some of them are not FIN indication.

In our experience, no delayed unions or non-unions have been reported in fractures of the humerus, both bones of the forearm, and femur [56]. But such complications may happen in tibial fractures such as those seen in adolescents: complex fractures resulting from direct impact that is unstable and impossible to reduce non-operatively are consequently a FIN contra-indication.

Immediate post-operative infection is a rare occurrence after closed FIN. Overall, 0.3 % of the patients had osteomyelitis, which, in most cases, occurred secondarily and resolved with appropriate antibiotic therapy. In some patients, infection was diagnosed several months after hardware had been removed.

An inadequate construct runs the risk of angular deviation which is not acceptable in adolescents who have a limited bone remodelling capacity. Rotational mal-union may be seen in the femur where reduction has not been performed in the horizontal plane. In the frontal plane, a post-operative axial correction of 10° can be achieved very gradually (maximum gain of 2° per year) in children aged less than 10 years at the time of the injury. With regard to tibial fractures, reduction is sometimes so difficult to achieve that two-thirds of our fractures managed with FIN required adjunctive immobilization in a cast-boot, plus plaster wedging in some cases to maintain correct alignment.

A certain number of patients sustained simple falls after their operation without this compromising the integrity of the construct. But we also had children who sustained severe trauma and re-fractured their bone with the nails in situ, and of course the nails got buckled. Manipulative reduction was successful in a certain number of patients with femoral or forearm fractures. But, if reduction is inadequate, one or both nails must be replaced.

A pre-existing leg length discrepancy will be either compensated for or worsened on the operated side. The average amount of bone overgrowth after FIN is comparable to that observed with non-operative treatments.

## Conclusions

Prima facie, FIN looks quite easy, but a number of surgeons have had to revise some of their cases due to inadequate constructs. Performing a FIN is more than just building a construct. It requires a perfect understanding of biomechanics and skill. Actually, it is pretty much like fine craft: the surgeon contours the nails by hand and must have some degree of creativity to adapt to the patient's anatomy and properly to orient the nails.

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