Humeral Shaft Fracture

13

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13.1 General

13.1.1 Epidemiology

Humeral shaft fractures are very infrequent in children (only 2–5% of all pediatric fractures) [1, 2]. Due to their etiology, they are predominantly seen in children aged less than 3 years or more than 12 years. As a matter of fact, most humeral shaft fractures, which occur in young children are the result of child abuse or birth trauma. In older children, they generally result from high-energy trauma and are sometimes associated with other injuries.

13.1.2 Mechanisms of Injury and Classifications

The simplest classification of humeral shaft fractures is based on location of the fracture site in the humeral diaphysis (proximal, middle, distal), alignment of fragments, and appearance of the fracture line. As to the mechanism of injury, it varies significantly according to age.

In the young child, fractures are often caused by twisting, particularly in abused children. Fractures from direct impact are rarer and have an oblique line, sometimes spiral shaped [3].

In contrast, adolescents will have transverse fractures due to direct impact, fall from a height, sport, or road traffic accident.

Birth trauma is a completely different story: it may occur when one arm presents with the head or during a difficult delivery. In this situation, it can be any type of fracture.

In older children, the clinical diagnosis is generally clear, based on the circumstances of the accident or the clinical picture: upper limb functional disability, severe pain, elbow supported with the other hand, and trunk bent to the affected side.

Radial nerve injury is the most commonly associated lesion due to the close proximity of this nerve, particularly in middle-third fractures. Before initiating a therapy, it is essential to rule out any other lesions and inform both the patient and his/her family of the examination results, although the presence of such lesions will not influence the therapeutic strategy.

13.2 Retrograde FIN Technique

The case we are presenting here is a displaced fracture of the middle third of the humeral diaphysis in an adolescent (Fig. 13.1) [4].

13.2.1 Anesthesia

General anesthesia is mandatory as regional anesthesia would require mobilization of the upper limb, which is almost impossible and could jeopardize neural structures, in particular, the radial nerve. A supraclavicular brachial plexus block can be performed, knowing that it will make postoperative neurological monitoring more difficult.

13.2.2 Patient Positioning

The child is positioned supine on the operating table, with the affected upper limb placed on a radiolucent

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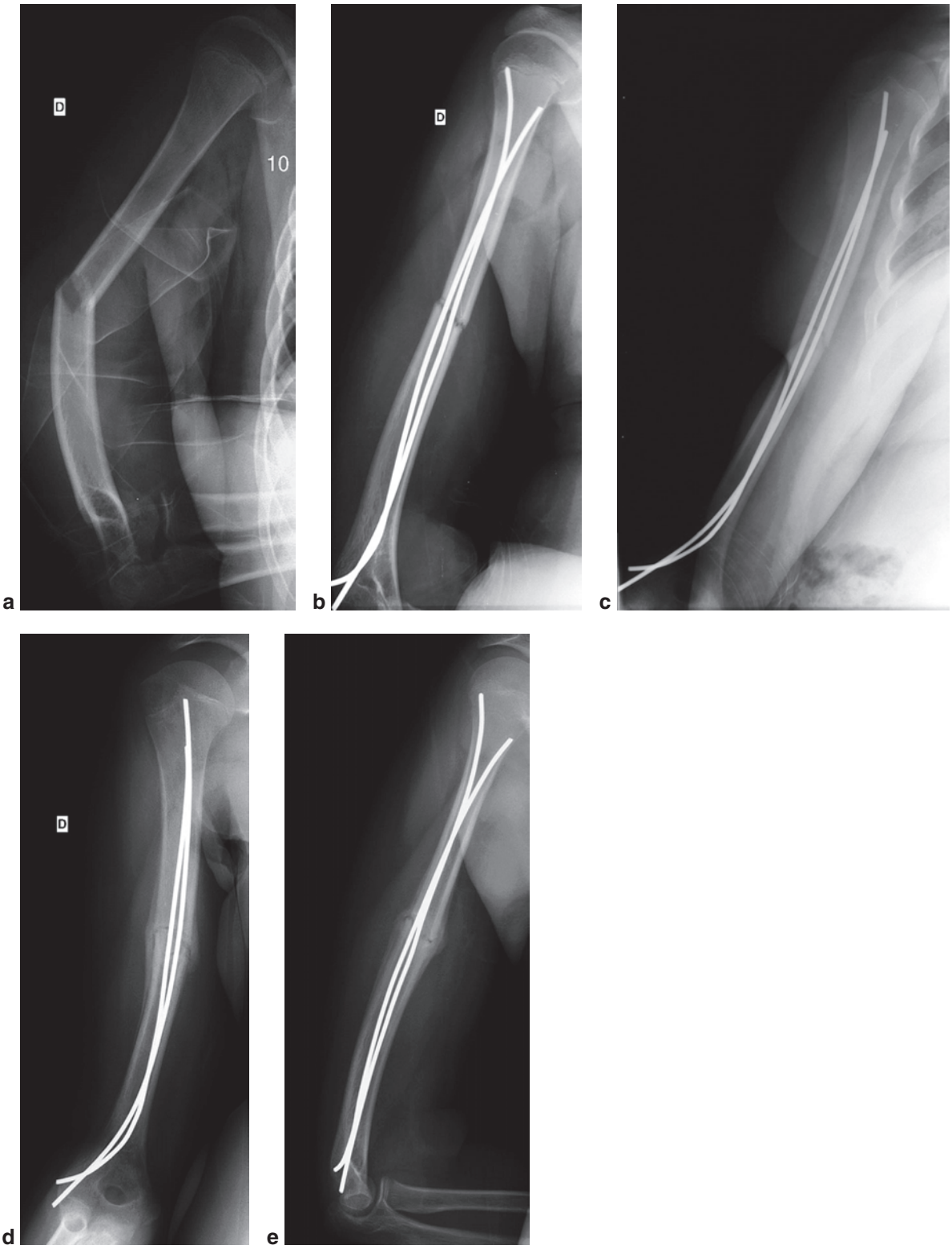


Fig. 13.1 A 12-year-old girl presented with a transverse fracture of the middle third of the humerus sustained in a fall on ice, with no neurovascular complications (**a**); unipolar retrograde flexible intramedullary nailing (FIN) using two 2.5 mm stainless steel nails (**b**, **c**); distinct external callus and evidence of union at 6 weeks (**d**, **e**)

arm table. The patient should be positioned as close as possible to the edge of the table to allow good visualization of the shoulder and proximal ends of the nails, next to the proximal metaphysis. It is not possible to use a tourniquet.

13.2.3 Image Intensifier

Image intensification is mandatory to control passage of the nails across the fracture site. The C-arm may be positioned right away to avoid further handling later on, but it will interfere with the assistant's workspace, or it may be positioned after draping has been completed. Whatever the option selected, the image intensifier should be positioned at the level of the axilla, parallel to the operating table and perpendicular to the arm table. The C-arm will need to be moved in a mediallateral plane to allow visualization of both the fracture site and the proximal humerus (Fig. 13.2).

Fig. 13.2 Patient is positioned on the table with the upper limb placed on an arm table, and C-arm properly positioned

13.2.4 Operative Field

The whole upper limb is sterile prepped up to the axilla and shoulder, as full mobilization of the arm and forearm will be required to perform reduction maneuvers and to access the fracture site (if necessary). A sterile upper extremity drape can be used that covers the arm table, the patient's trunk, and the lower limbs.

13.2.5 Selection and Preparation of the Implants

Either stainless steel or titanium nails can be used. The leading ends of some stainless steel nails need to be slightly rounded off and bent, whereas titanium nails are usually prebent. Follow the flexible intramedullary nailing (FIN) rule of thumb for nail diameter choice in upper extremities: Nail diameter = 33% of IM canal diameter. As the upper limbs are not weight-bearing, smaller diameter nails offer sufficient stability as well as easier crossing of the fracture site during insertion. The most commonly used diameters in adolescent humeral diaphyseal fractures range from 2.5 to 3.0 mm.

Then, both nails are gently contoured to achieve a curvature of 40° (approximately), the apex of which should be located at the fracture site at the end of the procedure.

13.2.6 Surgical Approach

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. 13.3). 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. During this step, the upper limb is internally rotated with the elbow in mid-flexion to provide good support. However, the distal metaphysis must be firmly held to avoid misdirection of the awl toward the anterior aspect of the elbow and damage to the neurovascular structures. The two nails are then successively inserted into the medullary canal using a T-handle. To

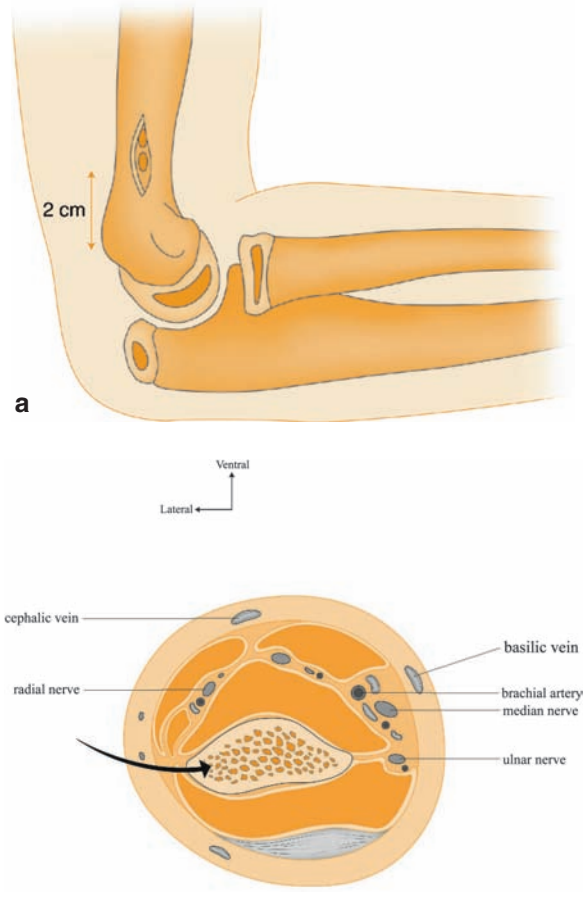


Fig. 13.3 Lateral supra-epicondylar incision: (**a**) both holes are made in the distal part of the lateral supracondylar ridge, approximately 20 mm from the physis; (**b**) schematic cross-section illustrating a lateral approach

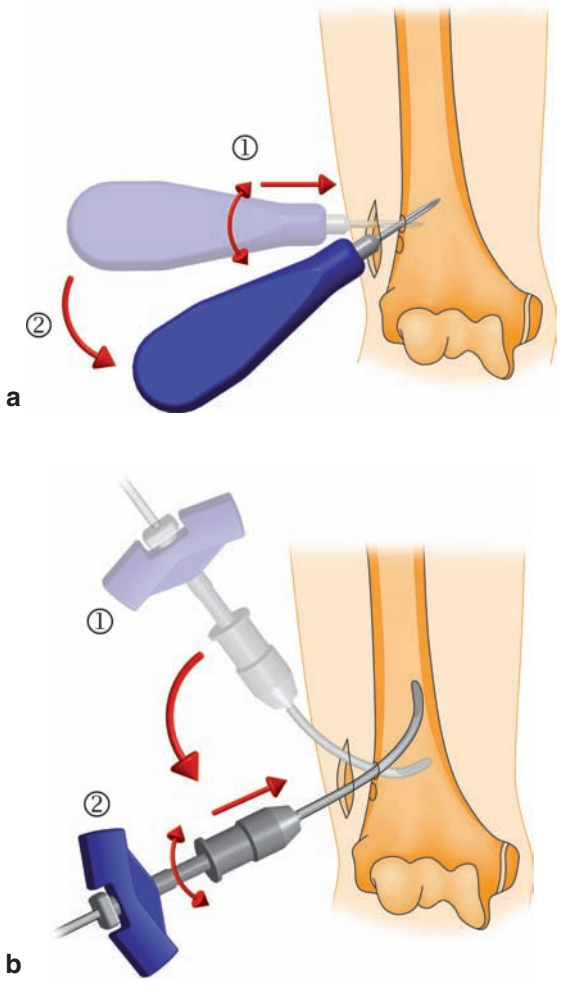


Fig. 13.4 The two holes are created one above the other with a short awl (**a**); the nail is initially positioned perpendicular to the hole and then advanced in an oblique upward direction (**b**)

facilitate advancement of the curved tip through the lateral column, the nail should be inserted in an upward rotational movement (with light hammer blows, if necessary) (Fig. 13.4).

13.2.7 Reduction and Crossing of the Fracture Site

Once the two nails have reached the fracture site, the assistant moves to the end of the arm table to hold the hand and wrist of the patient and apply axial traction, while a counter force is applied by a nurse to the child's armpit. If necessary, a drape may be wound up around the chest to act as a counter brace. The preferred position for the arm and forearm is supination with the elbow extended and the shoulder in 90° of abduction. Crossing of the fracture site (with the help of a slotted hammer) is performed under fluoroscopic guidance. Direction of the nails is dictated by the position of the proximal fragment; they should end up in the proximal canal, opposite to each other.

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 postoperative radial nerve palsy (Fig. 13.5). Once the fracture site has been passed, the nails can be advanced up to the proximal humerus.

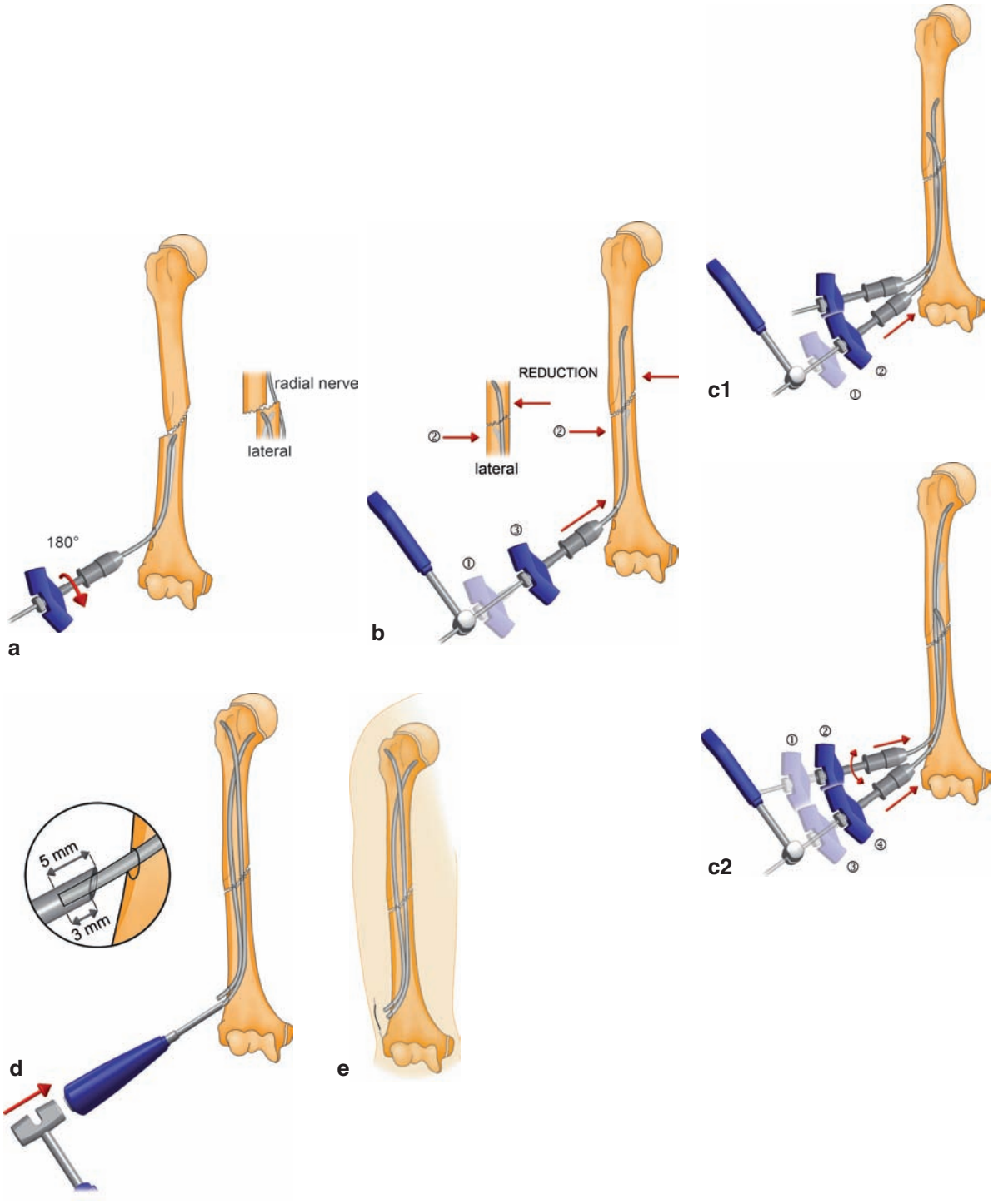


Fig. 13.5 The first nail is advanced up to the fracture site in the direction of the proximal fragment (in both AP and lateral planes). The nail must not be directed toward posterior soft tissues (**a**); (**b**) after reduction has been achieved, the nail is further advanced across the fracture site with the help of a slotted hammer; (**c1**) the second nail is inserted through the inferior lateral hole, advanced as far as the fracture site, and then across the fracture site with gentle tapping; (**c2**) it may be advisable to advance the first nail up to the neck of the humerus prior to driving the second nail across the fracture site; (**d**) once the two nails are properly positioned in the humeral neck, their distal ends are trimmed and impacted so that only 3–5 mm of the nails will protrude from the humerus; (**e**) final construct after wound closure

13.2.8 Final Reduction

When the nails are high enough in the medullary canal or cross the fracture site, the more proximal 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. After reduction has been achieved, if the position of the nails is satisfactory, gentle hammer blows are used to complete seating. Actually, the curves themselves assist in reducing the fracture: the bending moment created by a curved nail within a long bone tends to angulate the fracture in the direction and plane of the concavity of the curve. It means that a valgus angulation in the fracture site can be corrected by using the concavity of the curve to produce a varus shift. At the end of the procedure, the surgeon must check that the proximal ends of the nails are firmly anchored in the cancellous bone of the metaphysis to avoid secondary migration.

13.2.9 Wound Closure

It is at the entry points into the lateral epicondyle that nail ends are the most prominent. For this reason, the nails should be inserted at least 20 mm proximal to the tip of the lateral epicondyle. Furthermore, the nail ends must be carefully trimmed and recessed.

There are four useful tricks that help minimize the risk of skin irritation. One is to cut the nail to the desired length, slightly bend its distal end to facilitate later removal, push it with the help of a graft pusher so that it is just proud of the cortex, and proceed to final impaction. The problem with this method is that there is a risk of not correctly evaluating the length of the free end and cutting the nail too short. The second one is to leave the distal end straight as the inherent elasticity of the material will keep the nail flush against the outer cortex of the lateral column. The third one is to use plastic or titanium protective end caps. The fourth and most effective method is to use an impactor with a 3–5 mm cannulated tip.

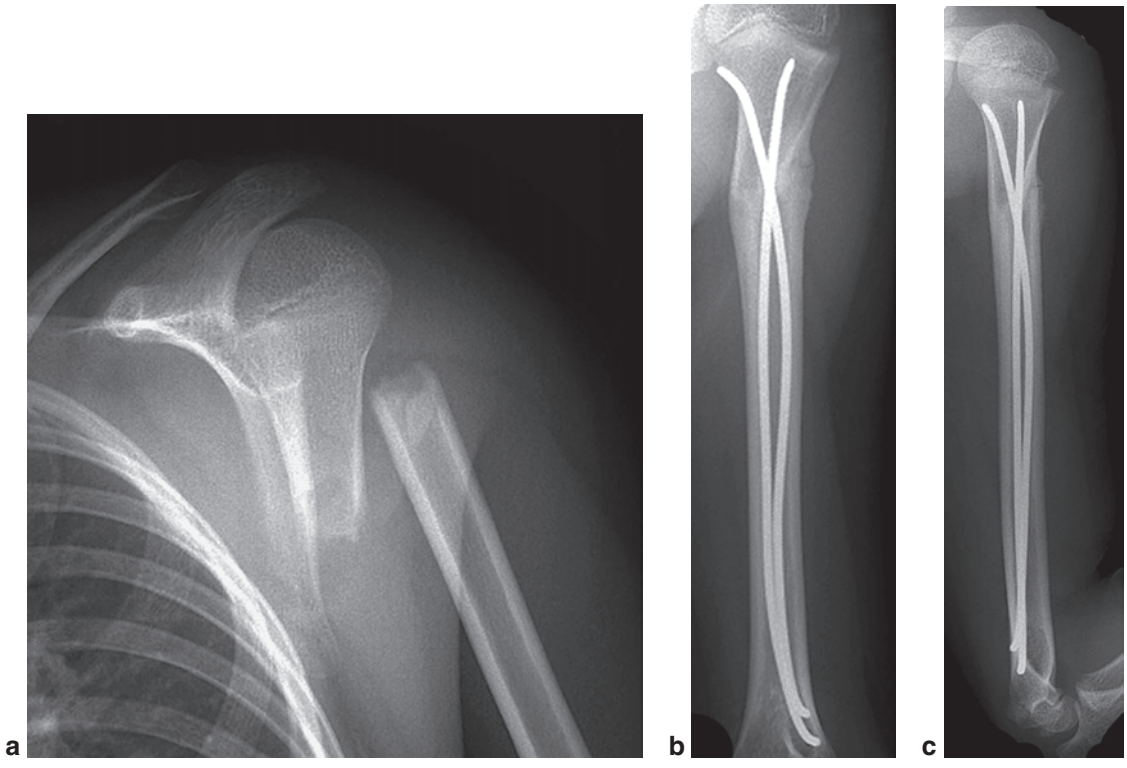


Fig. 13.6 A 12-year-old girl presented with a *left humeral fracture* at the middle-proximal third junction without associated complications (**a**). Due to the location of the fracture, their was a valgus displacement of the distal fragment and adduction of the proximal fragment that was pulled by the pectoralis major. FIN was performed from a lateral approach using two 3 mm titanium nails. Functional and radiological outcome was satisfactory (**b**, **c**)

Then, the wound is thoroughly irrigated and closed in two layers without drainage.

13.2.10 Types of Humeral Shaft Fractures

13.2.10.1 Proximal Third

These fractures are perfectly amenable to the retrograde FIN technique (as described above) (Fig. 13.6). However, care should be taken to perform maximum contouring just short of the bent tip. Should the apex of the arch not be located right at the level of the fracture site, it is advisable to use sharp nails, which will provide good purchase in the soft cancellous bone of the humeral head and will enhance stability of the construct. This technique is very similar to that used for fractures of the humeral neck.

13.2.10.2 Distal Third

It may not be possible to use the retrograde FIN technique in distal-third fractures, more especially as the fracture line is often oblique or spiral shaped. The problem is that the distance between the entry points on the lateral aspect of the distal humerus and the fracture site is too short to obtain an adequate arch (Fig. 13.7). In such situations, the first nail is inserted laterally and the second nail medially [5]. An entry

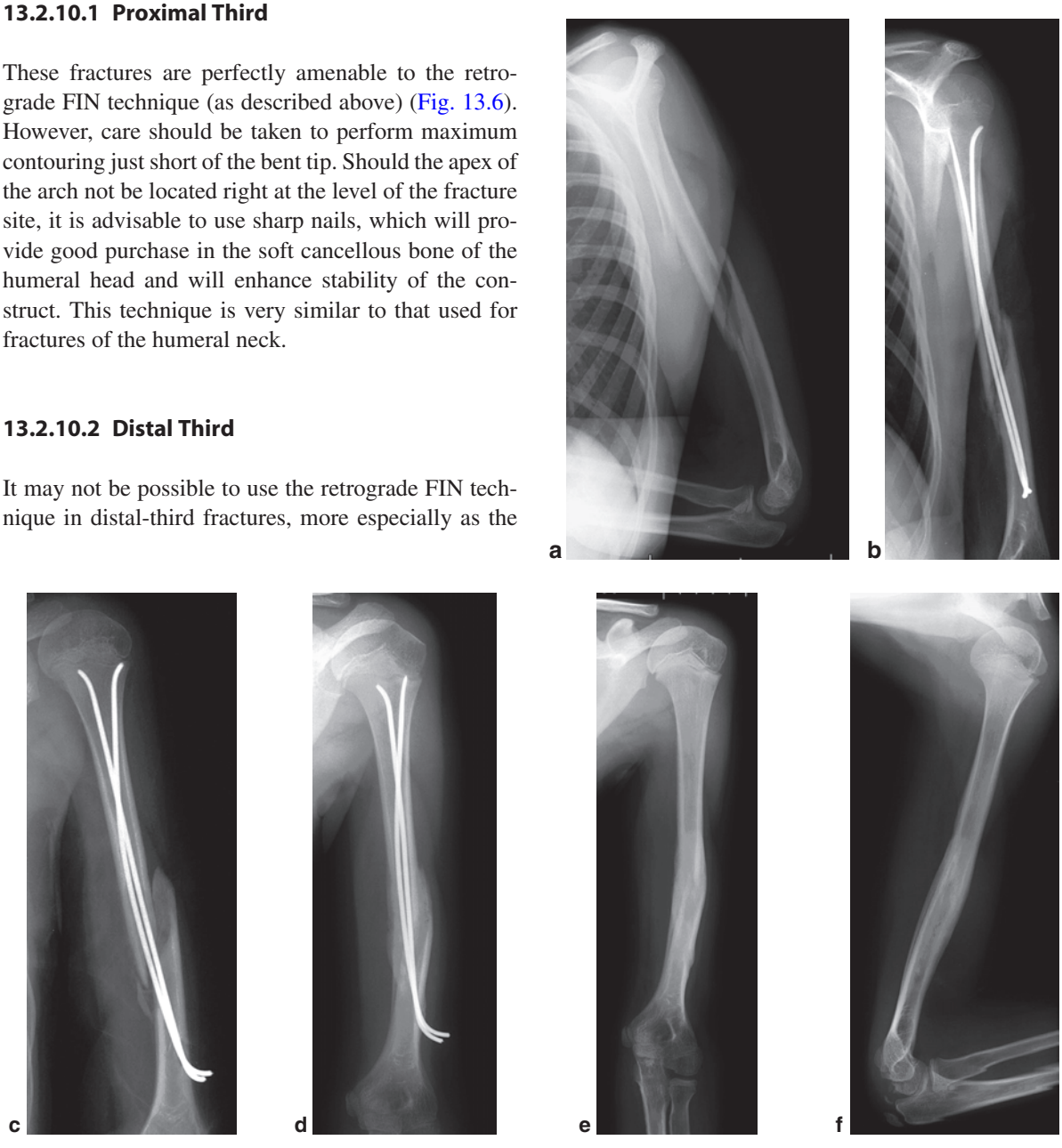


Fig. 13.7 A 13-year-old boy presented with a spiral fracture in the middle-distal third of the humerus caused by violent twisting during a brawl (**a**); unipolar retrograde FIN was performed using two 2.5 mm titanium nails, which provided good sagittal alignment (**b**). AP view shows inadequate reduction (**c**). Note that entry points were positioned too high; however, 2 months later, union was achieved (**d**); 4 months later, the radiological result was satisfactory (**e**, **f**)

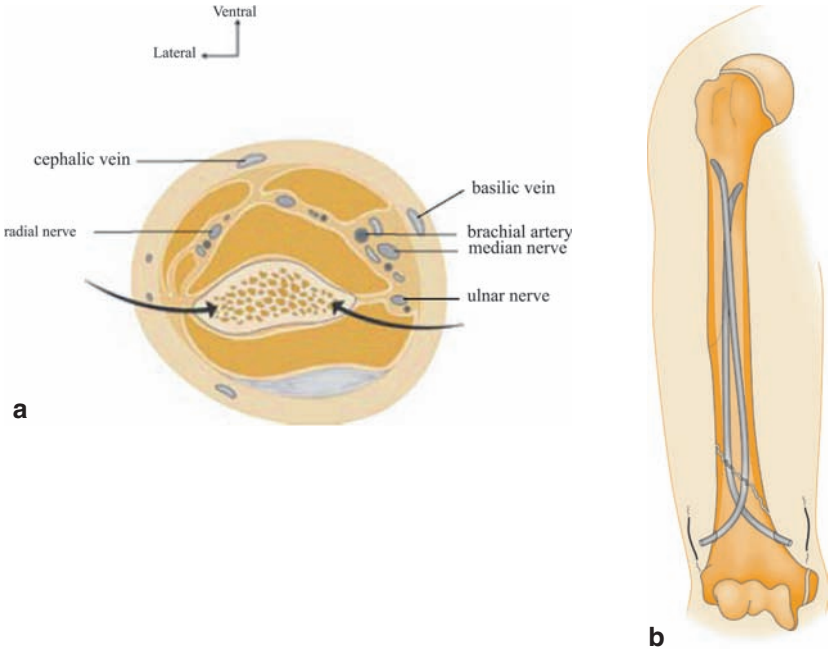


Fig. 13.8 Bipolar retrograde FIN technique using one lateral nail and one medial nail. Indicated in certain distal humerus fractures. (**a**) Crosssection illustrating the surgical approaches available; (**b**) final construct

point is created in the medial column (Fig. 13.8) just proximal to the medial epicondyle so that the two holes are aligned. When inserting the medial nail, it is recommended to pass behind the ulnar nerve to avoid interference with the neurovascular pedicle, on the medial aspect of the elbow. The nails are then advanced across the fracture site as previously described. To ensure that the curve will be in a distalmost position, both nails must be sequentially bent as they are advanced up the medullary canal (Case 1). In this way, a strong, symmetrical anchorage can be obtained both proximally and distally, with adequate bending.

Alternatively, unipolar antegrade FIN may be considered as in supracondylar fractures (see Chap. 14).

13.2.11 Postoperative Care

A dry dressing is applied to the wound surface. AP and lateral X-rays are taken without moving the arm.

Postoperative monitoring consists essentially in checking for the absence of radial nerve palsy, which may occur secondarily to postoperative swelling. In this case, it is transient and resolves spontaneously within a few days.

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 postoperative period, it is worn permanently to relieve pain, and then occasionally for 2–3 weeks.

When pain and swelling are controlled, that is, 2–3 days after surgery, the child is discharged from hospital.

13.2.12 Resumption of Activities

As soon as the child is back home, he/she can return to school but should continue wearing the sling. However, very rapidly, the child is encouraged 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. Any movement that places excessive load on the arm is strictly prohibited as long as healing is not complete.

A radiographic assessment is performed at 6 weeks. Return to sports is authorized only when bone union is achieved, that is, between 3 and 6 months after surgery, depending on the child's age and the type of sport.

13.2.13 Implant Removal

Prolonged implantation of the nails is not recommended as they will be all the more difficult to remove. When the humerus is approached laterally, there is little soft tissue coverage over the bone. For this reason, the distal ends of the nails are cut just short of the bone surface to prevent skin impingement. The problem is, as bone grows, the distal tips may become fully embedded in the epicondylar bone and can no longer be extracted. This is the reason why it is advisable to remove the nails as soon as bone union is obtained, between the fourth and the sixth postoperative month. The removal procedure is performed on a day-patient basis using the initial lateral incision. The child is then cautioned against returning to sports too early (within less than 1 month).

13.2.14 Postoperative Follow-Up

Depending on the age of the child, and in the absence of residual angulation (in which case bone remodeling would need to be closely monitored) or any complication that would necessitate special treatment, a radiographic assessment is routinely performed 1 year after removal of the device. If everything is fine, the child can be considered as permanently healed.

13.3 Complications

13.3.1 Initial Complications

13.3.1.1 Neurologic Complications

Neurologic complications [6] are the most frequent complications of middle-third fractures – although their rate is not accurately known. The radial nerve is involved in most cases due to its anatomic location. The result may be complete motor deficit, sensorimotor deficiency, or incomplete motor deficit with mild sensory dysfunction.

Both the child and his/her family must be informed of this preoperative status, and it should be recorded in the patient's chart. However, fracture-associated radial nerve palsy has no influence on the therapeutic strategy and is not a contraindication to FIN.

It may also occur after surgery. In this case, it is important to know whether it is complete or partial. The most frequent causes of postoperative radial nerve palsy are swelling and reduction maneuvers. Other causes include: misdirected nail, bone chip, radial nerve entrapped in the fracture site.

Although paresis has a good prognosis and usually regresses within a few days, complete radial nerve palsy must be monitored and evaluated at regular intervals. A specific rehabilitation program is necessary (see Chap. 10). If no signs of recovery are present at 3 weeks, electromyography is recommended. If signs are observed, monitoring and rehabilitation can be continued. Otherwise, surgical exploration of the radial nerve trunk should be performed [7].

Other nerve trunks are seldom involved.

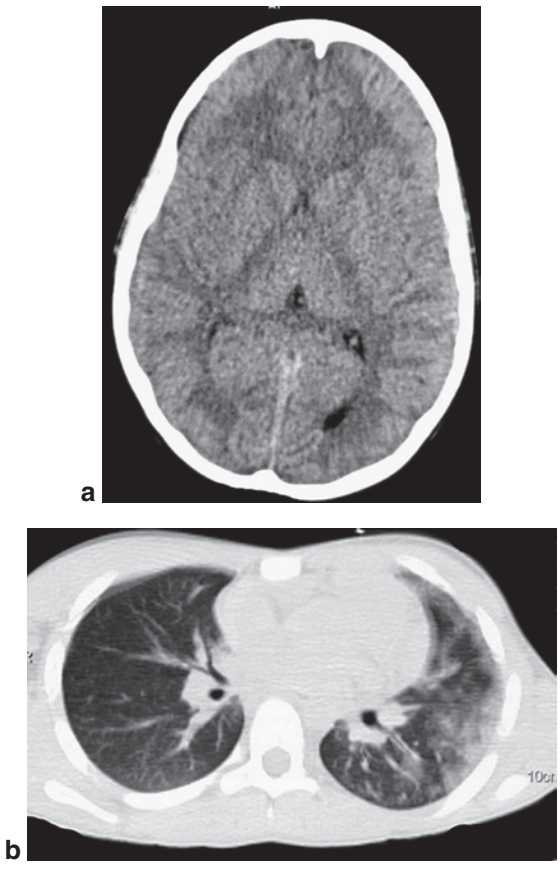


Fig. 13.9 A 12-year-old girl presented with multiple injuries sustained in a car accident that occurred at 7.00 am. Subdural hemorrhage along the falx cerebri (**a**), *left pulmonary contusion* (**b**)

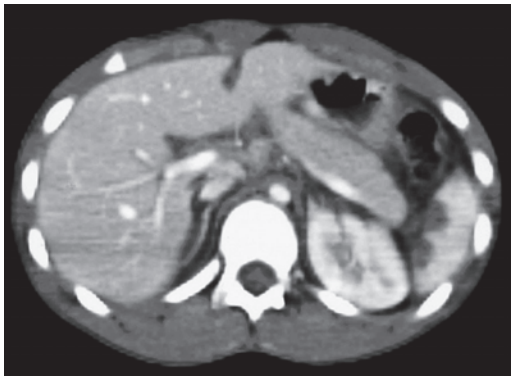


Fig. 13.9 (*cont.*) Hematoma of the inferior pole of the spleen (**c**), femoral fracture which will be treated by FIN (**d**) Cauchoix type II open fracture of the *left humerus* (**e**). Five hours later, two 2.5 mm titanium nails were inserted using an open FIN technique (**f**, **g**). Six weeks later, the healing process was going well (**h**, **i**)

13.3.1.2 Vascular and Skin Complications

Vascular and skin complications are exceptional. They are only seen in severely displaced fractures (Fig. 13.9).

13.3.2 Specific Complications

13.3.2.1 Difficult Reduction and Instability

In narrow medullary canals, particularly in young children, reduction may be difficult to achieve and insertion of the nails just impossible. Reduction may also be challenging in three-part fractures or in case of muscle entrapment. These exceptional situations require an open lateral approach to the fracture site.

Many fractures involving the distal third of the humerus are spiral shaped, which makes it difficult to achieve stabilization, using only a lateral approach. In this case, it is advisable to use a bipolar retrograde or unipolar lateral antegrade insertion technique.

13.3.2.2 Implant-related Problems

Implant-related problems are specific to the lateral epicondylar approach. As a matter of fact, in this area, the bone is right under the skin, with no soft tissue between the nail ends and the skin. For this reason, the entry points should be positioned 10–20 mm proximal to the lateral epicondyle. In addition, the distal ends of the nails should be cut just short of the bone surface, and the implants should be removed as soon as bone union is obtained.

13.3.2.3 Joint Stiffness

No elbow or shoulder stiffness has been reported, whatever the location of the fracture in the humeral shaft. But, skin irritation at the lateral or medial entry site may temporarily cause restriction of the elbow movement.

13.3.2.4 Delayed Union and Nonunion

As the upper extremity is nonweight bearing, it is not uncommon to have longer healing times than in other pediatric traumatic injuries. In practice, a long healing time means later return to sports activities. However, no nonunions have been reported so far.

13.3.2.5 Other Complications

Other complications may occur such as malunion (Case 1) or sepsis (Case 2), but they are very rare, have no specificity, and can be managed in the usual manner.

13.4 Indications

Indications for FIN in older children are justified considering the difficulty in immobilizing a humeral shaft fracture in these young patients. One considers that children aged 11–12 years or more with a middle-third fracture are amenable to internal fixation. Indications regarding distal-third fractures are even wider as this type of fracture is often unstable and difficult to manage by orthopedic means. In contrast, proximal fractures have a high potential to remodel owing to their close proximity to the proximal humeral physis, and they are also much easier to stabilize by closed means. Therefore, indications for internal fixation are rare [3, 8–12].

Gustilo type I and II open fractures are good indications for FIN as monitoring and postoperative management are facilitated.

Children with multiple injuries or fractures (Fig. 13.9) need stabilization of all their fractures to facilitate postoperative care and monitoring. FIN provides a straightforward way of dealing with these difficult cases: mini- incision approach, minimal blood loss, easier overall management of the child [13].

13.5 Contraindications and Limitations

The only contraindications to this technique are widely open fractures with severe skin and muscle damage. A major limitation to this technique is the presence of severe neurovascular lesions, which require a specific emergency treatment. In such a situation, it is wiser to use a strong fixation device, which will allow mobilization of the upper extremity. An external fixator may be a good option.

13.6 Case Reports

13.6.1 Case 1

After a fall from a horse, a 15-year-old girl presented with a short spiral fracture at the distal end of the humerus (a). As the fracture site was very unstable, a bipolar retrograde FIN with two 2.5 mm stainless steel nails was performed using a combined lateral and medial approach, which provided adequate reduction and good stability (b, c). However, impaction at the fracture site caused gradual migration of the nails, which eventually protruded through the skin (d, e). As union had not yet taken place, both nails were removed 1 month after implantation (f). A light bandage was immediately applied with elbow close to the body, and union was achieved within the following weeks. At 5 months, the young girl had regained full function of her elbow and shoulder and could return to sports in spite of a valgus malunion (g) (Fig. 13.10).

Note: The nails were too thin. Considering the age of the patient and the size of the humeral shaft, 3 mm diameter nails would have been more appropriate. Moreover, they crossed each other at the fracture site, which resulted in instability. The area of greatest convexity should have been located further distally.

Fig. 13.10 Case 1

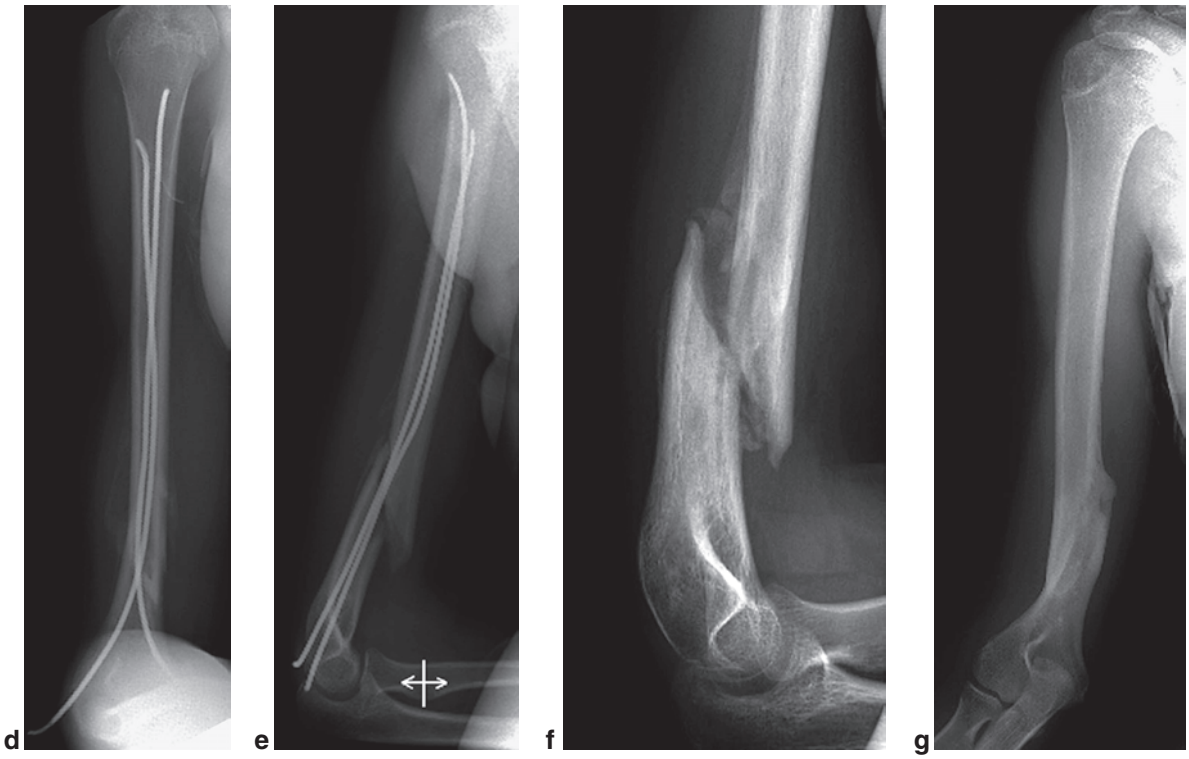


Fig. 13.10 (*cont.*) Case 1

13.6.2 Case 2

A 13-year-old girl sustained a transverse fracture of the middle third of the right humeral diaphysis (a). An emergency FIN procedure was performed using two 2.5 mm stainless steel nails. There were no associated skin or neurovascular lesions (b, c). Skin irritation at the entry sites was noted postoperatively. One month after implantation, the ends of the nails protruded through the skin at the lateral epicondyle, causing a hypertrophic response. The X-ray shows a normal healing process (d). In view of the local skin complication, it was decided to remove the implants (e). As a precautionary measure, a Mayo Clinic bandage was applied and healing progressed uneventfully until the fourth month. Then, a bone defect was observed at the fracture site without any clinical or biological symptoms (f). No complaint from the child for 1 full year, and then 18 months after the procedure, she was admitted again to hospital for a fistula opening on the lateral aspect of her arm at the level of the fracture site. Imaging confirmed both the bone sequestra and the fistula (g–i). She had to be reoperated on for excision of fistula tract and curettage of osteitis. She was treated with 3 months of antibiotic therapy, first intravenously and then per os. Bacteriological tests revealed the presence of staphylococcus aureus. Treatment was efficient, and after 3 months gradual filling of the defect was observed (j). At 6 months, functional outcome was excellent and bone union was achieved (k) (Fig. 13.11).

Note: the potential risk of osteomyelitis after surgical treatment of a fracture does exist, although the rate is very low; two cases in one thousand in our series).

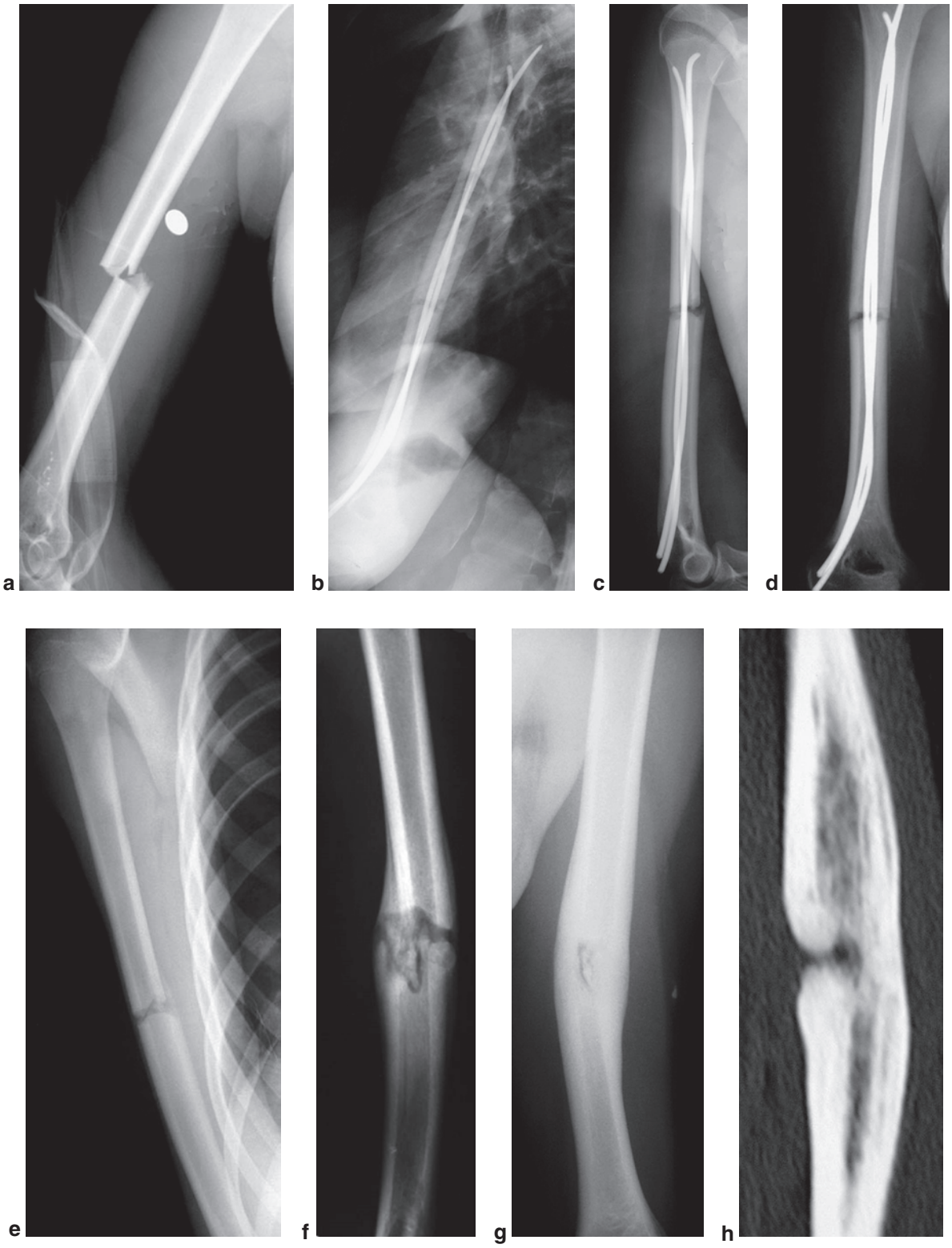
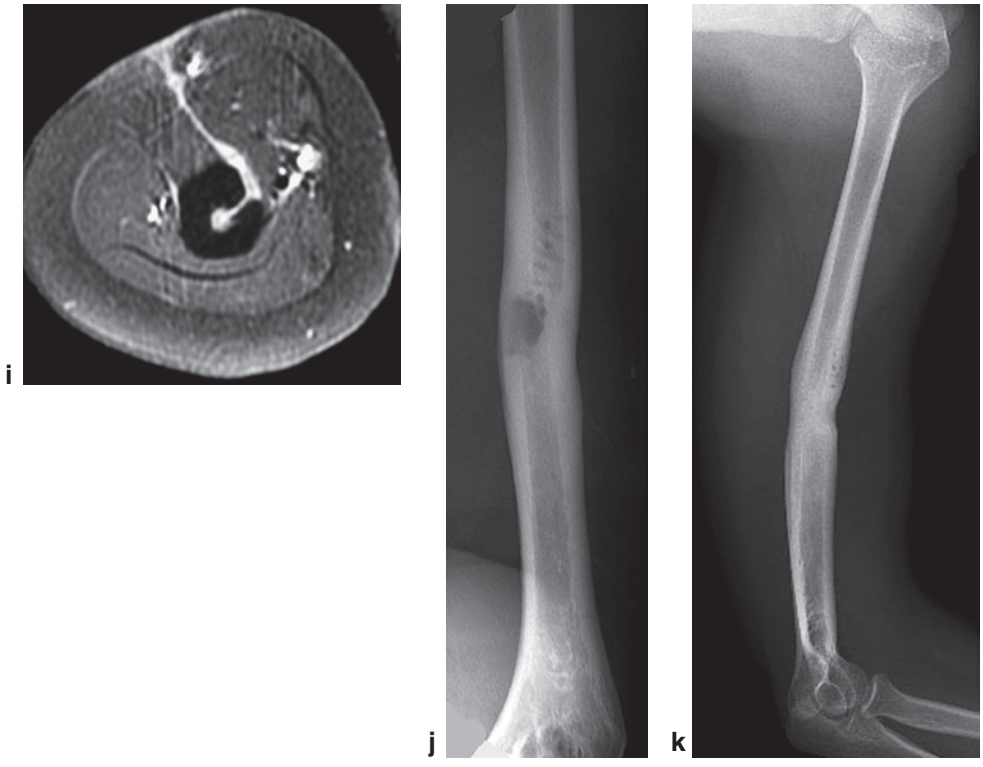


Fig. 13.11 Case 2

Fig. 13.11 (*cont.*) Case 2



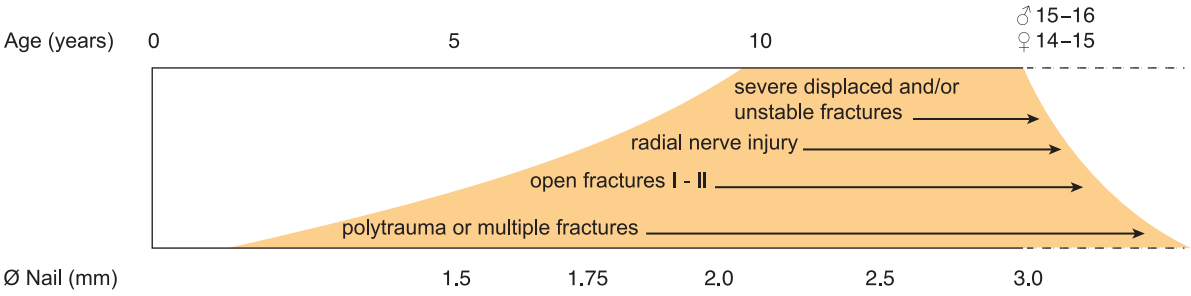
13.7 Six Key Points

- Two 2.5–3 mm diameter nails with curved tips should be used in adolescents.
- FIN is generally performed using a unipolar retrograde technique and a lateral supra-epicondylar approach.
- When crossing the fracture site, the nails should not be directed toward posterior soft tissues to avoid damage to the radial nerve.
- One of the two nails must be rotated 180° to meet the biomechanical principle of FIN, which is based on the symmetrical bracing of two elastic nails.
- The surgeon must be familiar with bipolar retrograde and unipolar antegrade techniques to treat distal-third fractures.
- Careful trimming of nail ends and skin protection are critical.

13.8 FIN and Humeral Shaft Fractures: Postoperative Management in the Absence of Complications

Day 0	• Postoperative AP and lateral radiographs • Vascular and neurologic monitoring • Operated arm is elevated • Pain killers + antiinflammatories
Day 1	• Protective sling; patient is allowed to get out of bed
Days 2–3	• Discharge with instructions • Early return to school • Gentle mobilization of shoulder and elbow, everyday
Three weeks postop.	• Sling removed • Self-rehabilitation
Six weeks to four months postop.	• Clinical and radiological follow-up • Implant removal is considered • Return to sports
One year postop.	• Clinical and radiological follow-up

13.9 FIN Indications: Humeral Shaft Fractures



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