12 Forearm Shaft Fractures

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12.1 Epidemiology

The incidence of radius and ulna shaft fractures out of all fractures of the forearm is 5 %, 19 % proximal radius and ulna (radial head and olecranon) and 76 % are distal radius fractures. The average annual incidence is 91 cases per 100,000 males and 196 cases per 100,000 females.

12.2 Etiology

The most common cause of diaphyseal fractures of the radius and ulna is a fall from standing height (35 %), followed by a direct blow (30 %), sport injuries (8 %), road traffic accidents involving vehicle occupants (4 %), road traffic accidents involving pedestrians (2 %), and a small number resulting from a fall from greater height or other miscellaneous reasons. The majority of fractures (60 %) were Association for the study of Osteosynthesis (AO) type A, that is, simple fractures of the ulna, radius, or both bones; 39 % were of B type and around 2 % were the more complex C type fractures [1].

12.3 Anatomy

Unique demands are made upon the forearm, which must serve the dual purpose of a rotational joint and a bony structure between the elbow and hand. The radius is curved in two planes, which allows for overriding of the ulna without restriction of pronation. Active forearm rotation is produced primarily by four muscles, two originating and inserting in the forearm (supinator and pronator quadratus) and two that cross the elbow joint (ponator teres, biceps). The forearm musculature is commonly considered as three separate compartments based on fascial divisons and nerve supply: the volar or flexor compartment innervated by the median and ulnar nerves, the dorsal or extensor compartment innervated by the posterior interosseous nerve, and the mobile wad of Henry (the brachioradialis and the extensor carpi radialis longus and brevis) innervated by the radial nerve. The divisions between the compartments delineate safe intervals for operative exposure. Anatomical studies suggest that the fascial divisions between these compartments are sufficiently pliant that fascial release of one compartment usually decompresses the remaining two.

12.4 Approaches

12.4.1 Ulna (Fig. 12.1)

The skin incision is on a line between the olecranon and ulnar styloid process. The incision falls in the plane between the medial and lateral posterior cutaneous nerves of the forearm. The dorsal cutaneous branch of the ulnar nerve crosses the extreme distal end of the ulna, running from volar to dorsal, and care must be taken to avoid injuring its branches. The posterior apex of the ulnar shaft defines the plane between the extensor carpi ulnaris innervated by radial nerve and the flexor carpi ulnaris innervated by ulnar nerve.

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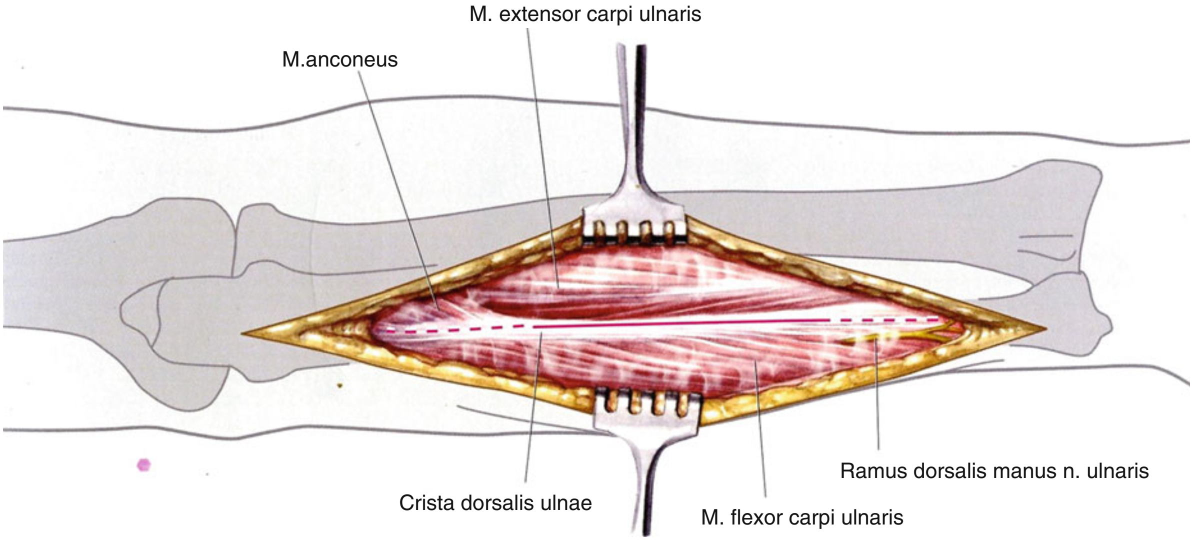

Fig. 12.1 Approach to the ulna. The skin incision is performed 5-mm volar or dorsal of the palpable edge of the ulna on a line between the olecranon and styloid process of the ulna. Between m. extensor and flexor carpi ulnaris a direct approach is made to the bone. Proximally, the anconeus m. must be detached. Care must be taken with the dorsalis manus branch of the ulnar nerve

Proximally, the ulna is exposed by detaching the anconeus. The ulnar nerve and artery lie underneath the flexor carpi ulnaris on top of the flexor digitorum profundus and are easily avoided, provided that elevation of the flexor carpi ulnaris is performed close to the bone and does not stray into its substance [2].

12.4.2 Radius

12.4.2.1 Thompson Approach (Fig. 12.2a–d)

The radial shaft can be exposed through either a dorsal or volar approach. The dorsal approach is commonly referred to by the eponym Thompson, the surgeon who popularized the approach [2].

The skin incision is a line between the lateral epicondyle and dorsal middle of the radius (Lister's tubercle). The elbow is slightly flexed and pronated. The fascia is divided at the radial border of extensor digitorum communis and further preparation is in the interval between this muscle and the extensor carpi radialis brevis. Distally, the abductor pollicis longus and extensor pollicis brevis emerge from between the mobile wad and dorsal compartment musculature in the distal half of the forearm. The fascia are incised at the proximal and distal border of these muscles. The bone is exposed by mobilization and retraction of both crossing muscles. The exposure of the proximal part of the radius requires identification and mobilization of the posterior interosseous nerve, as this nerve may lie almost adjacent to the bone at this level and could potentially be trapped beneath the plate. The posterior interosseous nerve emerges from beneath the superficial and deep heads of the supinator muscle, approximately 1 cm proximal to the distal limit of this muscle. It can be identified at this point and then dissected free from the muscle, preserving its muscular branches. After sufficient proximal mobilization of the nerve, exposure of the radial shaft can be performed by rotating the radius into full supination and detaching the insertion of the supinator from the anterior aspect of the radius [2].

12.4.3 Anterior or Henry Exposure

Exposure of the anterior surface of the radius is both safer and more extensile than a dorsal exposure (Fig. 12.3a–d) [3]. A straight longitudinal incision along a line between the lateral margin of the biceps tendon at the elbow and the radial styloid process at the wrist will afford access to the plane between the mobile wad and the flexor musculature of the forearm. This incision falls roughly between brachial cutaneous nerves. The deep fascia is incised adjacent to the medial border of the brachioradialis and a plane is developed between this radial nerve-innervated muscle and the median nerve-innervated flexor carpi radialis and pronator teres muscles. Dissection is initiated distally and proceeds proximally following the course of the radial artery. Arterial branches to the brachioradialis and the recurrent radial artery arising near the elbow are ligated and the radial artery is mobilized and retracted medially with the flexor carpi radialis

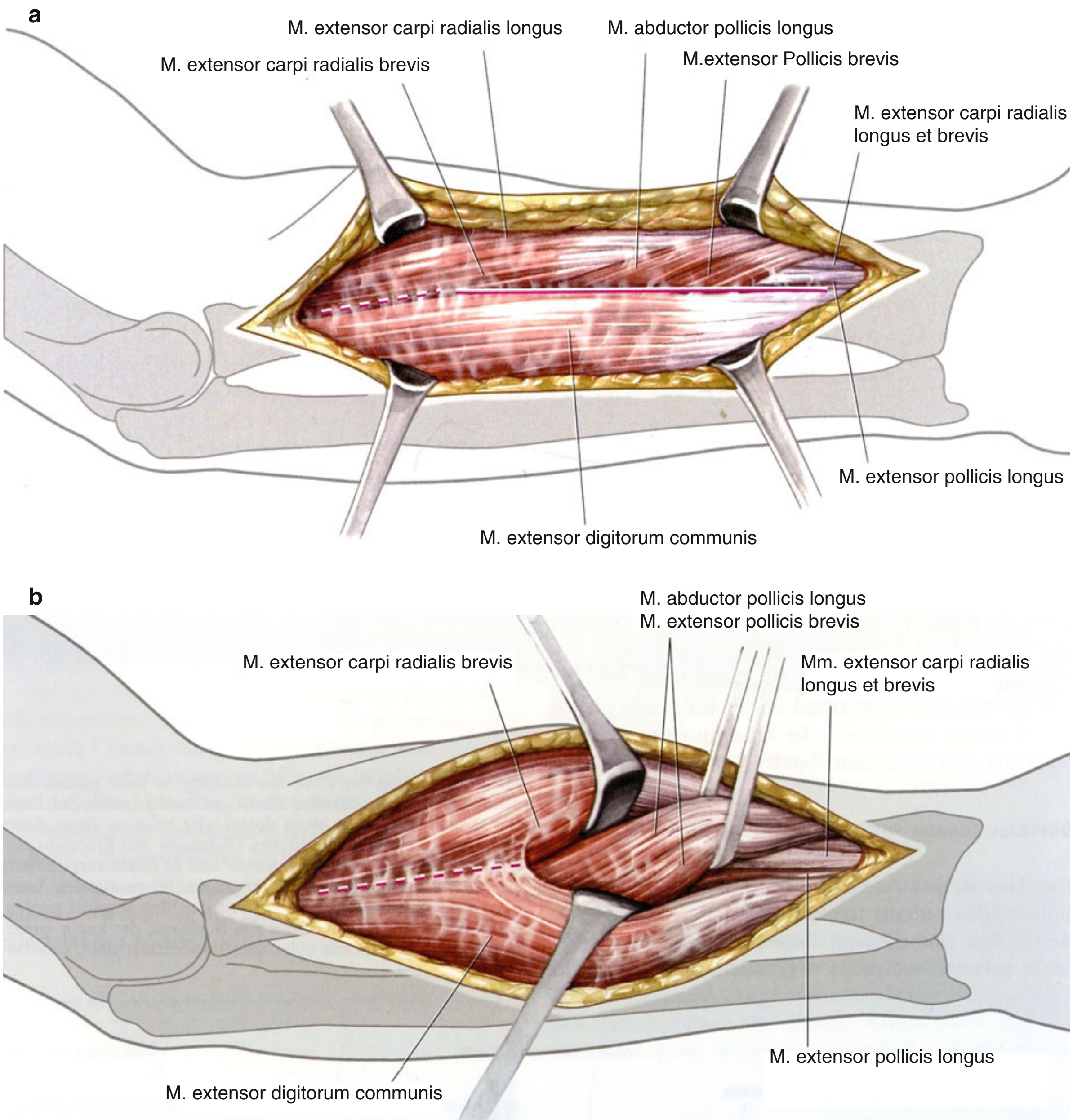

Fig. 12.2 Dorsal approach to the mid- and dorsal part of the radius. The skin incision is on a line between the radial epicondyle and Lister's tubercle. Incision of the fascia is made on the radial border of the extensor digitorum communis muscle and between this muscle and the extensor carpi radialis brevis muscle in the direct approach to the radius (**a**). Under distraction of both these muscles, awareness of the abductor pollicis longus and the extensor pollicis brevis muscle is required. The fascia is incised at the proximal and distal border. Both muscles are mobilized and tied with a loop (**b**). For proximal fractures, the supinator m. Must be identified (**c**). Three transverse fingers away from the radial head, the radial nerve can be felt, which is prepared by splitting of the supinator m (**d**)

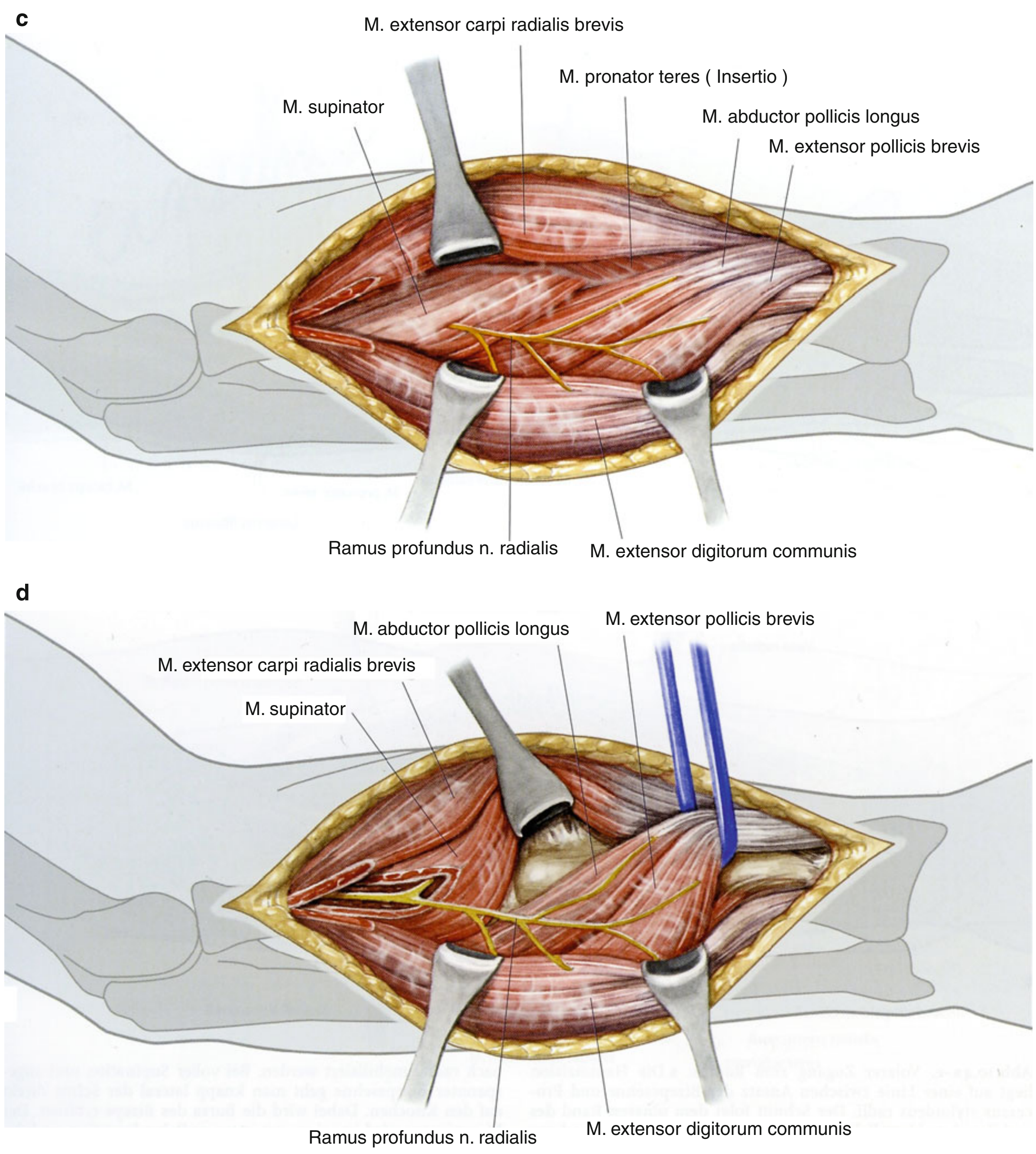

Fig. 12.2 (continued)

muscle. The superficial radial nerve is encountered on the undersurface of the brachioradialis and remains lateral with this muscle [2].

Deep dissection is initiated proximally where the biceps tendon is followed towards its insertion on the bicipital tuberosity of the radius. Full supination of the forearm displaces the posterior interosseous nerve laterally and brings the insertion of the supinator muscle anterior. The insertion of the supinator muscle is identified by the deepening of the muscular plane along the lateral aspect of the biceps tendon. Here, one may encounter a bursa between the biceps tendon and the supinator, which further facilitates this dissection. The posterior interosseous nerve (Fig. 12.4) remains well protected within the substance of the supinator muscle during elevation of its insertion from the radius, provided that excessive lateral traction is not applied.

The insertion of the pronator teres must be detached and the body of the flexor digitorum superficialis elevated in order to expose the midportion of the radius. This is performed by pronating the arm in order to bring the lateral limit of these structures into view.

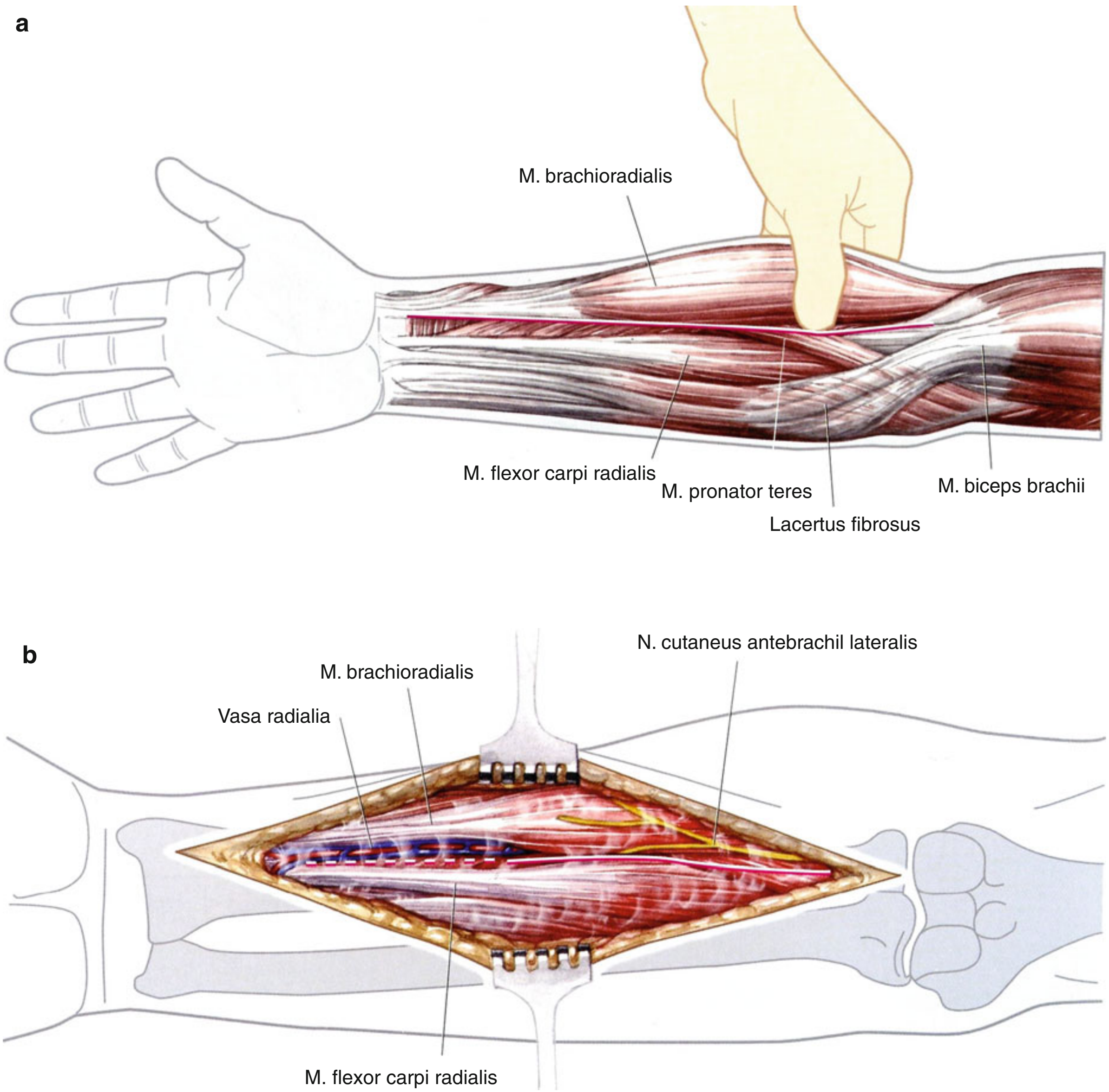

Fig. 12.3 Volar approach to the radius. The skin incision is on a line between the insertion of the biceps tendon and the radial styloid process (**a**). Thereafter, the incision follows the ulnar border of the brachioradialis muscle and the flexor carpi radialis m. Care must be taken of the cutaneous antebrachii n. on the brachioradialis m. (**b**). Mobilization of the of the brachioradial m. towards radial after ligation of braches of the radial artery. Underneath the brachioradialis m., the superficial branch of the radial n. can be seen. Incision of the fascia is at the lateral border of the biceps tendon. Preparation between the biceps tendon and flexor carpi radialis on one side and brachioradialis m. on the other side. Ligation of the radial recurrens artery. In full supination, approach to the radius at lateral border of the biceps tendon. The supinator m. is detached at the radial insertion (**c**). Under pronation, the proximal part of the radius is prepared. The deep branch of the radial nerve is dorsal and lateral. For the approach to the mid- and distal part of the radius, the pronator teres m. and the flexor digit. superfic. m. are detached in full supination (**d**)

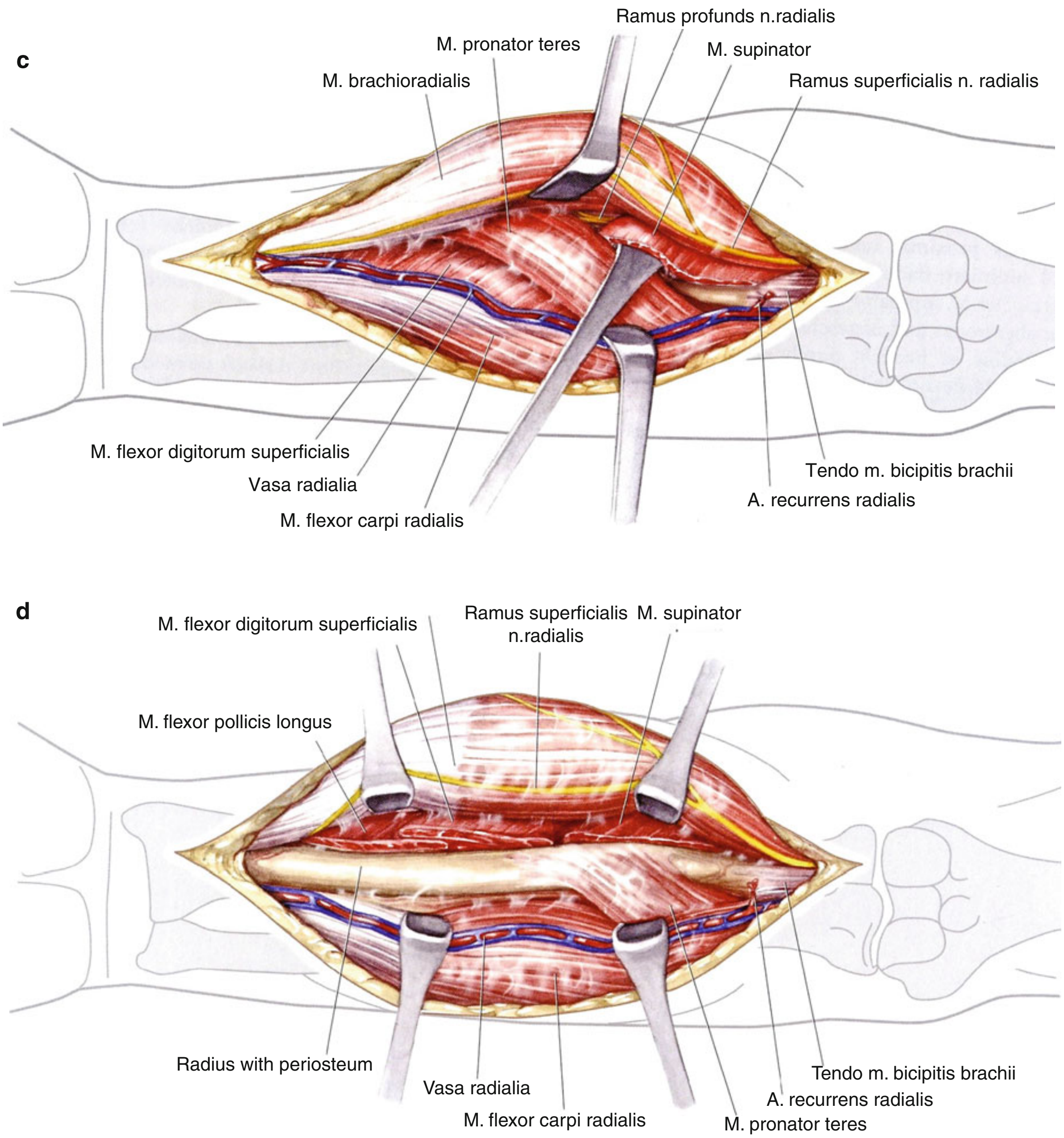

Fig. 12.3 (continued)

12.5 Surgical Technique

Conservative treatment of forearm shaft fractures results in a poor functional outcome, with the exception of the rare case of undisplaced fractures. Therefore, nearly all forearm shaft fractures are indications for plate osteosynthesis and early functional treatment (Fig. 12.5). Tissue of the forearm tends to scar. Therefore, special care of soft tissue is needed: adequate skin incision, indirect reduction when necessary,

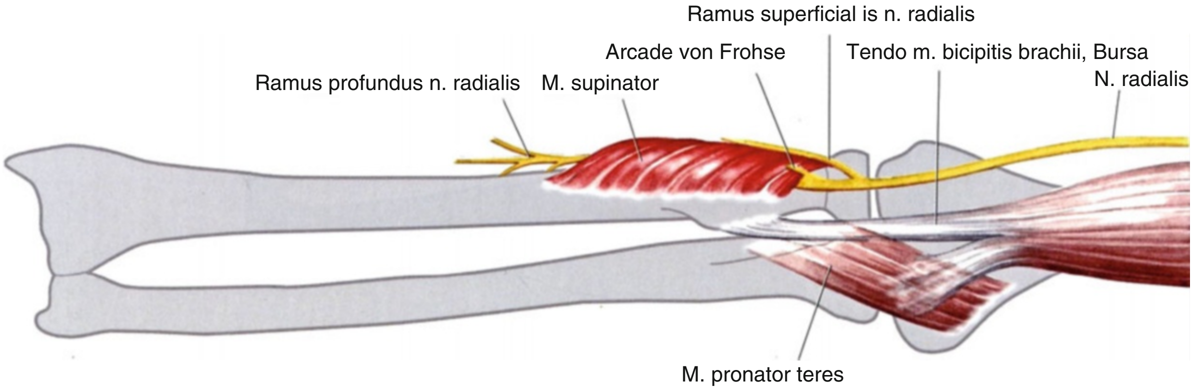

Fig. 12.4 Position of the radial nerve

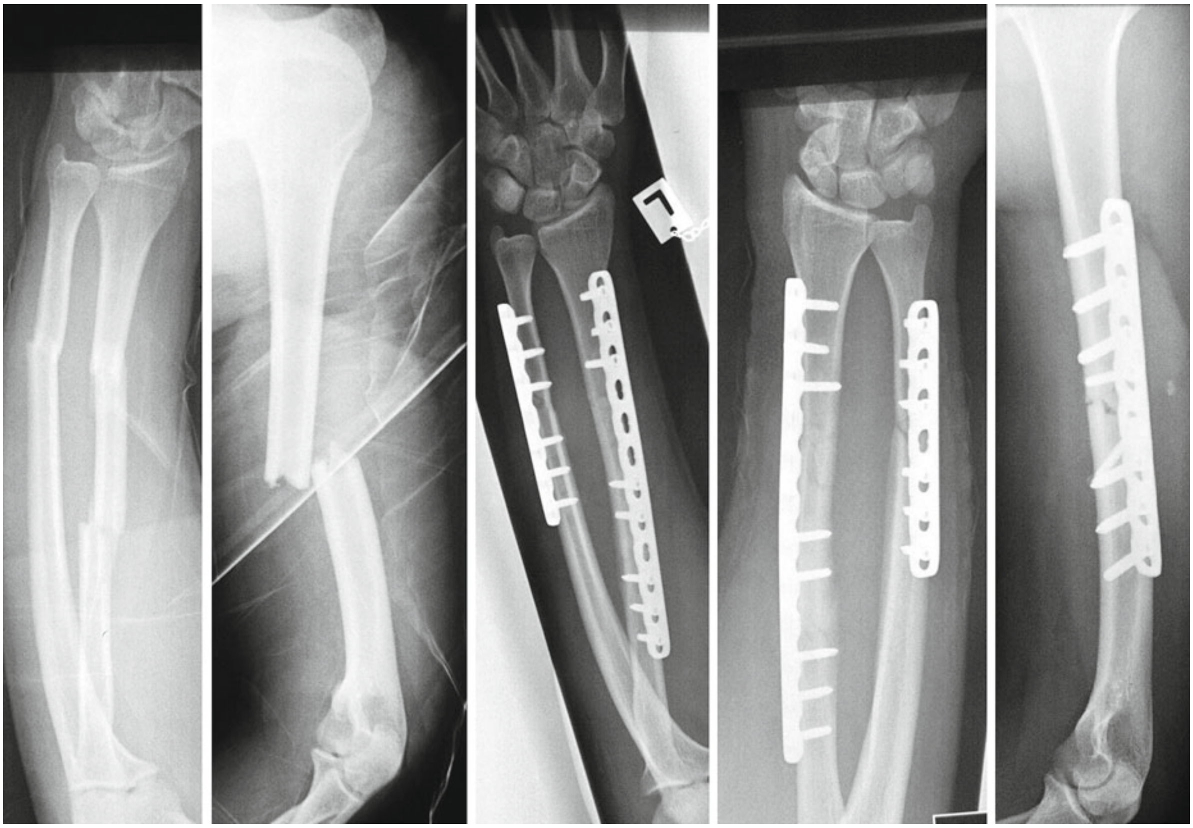

Fig. 12.5 Serial fractures of the humerus, radius and ulna. Plate fixation of all fractured bones in one surgery. X-rays preoperatively and 6 weeks postoperatively

only 2–3 mm dissection of the periosteum, no direct pressure, and denudation by Hohmann retractors. Reduction starts in complete forearm shaft fractures with the least severe fracture in most instances: the ulna.

12.5.1 Reduction Technique

Transverse or short oblique fractures of the radius or ulna are mostly easy to reduce and should always be

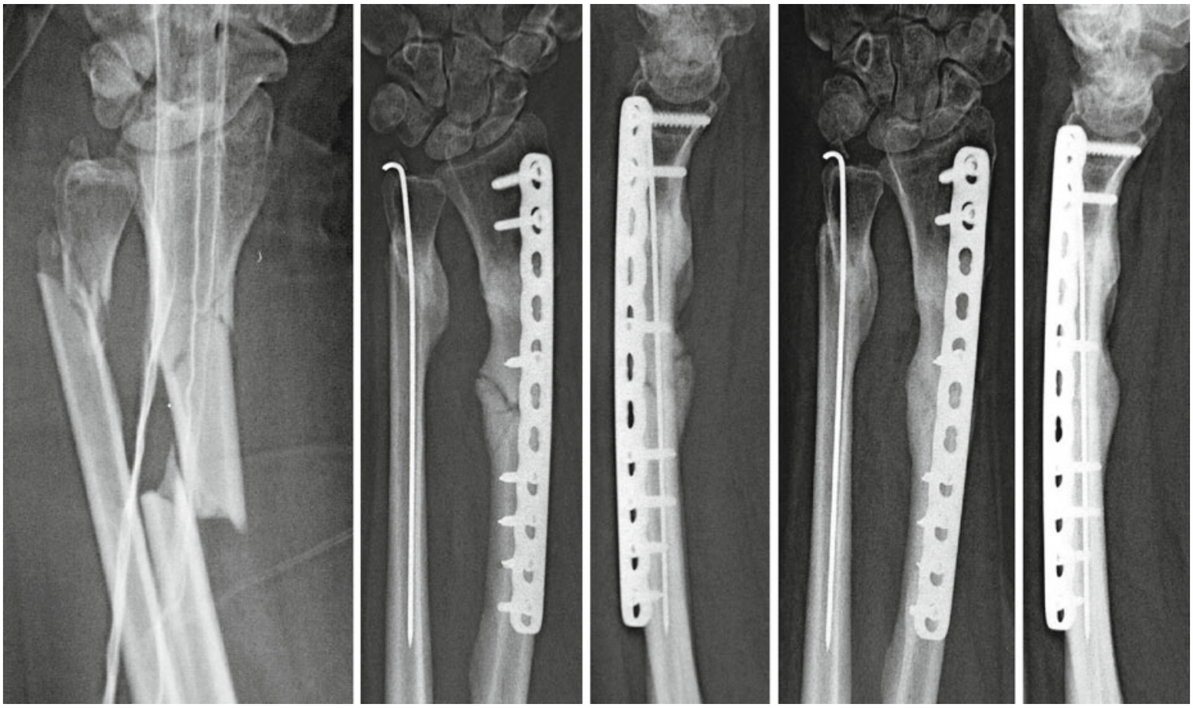

Fig. 12.6 Multiple-injured patient. Segmental fracture of the radius and distal ulna fracture. X-rays 6 weeks and 1 year after accident

approached first. Reduction can usually be obtained by manipulating either fragment with fine-pointed reduction forceps. An alternative is to loosely fix the plate (minimum seven–hole, 3.5-mm limited contact-dynamic compression plate (LC-DCP) or LCP (less contact plate)) with one screw to the main fragment and to subsequently reduce the opposite fragment to the plate. Attention must be paid to any rotational malalignment. We fix simpler fractures initially with a plate and two screws and then approach the other bone with the more complex fracture pattern. Once both bones have been stabilized, pronation and supination are controlled. As soon as there are one or more intermediate fragments, the indirect reduction technique should be applied. Again, usually a long 8- to 10-hole plate is fixed to one main fragment with one screw only. Close to the opposite end of the plate, a 3.5-mm cortical screw is introduced into the other main fragment. With the help of a small lamina spreader, which is placed between that screw head and the free end of the plate, distraction of the fracture can be obtained, thus allowing the fragments to fall into place or to be gently manipulated without stripping their soft tissue attachments. The plate can then be fixed to the bone as a bridge plate, not interfering with the comminuted area at all. If, on the other hand, some larger fragments can be fitted back anatomically, they should be fixed by small interfragmentary lag screws, always from the main fragment, while axial compression may be added by eccentric screw placement. Today, the implant of choice for both forearm bones is the 3.5-mm LC-DCP or LCP (Fig. 12.6).

Autogenous bone grafts are only suggested if there is a substantial bony defect or if the vitality of the fracture zone appears questionable (i.e., too extensive damage or exposure). Bone grafts should not, however, be placed close to the interosseous membrane.

12.6 Galeazzi Fracture

12.6.1 Definition

This uncommon injury involves a fracture of the shaft of the radius at the junction of the middle and distal thirds in association with dislocation at the distal radioulnar joint [4].

12.6.2 Biomechanics

Currently, most favour a mechanism that includes axial loading of a hyperpronated forearm [5]. As displacement continues, the force may be transmitted via the interosseous membrane to the ulna, causing dislocation of the ulnar head and tearing of the triangular fibrocartilage complex, with resultant loss of its stabilizing influence on the distal radioulnar joint [5].

12.6.3 Radiographic Findings

These include:

1. A short oblique fracture of the radius with dorsal angulation as seen on the lateral radiograph
2. Shortening of the radius in relationship to the distal ulna on the anteroposterior radiograph
3. Fracture of the ulnar styloid at its base
4. Widening of the distal radioulnar joint space on the anteroposterior radiograph
5. Dorsal displacement of the ulna relative to the radius, seen best on a true lateral radiograph

The last three findings, if associated with radial shortening of more than 5 mm, are suggestive of traumatic disruption of the distal radioulnar joint [6].

12.6.4 Treatment

Inability to reduce the distal radioulnar joint or its redislocation was originally thought to be an infrequent occurrence. If the distal radioulnar joint is reducible but unstable with forearm rotation, there exist several treatment alternatives. In those cases associated with a fracture of the ulnar styloid at its base, open reduction and internal fixation of the styloid fracture is recommended, using either Kirschner wires in conjunction with a tension band or a small screw.

Should there be no associated ulnar styloid fracture, the distal ulna may be transfixed to the radius using Kirschner wires with the forearm in 40° of supination. In this case, an above-elbow cast is recommended for 6 weeks. The Kirschner wires are removed after 6 weeks [7].

Almost all irreducible distal radioulnar joint dislocations reported to date have been caused by tendon entrapment. The tendons implicated include the extensor carpi ulnaris [8], extensor digiti minimi, or both [9]. In these cases, operative exposure of the distal radioulnar joint is recommended. Through a dorsal approach, the entrapped tendon is elevated, the joint reduced, and, if possible, the triangular fibrocartilage repaired. The forearm should be immobilized in an above-elbow cast for 6 weeks in 40° of supination [6].

12.6.5 Complications

Malunion results most frequently from a combination of the following: (1) inability to restore the radial bow and (2) alteration of location of the maximum radial bow. It has been shown that in patients with a malunion of the radius, there was a change in the magnitude of the radial bow and in its location. Schemitsch and Richards [10] showed that this usually resulted in forearm rotation of less than 80 % of normal with the difference being statistically significant.

12.7 Monteggia Lesion

12.7.1 Definition

In 1814, Giovanni Battista Monteggia described an injury of the forearm in which the proximal ulna fractured and the radial head was dislocated. Since then, this injury has been eponymously associated with his name [11, 12].

12.7.2 Classification

The internationally accepted classification of the Monteggia lesion was devised by Jose Luis Bado [13]. He classified this lesion into four distinct types. Percentages mentioned are those from his series.

Type I: Anterior dislocation of the radial head. Fracture of the ulnar diaphysis at any level with anterior angulation (60 %).

Type II: Posterior or posterolateral dislocation of the radial head. Fracture of the ulnar diaphysis with posterior angulation (15 %).

Type III: Lateral or anterolateral dislocation of the radial head. Fracture of the ulnar metaphysis (20 %).

Type IV: Anterior dislocation of the radial head. Fracture of the proximal third of the radius. Fracture of the ulna at the same level (5 %).

12.7.3 Mechanism of Injury

The different types of Monteggia lesions reflect different mechanisms of injury.

12.7.4 Clinical Features

The feature common to all types of Monteggia injuries is the degree of pain about the elbow and a mechanical block to forearm rotation. Assessment of the patient's neurological status is of paramount importance. The posterior interosseous nerve is the nerve most frequently reported to be involved.

12.7.5 Radiological Features

A line through the radial shaft and head should intersect the capitellum for any position of the elbow [14].

12.7.6 Methods of Treatment

While it is accepted that pediatric lesions often only require manipulative reduction and a cast, it is also agreed that adult lesions are an entirely different entity and the results of manipulative reduction prove unsatisfactory. The method of choice is careful reduction of the ulna and fixation by a plate. If the ulna is in a correct length, the radial head is reduced in most cases. Rarely, the radial head must be exposed and open reduced.

12.7.7 After Treatment

A cast is not necessary and movement is started immediately.

12.8 Essex-Lopresti Lesion

12.8.1 Description

Radial head fractures are associated with injury to the interosseous membrane and disruption of the distal radioulnar joint [15].

12.8.2 Mechanism of Injury

Most of these injuries are caused by a fall onto the outstretched hand with the forearm pronated. In this position, it is possible to disrupt the distal radioulnar joint as well as the interosseous membrane. In addition, the degree of radiocapitellar contact is high in pronation [16]. The axial force is therefore transmitted to the radial head, which abuts against the capitellum leading to fracture of the radial head [15, 17–19]. With sufficient force, the fracture fragments are displaced, and because of the concomitant disruption of the distal radioulnar joint and interosseous membrane, the radius will have a tendency to migrate in a proximal direction.

12.8.3 Clinical Presentation

Symptoms and signs at the elbow are similar to those of radial head fractures. Any evidence of instability of the ulnar head or asymmetric prominence of the ulnar head should be suggestive of acute disruption of the distal radioulnar joint. In addition, alteration of the normal relationship between the radial and ulnar styloid processes (as compared to the normal side), restriction of ulnar deviation at the wrist, or swelling of the forearm are corroborative of distal radioulnar joint injury and suggestive of an unstable forearm with the potential for proximal radial migration.

12.8.4 Radiographic Examination

It is imperative that all cases of comminuted radial head fractures should have the wrist examined radiographically.

A posteroanterior projection and a zero-rotation lateral projection as described by Epner [20] are extremely helpful in accurate determination of any proximal radial migration. Corroborative evidence may be gained by similar views of the contralateral wrist, which will provide information regarding the patient's normal ulnar variance. The upper limit of proximal migration of the radius during normal rotation of the forearm has been shown by Morrey et al. [21] to be 2 mm.

12.8.5 Treatment

The goals of treatment include restoration of radial length and stabilization of the distal radioulnar joint. This will depend to a large degree on the type of radial head fracture. Stability of the distal radioulnar joint must be tested. If stable, then external immobilization in supination should be extended for 4 weeks. If the ulnar head is not stable after reduction, it may be pinned to the radius with the forearm in 40° of supination for a similar period of 4 weeks, after which the pin is removed and forearm rotation is commenced.

12.8.6 Complications

Complications associated with the Essex-Lopresti lesion can be divided into those resulting from the severe radial head fracture alone and those resulting from its excision and instability of the forearm articulation [22]. Among the most troublesome complications are proximal radial migration, restriction of forearm rotation, and wrist pain associated with considerable loss of grip strength. In addition, excision of the radial head may be associated with valgus instability of the elbow [19] and heterotopic bone formation. Failure to achieve accurate reduction and fixation of the radial head or an untreated fracture of the radial head can lead to both post-traumatic arthritis and stiffness of the elbow.

12.9 Complications [23]

12.9.1 Compartment Syndrome

12.9.1.1 Incidence

Gunshot fractures of the forearm are particularly prone to compartment syndrome. Moed and Fakouri [24] recorded a 15 % overall incidence among 60 gunshot fractures of the forearm. Comminuted and severely displaced fractures are commonly associated with compartment syndrome.

12.9.1.2 Treatment

Release of the volar compartment is achieved via an incision that begins proximal to the humeral epicondyles, crosses the antecubital fossa obliquely, releasing the lacertus fibrosis, and then takes either a straight course down the ulnar aspect of the forearm (e.g., McConnell's combined exposure of the ulnar and median nerves as described by Henry [3]) or a curvilinear course over the mobile wad. With either approach, the incision then returns to the midline and crosses the wrist crease, ending in the mid-palm and allowing release of the carpal tunnel and Guyon's canal [3, 25]. This fasciotomy can be accomplished as a part of Henry's anterior exposure of the radius during open reduction and internal fixation [3]. If the compartment syndrome has progressed to include median nerve weakness, Gelberman et al. [25, 26] suggest exploring and releasing the nerve where it dives beneath the pronator teres and flexor superficialis muscles. Following volar compartment release, dorsal pressures are measured, and if they are still elevated, the dorsal compartment is released via a midline longitudinal incision.

12.9.2 Infection

When infection occurs, its eradication is not necessarily dependent upon implant removal. In early cases, as long as all bone fragments and soft tissues are well vascularized, stable internal fixation will facilitate wound care and help maintain length and alignment, as well as range of motion and overall function, without hindering treatment of the infection. Following successful eradication of the infection (with organism-specific antibiotics, debridement, and irrigation), the wound can be drained and closed.

In delayed cases, if bone debridement results in a substantial gap, this can be temporary filled with antibiotic beads. Vacuum sealing may be necessary in severe infections. Autogenous cancellous bone graft from the iliac crest or other sites may be added at the time of secondary wound closure. Bone loss is also common in gunshot fractures; early cancellous bone grafting in conjunction with stable plate fixation has been found to be effective. On the other hand, an external fixator may be the implant of choice in cases of severe infection or gunshot wounds, followed by plate fixation, according to soft tissue and bone conditions after 1–2 weeks.

12.9.3 Nonunion

12.9.3.1 Hypertrophic

Recommendations include the use of 3.5-mm dynamic compression plates or LCP applied in the compression mode to appropriate transverse and oblique fractures. In general, fixation to a minimum of eight cortices (four bicortical screws) on either side of the fracture is requisite in most cases [27].

12.9.3.2 Atrophic

In cases with atrophic nonunion comminution or bone loss, 10- or 12-hole plates should be utilized in conjunction with immediate autogenous iliac crest cancellous bone grafting. The current rate of nonunion is less than 2 % when proper technique is utilized in compliant patients [28]. Patients with stable plate and screw fixation are mobilized almost immediately postoperatively. Nonunions are ascribed to technical errors such as the use of plates of inadequate length, inadequate reduction, and failure to bone graft comminuted fractures.

12.9.4 Malunion

Failure to restore the location and magnitude of the radial bow to within 4–5 % of that of the normal arm was associated with greater than 20 % loss of forearm rotation. Grip strength was also reduced in malunited fractures. Dependent on the complaints of the patient, correction osteotomy must be performed.

12.9.5 Synostosis

Recent documentation of the local and systemic risk factors for the development of synostosis (including high-energy traumatic injury with soft tissue damage, fracture comminution, dislocation of adjacent joints and/or wide displacement of fracture fragments, prolonged immobilization and associated head injury, multitrauma, or burns) has illustrated the numerous similarities between this entity and heterotopic ossification. Post-traumatic radioulnar synostosis is more common with fractures of the radius and ulna at the same level [29, 30] and delayed internal fixation [31]. It occurs more commonly in the proximal and midforearm than in the distal forearm [32, 33].

12.9.5.1 Treatment

Suggested treatment consists of resection of the synostosis with interposition of various materials intended to discourage recurrence (silastic, muscle, or fat) [33–35]. Resection is associated with a risk of damage to neurovascular structures, especially in the proximal third of the forearm [33]. The overall reported recurrence rate following resection is approximately 30 % [33]. Noting the similarities between post-traumatic radioulnar synostosis and heterotopic ossification, postoperative radiation treatments have been attempted with some success in preventing recurrence [36, 37]. To this end, nonsteroidal anti-inflammatory agents (such as indomethacin) and frequent, early range of motion exercises may also be useful [22].

The timing of surgery is critical. With regard to heterotopic ossification of the hip and elbow, delayed intervention is most commonly advised to allow for the maturation of the new bone in the hope that this will decrease recurrence rates. However, the accepted measures of bone maturity (serum alkaline phosphatase level, radiography, and bone scanning) are of limited reliability, and excessive delay can lead to contraction of soft tissues with resultant limitations in maximal recovery of range of motion and function.

The difficulties of successful treatment of synostosis emphasize the importance of preventing this complication. Surgeon-related risk factors include violation of the interosseous space either by surgical exposure [33, 38] or via a screw of excessive length [33, 39], and placement of bone graft on the interosseous membrane [33]. Proper, stable internal fixation with early motion should help limit the occurrence of synostosis to patients with substantial risk factors such as brain injury.

12.10 Refracture

The risk of refracture following plate removal is believed to result from a combination of incomplete healing and osteoporosis that occurs under a plate as a result of some combination of disruption of the vascular supply to the bone and stress shielding. Animal experiments suggest that refracture may occur because the screw holes diminish energy absorption by 50 %. Risk factors for refracture following plate removal include fracture comminution and inability to gain compression of fracture fragments [2, 40, 41].

It is recommended that forearm plates remain in place unless (1) they cause local symptoms (e.g., tenosynovitis) or (2) the patient is an athlete returning to high-energy activities, in which case the ends of the plates might be expected to act as stress risers and increase the risk of fracture. On the basis of the existing literature, the risk of refracture following plate removal can be expected to be minimal if fractures are fixed with 3.5-mm LC-DCP or LCP, the plates are not removed until at least 2 years following the original injury (perhaps longer in cases in which the fracture was comminuted), and patients are advised to avoid high-energy activities for at least 2–3 months. If both bones are fractured, sequential removal with a time interval can reduce the refracture rate. Exact preoperative X-rays in four planes and, if uncertainty regarding bone healing exists, a CT are necessary.

12.10.1 Treatment

Treatment entails reosteosynthesis, either with LCP or LC-DCP. Additional bone grafting might be necessary in some cases.

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