

Traumatic disorders of forearm rotation: anatomy, biomechanics and treatment

The forearm is a complex structure which produces a wide range of movement. Forearm injuries are very common, but many injuries are missed or poorly treated. This article examines the anatomy and biomechanics of the forearm, and describes the important injuries to be recognized.

Injuries to the wrist and forearm are among the more common presentations to emergency departments, orthopaedic clinics and sports physicians. A spectrum of severity exists, and many of the more sinister injuries are missed, resulting in considerable functional loss. The forearm is a complex structure, coordinating a number of joints to produce a wide range of movement. By acting as an intermediate between the humerus and the wrist, the forearm gives additional degrees of freedom to the upper limb as a whole, enabling control of positioning and rotation while carrying out simple tasks. Rotation of the forearm is instrumental in the optimal function of the upper limb. For example, grasping objects and manoeuvring them with the hand requires a degree of forearm pronation in addition to wrist flexion or extension, while feeding and performing other simple lifting tasks requires a degree of forearm supination. Disorders of forearm rotation may consequently have considerable detrimental effects on activities of daily living and working life.

A range of disorders is recognized which affect pronosupination of the forearm. They can be broadly classified into traumatic, degenerative and congenital. An abnormality of one or more of the bony or soft tissue elements within the forearm unit may affect either pronation, supination or both. This article discusses the pathoanatomy of the forearm unit, with reference to the distal and proximal radioulnar joints and the interosseous membrane, and reviews the common traumatic conditions seen in the emergency department and orthopaedic clinic which, if missed or are poorly treated, may result in significant functional disability.

Pathoanatomy of the forearm

The forearm unit consists of the radius, the ulna, and their proximal and distal articulations, the proximal radioulnar joint and the distal radioulnar joint. The proximal end of the radius is much narrower than its

distal end, which flares transversely to form the radial styloid process at its distal, lateral tip, with the sigmoid notch of the distal radioulnar joint at the ulnar margin of the metaphysis. Cross-sectionally, the shape of the radius changes from a circular cylinder to a prismatic-triangle, which is concave towards the ulna and becomes broader distally, where it is quadrilateral in cross-section (Hsu et al, 1993). The anterior bow of the radius enables rotation around the ulna during pronosupination, and in its distal third lies parallel to the axis of rotation, which is about a line between the radial head and the ulnar head. The proximal radioulnar joint and distal radioulnar joint are both uniaxial pivot-type synovial joints, which act to allow a degree of rotation of the radius around the ulna, while between these two articulations, in the elliptical gap between the ulna and radius, sits the interosseous membrane. This structure has a range of functions including force transmission, and tethers the radius and ulna at the proximal radioulnar joint, and distally along the length of the ulna.

It is generally accepted that approximately 85° of pronation and 75° of supination are considered to be normal, functional ranges of rotatory forearm movement. For basic activities of daily living, 50° of pronation and supination are considered adequate. It has also been suggested that a loss of 20° in either pronation or supination is considered acceptable, as movements at the shoulder can compensate for a loss of both pronation and supination so that global limb function is not compromised. Disorders which result in disruption of the forearm unit can have a deleterious effect on its ability to rotate, which can therefore have a considerable effect on the overall functionality of a limb.

Anatomy of the distal radioulnar joint

The distal radioulnar joint comprises the articulation between the ulnar head and the sigmoid notch of the radius. Intrinsic stabilizers of the distal radioulnar joint include the triangular fibrocartilage complex, volar and dorsal radioulnar ligaments, the joint capsule itself, and the ulnar collateral ligament (Stuart et al, 2000). Furthermore, the morphology of the sigmoid notch itself contributes roughly 20% stability of the distal radioulnar joint; the larger diameter of the sigmoid notch relative to that of the ulnar head causes a shallow concavity, allow-

Dr Nisarg Mehta is Foundation Year 1 Trainee, Wirral University Teaching Hospital NHS Trust, Liverpool, **Mr Robert J MacFarlane** is Specialty Registrar in Trauma and Orthopaedic Surgery in the Department of Orthopaedics and **Mr Daniel Brown** is Consultant Hand and Wrist Surgeon in the Liverpool Upper Limb Unit, The Royal Liverpool University Hospital, Liverpool L7 8XP

Correspondence to: Mr RJ MacFarlane (robert.macfarlane@doctors.org.uk)

ing the ulna to translate both volar and dorsally during pronosupination, allowing crossing over of the radius upon the ulna. The mean ulnar head translation in pronation is 2.8 mm dorsally, while during supination it translates 5.4 mm volarly (Baeyens et al, 2006) (Figure 1).

Anatomy of the proximal radioulnar joint

The proximal radioulnar joint comprises the radial notch of the ulna, adjacent to the coronoid process, and the radial head. The head of the radius rotates within a recess formed by the radial notch and the annular ligament. The strong annular ligament attaches to the anterior and posterior margins of the radial notch and surrounds the radial head, providing stability during forearm rotation by keeping the radial head in contact with the ulna. Other ligaments contributing to proximal radioulnar joint stability include the accessory lateral collateral ligament (Figure 2), which acts to stabilize the annular ligament during varus stress, and the quadrate ligament, which covers the inferior margin of the annular ligament and inserts onto the ulna (Kaplan and Spinner, 1970).

Anatomy of the interosseous membrane

In simple terms, the interosseous membrane is a fibrous septum located between the radius and ulna consisting of a proximal and distal membranous portion and a much thicker central band. Additional accessory bands within this structure are less substantial and vary in their number and thickness. The interosseous membrane arises on the radius and extends distally and obliquely to insert at the distal 25% of the ulna, with the mean length at the radial and ulnar insertions reported to be 10.6 cm (McGinley and Kozin, 2001) (Figure 3).

The interosseous membrane has a range of functions which include forearm stability, provision of a tendinous sheet for deep extensor and flexor muscle attachments, a reducing structure in the event of bone separation, and load transfer. The central band, which provides 71% of longitudinal stability, is the major contributing structure to interosseous membrane stability (Moritomo, 2012).

What are the biomechanical principles of forearm rotation?

It is well recognized that the radius, rotating around the ulna about an oblique longitudinal axis, mediates forearm rotation. The distal pole of this axis intersects the transverse plane of the articular pole close to the fovea. Thus if the axis of the two forearm joints are not aligned coaxially, forearm rotation will be blocked (Morrey and Chao, 1978). The clinical implications are therefore considerable, with disruption of the forearm unit or alteration of the rotational axis potentially resulting in significant functional impairment.

The distal radioulnar joint promotes rotational and sliding movements between the ulna and radius, which is guided by the triangular fibrocartilage complex and other

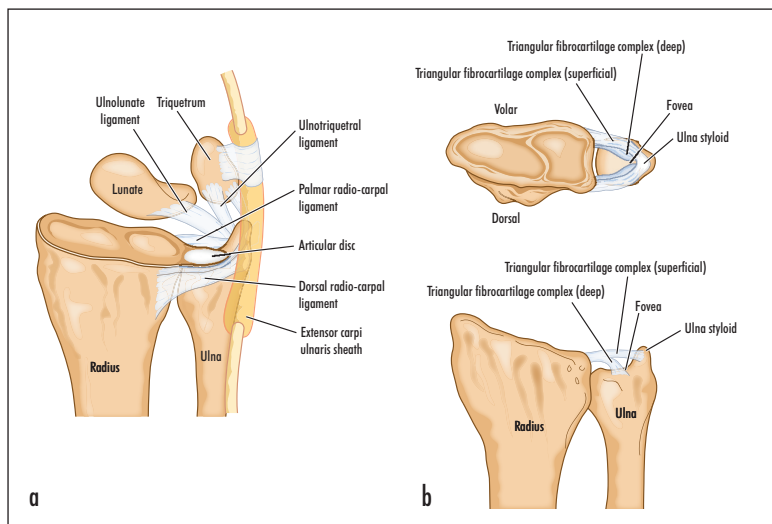


Figure 1. a. Anatomy of the distal radioulnar joint showing the triangular fibrocartilage complex. b. Deeper ligaments of the distal radioulnar joint.

Figure 2. The stabilizing ligaments of the proximal radioulnar joint. The radial collateral ligament and the annular ligament are the two main stabilizers.

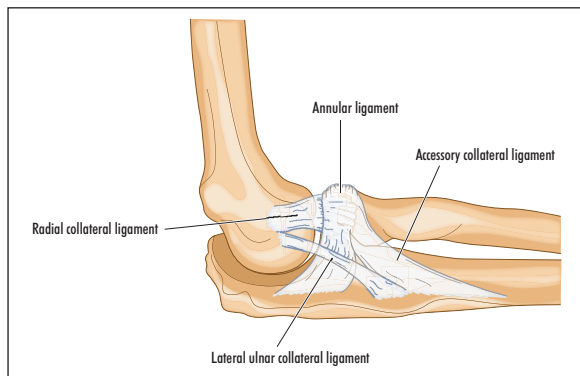
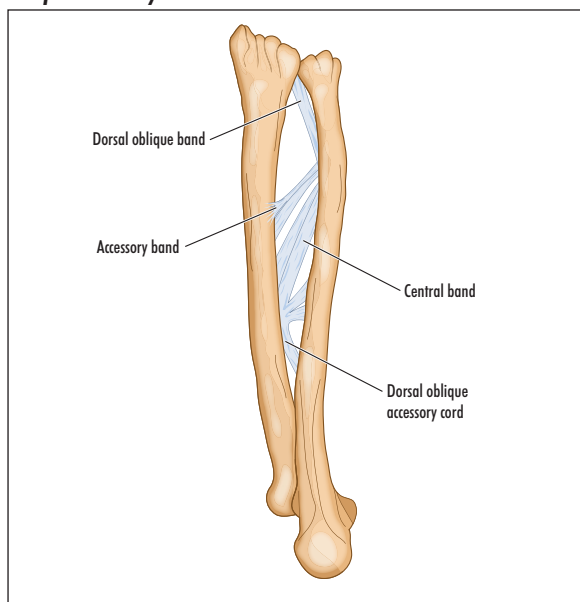


Figure 3. Components of the interosseous membrane including dorsal oblique band, accessory band, central band and dorsal oblique accessory cord.



soft tissues (Nagata et al, 2013). The superficial dorsal fibres, which include the dorsal radioulnar ligament of the triangular fibrocartilage complex, provide dorsal stability in pronation and palmar stability in supination. At the wrist joint approximately 20% of the load-bearing force is transmitted proximally via the ulna, whereas 80% is transmitted by the radius (Kapandji, 2001). These figures vary depending on the degree of ulnar variance (the length of the ulna compared with the radius), with negative variance leading to an increase in radiocarpal load bearing. At the radiocarpal joint, load transmission is reported to be 55% through the radiosaphoid and 35% through the radiolunate joints, while the remaining 10% passes through the interosseous membrane (Cooney et al, 1995). Subsequently, the interosseous membrane transfers this force between the radius and the ulna, while also providing longitudinal stability at the proximal radioulnar joint during load-bearing tasks (An and Werner, 1994). The interosseous membrane has an important role in force transmission as well as maintenance of forearm stability during load-bearing tasks. At the level of the elbow, when it is in an extended position, 60% of the load is transmitted via the radius and 40% via the ulna, and this distribution changes depending on the degree of elbow flexion.

Management of common forearm injuries affecting rotation

Assessment and imaging of forearm injuries

Forearm injuries affecting rotation require a systematic assessment to gauge severity and identify associated injuries. Following a thorough history, clinical examination and radiological investigations form the mainstay of assessing forearm injuries. The whole limb should be closely examined to evaluate the site of pain, soft tissue integrity, deformity, joint instability and neurovascular status. Plain radiographs of the wrist and forearm should be obtained including posteroanterior, lateral and, if necessary, oblique views (Kennedy and Hanel, 2013). If proximal injury is suspected, radiographs of the elbow should also be obtained. Stress radiographs may be helpful in assessing fracture fragments and patterns of instability.

Computed tomography may be used to improve fracture visualization, particularly useful in assessing intra-articular injuries of the distal radius or elbow, and aids preoperative planning. Axial views are particularly useful for visualizing the distal radioulnar joint and are useful in identifying subluxations or frank dislocations in addition to bony fragments suggestive of avulsions. Magnetic resonance imaging is generally used in cases where soft tissue injury is suspected (Chen and Jupiter, 2007).

Distal radius fracture

Distal radius fractures are the most common fractures seen in emergency departments, and the incidence of these injuries is rising with the overall increase in life expectancy.

A multicentre prospective study estimated the incidence of distal radius fractures to be 36.8/10 000 person years in women and 9/10 000 person years in men (O'Neill et al, 2001). There is a bimodal distribution of distal radius fractures: younger patients who sustain high energy trauma and elderly patients who sustain both high energy and insufficiency fractures (Chen and Jupiter, 2007).

Treatment is with closed reduction and casting, with wire insertion for unstable injuries, or open reduction and internal fixation for injuries which are unstable, complex or intra-articular. Despite a shift towards internal fixation with the advent of anatomical volar plate devices, the efficacy of this over other, simpler methods of treatment is still debated. A Cochrane review found no evidence favouring one method of fixation over another (Handoll et al, 2008). In general, attention to the radial length and inclination, and reduction of radially translated metaphyseal fragments, is important in restoring the anatomy of the sigmoid notch, to enable congruent distal radioulnar joint.

Distal radius fracture displacement tends to affect pronation more than supination and increasing dorsal angulation results in an increased torque, especially at the extremes of pronation and supination. In one study, a significant loss of rotation was not noted until 20° of dorsal angulation was combined with 10 mm dorsal translation (Fraser et al, 2009). A significant loss of forearm rotation can be expected if the distal radius fracture displacement reaches 30° of dorsal angulation or 10 mm of dorsal translation. An isolated dorsal angulation of 30° was associated with a significant loss of pronation but not supination; however, when dorsal angulation was combined with radial shortening, significant loss in pronation occurred at angles <30° (Fraser et al, 2009).

Distal radius fractures tend to cause rotational deficits as a result of distal radioulnar joint instability. Injuries to the distal radioulnar joint may occur in isolation or in the context of distal radius fractures, taking the form of instability, incongruity or late arthrosis. Patients often present with ulnar-sided wrist pain which, alongside stiffness in pronosupination following a distal radius fracture, suggests distal radioulnar joint involvement. The incidence of triangular fibrocartilage complex injuries following distal radius fractures ranges between 45 and 65% (Schneppendahl et al, 2012) and treatment of triangular fibrocartilage complex injuries begins with non-surgical measures (splinting or cast, modification of activity, and physical and/or occupational therapy). Failed conservative treatment or gross instability (e.g. in distal radius fracture-associated ulnar styloid fracture) warrants surgical intervention, which can be performed open or arthroscopically (Thomas and Sreekanth, 2012). In cases of significant instability of the distal radioulnar joint as a result of soft tissue disruption following internal fixation of distal radius fractures, kirschner wire fixation of the distal radioulnar joint with or without repair of the triangular fibrocartilage complex may be indicated (Nagata et al, 2013).

Galeazzi fracture–dislocation

Galeazzi described a fracture-dislocation of the forearm unit, characterized by fracture of the radius in its middle or distal third, with an associated dislocation of the distal radioulnar joint (Atesok et al, 2011) (*Figure 4*). Although the incidence of injury is low, the outcome can be extremely disabling. The disruption of the capsule and the volar and/or dorsal radioulnar ligaments renders the distal radioulnar joint unstable in many cases, and although adequate anatomical reduction of the radial bow is often achieved, distal radioulnar joint instability can be missed. It is important to test the distal radioulnar joint following internal fixation of the radius and, if necessary, screen the distal radioulnar joint under fluoroscopic control. Limitation to forearm rotation is common following this injury, as well as wrist pain and decreased strength (Mikic, 1975; Atesok et al, 2011). Radial shortening is observed in these fractures, as a result of muscular pull following distal radioulnar joint disruption. The distal membranous portion of the interosseous membrane is frequently injured, but the central band remains intact, preserving longitudinal forearm instability (Moore et al, 1985).

Isolated distal radioulnar joint injury

Other injuries affecting the distal radioulnar joint may compromise pronosupination. These include an isolated distal radioulnar joint dislocation and fractures of the radius with an intra-articular component causing arthritis of the distal radioulnar joint. Subluxation of the distal radioulnar joint following malunion of distal radial fractures may result in activity-related clunking and pain during rotatory movements, a restriction in pronosupination, or both. There is also evidence that instability of the distal radioulnar joint may cause an ulnar neuropathy as a result of subluxation of the ulnar nerve in association with ulnar head movement (Malone et al, 2012). Malunited distal radius fractures may be successfully treated by extra-articular osteotomy, with various authors reporting improved forearm rotation and functional outcomes following distal radius osteotomy, with restoration of radial length and articular tilt, and congruity of the distal radioulnar joint (Malone et al, 2006).

In isolated distal radioulnar joint injury, usually following a fall onto an outstretched hand or forced rotation of the forearm, reconstruction of the distal radioulnar ligaments has shown promising results. Using a palmaris longus tendon graft passed through bone tunnels adjacent to the sigmoid notch and through the ulnar head, Adams and Berger (2002) reported stability and pain-free pronosupination in 12 out of 14 patients followed up for between 1 and 4 years.

In the absence of distal radioulnar joint degeneration, malunion of a fracture involving the distal radioulnar joint can be treated with intra-articular corrective osteotomy, but in the presence of significant joint degeneration, surgical options include the Sauvé–Kapandji procedure (George et al, 2004), Darrach's procedure (Minami

et al, 2005), hemiresection and partial ulnar head replacement (Minami et al, 2005), or total joint replacement (Stanley and Herbert, 1992). Grawe et al (2012) demonstrated reliable long-term results for treating a symptomatic distal radioulnar joint after distal radius fractures using the Darrach procedure with excellent forearm range of motion at long-term follow up.

'Nightstick' fractures of the ulna

'Nightstick' fractures – isolated diaphyseal fractures of the ulna as a result of direct blunt trauma – traditionally occur with the forearm raised to shield a blow, e.g. from a truncheon or nightstick carried by policemen. Angulation of 10° in any plane and <50% displacement is considered acceptable and is not associated with significant reduction in forearm rotation (Zych et al, 1987). These fractures are associated with a high rate of complications such as impaired forearm rotation and function, non-union with a reported incidence of 1–12%, delayed union and mal-union (Handoll and Pearce, 2012).

Traditionally these injuries have been managed in an above elbow cast to eliminate forearm rotation and elbow flexion or extension. A Cochrane review (Handoll and Pearce, 2012) showed a trend towards a greater non-union rate with above elbow casts, which may be attributed to the splinting role of the interosseous membrane, although further work is needed to support this hypothesis. Displaced ulnar shaft fractures are generally treated by open reduction and internal fixation using a dynamic compression plate.

Radius and ulnar shaft fractures

Isolated radial shaft fractures (proximal two-thirds) are far less common than distal radius fractures and occur from a direct blow to the forearm or a fall on an outstretched hand. Forearm shaft fractures can be regarded as articular fractures as slight deviations in the spatial orientation of the radius and ulna will significantly decrease forearm rotation, thereby impairing the overall function of the hand. A cadaveric study showed that 10° angulation in one or both bones resulted in loss of range of motion of 20° pronation and supination (Matthews et al, 1982). Furthermore, with 20° angulation there was

Figure 4. Galeazzi injury characterized by a fracture of the shaft of the radius and disruption of the distal radioulnar joint.



significant restriction in passive rotation of the forearm as a result of extreme tension in the interosseous membrane (Matthews et al, 1982). Tarr et al (1984) showed that loss of forearm rotation depended on the location of deformity, with a significantly greater loss of range of motion in middle third deformities compared to distal third deformities. The greater decrease in range of motion in middle third deformities is attributed to the loss of radial bow, where the ulna and radius overlap at extremes of pronosupination. Surgical management of such fractures includes open reduction and internal fixation with a 3.5 mm dynamic compression plate.

Monteggia fracture–dislocation

Monteggia described a fracture of the proximal third of the ulna with an anterior dislocation of the proximal radioulnar joint or a dislocation of the radial head from its radio-capitellar joint (Ring, 2013) (*Figure 5*). These injuries are uncommon, representing 1–2% of all forearm fractures. In 1967, Bado classified these injuries into four distinct types with the most common mechanism of injury being forced pronation to an outstretched forearm (Bado, 1967). Effective treatment of Monteggia injuries is challenging. In the 1940s, Watson-Jones noted serious permanent disability in 32 out of 34 adults who had been managed for Monteggia fractures (Watson-Jones, 1943). Open reduction and internal fixation of the ulna, restoring its length and thus allowing reduction of the radius, is associated with good results in adults. Once the ulna has been restored to its anatomical length, healing of ligamentous structures around the elbow, such as the annular ligament and its relations, helps to establish proximal radioulnar joint stability (Ring, 2013). Monteggia fractures are frequently associated with heterotopic ossification, and in severe cases, radioulnar synostosis, with an incidence of 5.5% of conservatively treated cases and 9.5% of operated cases (Bauer et al, 1993). Clinically, this manifests as a progressive loss of elbow motion and of forearm rotation, with progressive functional impairment. Prophylactic measures to prevent heterotopic ossification include non-steroidal anti-inflammatory drugs, calcitonin and radiation therapy.

Figure 5. Monteggia injury characterized by a fracture of the proximal ulna and dislocation of the radial head.



Radial head fractures and Essex-Lopresti injuries

Fractures of the radial head are among the more common bony forearm injuries and usually occur secondary to a fall on an outstretched hand. Simple fractures of the radial head require little treatment except supportive measures such as analgesia and early movement. Intra-articular haematoma and surrounding soft tissue inflammation may render the elbow joint as a whole stiff, with supination in particular being limited in cases where early movement has not been instigated.

The management of comminuted radial head fractures can be challenging and must be approached in an anatomical fashion. Whereas in the past simple resection of the radial head was common, the subsequent distal radioulnar joint problems which can ensue as a result of gradual proximal migration of the radius, even in the absence of interosseous membrane injury, has led to a lower threshold for either internal fixation or replacement. In most cases radial migration amounts to 2–3 mm of posterior translation, and these patients generally remain asymptomatic. However, the combination of a radial head fracture with injury to the triangular fibrocartilage complex at the wrist and/or interosseous membrane – as seen in an ‘Essex-Lopresti’ type injury – may result in significant proximal migration of the radius >7 mm (Wegmann et al, 2012). This group of patients have a high incidence of complications, including distal radioulnar joint instability, limited pronosupination and considerable functional impairment, and may additionally develop longer term sequelae such as distal radioulnar joint and elbow joint osteoarthritis.

The Essex-Lopresti injury is easily missed and can cause significant disability. Described in 1951 by Peter Essex-Lopresti, the injury is characterized by proximal migration of the radius associated with a displaced radial head injury and an unstable distal radioulnar joint (Essex-Lopresti, 1951). For this to occur, a longitudinal force must be directed down the forearm, disrupting the triangular fibrocartilage complex, interosseous membrane and radial head. Various authors have demonstrated that the proximal migration of the radius occurs as a result of disruption of the central band of the interosseous membrane (Skahen et al, 1997).

One of the pitfalls of this pathology is failure to make an early diagnosis. Edwards and Jupiter (1988) demonstrated that a 6-week delay in diagnosis of an Essex-Lopresti injury leads to a poor outcome. A diagnosis should be suspected if there is a displaced or comminuted radial head injury, and clinical assessment should include examination of the wrist and distal radioulnar joint (Wegmann et al, 2012). If an isolated radial head fracture is displaced significantly, suspicion should arise of either an associated ulnar collateral ligament injury at the elbow with subsequent valgus displacement, or an injury to the triangular fibrocartilage complex and interosseous membrane with proximal migration of the radius. If there is

more than 2 mm shortening of the radius on ulnar variance views an Essex-Lopresti injury is the likely diagnosis (Wegmann et al, 2012).

Once identified, the Essex-Lopresti injury can be treated successfully with internal fixation of the radial head, with or without distal radioulnar joint reconstruction with temporary percutaneous wires, allowing soft tissue healing around the distal radioulnar joint. If the radial head fracture is not reconstructable, radial replacement should be performed with a silastic or metallic implant to prevent progressive proximal migration of the radius.

Conclusions

The distal and proximal radioulnar joints and interosseous membrane form a close relationship with the forearm bones and soft tissue envelope, providing both stability and sufficient degrees of freedom to perform the activities of daily living, and more skilled tasks when necessary. Disorders of forearm rotation are common, arising in the presence of an insult to either the proximal radioulnar joint, distal radioulnar joint, the interosseous membrane, or the bones of the forearms themselves, either alone or in combination. Understanding the pathoanatomy and functional biomechanics of forearm rotation, and associated disorders, will help diagnosis in a range of settings, and if treated accordingly may help to prevent the functional deficit caused by a loss of forearm rotation. **BJHM**

Conflict of interest: none.

- Adams BD, Berger RA (2002) An anatomic reconstruction of the distal radioulnar ligaments for post-traumatic distal radioulnar joint instability. *J Hand Surg* **27A**: 243–5
- An KN, Werner FW (1994) Biomechanics of the elbow and forearm. *Hand Clin* **10**: 357–73
- Atesok KI, Jupiter JB, Weiss AP (2011) Galeazzi fracture. *J Am Acad Orthop Surg* **19**(10): 623–33
- Bado JL (1967) The Monteggia Lesion. *Clin Orthop* **50**: 71–86
- Baeyens JP, Van Glabeek F, Goossens M, Gielen J, Van Roy P, Clarys JP (2006) In-vivo 3D arthrokinematics of the proximal and distal radioulnar joint during active pronation and supination. *Clin Biomech* **21**: 9–12
- Bauer G, Arand M, Mutschler W (1993) Post traumatic radioulnar synostosis after forearm fracture osteosynthesis. *Arch Orth Tr Surg* **11**(3): 142–5
- Chen NC, Jupiter JB (2007) Management of distal radius fractures. *J Bone J Surg* **89A**: 2051–62
- Cooney WP, Schuind F, Linscheid RL et al (1995) Force and pressure transmission through the normal wrist: a theoretical two dimensional study in the posteroanterior plane. *J Biomech* **28**: 1106–14
- Edwards Jr GS, Jupiter KB (1988) Radial Head Fractures with acute distal radio-ulnar joint dislocation. *Clin Orthop Relat Res* **234**: 61–9
- Essex-Lopresti P (1951) Fractures of the radial head with distal radioulnar dislocation. *J Bone Joint Surg* **33B**: 244–7
- Fraser GS, Ferreira LM, Johnson JA, King GJ (2009) The effect of multiplanar distal radius fractures on forearm rotation: in vitro biomechanical study. *J Hand Surg* **34A**: 838–48
- George MS, Kifehaber TR, Stern PJ (2004) The Suave-Kapandji procedure and the Darrach procedure for distal radio ulnar joint dysfunction after Colles fracture. *J Hand Surg* **29B**: 608–13
- Grawe B, Heincelman C, Stern P (2012) Functional results of the Darrach procedure: a long term outcome study. *J Hand Surg* **37A**: 2475–80
- Handoll HH, Huntley JS, Madhok R (2008) Different methods of external fixation for treating distal radius fractures in adults. *Cochrane Database Syst Rev* **23**(1): CD006522
- Handoll HHP, Pearce P (2012) Interventions for treating isolated diaphyseal fractures of the ulna in adults. *Cochrane Database Syst Rev* **13**(6): CD00052
- Hsu ES, Patwardhan AG, Meade KP, Light TR, Martin WR (1993) Cross-sectional geometrical properties and bone mineral contents of the human radius and ulna. *J Biomech* **26**: 11–18
- Kapandji AI (2001) Biomechanics of Pronation & Supination of the Forearm. *Hand Clin* **17**: 111–12
- Kaplan EB, Spinner M (1970) The quadrate ligament of the elbow: its relationship to the stability of the proximal radio-ulnar joint. *Acta Orthop Scand* **41**: 632–47
- Kennedy S, Hanel DP (2013) Complex Distal Radius Fractures. *Orthop Clin N Am* **44**: 81–92
- Malone KJ, Magnell TD, Freeman DC (2006) Surgical correction of dorsally angulated distal radius malunions with fixed angle volar plating: a case series. *J Orthop Trauma* **17**: 326–3
- Malone PSC, Hutchinson CE, Kalson NS, Twining CJ, Terenghi G, Lees VC (2012) Subluxation-related ulnar neuropathy SUN syndrome related to distal radioulnar joint instability. *J Hand Surg* **37E**: 652–64
- Mathews LS, Kaufer H, Garver DF, Sonstegard DA (1982) The effect of supination-pronation of angular malalignment of fractures of both bones of the forearm: an experimental study. *J Bone J Surg* **64A**: 14–17
- McGinley JC, Kozin SH (2001) Interosseous membrane anatomy and functional mechanics. *Clin Orthop Relat Res* **383**: 108–22
- Mikic ZDJ (1975) Galeazzi fracture-dislocation. *J Bone Joint Surg* **57A**: 1060–71
- Minami A, Iwasaki N, Ishikawa J (2005) Treatment of osteoarthritis of the distal radio-ulnar joint: long term results of three procedures. *Hand Surg* **10**: 243
- Moore T, Lester DK, Sarmiento A (1985) The stabilising effect of soft tissue constraints in artificial galeazzi fractures. *Clin Orthop* **194**: 189–94
- Moritomo H (2012) The distal interosseous membrane: current concepts in wrist anatomy and biomechanics. *J Hand Surg Am* **37**(7): 1501–7
- Morrey BF, Chao EY (1978) Three-dimensional rotation of the elbow. *J Biomech* **11**: 57–73
- Nagata H, Hosny S, Giddins GE (2013) In-vivo measurement of distal radio-ulnar joint translation. *Hand Surg* **18**: 15–20
- O'Neill TW, Cooper C, Finn JD et al (2001) Incidence of distal forearm fracture in British men and women. *Osteoporosis Int* **12**: 555–8
- Ring D (2013) Monteggia fractures. *Orthop Clin North Am* **44**: 59–66
- Schnependahl J, Windolf J, Kaufmann RA (2012) Distal radius fractures: current concepts. *J Hand Surg* **37A**: 1718–25
- Skahan JR, Palmer AK, Werner FW (1997) The interosseous membrane of the forearm: anatomy and function. *J Hand Surg* **22A**: 981–5
- Stanley D, Herbert TJ (1992) The Swanson ulna head prosthesis for post traumatic disorders of the distal radio-ulnar joint. *J Hand Surg* **17B**: 682–8
- Stuart PR, Berger RA, Linscheid RL, An KN (2000) The dorsopalmar stability of the distal radioulnar joint. *J Hand Surg* **25A**: 689–99
- Tarr RT, Garfinkel AI, Sarmiento A (1984) The effects of angular and rotational deformities of both bones of the forearm: an in-vitro study. *J Bone J Surg* **66A**: 65–70
- Thomas B, Sreekanth R (2012) Distal radio-ulnar joint injuries. *Indian J Orthop* **46**(5): 493–504
- Watson-Jones R (1943) *Fractures and Joint Injuries*. 3rd edn. Williams and Wilkins, London
- Wegmann K, Dargel J, Burkhart KJ, Bruggemann GP, Muller LP (2012) The Essex-Lopresti lesion. *Strategies Trauma Limb Reconstr* **7**: 131–9
- Zych GA, Latta L, Zagorski JB (1987) Treatment of isolated ulnar shaft fractures with prefabricated functional braces. *Clin Orthop* **219**: 194–200

KEY POINTS

- The forearm coordinates a number of joints to produce a wide range of movement.
- Injury to a bony or soft tissue component may restrict forearm rotation and lead to considerable functional problems.
- A high index of suspicion and prompt diagnosis of injuries which affect forearm rotation are key to restoring normal anatomy and biomechanics.