Hand Trauma

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Contents

Abstract

Hand injuries account for a large proportion of all injuries presenting to emergency departments. Avulsion injuries of the FDP tendons are a common sporting injury. Bowstringing of the flexor tendons are an important imaging sign of multiple annular pulley injuries. Mallet finger is the most common closed tendon injury in a sportsman. Rupture of the volar plate is a common complication of hyperextension injury. Imaging plays a crucial role in management of collateral ligament injuries. The extensor mechanism of the fingers is extremely intricate. Understanding relevant anatomy is quintessential for diagnosing and treating extensor mechanism injuries. Intra-articular metacarpal base fractures are commonly missed on initial presentation and pronated oblique radiographs help demonstrate the severity of this injury. Imaging evaluation of sports-related injuries of the hand should begin with radiographs. Ultrasound and magnetic resonance imaging play a vital role in diagnoses of soft tissue injuries. CT may be useful in understanding complex bony injuries.

1 Introduction

Traumatic hand injuries account for a large proportion of the workload of all emergency departments. Of a study of 50,272 patients, Angermann and Lohmann found that hand and wrist injuries made up 28.6 % of all injuries (Angermann and Lohmann 1993). Of these, 87 % involved the hand. Hill et al. found that the majority of isolated cases of hand and wrist

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injuries arise from either a fall or sports-related injury (Hill et al. 1998).

In this chapter, we describe the most common traumatic soft tissue and bone injuries to the hand. We pay attention to the anatomy and mechanism of injury as this is fundamental to understanding and recognising patterns of injury on imaging. We also briefly mention some of the key management options that are important to be aware of whilst assessing the imaging of these injuries.

2 Volar Soft Tissue Injuries

2.1 Flexor Tendons

First described by Von Zander in 1891, avulsion injuries of the flexor tendon are common injuries in athletes. However, flexor tendon injuries are not as common as injuries to the extensor apparatus (Clavero et al. 2002).

The flexor mechanism of the digits comprises two tendons: the flexor digitorum superficialis (FDS) that inserts on the midportion of the middle phalanx, and the flexor digitorum profundus (FDP) which inserts on the volar aspect of the base of the distal phalanx. At the metacarpal head, the FDS splits and passes round the FDP tendon forming a ring aperture through which the FDP passes to become the more superficial tendon at the level of the proximal phalanx shaft (Clavero et al. 2002). These tendons run underneath the annular (A1–A5) and cruciform (C1–C3) pulleys lined by a synovial sheath that provides lubrication and nutrition. The vincula, which also provide blood supply to the tendons, connect the tendon to the synovial sheath (Hunter 1984).

Based on the mechanism of injury, these can be classified as open or closed injuries. For further discussion, we will concentrate on closed injuries. Open injuries are commonly due to lacerations. Closed injuries commonly occur when the finger is forcibly extended during maximum contraction of the profundus muscle—when a player is attempting to make a tackle and the ring finger slips off of the opposing player's shorts or jersey, hence the name "Jersey finger"(Aronovitz and Leddy 1998). Although it can occur in any finger, the ring finger is the most commonly involved finger accounting for 75 % cases (Hong 2005). McMaster in 1933 showed that the tendon was the strongest link in the musculotendinous chain and that rupture most commonly occurs at the bony insertion (McMaster 1933). When the tendon ruptures from its insertion, it may or may not avulse a bone fragment of variable size.

The most reliable finding is a complete loss of active flexion at the Distal Interphalangeal (DIP) joint (Buscemi and Page 1987). Because pain and swelling often mask the inability to flex the DIP joint (DIPJ), it is not uncommon for this injury to be missed initially and go untreated (Aronovitz and Leddy 1998).

Treatment and prognosis are influenced by several of the following factors: the level to which the tendon retracts, the remaining blood supply to the tendon, the length of time between injury and treatment and the presence and size of a bony avulsion fragment (Aronovitz and Leddy 1998). Based on the level of retraction and presence of bony fragment, Leddy and Packer have classified this injury into three main types (Table 1).

Buscemi et al., after describing four cases of FDP tendon injuries have suggested that avulsion of the FDP tendon with a separate intra-articular fracture of the base of the distal phalanx should be classified as a Type IV injury in the Leddy and Packer classification (Buscemi and Page 1987).

Radiographs may show an avulsed bone fragment from the distal phalanx. Severe comminution of the distal phalanx precludes accurate restoration of the articular surface and is important to note as it is a contra-indication to early FDP re-insertion (Jebson 1998).

At ultrasound, normal tendons are echogenic in the hand and wrist compared to muscle. They also show a typical fibrillar echotexture, which reflects their histological structure of longitudinally oriented bundles of collagen fibres (Jeyapalan et al. 2008). In cases of tendon rupture, discontinuity with a gap in the flexor tendon may be seen. The gap may be filled with disorganised, echogenic fibrinous material (Jeyapalan et al. 2008). In the presence of tendon rupture, discontinuity of the flexor tendon is seen with the gap at the rupture site (Figs. 1 and 2). In some patients, the tendon remains in continuity but is attenuated with subtle loss of fibrillar pattern due to partial division. These tendons may show less excursion than tendons in the neighbouring fingers on dynamic ultrasound assessment (Jeyapalan et al. 2008).

Table 1 Leddy and Packer classification of closed FDP injuries (Leddy and Packer 1977)

Type I	Retraction of the tendon into the palm with disruption of the vincular system resulting in loss of blood supply to the tendon
Type II	Most common type. Tendon retracts to the level of PIP joint, being held by the intact long vinculum preserving some blood supply
Type III	Large bony fragment that gets held in place by the A4 pulley
Type IV (Buscemi and Page 1987)	Tendon rupture with attached bony fragment and concomitant separate intra-articular fracture fragment

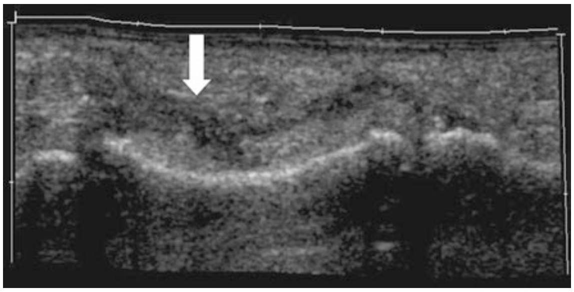

Fig. 1 Ultrasound of the finger using a linear probe in longitudinal plane showing empty FDP tendon sheath (*arrow*). DIPJ and PIPJ are on the *left* and *right* side of the image, respectively

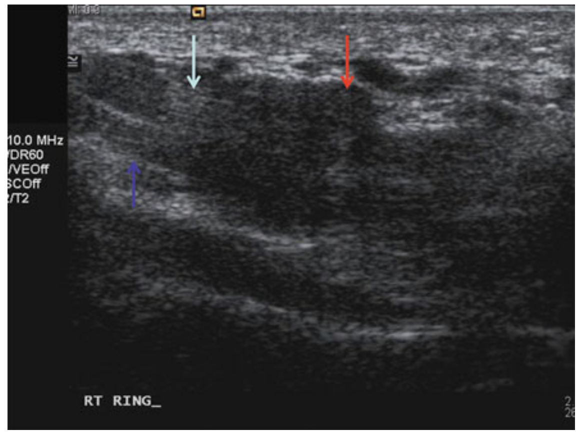

Fig. 2 Ultrasound of the ring finger using (different patient to Fig. 1) a high-frequency linear probe showing FDS rupture (*Red arrow* – at torn end), FDS (*Green arrow*) lying superficial to the FDS (*Blue arrow*)

On all magnetic resonance (MR) sequences, the flexor tendons appear as low-signal-intensity structures. In general, T1-W images provide good anatomical detail, while T2-W images are useful in assessment of inflammatory change that is associated with most pathological conditions (Clavero et al. 2002). Magnetic resonance imaging provides a non-invasive method to identify the site of tear, the degree of retraction of the torn fibres and other associated soft tissue injuries (Peterson and Bancroft 2006). In the presence of trauma, the associated oedema, haematoma and fibrosis compromise the tendon image quality and a tendon rupture is unlikely to be identified (Beltran et al. 1987).

Based on the current literature review, there is a general consensus that prompt reinsertion of an acute FDP avulsion injury is the preferred choice of treatment. In chronic injuries, the patient may be asymptomatic as they adapt by passively assisting DIPJ flexion, and do not require any further treatment (Aronovitz and Leddy 1998; Jebson 1998). If there is instability of the DIPJ with weakness of pinch or recurrent dorsal dislocations, joint arthrodesis or tenodesis should be considered (Aronovitz and Leddy 1998).

2.2 Annular Pulleys

Normal finger flexion is a complex fine motor action that requires the integrity and orchestration of a number of delicate structures that are centred around the flexor tendon system (Hauger et al. 2000). The flexor tendon sheath pulley system is of paramount biomechanical importance in flexion, not only for accurate tracking of the tendon but also to maintain the apposition of tendon and bone across the joint and provide a fulcrum to elicit flexion and extension (Lin et al. 1989). Doyle and Blythe in 1975 originally defined a pulley system of four annular and three cruciate pulleys. In 1981, Kleinhert and Broudy defined an additional fifth pulley arising distal to the fourth annular pulley.

In recent years, the number of people involved in climbing sports has increased exponentially as a result of easy and readily available access to artificial rock-climbing walls and indoor rock climbing facilities. The annular pulley injuries are caused by climbing techniques where the entire body weight is placed on one or two fingerholds, especially in overhung wall climbs. These techniques place high forces on the proximal interphalangeal (PIP) joint and the digital pulley system, resulting in finger injuries known as climber's finger (Klauser et al. 1999). The ring and middle fingers are most commonly affected, as they are most often used in climbing and are diagnosed in up to 30 % of climbers with finger injuries (Le Viet et al. 1996). Injury to the pulley system can result in loss of strength and decreased range of motion within the affected finger, bowstringing of the FDP tendon and fixed flexion contracture of the PIP joint (PIPJ). Pain and soft tissue swelling can make clinical evaluation a difficult and limited exercise. Many studies have claimed that bowstringing of the FDP tendon across the PIPJ with resisted flexion of the fingertips is diagnostic of A2 pulley rupture. However, in a laboratory study of 21 cadaveric fingers by Marco et al. (1998), isolated or even combined rupture of A2 and A4 pulley did not result in detectable bowstringing. Rupture of at least three pulleys was required to produce obvious bowstringing in this study. Early recognition of the injury and appropriate treatment are important in avoiding complications like fixed flexion contractures (Bollen 1990).

The A2 and A4 annular pulleys, located at the proximal third of the proximal phalanx and middle phalanges, respectively, are the broader and the most functionally important annular pulleys (Lin et al. 1989). Experimental studies performed by Marco et al. (1998) showed that the A4 pulley is predisposed to rupture first when the hand is in the crimp grip. The A2 pulley usually fails from its distal to its proximal edge, whereas the A4 pulley tears from its proximal to its distal edge (Marco et al. 1998). It is important to accurately differentiate the complete from incomplete tears, as decision for operative versus non-operative management depends on this vital finding.

Various studies have been published advocating the use of ultrasound (Klauser et al. 1999, 2002; Martinoli et al. 2000; Hauger et al. 2000); computed topography (CT) (Le Viet et al. 1996) and MR (Hauger et al. 2000, Klauser et al. 2002). An inability to directly delineate the pulleys along with the exposure to ionising radiation and relatively higher cost in comparison to ultrasound, make CT an unsuitable modality for diagnosing pulley injuries.

The magnetic resonance imaging (MRI) criteria for identifying pulley injuries include direct signs such as disrupted A2 and A4 pulleys (Hauger et al. 2000) or indirect signs like bowstringing (appreciated as increased tendon–phalangeal (TP) distance) or fluid in between the phalanx and tendon (Gabl et al. 1998). The MR has been the most accurate modality for imaging in the diagnosis of A4 lesions (Hauger et al. 2000). However, the expense, length of the examination and lack of real-time assessment are some of the drawbacks of MR examination.

Dynamic assessment gives ultrasound an advantage in the evaluation of pulley injuries. Ultrasound can demonstrate visualisation of fluid between the tendon and phalanx and allows assessment of the gliding ability of the tendons. Ultrasound demonstrated a sensitivity of 98 %, specificity of 100 %, a positive predictive value of 100 % and a negative predictive value of 97 % for the detection of finger pulley injuries (Klauser et al. 2002). Martinoli et al. (2000) demonstrated that examination in the longitudinal plane alone was sufficient as transverse sonograms added no significant information. Hauger et al. (2000) has suggested using TP distance measurements following a study performed using a cadaveric model (see Figs. 3a, b and c). A TP distance of greater than 1.0 mm was indicative of pulley system injury. An increase of the TP distance with forced flexion less than 3.0 mm was considered a sign of incomplete A2 pulley rupture, while a distance greater than 3.0 mm was considered a sign of complete rupture. Further increase in the TP distance to more than 5.0 mm was used as a sign for complete combined rupture of A2 and A3 pulley. An increase of TP distance equal to or greater than 2.5 mm was used as a sign for complete rupture of A4 pulley. Maximal active forced flexion during dynamic ultrasound examination is the most important factor for assessment of TP distance and detection of finger pulley injuries (Klauser et al. 2002).

Indications for non-operative or operative treatment are based on the clinical finding of bowstringing, functional disability, persistent pain, failure of

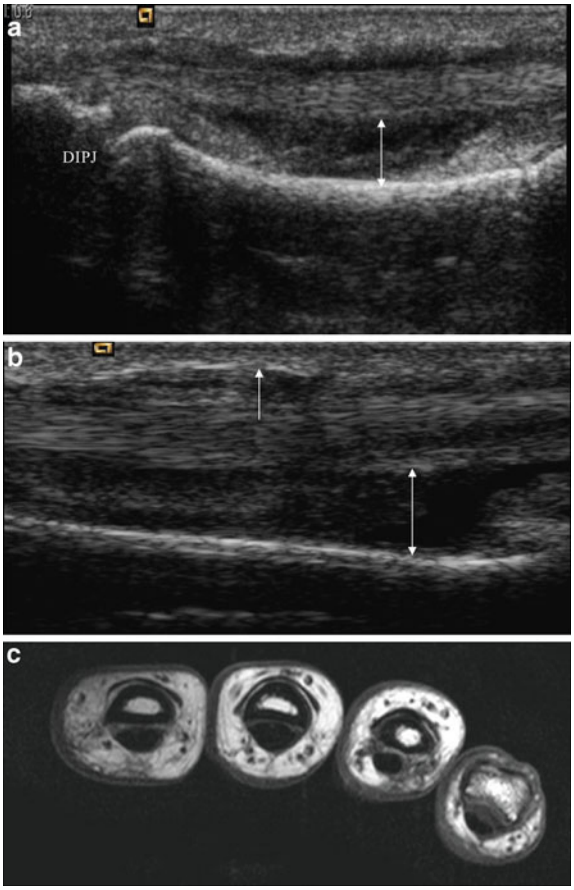

Fig. 3 **a**, **b** Both images taken in the same patient show increased tendo-phalangeal distance (*double arrow heads*) over the middle and proximal phalanges respectively, indicating rupture of the A2 and A4 pulleys. *Arrow* in **b** shows the ruptured A2 pulley. **c** Axial MR image shows increased tendo-phalangeal distance (*double arrow heads*) due to chronic rupture of the A2 pulley

non-operative treatment and on the amount of bow-stringing of the involved flexor tendons (Gabl et al. 1998). Incomplete tears are normally treated conservatively, while complete tears are treated surgically. The treatment of complete tears with surgery has been controversial. In a study conducted by Gabl et al. (1998), complete ruptures were treated with surgery after non-operative treatment had failed. In the same study, functional outcome after non-operative and operative therapy was equal. Diagnosis and treatment at an early stage will prevent the progression of lesions and decrease the risk of long-term complications that are associated with fixed finger contracture (Hauger et al. 2000).

2.3 Volar Plate

Volar plate (VP) injury results as a consequence of hyperextension injury to the PIPJ. There may or may not be an associated intra-articular fracture (Yoong et al. 2010). Even when present, the fracture can be easily overlooked resulting in significant instability of the PIPJ (Nance Jr et al. 1979).

The VP is a multi-layered condensation of dense fibrocartilaginous tissue that lies between the flexor tendons and the PIPJ capsule. The VP attaches firmly only at the critical corner of the middle phalanx base, without strong insertion centrally. Proximally, the VP blends directly with the periosteum rather than direct insertion into the bone (Williams et al. 1998). Its important functions at the PIPJ level include providing stability against hyperextension, acting as a meniscus at the PIPJ, forming part of the intracavitary lining of the PIPJ and providing a smooth gliding surface for the flexor tendon (Williams et al. 1998).

The most common mechanism of injury is forced or sudden hyperextension at the PIPJ (Phair et al. 1989). The diagnosis of VP injury is usually made clinically, with tenderness over the volar aspect of the PIPJ, pain on passive hyperextension and instability with loss of pinch power (Nance Jr et al. 1979). The commonly used classifications are shown in Tables 2 and 3 below.

Along with AP and lateral views of the involved PIPJ, oblique views can also be helpful. In a study of 58 cases conducted by Nance Jr et al., 65 % of the fractures were best seen on the lateral view, while most of the others were best appreciated on the oblique projection (Nance Jr et al. 1979). Subtle dorsal subluxation can be identified by observing a V-shaped gap between the articular surfaces of the PIP joint—'V' sign. On ultrasound examination, the VP is seen as a wedge-shaped structure of intermediate echogenicity interposed between the flexor tendon and underlying PIPJ (Yoong et al. 2010). The complex three-layered collagen fibres running in different orientations (Williams et al. 1998) probably account for its mixed echogenic appearance on ultrasound. The VP is best seen in the sagittal plane and is of low signal on all MRI sequences (Fig. 4) (Yoong et al. 2010). To the best of our knowledge, there are currently no studies comparing the efficacy of ultrasound or MRI for diagnosing VP injuries.

Table 2 Eaton classification of VP injuries (Eaton 1971)

Type 1	No fracture or dislocation
Type 2	Dorsal dislocation without fracture
Type 3 stable	Fracture–dislocation with <40 % PIP joint surface
Type 3 unstable	Fracture–dislocation with >40 % PIP joint surface

Table 3 Stability-based classification (Keifhaber and Stern 1998)

Stable	<30 % articular surface
Tenuous	30–50 % articular surface
Unstable	>50 % articular surface

Fig. 4 Sagittal T1 W MR image of the thumb showing chronic type 1 volar plate injury (*White arrow*)

There is a consensus that the stable injuries involving less than 30 % of articular surface are treated conservatively either by splinting with extension-block or neighbour strapping. Various studies (Phair et al. 1989; Gaine et al. 1998) have shown favourable results with early active and passive mobilisation rather than splinting. Unstable injuries involving >50 % of articular surface are treated surgically with open reduction and internal fixation using various techniques or palmar plate arthroplasty, with later being preferred (Keifhaber and Stern 1998). The tenuous fractures involving 30–50 % of articular surface can be treated conservatively, if the articular surface congruity can be maintained with 30° flexion; if not they are best managed operatively (Keifhaber and Stern 1998).

3 Extensor Mechanism Injuries

3.1 Anatomy

The anatomy and function of the extensor mechanism of the hand comprise of a complex set of interlinked muscles, tendons and ligaments that are intricately coordinated to bring about the fine movements of the digits. The extensor mechanism of the hand can be divided into eight zones to aide in the evaluation and treatment of acute injuries (Kleinhert and Verdan 1983). The even-numbered zones are over bones, with the odd-numbered zones over the joints. Owing to the lesser number of the phalanges in the thumb, the numbering system is slightly different.

The extrinsic and intrinsic muscles of the hand make up the extensor mechanism. Zone VIII, containing the musculotendinous junctions of the extrinsic muscles is the most proximal zone. In zone VII, the extensor tendons are contained within the extensor retinaculum over the wrist joint. In zone VI, the tendons of the middle, ring and little finger are connected by juncturae tendinum. These interconnections must be considered when evaluating extensor tendon injuries (Newport 1997). In zone V, the extensor tendons are located centrally and are stabilised over the dorsum of the metacarpal head by the extensor hood. The sagittal bands (SB) are the main components of the extensor hood, which starts at the VP and has a dorsal tendinous point of insertion, gliding with the extensor system as the digit moves (Clavero et al. 2002). Distal to metacarpophalangeal (MCP) joint, the extensor mechanism becomes more complicated as the extrinsic and intrinsic muscles blend into the dorsal apparatus. The extrinsic extensor tendons divide into central and lateral slips with the central slip inserting into the dorsal aspect of the base of middle phalanx. The intrinsic muscles contribute to form the lateral slips to form conjoint tendons, which converge distally to form the terminal tendon that inserts on the base of the distal phalanx (Kleinhert and Verdan 1983). The intrinsic tendons are directed volar to the axis of MCP joint (MCPJ), flexing this joint and directing dorsal to the axis of PIPJ and DIPJs, extending these joints (Newport 1997).

On MR images, the normal extensor apparatus appear as low-signal structures at the expected locations, axial and sagittal planes being most useful (Clavero et al. 2002).

3.2 Mallet Injury (Zone 1)

Disruption of the terminal extensor tendon at the DIPJ, caused by sudden forced flexion of the extended finger results in extension lag deformity at the DIPJ called mallet finger. Other terms like 'baseball finger' and 'drop finger' have been used to describe this. This terminal extensor tendon can rupture at or near its insertion into the distal phalanx (soft tissue mallet injury) or can avulse a bony fragment from the base of distal phalanx (bony mallet injury) (Handoll and Vaghela 2004). As a result of this injury, the DIPJ cannot be actively extended. A mallet finger may be open, but is more often a closed injury (Rockwell et al. 2000). It is the most common closed tendon injury in sports persons (Posner 1977) and can occur either after a direct blow to the DIPJ or a relatively minor trauma to the fingertip. The middle finger is most often involved, followed by the little finger (Stark et al. 1962). Doyle has classified this injury into four types as follows (Table 4).

Table 4 Doyle classification of mallet injuries (Doyle 1999)

Type 1	Closed or blunt trauma, with or without avulsion fracture (most commonest type)
Type 2	Rupture of the tendon near or at the DIP joint
Type 3	Open, with deep abrasion of the tissues
Type 4	Trans-epiphyseal fracture in children, fractures involving a large part of the joint surface

The patient may present with swelling and bruising over the DIPJ. This being a rarely painful condition, patients frequently seek help late in the course of the event (Perron et al. 2001). Also, the extensor lag at the DIPJ may not appear for several days. Patients rarely complain of functional disability because there are relatively few activities which require full digital extension (Brzezienski and Schneider 1995). On clinical examination, apart from the fixed flexion deformity, the patient will be unable to actively extend the DIPJ. However, the deformity is correctable by passive extension.

Plain radiographs are routinely performed to exclude bony involvement (Fig. 5). Ultrasound may demonstrate: discontinuity of the extensor tendon with partial or complete tear; avulsion fracture; no real-time movements of the extensor tendon; and fluid in the region of the extensor tendon insertion (Kleinbaum et al. 2005). These findings can be used to differentiate traumatic mallet finger from others caused by fixed flexion deformity. In cases with no bone avulsion on plain film, sagittal MR images can be used to assess for terminal extensor tendon injuries and thus can be used to decide treatment (Clavero et al. 2002; Tabbal et al. 2009).

The most common type of mallet injury, closed type 1 injuries are generally managed conservatively with hyperextension splint for around 6–8 weeks. This is followed by further 4 weeks of splinting at night. Surgical treatment is usually reserved for open injuries, DIPJ instability/subluxation or a large (>30 %) displaced articular fracture fragment. A cadaveric study conducted by Hussain et al. concluded that palmar subluxation of a DIPJ without pre-existing arthritic deformity is expected when more than one half of the dorsal articular surface is injured (Hussain et al. 2008).

3.3 Boutonniere Deformity (Zone III Injury)

A boutonniere deformity occurs as a result of an injury to the central slip at or near its insertion at the base of the middle phalanx. The term *boutonniere* is derived from the French for 'buttonhole', as the head of the proximal phalanx can pass through the defect in the extensor mechanism (Aronowitz and Leddy 1998). Most of these are caused by an unrecognised volar lateral dislocation of the PIPJ or less commonly by a blow to the dorsal aspect of the middle phalanx that forces the PIPJ into flexion while the finger is being actively extended (Aronowitz and Leddy 1998; Perron et al. 2001). This injury can either be open or

Fig. 5 AP and Lateral radiographs of right little finger. Lateral radiograph demonstrates avulsion fracture (*white arrow*) at the site of extensor tendon insertion into the base of the terminal phalanx, usually seen in closed traumatic extensor tendon disruption with avulsion fracture (type 1)

closed, and the central slip may avulse with or without a bony fragment.

The patient usually presents with pain and swelling with maximal tenderness at the PIPJ. The classic boutonniere deformity is rarely seen in the acute phase (Aronowitz and Leddy 1998). In the early acute phase, active extension is retained by the normally orientated lateral slips; but the head of the proximal phalanx eventually goes through the central slip resulting in migration of the lateral slips palmar to the PIPJ, which flexes the PIPJ and hyperextends the DIPJ resulting in the classic boutonniere deformity (Griffin et al. 2012). The above described deformity usually occurs 1–2 weeks after the initial injury (Hart et al. 1993).

Burton has described three stages of the boutonniere deformity (Table 5).

The Elson test, which demonstrates rigidity of the DIPJ during attempted PIP extension from a flexed position, has been shown to reliably diagnose an early central slip injury. However, the drawbacks of this test are it will not demonstrate partial rupture of the central slip and may be impeded by pain (Elson 1986). Initially, plain radiographs are obtained to evaluate for an avulsion fracture at the base of the middle phalanx (Fig. 6). In equivocal cases, where clinical evaluation is difficult owing to pain and swelling, MRI can be an effective method for detecting central slip lesions (Clavero et al. 2002). Magnetic resonance imaging can also provide valuable information about associated VP and ligamentous lesions of the PIPJ. To the best of our knowledge, there are no current studies available comparing the efficiency of clinical examination, ultrasound or MRI in diagnosing the central slip injuries.

Treatment of central slip injuries remains highly controversial. Generally these are treated closed with extension splinting of the PIPJs for 4–6 weeks followed by 2 weeks of night time splinting (Aronowitz and Leddy 1998). Surgical treatment is implemented when (1) displaced avulsion fracture, (2) axial and lateral instability of the PIPJ associated with loss of active or passive extension of the joint and (3) failed conservative treatment (Griffin et al. 2012). However, surgical reconstruction is the treatment of choice for a chronic symptomatic boutonniere deformity (Aronowitz and Leddy 1998).

Table 5 Stages of the boutonniere deformity (Burton 1982)

Stage 1	Dynamic imbalance, fully correctable passively
Stage 2	Extensor mechanism contracture, not passively correctable but does not involve the joint structure
Stage 3	Fixed contracture with joint changes involving collateral ligament, volar plate scarring and intra-articular adhesions

Fig. 6 Lateral radiograph showing a subtle avulsion fracture (*white arrow*) with associated soft tissue swelling at the base of the left middle finger intermediate phalanx

It is important to differentiate between a boutonniere and a pseudo-boutonniere deformity so that appropriate treatment plan can be implemented. Although, the appearances may be similar their aetiology is different. The pseudo-boutonniere deformity results from a PIPJ VP injury due to PIPJ hyperextension and resulting in PIPJ flexion contracture, rather than an injury to the central slip (Hong 2005). Typically, the flexion contracture of the PIPJ is fixed, and passive extension is not possible (Aronowitz and Leddy 1998). In a pseudo-boutonniere deformity, radiographs may slow calcification along the volar lateral aspect of the proximal phalanx. These injuries are managed conservatively by dynamic splinting, if the flexion contracture is less than 45° and surgical release may be needed to restore extension if the PIP flexion contracture is more than 45° (Aronowitz and Leddy 1998).

3.4 Boxer's Knuckle (Zone V Injury)

The extensor hood at the MCPJ is a retinacular system comprising the sagittal, oblique and transverse bands that stabilise the extensor tendon at the dorsal aspect of the MCPJ and keeps the tendon in place during flexion and extension. The SB is the most important structure of the extensor hood; this composes of a superficial and deep layer forming a tunnel through which the extensor tendon passes through (Kichouh et al. 2011). Sagittal band ruptures referred to as 'Boxer's Knuckle' can occur spontaneously, secondary to trauma or can be associated with synovial disorders like rheumatoid arthritis (Kichouh et al. 2011). Congenitally absent or lax SBs have been previously reported (Inoue and Tamura 1996). The most commonly injured finger is the middle finger, and the most frequently involved SB is the radial with ulnar instability (Rayan and Murray 1994). It has been thought that underlying normal ulnar inclination of the index and middle finger may predispose them to radial band disruption (Lopez-Ben et al. 2003). However, ruptures of the ulnar SB resulting in radial instability have also been reported in the literature. Patients commonly present with pain, swelling, loss of full extension and subluxation of the extensor tendon. Rayan and Murray classified SB injuries into three types as shown in Table 6.

However, the overlying soft tissue swelling and pain can make clinical assessment difficult to diagnose tendon subluxation (Lopez-Ben et al. 2003). As a result, accurate diagnosis of SB rupture may be difficult without imaging. Advantages of ultrasound over MRI include dynamic assessment, cost-effectiveness and easy availability.

Various studies have been published describing the use of ultrasound and MRI for diagnosing SB injuries. The SB is best seen in the axial plane with the MCP in slight flexion, appearing as a linear hypoechoic structure. Focal hyperechoic thickening of the SB or disappearance of the normal architecture of the SB can be demonstrated in patients with extensor hood injuries (Kichouh et al. 2011). Dynamic ultrasound

Table 6 Rayan and Murray classification of sagittal band injuries (Rayan and Murray 1994)

Type I	Mild injury with no instability
Type II	Moderate injury with extensor tendon subluxation
Type III	Severe injury with tendon dislocation

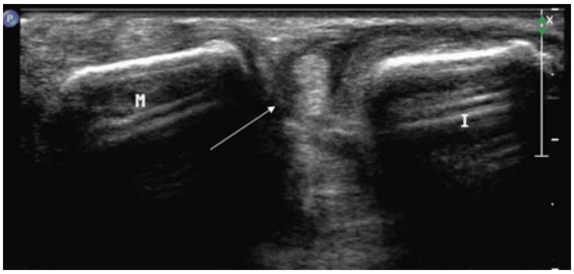

Fig. 7 Ultrasound image at MCPJ level shows subluxation of the index finger (I) extensor tendon (*white arrow*), secondary to extensor hood injury (not shown in this image)

with the fingers alternatively extended and then flexed in a clenched fist enables excellent visualisation of extensor tendon subluxation and dislocation at the MCPJ (Fig. 7) (Lopez-Ben et al. 2003).

On MRI, the SB is depicted as uniform low-signal intensity structure on all sequences. The T2W sequences are more accurate than T1W or post-contrast T1W sequences and post-contrast imaging does not improve the sensitivity in depicting the SB (Drape et al. 1994). The MR findings in acute injuries include morphologic and signal intensity changes, together with poor definition, focal discontinuity and focal thickening (Clavero et al. 2002). Magnetic resonance imaging of MCPJs in different kinematic positions has also been found useful in diagnosing SB injuries (Lopez-Ben et al. 2003). The role of oblique and transverse bands is not well known currently and these are also difficult to demonstrate on ultrasound and MRI (Kichouh et al. 2011).

Like other extensor mechanism injuries, the treatment of SB injuries also remains highly controversial. Ritts et al. advocate conservative treatment with splinting of the MCPJ in extension, while Hame and Melone Jr concluded that direct surgical repair with realignment of the central tendon is highly successful (Ritts et al. 1985; Hame and Melone Jr 2000). These will need to be treated as open infected injuries if the extensor mechanism or the SB injury is secondary to human bites with surgical debridement, intravenous antibiotics and splinting (Matzon and Bozentka 2010).

4 Collateral Ligament Injuries

4.1 Ulnar Collateral Ligament of the Thumb

The ulnar and radial collateral ligaments are primary stabilisers of the thumb MCPJ against radial and ulnar stress, respectively. Injury to these structures may result in joint instability, leading to significant disability and pain (Tang 2011). A correct early diagnosis influences management decisions and treatment outcomes (Sollerman et al. 1991). The thumb MCPJ is stabilised by static and dynamic stabilisers (Tsiouri et al. 2009). The static restraints include the VP, the dorsal capsule and the ulnar and radial collateral ligaments. The extrinsic and intrinsic muscles of the thumb make up the dynamic stabilisers. The ulnar collateral ligament (UCL) comprises a proper and an accessory ligament (Tsiouri et al. 2009). In flexion, the proper collateral ligament is taut, while the accessory collateral ligament is taut in extension.

Two acronyms are commonly used to describe UCL injuries, Gamekeeper's thumb and Skier's thumb. Gamekeeper's thumb was first reported by Campbell in 1955 to describe chronic attritional attenuation of the UCL in Scottish gamekeepers, secondary to strain induced on the first Web space (Campbell 1955). The Skier's thumb is used to describe acute injuries where the thumb is forced into abduction and hyperextension against the ski pole (Gerber et al. 1981). Thumb UCL injuries are the second most common skiing-related injury, after medial collateral ligament injury of the knee (Tsiouri et al. 2009).

Injury to the UCL is caused by sudden excessive valgus stress on the thumb MCPJ. Although this was attributed to the straps of the ski pole initially, later studies have showed that the incidence of the injury remained the same even with new pole designs without a strap (Derkash et al. 1987). In approximately 90 % of cases, the thumb UCL avulses from the base of the proximal phalanx (Coyle 2003). Although less frequent, it can avulse from proximal attachment or tear in the midsubstance. In 1962, Stener described a lesion in which the distal end of the avulsed UCL is displaced superficial to the adductor aponeurosis and is prevented from reapproximation to its anatomic insertion site (Stener 1962). Avulsion of UCL can be accompanied by more than one bony avulsion fragment with failure of the ligament bone complex at the site of the ligament–bone interface and also within the bone itself (Giele and Martin 2003).

Patients with acute injuries present with pain, swelling and reduced range of motion. Chronic presentations include deformity and loss of strength in particular pinching or grasping. On examination, tenderness to palpation will be present at the site of injury. A palpable mass on the medial side may represent the superficially displaced end of the UCL, suggestive of a Stener lesion. However, the absence of a palpable mass does not definitively rule out a Stener lesion (Heyman et al. 1993).

Evaluation of joint stability is the most important part of examination. The primary aim is to determine whether the injury is incomplete (Grade 1 or 2) or complete (Grade 3) (Tang 2011). Current consensus include testing the joint in zero degrees of extension and 30° flexion to evaluate accessory and proper collateral ligament components, respectively. Instability is defined as radial deviation of the proximal phalanx on the metacarpal head of >30–35° (Heyman et al. 1993). Stress examination demonstrating a firm end-point indicates an incomplete tear whilst opening of the MCPJ without a firm end-point indicates a complete tear (Patel et al. 2010).

Plain radiographs are routinely performed to rule out a fracture or subluxation (Fig. 8a). Previously, stress radiography, ultrasound and MR with or without arthrography have been used to assess thumb UCL injuries. In addition to the discrepancies concerning the performance and interpretation of stress radiographs, the most significant drawback is their inability to direct the treatment because they do not differentiate between a non-displaced tear and a Stener lesion (Green and Rowlan 1984). In a study conducted by Harper et al. comparing the efficacy of stress radiography versus MR examination with and without arthrography, the overall sensitivity of stress radiography was found to be only 64 % (Harper et al. 1996).

Ultrasound is useful in detecting partial and complete tears of the thumb UCL and has shown promising results in differentiating between complete tears and Stener lesions (Schnur et al. 2002). The normal thumb UCL appears as a hyperechoic structure spanning the ulnar side of the first MCPJ. Displaced UCL tears appear as a retracted, folded-on-itself structure which is displaced proximal and superficial to the adductor aponeurosis, creating the appearance of a 'yo–yo on a string' on coronal MRI scans (Ebrahim et al. 2006). The positive predictive value for ultrasound in identifying UCL tears is very high (87.5 % Schnur et al. and 94 % Jones et al.). However, the specificity varies between 83 % for displaced ruptures and 91 % for non-displaced ruptures (Hergan et al. 1995). Inexpensive and easy availability along with good overall comparable results with MR make ultrasound an attractive tool for evaluation of UCL tears. The primary disadvantage of ultrasound is that it is operator dependent. Ultrasound has been recommended to be used only in the 1st week after injury, as scarring may decrease accuracy of the method (Hergan et al. 1997).

Excellent soft tissue characterisation makes MR examination a very good modality to use in UCL injuries (Fig 8b). The sensitivity and specificity have been shown to be 100 % (Harper et al. 1996; Hergan et al. 1995). Thus, MR plays a vital role in making management plans for patients with UCL tears. Cost-effectiveness and availability remain the major deterrents for using MR as the primary modality in diagnosing UCL tears. Various pitfalls as described by Hergan et al. (1997) can cause misinterpretation between displaced and non-displaced UCL tears which can have serious implications on patient recovery. Hence, MR examination has been advocated when a non-displaced UCL tear is suspected by ultrasound (Hergan et al. 1997).

Conservative versus surgical management of UCL tears has been controversial and extensively debated over the last four to five decades. Grade 1 and 2 tears are managed conservatively. Surgery is indicated in the following instances: a Stener lesion is suspected; a displaced avulsion fracture exists, where there is an acute, grossly unstable joint; in symptomatic chronic injury; and in cases of volar subluxation seen on radiographs (Smith 1977). Surgical treatment has been widely accepted as treatment of choice for Grade 3 UCL tears.

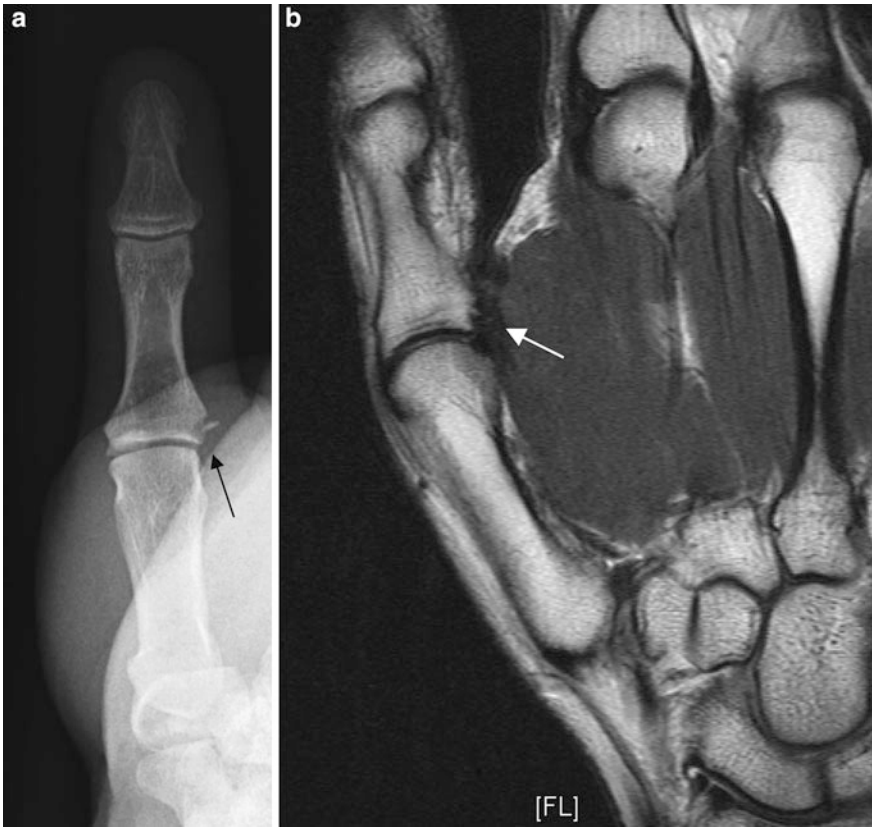

Fig. 8 **a, b** Plain radiograph AP view (**a**) and Coronal T1W MRI (**b**) showing bony avulsion fracture (*arrow*) at the site of UCL insertion

4.2 Radial Collateral Ligament

Injuries of radial collateral ligament (RCL) comprise 10–14 % of the collateral ligament injuries to the thumb MCPJ (Coyle Jr 2003). These have been referred to as “reverse gamekeeper’s thumb” (Cooney et al. 1990).

The RCL originates dorsally on the lateral condyle of the metacarpal head and extends in a distal and palmar direction to insert into the lateral tubercle of the proximal phalanx. (Edelstein et al. 2008). Like UCL, the RCL also consists of proper and accessory collateral ligaments which act as static restraints when MCPJ is in flexion and extension, respectively.

Injuries of the RCL result from forced and sudden adduction of the MCPJ which can occur from a fall or during sports when a ball or player strikes the thumb. Acutely, the patient presents with pain, stiffness, swelling and deformity. In the chronic situation, once the swelling and pain has subsided, patients present with persistent pain with activities that require a radial-sided force such as closing a door (Edelstein et al. 2008).

It is important to identify partial from complete RCL tears as complete tears are treated surgically, while partial tears are treated conservatively. Radial stress test and drawer tests may be used to assess for RCL injury. A recent study by Coyle Jr found proximal tears (55 %) are commoner than distal (29 %) or midsubstance tears (16 %) (Coyle 2003). This can be explained by the fact that the distal width of the RCL insertion is equal to or wider than the RCL origin at the metacarpal (Lyons et al. 1998). Complete RCL tear can result in both static and dynamic instability (Edelstein et al. 2008). Although there are several classification systems for UCL injuries, there are no specific ones for the RCL injuries. A generalised classification is used instead. Grade 1: Small incomplete tear, Grade 2: larger but still incomplete tear and Grade 3: complete tear.

Conventional radiographs are obtained to assess for avulsion fractures and subluxation. Volar subluxation of the phalanx >3 mm is much more common with RCL injury than with the UCL injury (Tang 2011) as RCL is a primary support preventing volar subluxation. Stress dynamic fluoroscopy may also aid

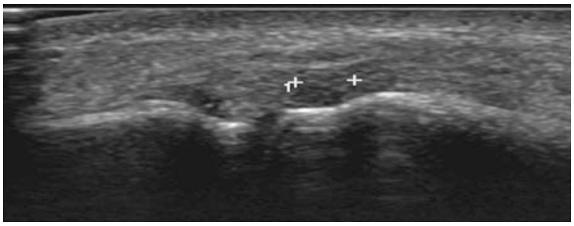

Fig. 9 Longitudinal ultrasound image showing rupture of radial collateral ligament

in evaluation of instability. Because of the high correlation between stress examination and operative findings, arthrography, ultrasonography (Fig. 9) or MRI are usually not needed (Edelstein et al. 2008).

On the basis of the current available literature, RCL and UCL injuries can be managed in a similar manner (Patel et al. 2010). Generally, Grade 1 and 2 injuries are treated conservatively, while treatment of Grade 3 injuries remains controversial. Various surgical methods have been described in the literature for Grade 3 injuries and no general agreement is present.

5 Fractures

Among the injuries sustained during sporting activities in the general population, it is fractures of the upper limb that predominate. The vast number of patients attending emergency department due to these injuries reflects this. In a retrospective study conducted by Aitken and Court-Brown looking at nearly 6000 fractures, 24 % of them occurred in hand and 22.4 % of these were sporting injuries. The thumb and the little fingers were most commonly involved fingers accounting for up to 57.3 % (Aitken and Court-Brown 2008). Metacarpal fractures of the thumb and little fingers are discussed below.

5.1 Thumb Fractures

The thumb provides up to 40 % of hand function (Carlsen and Moran 2009). Injuries to the thumb are predominantly fractures of the proximal phalanx or the metacarpal and ligamentous injuries around the MCPJ. Ligamentous injuries have been discussed in detail along with other soft tissue injuries of the hand. Thumb fractures are found to occur most commonly in children and the elderly (Stanton et al. 2007).

Thumb metacarpal base fractures form an important subset and will be discussed further.

5.1.1 Bennett Fracture

In 1882, Edward Hallaran Bennett first described the fracture involving the base of the thumb metacarpal. However, a Bennett fracture now refers to a two-part intra-articular fracture or dislocation involving the base of the thumb metacarpal (Rettig 2004). The mechanism of injury is classically an axial load to the flexed and adducted thumb (Hong 2005). The volar–ulnar fragment is held in place by its ligamentous attachment to the trapezium, known as the anterior oblique ligament, also described as the beak ligament (Bettinger et al. 1999). As a result of the injury, the remainder of the first metacarpal shaft subluxes in a dorsal, proximal and radial direction due to the pull of the abductor pollicis longus, extensor pollicis longus, extensor pollicis brevis and the adductor pollicis longus (Carlsen and Moran 2009). Gedda in 1954 has classified Bennett fractures as follows (Table 7).

Following clinical examination, a radiographic evaluation forms an integral part of the initial clinical assessment (Fig. 10). True antero–posterior and lateral views can be obtained with the Robert's and Bett's view, respectively, to look for fracture displacement and joint congruency (Carlsen and Moran 2009). These fractures are unstable and should be promptly referred to a hand surgeon for appropriate management. Closed reduction with percutaneous pin fixation is recommended if the fragment is less than 25 % of the articular surface and if the fragment is larger than 25 % of articular surface, and those irreducible by closed techniques should be opened, reduced and internally fixed (Weinstein and Hanel 2002).

5.1.2 Rolando Fracture

This was first described by Silvio Rolando in 1910, a Y-pattern fracture of the thumb metacarpal base (Fig. 11). Currently, this eponym is used widely for any comminuted intra-articular fracture of the thumb metacarpal base (Hong 2005). These are similar in location and etiology to Bennett fracture (Hong 2005). This fracture pattern is considerably more difficult to treat and has a worse prognosis than that of the Bennett fracture (Carlsen and Moran 2009). When there are two large fragments without considerable comminution, open reduction and internal fixation can

Table 7 Gedda classification of Bennett fractures (Gedda 1954, cited by (Carlsen and Moran 2009)

Type 1	Large single ulnar fragment and metacarpal base subluxation
Type 2	Impaction fracture without metacarpal base subluxation
Type 3	Small ulnar avulsion fragment with metacarpal dislocation

Fig. 10 Lateral radiograph of thumb showing fractures of the metacarpal base (Bennett fracture type 1) and proximal phalanx shaft

Fig. 11 Rolando fracture of the metacarpal base on a lateral radiograph of the thumb

be successful. For markedly comminuted fractures, distraction and reliance on ligamentous reduction of the fragments may be necessary (Carlsen and Moran 2009).

5.2 Boxer's Fracture

The most common fracture of the hand is fracture of the little finger metacarpal, accounting for up to 50 % of all metacarpal fractures and 20 % of all fractures of the hand (Lee and Jupiter 2000). A fracture to the little finger metacarpal neck is referred to as boxer's fracture. These result from incorrect technique in swinging a fist, that puts an oblique force applied to the smallest, weakest metacarpal (Walsh 2004). The fracture occurs just below the metacarpal head and is normally displaced in a volar direction (Fig. 12). It is important to assess for malrotation by examining the direction of the fingers in flexion (Hong 2005). Apex volar angulation of up to 40° is acceptable and can be treated conservatively with immobilisation in a gutter splint with ring and little finger MCPJs in a 90° flexed position (Hong 2005). Fractures that are markedly comminuted or angulated may need open reduction and internal fixation (Peterson and Bancroft 2006).

5.3 Intra-articular Fractures and Dislocations of the Carpometacarpal Joints

Intra-articular metacarpal base fractures are high-energy injuries that are often missed on initial presentation (Liaw et al. 1995). These are associated with carpometacarpal (CMC) dislocations and most commonly occur in the ring and little fingers.

The mechanism of injury involves axial load transmission through the fourth metacarpal onto the carpal bones (Cain et al. 1987). The ring and little finger CMC joints being modified saddle joints, allow considerable movement in the antero–posterior plane that predisposes these joints to dislocation (Liaw et al. 1995). At a certain stage when the ring finger metacarpal is unable to dissipate the force, a fracture occurs resulting in shortening of the ring finger metacarpal. The axial load is then transferred to the little finger metacarpal causing the little finger CMC joint injury (Liaw et al. 1995). The degree of the little finger metacarpal flexion determines the type and degree of hamate injury (Cain et al. 1987). Flexion of

Fig. 12 AP and oblique radiographs showing little finger metacarpal neck fracture (Boxer's fracture) with volar angulation

the metacarpal during impact may cause dorsal dislocation of the little finger metacarpal base, dorsal CMC ligament disruption and hamate fracture. In the little finger, the ECU, FCU and abductor digiti minimi tendon exert deforming forces on the fracture fragments (Weinstein and Hanel 2002). Cain et al. in 1987 have classified the combined ring and little finger metacarpal fracture and little finger CMC joint injury into three categories as follows (see Table 8).

The routine AP and lateral radiographs of the hand may not reveal the full extent of the ring and little finger CMC joints (Fig. 13) and a CT scan may be needed to demonstrate the full extent of the injury (Fig. 14). The 45° pronated oblique and 15° pronated oblique views are helpful in assessing the severity of this injury (Liaw et al. 1995).

The treatments of these injuries depend on the severity and stability of the CMC joints. Type 1 stable injuries treated conservatively. Closed reduction and percutaneous pinning can be used to treat unstable type 1 injuries (Cain et al. 1987). Type 2 and 3 injuries are potentially unstable and will require open reduction and internal fixation (Liaw et al. 1995).

Table 8 Cain et al. classification of intra-articular fractures and dislocations of carpometacarpal joints (Cain et al. 1987)

Type	Characteristic features
1A	Subluxation or dislocation of the little finger metacarpal base without hamate fracture
1B	Type 1A + small dorsal rim hamate avulsion fracture
2	Dorsal hamate comminution is present
3	Coronal splitting of the hamate

5.4 Phalangeal Fractures

Phalangeal fractures can occur at head, neck, shaft or base of the phalanges. There are many variations of these involving various locations. Shaft fractures can be transverse, oblique, spiral or comminuted (Hong 2005). Displacement and angulation of phalangeal fractures result from a combination of two main factors: the mechanism of injury and the deforming nature of the fracture (Peterson and Bancroft 2006). A direct blow can result in transverse or comminuted fracture, while a twisting injury often results in an oblique or spiral fracture (Lee and Jupiter 2000).

Condylar fractures of the head of proximal phalanx are typically the result of axial loading. London described three types of Condylar fractures that influence prognosis and management: a type I stable, undisplaced unicondylar fracture; a type II unstable, displaced, unicondylar and type III comminuted bicondylar fracture (London 1971).

Along with standard AP and lateral radiographs, CT can provide further information that may assist the surgeons in management.

Fig. 13 AP, lateral and oblique radiographs of the right hand showing little finger CMC joint dislocation. Note hamate fracture (seen on CT—Fig. 14) is not visible on these plain films

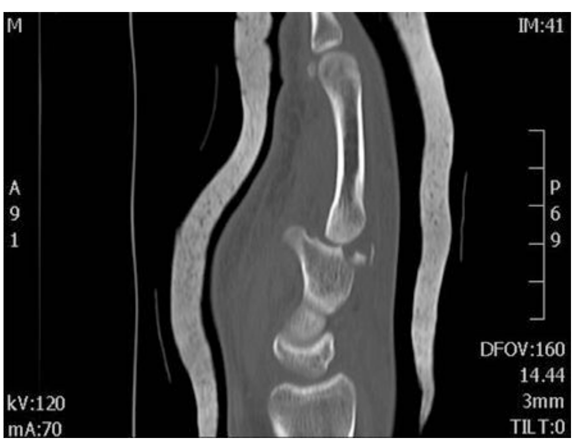

Fig. 14 Sagittal CT image shows little finger CMC joint subluxation with rim fracture of the hamate (Cain et al. type 1B CMC joint injury)

Oblique or spiral fractures may be associated with malrotation. No malrotation is acceptable for phalangeal fractures, because this leads to overlap and malalignment of the digit (Peterson and Bancroft 2006). Acceptable reduction is less than 6 mm of shortening, less than 15° of angulation and with no rotational deformity (Lee and Jupiter 2000).

Non-displaced fractures are treated conservatively, while displaced and malrotated fractures should be reduced; closed at first, but then surgically if needed (Hong 2005). For condylar fractures, London types II and III are treated surgically and stable type I injuries are managed conservatively (Stern 2005).

5.5 Interphalangeal Joint Dislocations

Interphalangeal (IP) dislocations are common injuries in athletes. These injuries usually result from significant force and may result in ligamentous injury or tear. Most IP joint dislocations involve the PIPJ (Morgan et al. 2001). The PIPJ is susceptible especially to forced abnormal motion produced in ball sports and in sports resulting in axial loading of the digit (Morgan et al. 2001). Most IP joint dislocations are dorsal, with dorsal dislocation of the middle phalanx and disruption of the VP (Fig. 15) (Hong 2005).

Fig. 15 AP, oblique and lateral radiographs of the middle, ring and little fingers showing dorsal dislocation of the proximal interphalangeal joints

6 Conclusion

This chapter has described the most common soft tissue and bone injuries to the hand. We have related the anatomy and mechanism of these injuries to the imaging assessment. We have also discussed factors that influence management decisions which enable a more thorough imaging assessment.

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