Imaging the Post-Operative Wrist and Hand

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Contents

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Abstract

Orthopaedic procedures of the hand and wrist are performed for a wide variety of pathologic conditions. Acute fracture fixation and treatment of fracture complications account for the majority of surgical interventions. Other indications for surgery include management of chronic arthropathy, ligament or tendon injury, soft tissue and bone tumours and infection.

1 Introduction

Orthopaedic procedures of the hand and wrist are performed for a wide variety of pathologic conditions. Acute fracture fixation and treatment of fracture complications account for the majority of surgical interventions. Other indications for surgery include management of chronic arthropathy, ligament or tendon injury, soft tissue and bone tumours and infection.

It is important for the radiologist to understand the primary aims of surgical treatment in order to accurately assess the post-operative imaging to identify potential complications. The aims of surgery include:

- Restoration of normal anatomy
- Pain management

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- Restoration of function
- Treatment of cosmetic disfigurement
- Prevention of secondary osteoarthritis (OA)

There are a large number of fixation devices and prostheses available to the orthopaedic surgeon, and radiologists should be familiar with the most commonly used devices. It is important to distinguish between acceptable and unacceptable alignment of the bony structures and metalware, and to recognise when poorly positioned devices may lead to complications. In soft tissue reconstruction, it is necessary to know when normal structures have been utilised to achieve the repair (e.g. tendon harvesting), in order to be able to recognise the anatomy on cross-sectional imaging.

Common complications include non-union and mal-union of fractures, poor operative correction of bone and joint deformity and mal-positioned orthopaedic hardware. Non-union of joint arthrodesis, implant failure and infection may also be encountered.

Radiographs are the primary imaging modality used to supplement clinical examination in the post-operative period. Cross-sectional imaging may be required when complications arise. The choice of image modality is guided by clinical findings, and may depend on the presence of orthopaedic metalware which limits the use of MRI in particular.

CT is excellent for documenting bony detail and is useful for assessment of fracture healing and some hardware complications. US is a useful alternative to MRI for assessment of the soft tissues. Nuclear medicine studies are rarely required, but white cell scans may occasionally be useful for evaluation of infected implants.

2 Fracture Fixation

2.1 Indications

Fixation of hand or wrist fractures is indicated when the fracture fragments lie in an unacceptable position, or the fracture pattern is unstable and redisplacement likely.

Fixation of a hand or wrist fracture would also be considered in certain circumstances where the patient's personal circumstances or characteristics would make such treatment more appropriate. These relative indications include:

- Co-existent skeletal injuries where mobility will be assisted by crutches or load bearing through the wrist
- Bilateral hand or wrist fractures
- Co-existent soft tissue injuries which require early treatment, physiotherapy or rehabilitation out of plaster cast
- Patient request (e.g. professional sportsman/woman)

2.2 Implant Choice

A variety of implants are used to stabilise fractures in the hand and wrist. These are either applied to directly stabilise the fracture fragments (Kirschner wires, or internal fixation materials), or applied indirectly to stabilise the fracture fragments from a distance (external fixators).

2.2.1 Kirschner Wires

These are small, thin pins made of stainless steel or titanium. They come in a variety of diameters, typically 1.0–1.6 mm in diameter. They have a sharp tip at one end or both ends ("double-ended"). K-wires with a threaded tip are designed for use as guide wires for cannulated devices and should never be left in situ, since removal is extremely difficult without adequate anaesthesia.

When inserted, the K-wires should engage both cortices to be mechanically effective. They cannot compress fracture fragments, and will only maintain a reduction achieved by other means. Most often, they are inserted percutaneously after a closed reduction, but may occasionally be used following open reduction. K-wires may need to cross joints to be mechanically effective in some circumstances, and this provides a potential route for spread of infection (Fig. 1).

2.2.2 Internal Fixation Materials

Internal fixation may be achieved by the use of compression screws, plate and screw devices or bone anchors.

The best known screw, the Herbert screw, was designed for use in the scaphoid. The pitch varies along the length of the screw, so that differential longitudinal movement occurs in the fracture fragments at each end of the screw as it is tightened, bringing the fragments closer together resulting in fracture compression. The 'Headless Compression Screw' (HCS), which provides significantly greater

Fig. 1 AP and lateral radiographs acquired a few weeks following K-wire fixation of an open fracture of the distal phalanx due to a dog bite. There is osteomyelitis of the distal phalanx with marked lytic bony destruction. In addition, the presence of the K-wire has allowed spread of infection across the DIP joint into the middle phalanx, with diffuse osteopaenia and periosteal reaction

fracture compression and stability, has now largely replaced the Herbert screw. It is sometimes possible to fix fractures percutaneously by utilising cannulated screws, which have a central channel through which a thin guide wire can be inserted under image guidance across the fracture allowing the screw to be introduced over the temporary guide wire (Fig. 2).

Traditional 'plate and screw' implants for the hand and wrist have undergone a revolution in design in recent years. These changes have involved three separate developments:

- Angular stability
- Anatomic implants
- Indirect reduction technique (in distal radius fractures)

Anatomic implants such as the volar plate are commonly used in distal radial fractures. Modified contoured implants traditionally used by craniomaxillofacial (CMF) surgeons in the maxilla, mandible and facial bones have been adapted for use in the small bones of the fingers.

Bone anchors are small metallic or absorbable implants which are inserted into a small drill hole made in bone. Pre-threaded with suture material, they allow soft tissues to be reattached to the bone when this interface has been disrupted by injury. The most common use of these implants in the hand and wrist, is in the treatment of ulnar collateral ligament (UCL) injuries in the metacarpophalangeal (MCP) joint of the thumb (skiers thumb).

2.2.3 External Fixation

This technique involves the application of two or more threaded pins into the bone on each side of the fracture. These pins are then connected by means of an externally applied rigid bar, which may be radiolucent to help in assessment of radiographs. The pins must engage the cortex on both surfaces to withstand the forces attempting to redisplace the fracture.

When the distal fragment is large and not comminuted, two pins can be placed in the distal fragment, so that the fixator does not cross the adjacent joint (non-bridging fixator), and does not prevent joint movement. However, if one fracture fragment is small, and unable to securely hold two threaded pins, the pins must be placed in a bone beyond the adjacent joint.

2.3 Distal Radial Fractures

Traditionally, K-wires were used to treat extra-articular and simple-articular fractures in the elderly, although evidence has suggested that they may be significantly less effective in maintaining reduction in osteoporotic bone (Greatting and Bishop 1993). For this reason, internal fixation is increasingly employed in the elderly wrist fracture, although K-wires are still utilised for unstable epiphyseal fractures in children (Fig. 3). Radiographs are utilised to ensure K-wire and fracture alignment is maintained until fracture healing is achieved and the wires can be removed.

Implants placed on the dorsal surface of the distal radius were commonly complicated by attrition rupture of the extensor tendons, and are now less frequently utilised.

Current implants are 'anatomic' and designed to fit flush to the volar surface of the distal radius. The plate

Fig. 2 Oblique PA radiograph (**a**) demonstrating an un-united waist of scaphoid fracture at 6 weeks. The fracture has been stabilised by a cannulated screw (**b**), and has now fully united. Note that the pitch of the screw is wider distally than proximally. NB: the screw is inserted distal to proximal, so the tip of the screw is in the proximal scaphoid

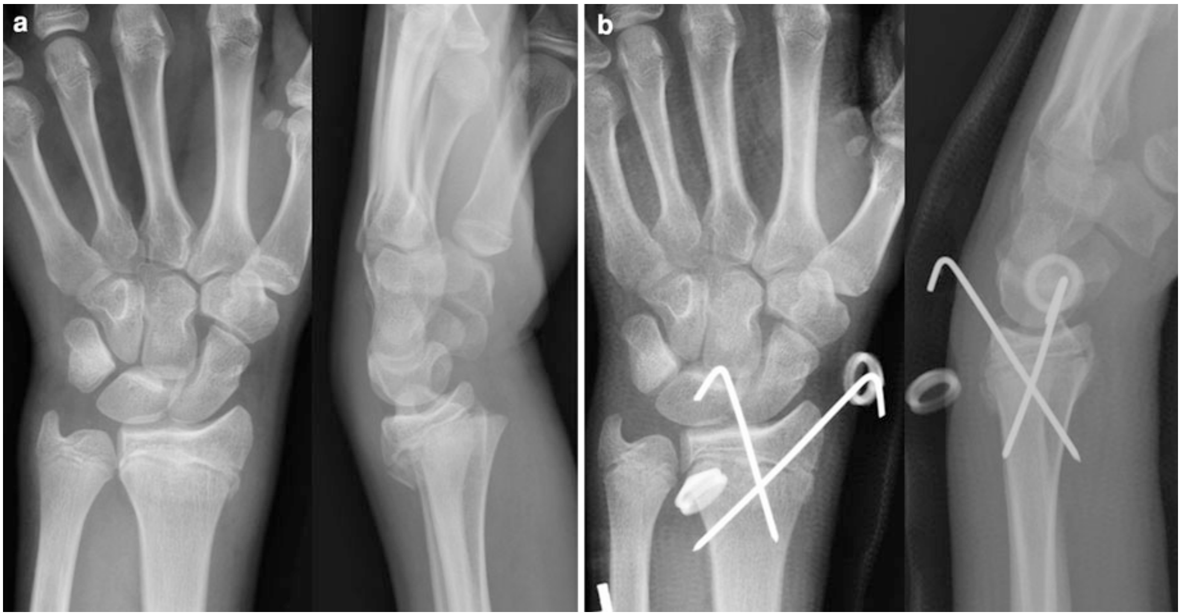

Fig. 3 PA and lateral radiographs (**a**) of a teenager with an unstable Salter–Harris type II fracture. The PA and lateral radiographs (**b**) acquired following K-wire fixation demonstrate good fracture reduction. Each K-wire traverses two bony cortices, ensuring mechanical stability

forces the distal fragments to re-align in a perfect position with multiple sub-chondral angularly stable screws (Fig. 4). This technique is known as 'indirect reduction' and is widely used in all types of distal radius fractures. It has the added advantage of automatically correcting any malrotation of the distal fragment. There are over 40 different designs of volar locking plates for the distal radius currently available.

A variety of neurovascular, soft tissue and osseous complications may arise as a result of volar plate

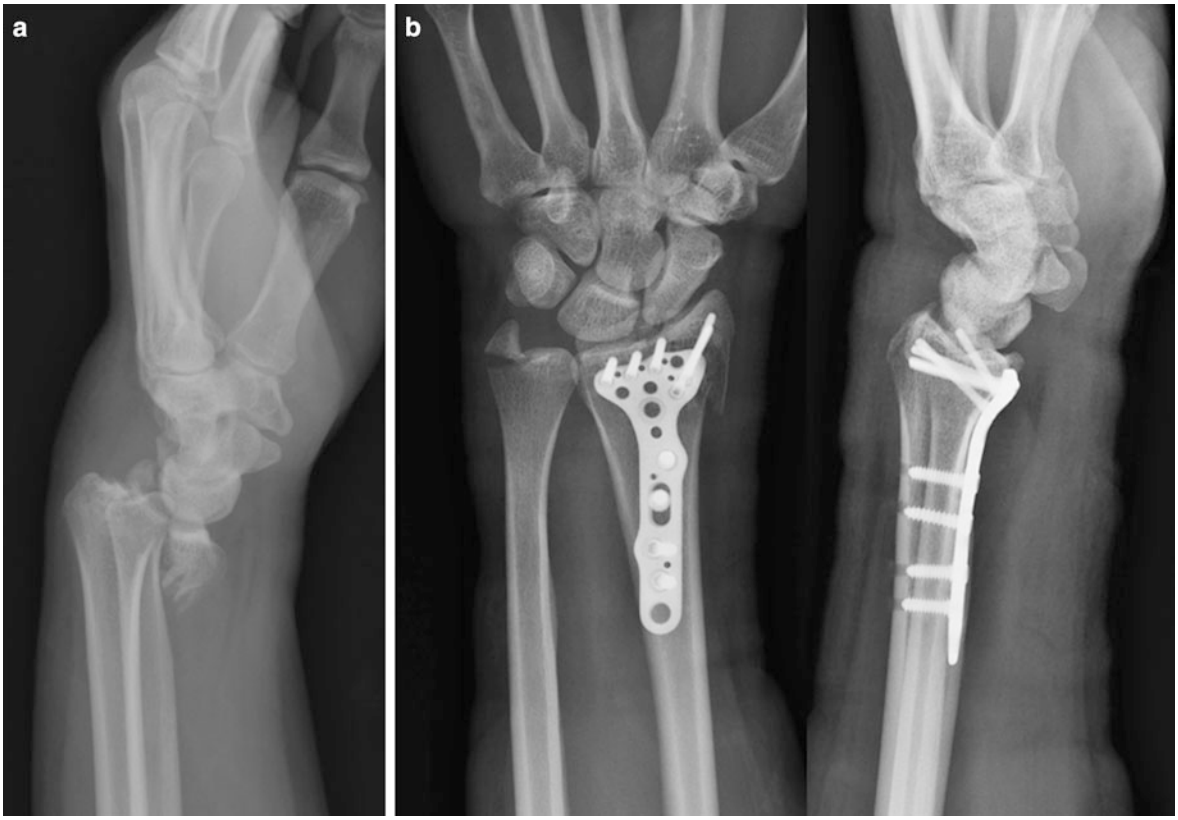

Fig. 4 Lateral radiograph (**a**) of a displaced volar shearing, comminuted and intra-articular fracture of the distal radius. PA and lateral radiographs (**b**) acquired following volar plate fixation demonstrate good restoration of anatomical alignment, with the articular fragments maintained by the sub-chondral screws. The screws in the proximal plate do not engage the dorsal cortex of the distal radial metaphysis, consequently they do not protrude into the soft tissues, but the resulting lack of bicortical fixation may be prone to early redisplacement. Note also the minimally displaced fracture at the base of the ulnar styloid

fixation (Berglund 2009). Flexor pollicis longus tendinopathy and rupture may be associated with a distally mal-positioned volar plate and plate 'lift-off'. Fracture mal-reduction may also contribute to tendon rupture. Extensor tendon ruptures may be seen with overlong or mal-positioned screws (Fig. 5). Intra-articular screw placement within the radio-carpal joint may also be encountered, and pre-dispose to accelerated secondary OA change. Other complications include carpal tunnel syndrome, complex regional pain syndrome and delayed union (Arora et al. 2007).

Patients' with pain or crepitus over the flexor or extensor tendons may be assessed by US to identify tendon impingement with the volar plate and exclude tendinopathy, and tendon rupture. The relationship of mal-placed screws to tendons can also be assessed. Significant tendon disease may necessitate removal of the volar plate once bony union is achieved.

External fixation is usually reserved for open or excessively comminuted fractures, although this mode of fixation is the preferential choice for some surgeons. Pins are placed in the radial shaft and the shaft of the index (second) metacarpal. The pins must engage the cortex on both surfaces to withstand the forces attempting to redisplace the fracture, and it is important to obtain consistent positioning of serial post-operative radiographs to ensure there is no metalware failure, and the pins remain fixed in the bone cortices.

2.4 Scaphoid Fractures

Internal fixation is indicated in the treatment of displaced waist of scaphoid fractures and undisplaced proximal pole scaphoid fractures. It is most frequently employed in the treatment of non-union of scaphoid

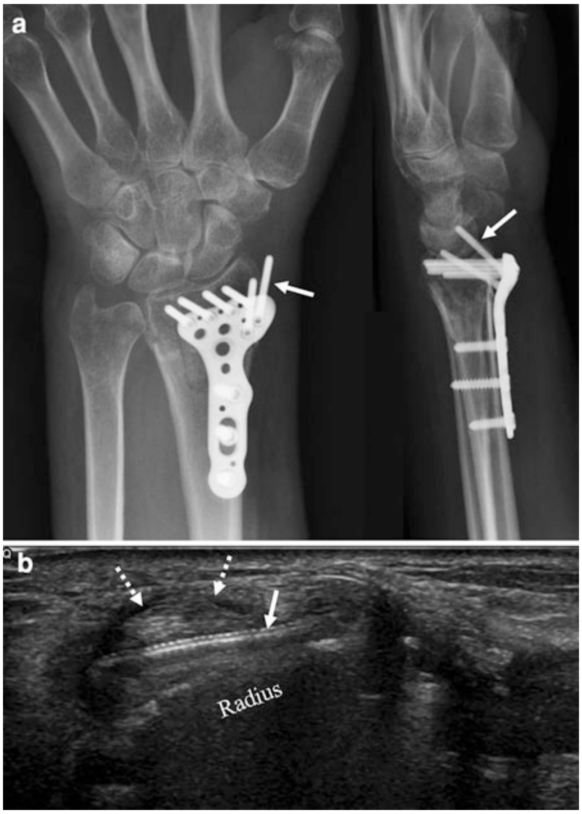

Fig. 5 PA and lateral radiographs (**a**) of a distal radial fracture fixated with a volar plate. The plate is positioned too far distally, and is not aligned with the centre of the shaft of the distal radius. One of the radial styloid screws is extra-osseous (*white arrows*). An oblique transverse US image (**b**) shows the screw (*white arrow*) extending into the extensor group I tendons (*broken white arrows*)

fractures in order to improve the chances of bony union. Cannulated screws are most commonly used and stabilise both the fracture fragments and interposed bone graft.

Grafting and fixation of scaphoid non-union is not indicated if there is established OA, and other salvage procedures such as denervation, proximal row carpectomy or wrist arthrodesis may be required. Radiographs are notoriously inaccurate in demonstrating avascular necrosis of the proximal pole (Downing et al. 2002). Pre-operative MR imaging is more accurate in assessing the vascularity of the proximal fragment.

Fracture non-union and hardware failure occurs in up to 8% of patients undergoing dorsal percutaneous cannulated screw fixation of undisplaced scaphoid fractures (Bushnell et al. 2007). Fracture healing on serial radiographs is normally expected by 12 weeks

Fig. 6 PA radiograph (**a**) of a fractured scaphoid stabilised by a cannulated compression screw. It is difficult to assess fracture union on this examination, although there is clear evidence of lysis around the screw, suggesting loosening due to non-union. Sagittal oblique CT (**b**) confirms the presence of fracture non-union. In addition the proximal end of the screw impinges within the scapho-trapezial joint

post-fixation, and a persistent fracture line indicates delayed or non-union. Persistent non-union is more frequent in patients undergoing fixation of chronic non-union, even with bone grafting, and occurs in up to one-third of cases (Megerle et al. 2008). If radiographs are equivocal, CT is a reliable method of evaluating the status of fracture healing (Fig. 6). Progressive lucency around the screw is indicative of screw loosening. Avascular necrosis of the proximal pole segment is manifest by sclerosis, sub-chondral flattening and fragmentation. Screw fracture is rarely encountered.

2.5 Hamate Fractures

The treatment for non-displaced hamate fractures is usually conservative. However, the majority of displaced fractures are treated by either fixation with pins or screws (Fig. 7), or by excision of the fragment (Walsh and Bishop 2000) if a symptomatic non-union of the hook of the hamate is present. Non-union is common in displaced fractures managed non-operatively, although long-term outcome may be no worse than those treated operatively (Scheufler et al. 2005). Compression screw fixation generally achieves better fracture stability than fixation with Kirschner wires, although this does not necessarily correlate with outcome scores (Wharton et al. 2010).

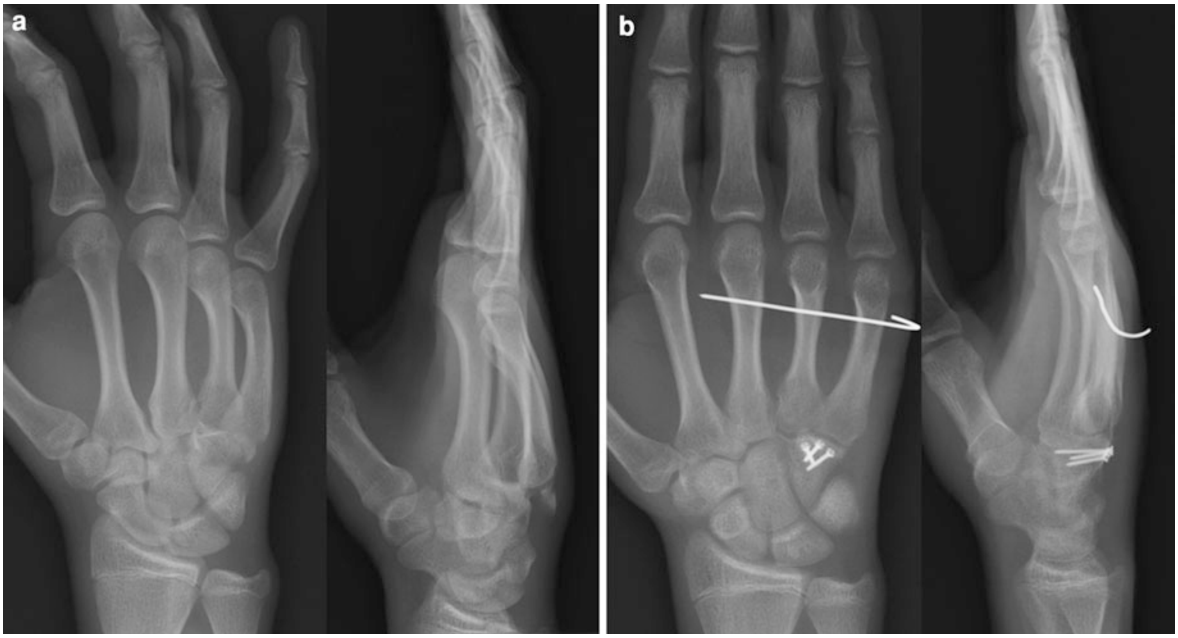

Fig. 7 Oblique PA and lateral radiographs (**a**) of a displaced dorsal hamate fracture associated with dislocation of the fourth and fifth metacarpal bases. The post-operative PA and lateral radiographs (**b**) demonstrate good anatomical alignment of the fracture fragment maintained by three cortical screws. The metacarpal dislocation has been reduced, and the K-wire transfixing from third to fifth metacarpals helps maintain stability during ligamentous healing

CT imaging of hamate fractures is utilised to detect occult fractures (Welling et al. 2008), to aid surgical planning of complex fractures, or to diagnose fracture non-union. Serial radiographs are required post-operatively to assess progression of bony union and exclude hardware failure. The PA and oblique views may be supplemented with a lateral view in cases with associated carpo-metacarpal dislocation, to assess adequacy of reduction. CT is rarely required in the post-operative period but may be helpful where bony union is equivocal.

2.6 Other Carpal Bones

Carpal fractures at other sites occur much less frequently. The peculiar anatomy of each carpal bone (irregular shape and significant surface area coverage by articular cartilage) does not lend itself to an easy solution when designing an internal fixation implant. However, the usually dense cancellous bone in this region, allows intraosseous devices to be designed, which will stabilise each carpal bone fracture appropriately.

When carpal bones dislocate, they are usually held in a reduced position by multiple K-wires inserted percutaneously. These are an excellent implant choice because compression is not required between bones as the ligaments heal. K-wires used for these indications will normally remain in place for approximately 8 weeks.

2.7 Metacarpal and Phalangeal Fractures

K-wires remain popular in the management of metacarpal fractures because of the high cortex:cancellous ratio of these bones. A combination of PA, oblique and true lateral post-operative radiographs, dependant on fracture location, may be required to assess fracture alignment. Good fracture reduction is especially important for intra-articular fractures to maintain function and prevent long-term secondary OA.

Internal fixation using plates and screws is indicated in unstable, irreducible and open fractures. They are employed in cases where early skeletal stabilisation will facilitate earlier movement and rehabilitation.

Fig. 8 Oblique radiograph (**a**) of an angulated, transverse fracture of the proximal phalanx of the middle finger. The PA and lateral radiographs (**b**) demonstrates anatomical fracture reduction and fixation with a CMF type implant. Note that the screws transfix the opposite cortex. The limited thickness and small size of the implant, combined with the lateral placement of the plate, suggest that this fixation is at significant risk of early redisplacement and failure. Larger implants situated on the dorsal surface of the bone (to resist the force of the flexor tendon) have a greater chance of success

Scaled down versions of standard long bone implants are too bulky for the confined areas adjacent to the bones of the hand, and often cause adhesion of the soft tissues in contact with the implant, requiring plate removal and division of peritendinous adhesions (tenolysis), as a second surgical procedure in up to 75% of cases (Buchler and Fischer 1987). Hand fracture implants now closely match the original CMF implants rather than orthopaedic implants. A whole new generation of anatomic implants for use in certain pre-defined areas of the hand has evolved (Fig. 8), such that external fixators are now rarely used in the hand (Fig. 9).

Radiographs are evaluated for fracture or displacement of either the plate or screws.

3 Prosthetic Joint Replacement

3.1 Indications

Joint prostheses are rarely indicated in the management of hand and wrist conditions. Finger joints require flexibility and mobility to be useful. Implants can rarely provide this since the surgical approach itself will result in stiffness. The function of the wrist joint demands both stability and flexibility, both of which are difficult to create and match in a prosthetic joint.

The commonest indication for arthroplasty in the hand and wrist is rheumatoid arthritis. Prosthetic joint replacement is indicated when an individual's personal needs or lifestyle are such that arthrodesis would be unsuitable. In some instances, this may be unilateral, with an arthrodesis preferred in the opposite wrist to provide maximum stability and strength.

Osteoarthritis is more common than rheumatoid arthritis, but OA patients have very different demands of hand and wrist function, and prosthetic replacement is usually unsuitable because of their greater functional needs. Prosthetic replacement may be considered for secondary OA of a single interphalangeal joint, when the remaining interphalangeal joints are unlikely to develop similar changes, but their function can be significantly downgraded by the arthritic changes present in the affected joint.

3.2 Implant Choice

3.2.1 Wrist

There are a number of different implants available, although none have proved overwhelmingly successful. Most have two parts, one for each side of the wrist 'joint'. They are made of metal, although a high density plastic insert is situated between the components in most implants.

Prostheses can either be described as 'constrained' or 'unconstrained', depending on the design characteristics and the relative freedom of movement between the components, or as 'cemented' or 'uncemented'. Newer designs try to mimic the natural movements of the wrist and carpal bones/ligaments.

Serial radiographs should be assessed for prosthesis alignment and migration, and bony osteolysis (Fig. 10). Early designs were subject to distal component loosening, although this is less frequently encountered with newer implants. Proximal subsidence may be identified but is often non-progressive and asymptomatic (Adams 2004). However, outcome measures for wrist arthroplasty are comparable or slightly worse than wrist fusion (Cavaliere and Chung 2008), and surgical options need to be carefully assessed.

Prosthetic surgery in the distal radioulnar joint (DRUJ) is more frequently indicated than in the

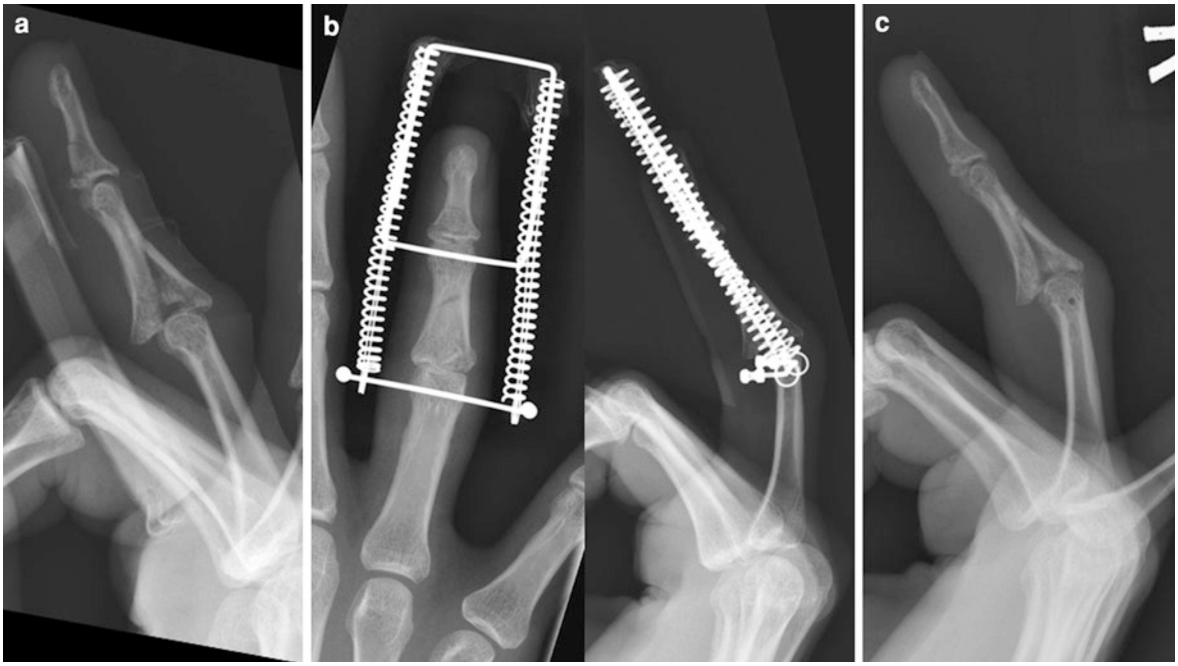

Fig. 9 Lateral radiograph (**a**) of a longitudinal, coronal plane fracture of the base of the middle phalanx, with separation and depression of the intra-articular fragments. The fracture has been stabilised with an external fixator (**b**), although fracture reduction is difficult to assess on the lateral view due to the presence of the fixator. The PA view demonstrates persistent displacement of an articular fragment on the ulnar side of the base of the phalanx. Following removal of the fixator, the lateral radiograph (**c**) demonstrates incomplete fracture reduction and incomplete bony union

radiocarpal joint (Kopylov and Tagil 2007). This type of surgery is most frequently performed to stabilise the unstable distal ulnar stump after excision (Darrach's procedure). Prosthetic surgery is also indicated in degenerative disease of the DRUJ and after unreconstructible fracture of the ulnar head. Prostheses either replace the distal ulna alone (distal ulnar prosthesis) (Fig. 11), or both the distal ulna and sigmoid notch of the distal radius (DRUJ prosthesis). They are usually uncemented.

3.2.2 Hand

Interphalangeal or metacarpophalangeal replacements are either made of:

- Silicon
- Metal and plastic
- Pyrocarbon

Silicon implants are commonly used for multiple MCP joint replacements in rheumatoid arthritis. Long-term outcomes for silicone implants are good with 63% survivorship at 17-year follow up (Trail et al. 2004), and have better outcomes than non-surgical groups (Chung et al. 2009). Metal and plastic implants mimic other large joint prostheses in other areas of the body but are almost always inserted without the use of cement. Pyrocarbon implants are radiopaque and are always inserted cementless.

Post-operative radiographs are assessed for the position of each implant, and joint alignment. At long-term follow up, loosening, bony osteolysis and prosthetic deformity and fracture may occur (Fig. 12). Fracture of silicone prostheses eventually occurs in up to two-thirds of cases, although clinical outcomes may not be adversely affected (Trail et al. 2004). Amyloid- and silicone-induced synovitis is a well documented complication of silicone implants and is also referred to as giant cell arthritis. Patients present with pain and swelling localised to the affected joint. Onset of symptoms can vary from 6 months to 9 years. Radiographs may show nodular soft tissue swelling, well defined sub-chondral lytic defects and erosions. The bony changes evolve over time and must be distinguished from pre-existing arthropathy which necessitates review of previous radiographs. MRI demonstrates effusions with peri-articular low signal intensity silicone particles and fibrosis in

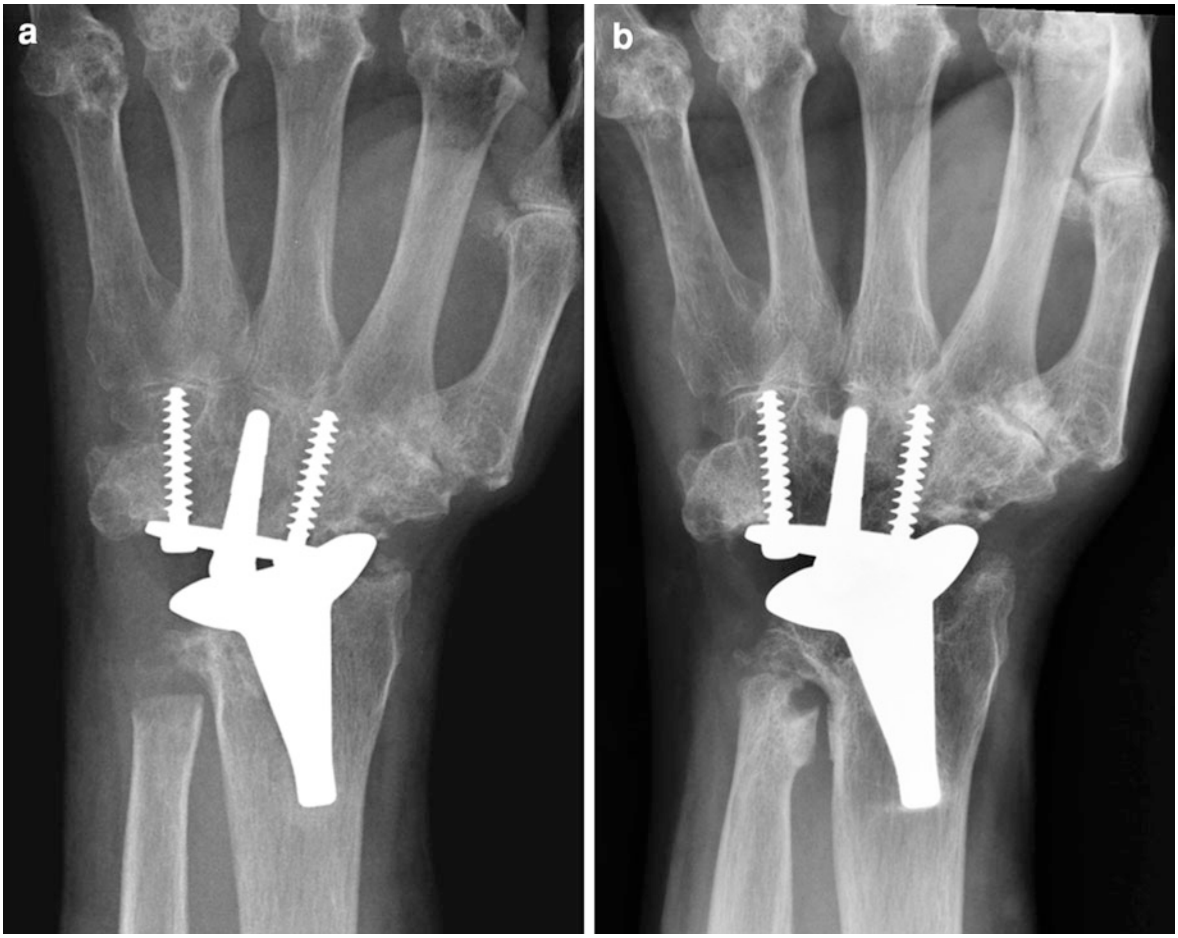

Fig. 10 PA radiograph (**a**) of a 'Re-Motion' wrist prosthesis, in a patient with severe rheumatoid arthritis. The prosthesis is angulated and there is reasonable bone density around the wrist. Although there is no subsidence or change in position of the prosthesis, a follow up radiograph (**b**) acquired 3 years later, demonstrates progressive bony lysis around both proximal and distal components, due to either infection or sterile loosening caused by repetitive loading on the radial border of the prosthesis secondary to malposition

addition to prosthetic deformity and fracture. The sub-chondral lucencies are lower signal intensity on T2W images than typical sub-chondral cysts (Chan et al. 1998). However, most diagnoses can be made on conventional radiographs.

4 Arthrodesis

4.1 Indications

Arthrodesis (surgical fusion) is performed to stabilise a joint by permanently removing its movement in order to remove pain or improve the position of a stiff joint. Surgical removal of the remaining cortical bone is performed on each side of the joint, so that a healthy, vascular bed of cancellous bone is exposed. Opposing cancellous surfaces are brought together and an implant is used to stabilise them whilst osseous healing occurs. Following successful fusion, the implant may be removed in a second surgical procedure if there are soft tissue complications.

Arthrodesis of the wrist may be total or partial. A total wrist arthrodesis involves the radiolunate, radioscaphoid, scapholunate, scaphocapitate and capitolunate joints. The third CMC joint is not always surgically prepared for fusion, but is often left untouched with the intention of removing the stabilising

Fig. 11 PA radiograph of an uncemented distal ulnar prosthesis inserted to treat instability of the distal ulnar stump after excision of the ulnar head (Darrach's procedure)

implant at a later date once fusion is sound. This preserves an important movement in the hand, allowing 'cupping' of the fingers and improved dexterity.

A 'partial' wrist arthrodesis is otherwise known as 'intercarpal arthrodesis'. Adjacent carpal bones are arthrodesed to produce a specific anatomical fusion depending on the primary condition (rheumatoid arthritis, OA or carpal instability). Radiolunate arthrodesis is indicated in rheumatoid arthritis to prevent ulnar drift of the hand from the radius. Scaphotrapeziotrapezoid joint arthrodesis is indicated for OA, and when preservation of carpal height is required.

OA of the first CMC joint is very common and a wide range of surgical options are available including arthrodesis. In the hand, the most commonly fused joint is the MCP joint of the thumb. Instability and pain may produce loss of power and precision grip. The terminal joints of the thumb and the fingers are usually fused for patients with OA to restore the effective length of the digit, and improve stability, pain, dexterity and fine movements.

4.2 Implant Choice

4.2.1 Wrist

4.2.1.1 Total Wrist Arthrodesis

Total wrist arthrodesis can be difficult to achieve in patients with OA, and requires specifically designed implants which are strong, but which do not cause irritation of the overlying gliding tendons. These implants come with two different pre-set angles, so that the wrist is arthrodesed in either 20° of extension (commonly utilised) (Fig. 13) or in neutral flexion/extension. One of each type may be used in bilateral arthrodesis to give different abilities with each wrist. The newer versions of these implants include locking screw options to provide angular stability when used in osteoporotic bone.

Rheumatoid patients often have a thin dermis and a potential for poor wound healing. Successful bony fusion can be achieved by the use of an intramedullary stainless steel pin (usually of 3 or 4 mm diameter), without the risks of a substantial metal implant. This is introduced through the head of the middle metacarpal (or occasionally in the second intermetacarpal space) and passed across the carpus and into the medullary canal of the radius (Fig. 14). No rotational stability is provided by this implant, but healing is usually so rapid that this is not a functional problem.

4.2.1.2 Partial Wrist Arthrodesis

Four corner fusion of the lunate, triquetrum, hamate and capitate using a circular plate device was introduced in 1999. It is usually performed in combination with total excision of the scaphoid, as a salvage procedure for scapholunate advanced collapse (SLAC), and scaphoid non-union advanced collapse (SNAC), and has largely replaced traditional fusion procedures using wires, staples and compression screws (Fig. 15). Scaphoidectomy alone would result in inevitable carpal collapse, and a 'four corner arthrodesis' prevents this complication.

Early studies demonstrated higher complications rates than with conventional methods of fusion. Radiographic non-union (26%) and dorsal hardware

Fig. 12 PA radiograph (**a**) of a patient with severe interpalangeal (IP) joint erosive OA with joint deformity and subluxation. The post-operative radiograph (**b**) illustrates the silastic implants from the second to fourth PIP joints, with restoration of normal joint alignment. There has also been an arthrodesis of the DIP joint of the index finger. A follow up film (**c**) 2 years later (after removal of the arthrodesis screw) shows early deformation of the implants, with early bony resorption of the cut ends of the proximal phalanges. There is recurrent ulnar drift particularly affecting the middle finger. There is no fracture of the implants, and no soft tissue swelling

impingement (22%) are most frequently encountered (Vance et al. 2005). Other complications include implant breakage or back-out, and carpal tunnel syndrome (Bedford and Yang 2010). However, a recent study has shown a much higher rate of radiographic union, achieved over a mean follow up period of 22 months, with very few other complications observed (Bedford and Yang 2010).

Serial radiographs are used to assess the progress of bony union and identify hardware failure. Cross-sectional imaging is rarely required, but US may have a role when dorsal impingement or protruding screw tips through the carpal tunnel floor are suspected clinically.

4.2.2 Hand

Arthrodesis of the first CMC joint with screw and plate fixation may be complicated by plate failure and non-union (Fig. 16). However, there is no evidence that other surgical options such as trapeziectomy and ligament reconstruction offer any significant advantage (Wajon et al. 2009). Complications include tendon adhesion or rupture and complex regional pain syndrome (type I). These occur in up to 10–22% of patients.

Crossed K-wires or small intraosseous screws (such as mini-Herbert screws or HCSs) are used to arthrodesis finger joints (Fig. 17). If the finger joint is larger in cross-sectional area, a dorsal tension band wiring system may be used which gives the advantage of allowing early movement. The tension band wiring system consists of two parallel K-wires crossing the fusion site obliquely, with a dorsal 'figure-of-8' wire loop (Fig. 18).

Screw fixation results in bony fusion in 85–100% over 7–10 weeks (Leibovic 2007). Complications include screw migration, breakage and infection (Fig. 19). K-wire fixation allows fusion in 5–10% of flexion which improves dexterity, but is associated with higher rates of non-union and other complications.

5 Osteotomy

5.1 Indications

Osteotomy is indicated when the shape of a bone requires modification. In the wrist, this is most commonly required for fracture malunion of the distal

Fig. 13 Lateral radiograph of total wrist arthrodesis using a wrist fusion plate. The arthrodesis has been performed with the wrist in slight extension to allow improved power grip

Fig. 14 Wrist arthrodesis in a rheumatoid patient achieved using a single longitudinal Steinman pin

radius, usually for an extra-articular deformity, but occasionally for more complex intra-articular deformity. The relative shortening of the radius caused by fracture is usually a 3D deformity which requires radial osteotomy and bone grafting to correct it. However, in unusual circumstances, if the radial deformity is simply one of shortening, an ulnar shortening osteotomy alone will realign the DRUJ surfaces (Fig. 20).

Osteotomy is also sometimes indicated for malunion of the scaphoid, when the classical 'hump back' deformity of a flexed scaphoid has resulted in secondary carpal instability, or in finger fractures which have healed with rotation. This produces a significant functional problem as the fingers 'cross over' each other as they bend into a fist.

Other indications for osteotomy relate to altering the pattern of load transfer across the joint. This used to be frequently performed for early OA, but is now reserved for conditions such as Kienbocks disease (where the radius is usually shortened at the metaphyseal level), and ulnar abutment (where the distal ulnar shaft is shortened to reduce the force across the degenerate or damaged TFCC).

5.2 Implants

Standard internal fixation implants are used for stabilisation of osteotomies around the wrist. For the distal radius, these are usually angularly stable implants, because indirect reduction techniques are used to correct the misshaped bone (Fig. 21).

Increasingly, surgeons are using 'anatomic' implants (shaped like the bone they are trying to correct) in radial osteotomy. These are usually applied on the volar surface of the distal radius. This did present problems in placing a large piece of cortico-cancellous bone graft into the defect when the 'natural' access for the graft was from the larger gap

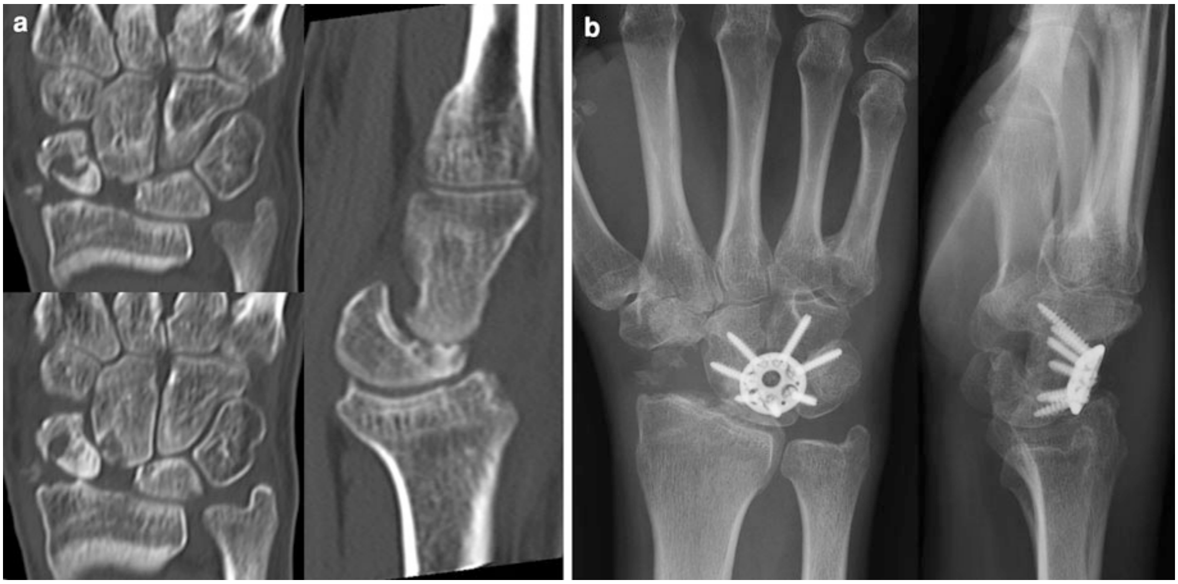

Fig. 15 Coronal and sagittal CT images (**a**) of a patient with a SNAC wrist. There is scaphoid non-union, scapholunate diastasis, DISI deformity and carpal collapse with secondary OA in the mid-carpal joint. There is also an un-united fracture of the radial styloid. A PA radiograph of the hand (**b**) shows the post-operative appearances following scaphoidectomy and a four corner fusion. The screws are well-sited in the capitate, hamate, lunate and triquetrum. However, there is residual dorsal angulation of the lunate with minor volar subluxation due to insufficient seating of the plate

Fig. 16 Lateral radiograph of the thumb following arthrodesis of the first CMC joint with a mini fragment screw and plate fixation. The plate has fractured due to non-union of the arthrodesis with recurrent subluxation of the CMC joint

on the dorsal bone surface. However, the significant mechanical strength and stability provided by modern locking plates allows morselised cancellous bone or bone substitute to be packed into the defect through a small aperture.

Radial and ulnar osteotomies are generally very successful procedures. Complications are usually technique-related such as incomplete correction of deformity, implant-related issues (incorrect screw length, malposition of the implant) or delayed/non-union of the osteotomy. Similar complications exist in osteotomy of the scaphoid and fingers, but non-union is a more significant risk in scaphoid osteotomy than wrist or finger osteotomy.

6 Curettage and Bone Graft

6.1 Indications

Bone cysts are not uncommon in the phalanges, but are rare in the wrist. Occasionally, benign bone cysts and tumours, such as enchondromata, will require curettage and bone grafting.

Bone grafting is used more frequently to promote healing in conditions such as scaphoid non-union or after radial osteotomy.

Fig. 17 Lateral radiograph showing satisfactory alignment of an IP joint arthrodesis with a compression screw. The joint is fixed in approximately 45° of flexion to help preserve function

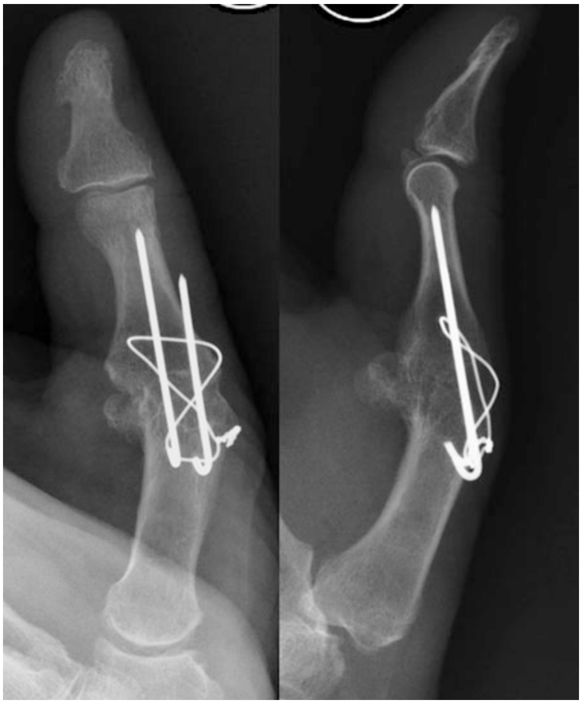

Fig. 18 PA and lateral radiographs of a first MCP arthrodesis performed for an unstable joint with secondary OA. The joint has been stabilised with K-wire and dorsal tension band wiring. Sound bony union has been achieved with the joint in flexion, although ideally the wires should penetrate the palmar cortex

6.2 Implant Choice

A structural bone graft is important in certain circumstances, and this will usually be harvested from the iliac crest (non-vascularised) or the distal radius on a vascular pedicle (vascularised). If the area to be grafted is stabilised by an appropriate strong implant (such as in corrective osteotomy for distal radius malunion), cancellous autograft or, increasingly, bone substitute will be indicated. Cancellous autograft can be harvested from the ipsilateral distal radius or the olecranon. Bone substitutes are either osteogenic (such as those containing bone morphogenic proteins (BMP) or hydroxyapatite) or inert stimulators of new bone growth (such as calcium sulfate). The former are more likely to be radiologically visible for months or even years after implantation, whilst the latter are usually only visible radiologically for a few weeks.

Radiographs are usually sufficient for follow up evaluation. MRI is indicated in cases where tumour recurrence is suspected (Fig. 22). The increasing use of bone substitutes has developed in response to the complications associated with harvesting of bone graft—particularly from the iliac crest. Haematoma, meralgia paraesthetica (injury to the lateral cutaneous nerve of the thigh) and scar tenderness may be encountered.

7 Tendon Repair

7.1 Indications

Tendon repair is indicated after traumatic division, attrition rupture or avulsion of the tendon insertion.

7.2 Implant Choice

No implants are used in primary tendon repair, which is achieved by intratendinous suturing of the tendon ends using non-absorbable suture material. Secondary reconstruction is performed when primary repair is not possible due to delayed presentation, infection, poor skin cover or other associated injuries. This usually involves two separate surgical procedures. The first stage is a re-creation of the tunnel for the tendon graft, which is necessary because of scarring and adhesions within the tendon sheath. It is achieved by the anatomical placement of a silastic rod (usually 2 mm

Fig. 19 Two examples of screw complications. In a PIP joint arthrodesis (**a**), the screw is placed too close to the dorsum of the cortex in the proximal phalanx, leading to loosening and bony lysis around the screw with non-union of the arthrodesis and recurrent joint malalignment. In the DIP joint arthrodesis (**b**), the screw is not sufficiently engaged within the middle phalanx. This arthrodesis will almost certainly fail, so a repeat arthrodesis was performed (**c**) which showed good screw alignment, but with some lysis around the screw indicating early loosening

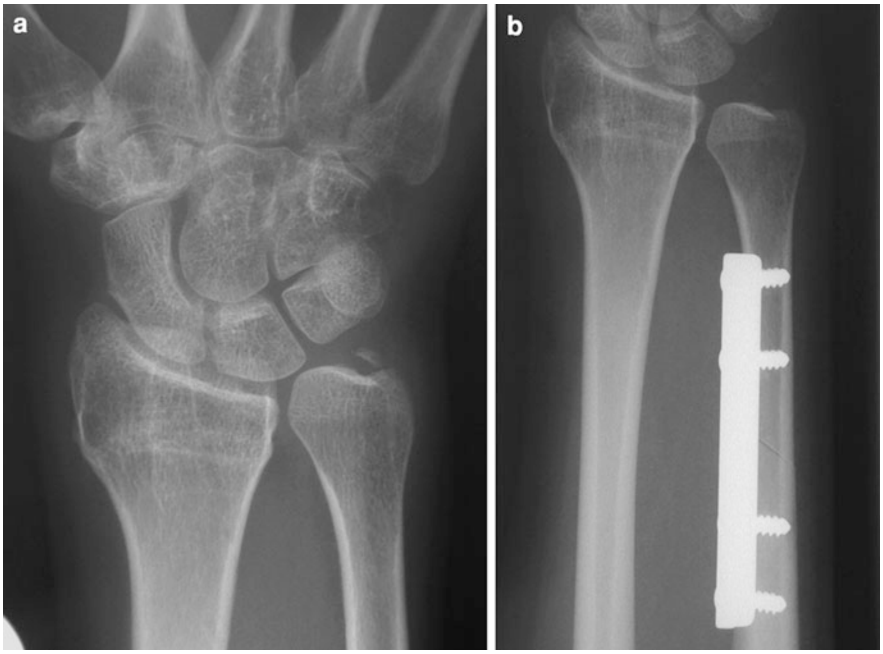

Fig. 20 PA radiograph (**a**) demonstrating uniplanar radial malunion with resultant length discrepancy between the radius and ulna, and abutment of the distal ulna onto the lunate and triquetrum. The post-operative radiograph (**b**) following shortening osteotomy of the ulna using a compression plate shows restoration of radioulnar alignment

Fig. 21 PA and lateral radiographs (**a**) of a young adult with malunion of a distal radial fracture with residual dorsal angulation. There is also non-union of the ulnar styloid, and the DRUJ was clinically unstable. The post-operative radiographs (**b**) demonstrate bony union across the radial osteotomy which has been maintained in anatomic alignment with a volar plate. The ulnar styloid fracture has been stabilised with a compression screw to attempt to stabillise the DRUJ

diameter) along the whole length of the tendon sheath, around which a smooth lining forms over a number of months. It is replaced (in a second operation) with a tendon graft, which can now glide smoothly. This technique is most frequently performed on the flexor surface, but can also be used in extensor tendon defects.

Adhesion formation within the tendon sheath is common following tendon repair. Other complications include tendon re-rupture, pulley failure (or failure to recognise pulley injury at the time of repair), joint contracture and triggering (Lilly and Messer 2006). Breakdown of the repair requires further surgical repair, but clinical differentiation from adhesion formation may be difficult.

US can reliably assess the tendon repair, although access may be limited by finger flexion. Small headed 'hockeystick' probes allow improved visualisation. The repaired tendon is thickened and hypoechoic, and is surrounded by low reflective granulation tissue. Suture material is echogenic. Dynamic US evaluation of the tendon during gentle passive and active flexion/extension demonstrates paradoxical movement of the tendon ends when there is breakdown at the repair site.

8 Ligament Repair

8.1 Indications

Intrinsic ligament repair of the wrist is usually restricted to the ligaments of the proximal carpal row (the scapholunate and lunotriquetral ligaments). Surgical repair can be performed in the acute situation (usually within 3–4 weeks of injury) when the procedure is a true 'repair'. A high index of suspicion is essential to make an early diagnosis. Late presentation is more common and requires reconstruction rather than repair because of the irreversible shrinkage that occurs in the torn ligament surfaces over time.

Ligament injury secondary to joint dislocation is common in the thumb and fingers, although surgical repair is rarely necessary. Radiological monitoring of joint congruity will be necessary for 3–4 weeks after injury. Tears of the UCL of the thumb are caused by forced hyperextension and abduction. The ligament may either be partially or totally ruptured. Displaced UCL tears with the ligament remnant overlying the adductor aponeurosis (Stener lesion) will not heal and

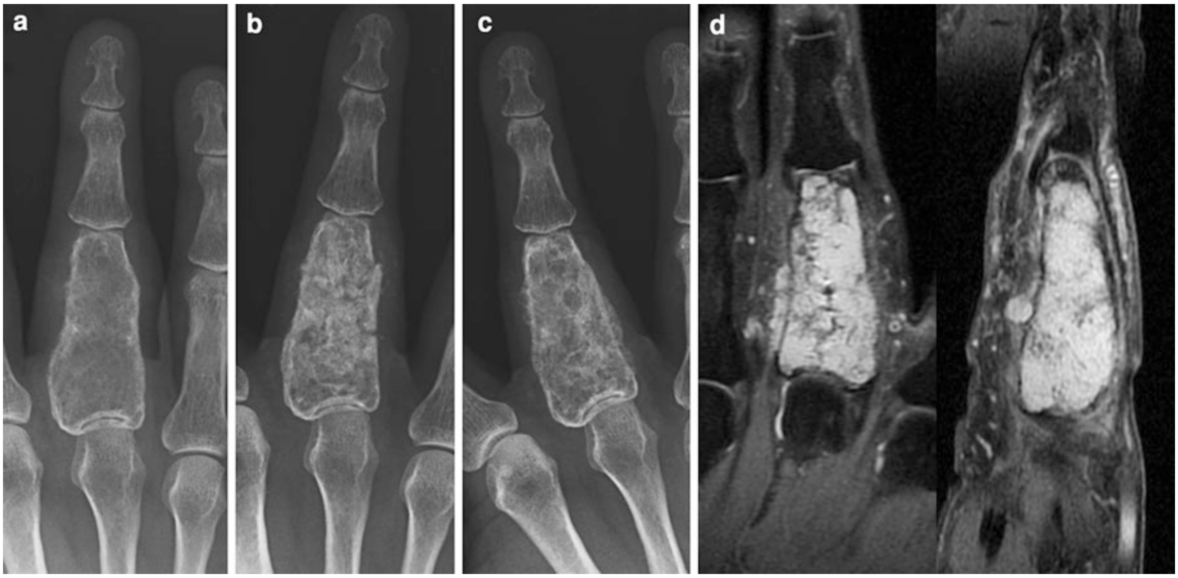

Fig. 22 PA radiograph (**a**) of a benign enchondroma within the proximal phalanx. The lesion has been treated by curettage and non-vascularised bone graft (**b**). However, several years later the patient represented with recurrent swelling and pain, and repeat radiograph (**c**) shows resorption of the bone graft material with internal lucency, cortical breakthrough and periosteal reaction. The coronal and sagittal T2FS MRI images (**d**) show high SI cartilage matrix. The appearances are strongly suggestive of chondrosarcoma transformation, which was confirmed following ray amputation

requires surgical repair or reattachment using a bone anchor.

8.2 Implant Choice

8.2.1 Wrist

Acute intrinsic ligament repairs must be stabilised until healing has occurred. This is either performed with multiple K-wires between the adjacent carpal bones, or with a small intraosseous screw, placed so as to hold the two adjacent bones tightly together. In both situations, the implants are always removed.

Reconstruction of an intrinsic ligament requires the same post-operative internal stabilisation as acute repair. Reconstruction of the scapholunate ligament is achieved by the use of a tendon graft, most usually from the flexor carpi radialis (FCR), passed through a substantial hole made in the scaphoid (up to 3 mm in diameter), and anchored to the lunate with a small bone anchor. This is termed as a Brunelli procedure, although other modifications are described (Brunelli and Brunelli 1995; Van Den Abbeele et al. 1998) (Fig. 23). The majority of patients experience improvement in pain and grip strength, although there is no long-term evidence to confirm that this will reduce the risk of development of OA.

A similar ligament reconstruction using tendon grafts is occasionally undertaken for instability of the first CMC joint of the thumb (Fig. 24). The procedure was described by Eaton and Littler using the FCR tendon, although other tendon grafts can be used (Brunelli et al. 1989; Eaton and Littler 1973). Long-term follow up has demonstrated good outcomes in the majority of patients, with prevention of secondary OA in those patients without pre-existing arthropathy (Eaton et al. 1984).

Post-operative radiographs demonstrate the location of drill holes and bone anchors, and the alteration in radiological measurements of instability. The radiographic appearances of scapholunate diastasis may persist post-operatively. Failure of reconstruction may be indicated by anchor migration. MRI can visualise the ligament reconstruction, but integrity throughout the whole of the tendon graft may be difficult due to magic angle effects. Interpretation of MRI will depend on knowledge of the exact procedure.

8.2.2 Hand

Stabilisation of an unstable finger dislocation is performed with a trans-articular K-wire, usually left in situ for 3 weeks.

Fig. 23 PA radiograph (**a**) acquired following a Brunelli procedure for reconstruction of the scapholunate ligament. The tunnel within the scaphoid is clearly evident, and there is persistent scaholunate diastasis. The coronal (**b**), sagittal (**c**) and axial (**d**) T1W MR images also clearly show the scaphoid tunnel and ligament graft as low-signal intensity (*black arrows*). There is susceptibility artefact from the resorbable bone anchor in the dorsal aspect of the lunate (*broken arrow*). The graft appears intact. However, there is early articular cartilage loss on the proximal scaphoid (*white arrow*), which was not present on the pre-operative imaging, and there is residual dorsal tilt of the lunate

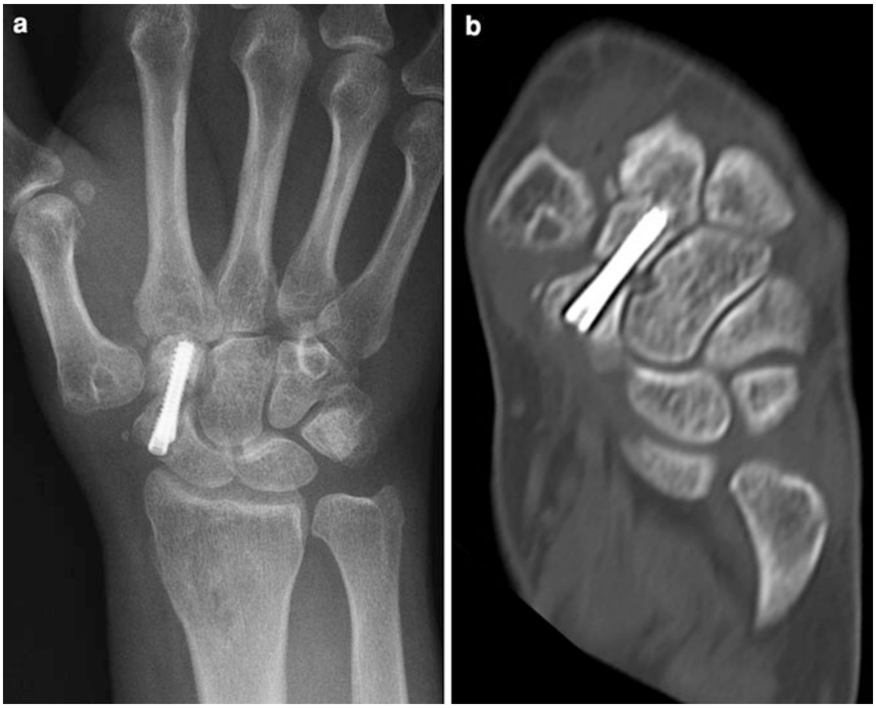

Fig. 24 PA radiograph (**a**) of a patient following trapeziectomy and arthrodesis of the scaphotrapezoid joint, and ligament reconstruction of the first CMC joint performed to treat pain and instability secondary to OA. The osseous tunnel, created for ligament reconstruction, is seen in the base of the first MC which remains subluxed. The screw has an area of lysis around it, suggesting loosening and persistent non-union. A coronal oblique CT image (**b**) confirms non-union of the arthrodesis and demonstrates the osseous tunnel within the first MC

Reattachment of an avulsion of the UCL of the thumb is usually performed with a small bone anchor. US may be utilised to identify failed ligament reconstruction. The ligament will be thickened and hypoechoic, and dynamic evaluation with radial stress helps identify abnormal joint widening. Adhesions between the repaired UCL and the adductor aponeurosis may cause pain and limitation of movement of the aponeurosis, which may be seen on US during flexion and extension of the MCP joint. Treatment is with physiotherapy.

Avulsion of the palmar (volar) plate is a common injury caused by hyperextension of, usually, the proximal interphalangeal joint. A small fleck of avulsed bone can often be seen adjacent to the palmar surface of the middle phalangeal base, or more subtle changes of erosion or blunting of the edge of the middle phalanx may also be noted. Avulsion of a fragment of bone which comprises more than one-third of the total articular surface will lead to inevitable instability of the joint and must be very carefully monitored. Subtle radiological evidence of dorsal subluxation of the affected joint must be sought in the first few weeks after injury, or in cases where functional recovery is delayed. If persistent subluxation or frank instability of the joint is identified, surgical reattachment of the volar plate to the base of the middle phalanx is indicated.

9 TFCC Repair

9.1 Indications

The triangular fibrocartilage complex (TFCC) stabilises the ulnar side of the wrist and the DRUJ. It is often injured during a fall onto the outstretched hand, and is associated with distal radius fractures. Injury to the ulnar styloid can be associated with a TFCC tear—especially if the ulnar styloid is fractured at its base. Repair of the TFCC is indicated if there is instability of the ulnocarpal joint or the DRUJ.

It is important to stress that not all abnormalities of the TFCC are true tears secondary to physical injury. Defects are commonly seen in the TFCC as either a congenital finding or a degenerative feature and the term 'TFCC *tear*' should be used with discretion, as this implies a traumatic aetiology. It may be prudent to describe these findings as 'TFCC *defects*'—where their aetiology is uncertain or yet to be determined.

9.2 Implant Choice

Repair is either performed through an open approach or arthroscopically. Whichever method is chosen, a

Fig. 25 PA and lateral radiographs (**a**) of the wrist following a ligamentous reconstruction of the DRUJ. Osseous tunnels can be seen in the distal radius (*white arrows*) and ulna (*broken white arrows*). The patient had persistent symptoms of pain and instability, and there is separation of the radius and ulna at the DRUJ. An axial T2WFS MR image (**b**) demonstrates a part of the tendon graft (*curved white arrow*) deep to the ECU tendon. However, the graft did not appear continuous and no graft is seen entering either the radial (*white arrow*) or ulnar (*broken white arrow*) tunnels. There is also marked recurrence of volar DRUJ instability indicating failure of the graft reconstruction

series of strong nylon sutures are passed through the cartilage disc to secure it to the external joint capsule. If the TFCC is irreparable, then a DRUJ ligament reconstruction may be indicated. The Adams procedure utilises a palmaris longus tendon graft to stabilise the DRUJ with drill holes placed through the distal radius and ulna (Adams and Berger 2002) (Fig. 25). Instability of the DRUJ in the presence of skeletal deformity, should first be addressed by correction of the skeletal deformity, which may be sufficient to restore complete stability (Lawler and Adams 2007). Recovery of strength and motion after repair, is seen in 85% of patients with chronic DRUJ instability (Adams and Lawler 2007).

If symptoms persist following TFCC repair, imaging may be required to exclude other causes of ulnar sided wrist pain, including ECU tendonitis or tendon subluxation, ulnar impaction, pisotriqutral chondromalacia or OA, and secondary OA of the DRUJ. In recurrent injury repeat MR arthrography may be required. Complications of DRUJ stabilisation include recurrent pain and instability. Radiographs document the location of the drill holes and the alignment of the DRUJ.

10 Conclusions

Radiological interpretation of the post-operative hand and wrist requires a thorough knowledge of the objectives of treatment in order to distinguish between acceptable findings and genuine complications on post-operative radiographs. Radiologists should be aware when cross-sectional imaging is indicated to provide diagnostic information that can help determine management protocols.

The range of orthopaedic implants and techniques of soft tissue reconstruction continue to evolve, and it is important to engage with the hand surgeon to be conversant with new techniques and procedures that are introduced in order to be able to correctly interpret radiological investigations.

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