24 Wrist Registration: Conventional Radionuclide and SPECT/CT Imaging

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Contents

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24.1 Introduction

The complexity of the wrist anatomy can present a significant challenge to the diagnosis and subsequent management of hand and wrist pathology (Forman et al. 2005; Viegas 2001; Nagle 2000). Wrist pain is a common orthopaedic and rheumatological presentation, typically first investigated with plain radiography. The differential diagnosis is often extensive; the source of wrist pain can be mechanical, neurological or systemic. Causes of acute painful conditions include lacerations, fractures, tendonitis and infection, and chronic conditions include enthesopathy, tendinopathy, chronic muscle and ligament injuries, tunnel syndromes, stress fractures, degenerative change, nerve entrapment, bursitis and instability (Forman et al. 2005; Nagle 2000; Almquist 2001; van Vugt et al. 1999; Kawamura and Chung 2007; Dalinka et al. 2000).

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Table 24.1 Advantages and limitations of radiological imaging of the wrist

X-ray	Ultrasonography	CT	MRI
Advantages	*Advantages*	*Advantages*	*Advantages*
Useful screening tool	Widely available	Accurate Localisation	Superior soft tissue contrast
Easily available	Low cost	Characterisation	Anatomy of intra-articular components
Least expensive	No ionising radiations	Cortical bone details are well defined	Multiplanar imaging
Limitations	Dynamic scanning of tendon movements can be performed	Multiplanar reformatting	No radiation
Provides two-dimensional information	*Limitations*	Three-dimensional visualisation of carpal bones	*Limitations*
Less useful and sensitive in the early stages of an injury	Limited structural bone changes	Widely available	Limited availability
Approximately 25 % of the fractures are often missed	Limited field of view Operator dependent Deeper structures poorly visualised	*Limitations* Soft tissue/tendon evaluation compared to MRI is limited Radiation	Metal artefacts Assessment of fracture healing is often difficult

Early and accurate diagnosis of wrist pathology is achieved through the appropriate use of the many imaging modalities available to clinicians. The choice of investigation is determined by several factors including cost, radiation burden and availability but most importantly, diagnostic accuracy. Each modality has strengths and weaknesses and, the emergence of hybrid imaging challenges the dogma that MRI is the best second-line investigation, after plain imaging, for the evaluation of many wrist pathologies. This section discusses the benefits and weaknesses of the imaging modalities available for investigating the wrist, focussing in particular on hybrid SPECT/CT imaging, in order to outline potential clinical applications.

24.2 Part I: Conventional Radiological Imaging of the Wrist

24.2.1 X-Ray

Plain imaging is an excellent first-line investigation for evaluating the wrist and, if not initially diagnostic, will often exclude important pathology and may lead clinicians in the right direction (Table 24.1). It is readily available, very cost-effective and for the non-diagnostician, usually easier to interpret than other imaging modalities. Although relatively specific, it is not a particularly sensitive modality, and second-line imaging may be required if the image findings are equivocal or if the clinical suspicion is high. In addition to the mandatory anteroposterior and lateral views of the wrist; other projections including oblique, scaphoid, clenched fist and carpal tunnel views can be obtained to increased accuracy. This is particularly important in the context of trauma as, for example, only 85–90 % of scaphoid fractures are demonstrable on plain films and many of these are only seen on additional views (Boles 2007). Hamate fractures can be even harder to detect, with a reported sensitivity of plain imaging (including carpal tunnel views) of 72 % (Andresen et al. 1999), but CT is reportedly 97 % accurate (Bishop and Beckenbaugh 1988). Follow-up plain imaging of potential fractures at 2 weeks can also provide value, particularly in children, and Evenski demonstrated that up to 30 % of scaphoid fractures in children will become apparent on the 10–14-day image, after an initially normal x-ray (Evenski et al. 2009).

Plain imaging will not detect the early changes of degenerative or inflammatory arthropathy, but early imaging is useful providing a baseline for future comparison. The later changes of arthropathy are well demonstrated by plain imaging, and often, the features are classical for a specific entity. The presence or absence of joint space narrowing, osteophyte formation, juxta-articular osteopenia, cystic change, erosions, sclerosis, chondrocalcinosis and the location of these changes can be used to accurately distinguish osteoarthritis, rheumatoid arthritis, gout and pseudogout (Haugen and Bøyesen 2011; Feydy et al. 2009; Zacher et al. 2007; Kloppenburg and Kwok 2011; Talwalkar et al. 2008). Plain imaging remains a useful imaging modality for monitoring the morphologic changes of the arthropathies (Zacher et al. 2007).

Some clues of early infection may be seen on plain imaging, particularly oedema and effusions, and occasionally, foreign bodies; however, the morphologic changes of osteomyelitis are not radiologically apparent until more than 50 % of the bone has been destroyed (Elgazzar et al. 1995). Erosions and periosteal reaction secondary to infection usually become apparent within 2 weeks. In this context, early plain imaging is performed to guide further imaging and management.

Post-operative and post-manipulative changes are always evaluated with plain X-rays as a means for ensuring anatomical alignment, satisfactory placement of fixatory devices and to monitor bone healing. Chronic wrist pathology including congenital abnormalities (Madelung's deformity, significant ulna variance etc.) and advanced degenerative changes are often followed in the long term with plain X-rays. Plain imaging also retains a strong role in evaluating tumours, many of which have classical X-ray appearances. Tumours of the wrist bones are not common but include benign and malignant, as well as primary and secondary lesions. If the presence of a tumour is suspected, further imaging with MRI and scintigraphy usually follows.

24.2.2 Magnetic Resonance Imaging

The exquisite soft tissue resolution and ability to image in all planes allows MRI to readily demonstrate even the most subtle of soft tissue abnormalities. Increasingly, MRI is being used to diagnose potentially debilitating arthritis such as rheumatoid arthritis and osteoarthritis in the earliest phase, thus allowing earlier treatment and the delaying and/or prevention of complications. MRI is currently the pre-eminent modality in the evaluation of arthritis with regard to the presence and degree of synovitis, tenosynovitis, chondral loss and erosive change (McQueen 2008), particularly when gadolinium contrast is administered (Xanthopoulos et al. 2007). The increasing clinical availability of 3T MRI scanners has recently added a new layer of morphologic detail (and complexity) to images, and this is now the clinical gold standard for soft tissue imaging. MR arthrography may add further diagnostic potential when examining subtle intra-articular ligamentous structures such as the triangular fibrocartilagenous complex (Quinn et al. 1989).

MRI is very good at evaluating bones and is ideal for cancellous bone and marrow evaluation, but subtle cortical abnormalities may be overlooked, as dense calcium (cortical bone) is of low signal (dark) on all MRI sequences. In this regard, CT remains superior to MRI (Stewart and Gilula 1992; Oneson et al. 1996a). MRI has been shown to be highly accurate for detecting radiologically occult scaphoid fractures and other wrist fractures, with a reported diagnostic accuracy of above 95 % (Raby 2001; Amarani 2005; Breitenseher et al. 1997). Pierre-Jerome et al. demonstrated that up to 62 % of patients with wrist pain and a normal X-ray after trauma will have occult pathology demonstrable on MRI and 23 % of this group had a fracture line visible on MRI (Pierre-Jerome et al. 2010). However, MRI remains a second-line modality when evaluating the wrist for traumatic injuries.

Early changes of infection and inflammation are readily identifiable on MRI, but the changes are non-specific. The additional use of gadolinium contrast can assist in determining sites of abscess formation, viable and non-viable tissue and assessment of compartmental and osseous involvement (Vijayanathan et al. 2009). CT can be more useful than MRI following bone surgery unless there is concern for infection or tissue non-viability, as bone oedema may persist for many months and can limit interpretability.

MRI is the pre-eminent modality for evaluating bone tumours and accurately demonstrates the margins of the lesion and the degree of compartmental involvement and thus can assist surgical planning (Nguyen et al. 2004). MRI is radiation free, however is contraindicated in patients with permanent pacemakers, internal defibrillators and other metallic implants (not joint prosthetic implants) and is used sparingly in people who are claustrophobic or who have renal failure (if contrast is required), but it is becoming increasingly available and its role will continue to evolve.

24.2.3 Ultrasound

The role of ultrasound is limited to the evaluation of soft tissues, but it has the advantage of providing real-time functional assessment of muscles and tendons whilst remaining cost-effective, readily available and radiation free (Harish et al. 2009; Wong et al. 2009; Jacob et al. 2007). In the experienced hands, it can be an extension of the physical examination, and in relation to the wrist it can readily demonstrate the presence of foreign bodies, soft tissue oedema/fluid, intra-articular effusions, the presence and extent of bursal disease, ganglia, surgical emphysema, foreign bodies, soft tissue tumours and impingement syndromes. It guides minor procedures such as injections and aspirations of joints, bursae, cysts and collections. Although some superficial bony details can be determined on ultrasound (obvious fractures, subperiosteal collections), its use in evaluating bones and deeper structures is very limited.

24.2.4 Computed Tomography

Modern CT scanners provide exquisite spatial resolution for osseous structures and are unmatched as a modality when evaluating cortical bone pathology, especially subtle fractures (Kaewlai et al. 2008). Cancellous bony pathology is also readily demonstrated; however, the presence of minor (and often irrelevant) changes such as bone islands, small cysts and prominent marrow spaces may add confusion, and in this regard, MRI and SPECT/CT bone scan have a clear advantage. CT provides an excellent tool for surgical planning, particularly for the complicated wrist, and with modern systems limiting the effects of metallic artefacts, CT is the modality of choice for evaluating the position and alignment of surgical hardware and grafts. Indications for CT rather than MRI include the search for an occult fracture, the need for better definition of a known fracture, the assessment of fracture healing and complications and the evaluation of bone bridging and graft incorporation (Stewart and Gilula 1992; Oneson et al. 1996a).

CT can detect bone infection earlier than plain imaging, but its sensitivity does not match scintigraphy or MRI in this regard (Termaat et al. 2005; Ma et al. 1997). CT will accurately delineate sequestra and involucra associated with chronic osteomyelitis; however, MRI will better evaluate a sequestra for viability (Fayad et al. 2007). Many bone tumours can be accurately diagnosed and characterised with CT, particularly ones containing fat, calcium and cartilage. The radiation burden of an optimised CT wrist can be as low as a CXR (0.03 mSv) (Biswas et al. 2009), and certainly, most systems usually deliver a radiation burden of less than 1 mSv (Gnanasegaran et al. 2009). Although reconstruction algorithms can improve the visualisation of soft tissues, the limited contrast resolution between adjacent soft tissues in this anatomically complex region gives MRI and US a clear advantage over CT. CT arthrography, however, may provide an alternative to MRI for detecting intra-articular ligamentous tears (Moser et al. 2008), a common source of pain and a precipitant of degenerative arthropathy and functional impairment. CT does not provide a recognised functional evaluation of the wrist.

24.3 Part II: Radionuclide Imaging of the Wrist

24.3.1 Conventional Radionuclide Imaging of the Wrist

Radionuclide bone scanning (two-phase or three-phase) with 99mTechnetium-Methylene diphosphonate (99mTc-MDP) has an important role in imaging the hand and wrist and is used in both acute and chronic conditions (Hawkes et al. 1991; Mohamed et al. 1997; Nielsen et al. 1983; Dubowitz and Miles 1994; Maurer et al. 1983; Maurer 1991; Collier et al. 1993; Dias et al. 1990; Ozturk et al. 2007; Mulholland et al. 2006; Groves et al. 2005a, b; Patel et al. 1992; Gnanasegaran et al. 2012) (Figs. 24.1 and 24.2). The sensitivity of radionuclide bone scans facilitates the detection of such benign diseases as malunion, occult fractures and osteonecrosis, but the modality is of limited specificity (78 %) (Hawkes et al. 1991; Mohamed et al. 1997; Nielsen et al. 1983; Dubowitz and Miles 1994; Maurer et al. 1983; Maurer 1991; Collier et al. 1993; Dias et al. 1990; Ozturk et al. 2007; Mulholland et al. 2006; Groves et al. 2005a, b; Patel et al. 1992; Gnanasegaran et al. 2012). Further, precise localisation is often difficult which can limit the overall utility of this modality.

24.3.2 Conventional Two-Phase Bone Scan with X-Ray Registration of the Wrist

The co-registration of bone scans with radiography [wrist registration scintigraphy (WRS)] presents a solution to the low spatial resolution of bone scans and has often proven beneficial narrowing down localization to single carpal bones (Hawkes et al. 1991; Mohamed et al. 1997; Wraight et al. 1997; Vande Streek et al. 1998).

24.3.3 Imaging Protocol

24.3.3.1 Wrist Registration Mould

A wrist registration mould must be made using the following equipment: (1) A water bath that is able to heat water to over 70 °C, (2) suitable-sized piece of thermoplastic material, (3) tongs, (4) small lead (Pb) markers (15 mm wide, 30 mm long, 1–2 mm thick, with a hole in the centre of the marker) and (5) polystyrene triangles to act as finger spacers.

Once the water in the bath is at the required temperature, place a piece of the thermoplastic material into the water and leave until it becomes malleable. Place the patient's hand and forearm under investigation on a flat surface, and spread their fingers. In between the fingers, place appropriate size spacers, and tape these spacers to the flat surface. This can be achieved by putting a piece of tape on the bottom of each spacer. Once the spacers are in place, ask the patient to carefully remove their hand.

Once the mould is malleable, carefully remove it from the hot water using pairs of tongs and remove any excess water with a towel. Then place the piece of thermoplastic over the finger spacers, and ask the patient to place their hand and forearm onto the mould, and press their fingers down between the spacers. Mould the thermoplastic material to the shape of the patient's hand and forearm, ensuring that there is a flat area left above the fingers and in the area of the mid-forearm (Fig. 24.3).

Remove the hand from the mould once it has cooled. To the thermoplastic mould, tape three of the lead markers – one above the fourth finger, and another above the first finger and the last one at the level of the mid-forearm.

24.3.3.2 Dual Phase Planar Wrist Scintigraphy

Immediately following the injection of 99mTc-MDP has been given, place both hands (palms down) on the camera face, and acquire a static image for 300 s (5 min) using a 256 × 256 matrix, or following the department protocol to acquire a blood pool study. Delayed imaging is performed at 3–4 h in the same mould; place both hands on the camera face, palms down and acquire a static image for 900 s (15 min) using a 256 × 256 matrix, or following the department protocol.

While the image is being acquired, use cobalt (Co-57) or technetium (Tc-99m) point source

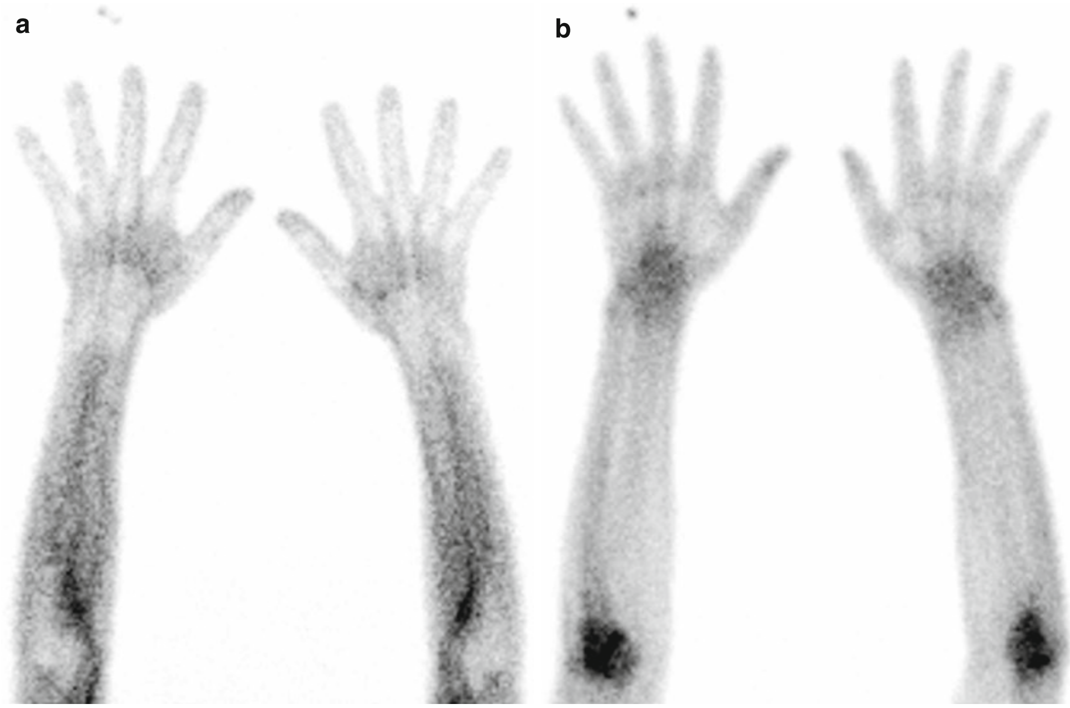

Fig. 24.1 Normal scan: There is normal vascularity and uptake in the early blood pool (**a**) and delayed images (**b**)

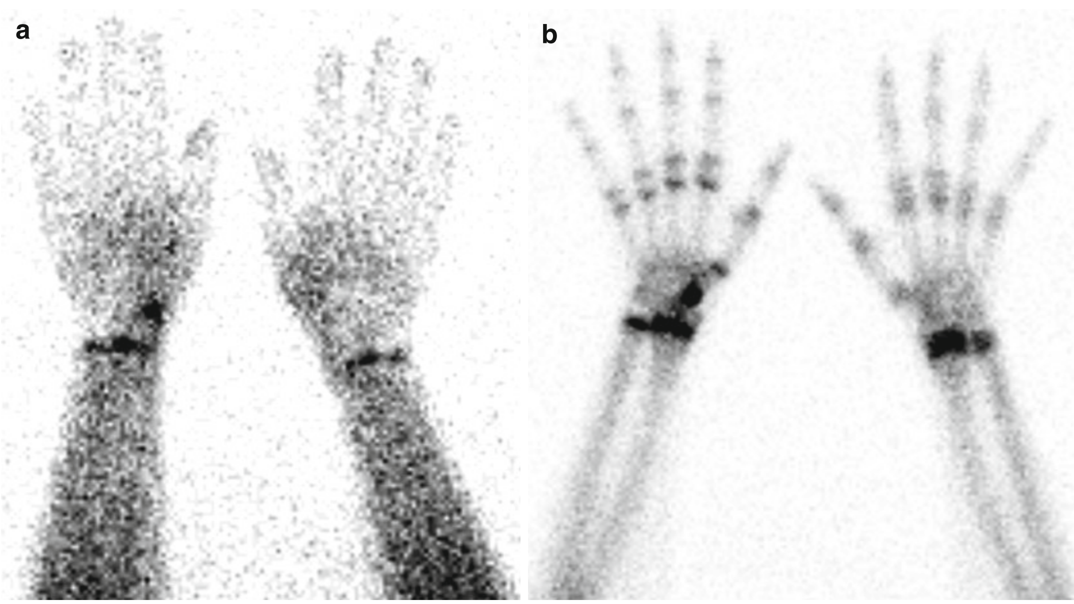

Fig. 24.2 Scaphoid fracture: (**a**) There is increased vascularity and (**b**) increased tracer uptake in the right scaphoid bone consistent with a fracture (Image courtesy: Dr. G. Shabo, UK)

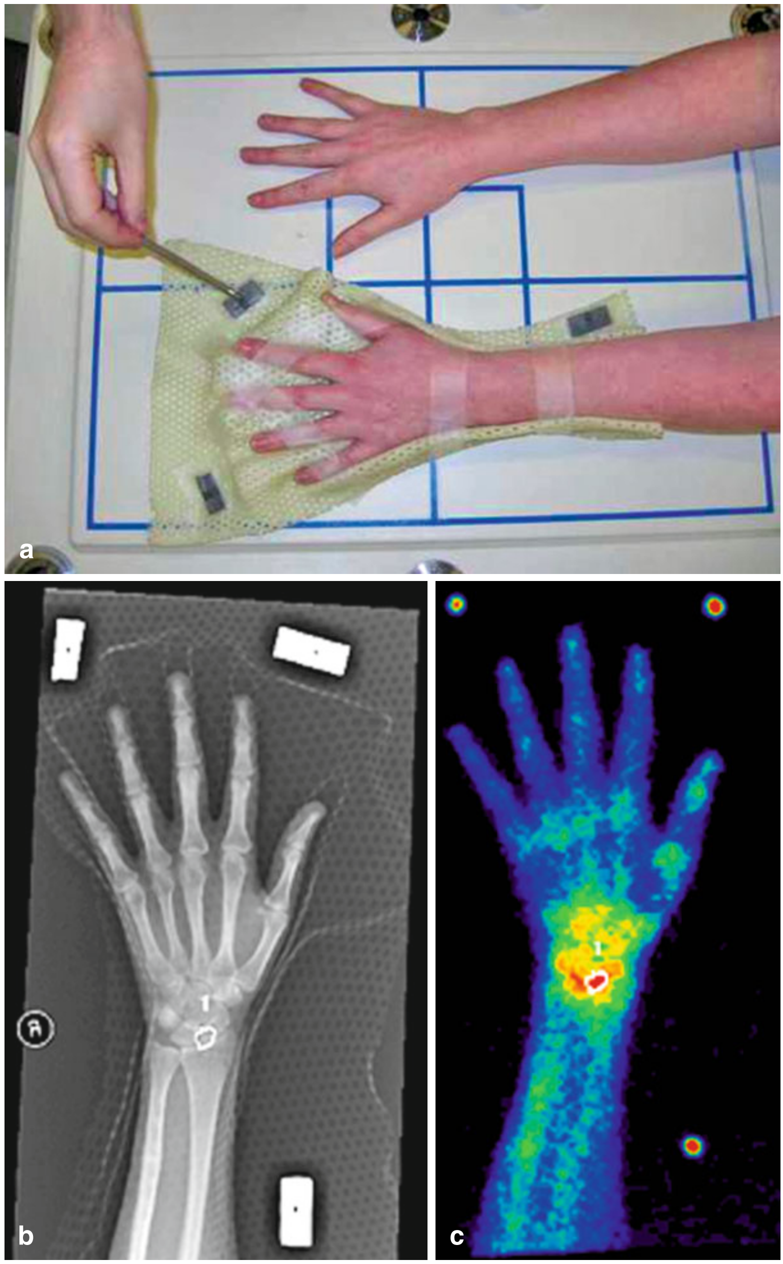

Fig. 24.3 (**a**) Positioning of mould and markers. (**b**) Example of a wrist X-ray with markers in place. (**c**) The scintigram with corresponding 57Co point sources and region of interest after registration

over the hole of one of the lead markers, and leave until a dot appears on the image. Repeat this for the other lead markers. A radiograph of the hand in the mould is then obtained and checked to ensure the three markers are in the X-ray field of view.

24.3.4 Image Processing

The wrist X-ray which is acquired and is sent in DICOM format via file transfer protocol from the PACS to a Hermes® (Nuclear Diagnostics, Sweden) work station, converted to interfile format and stored. The X-ray is reoriented to match orientation of the delayed bone scan. Both images are adjusted for differences in matrix size. At this stage any extraneous activity that may interfere with the interpretation of the scan is masked out of the field of view.

All post-processing is carried out on a Dell Precision 360 workstation. Both datasets are then loaded into the commercially available Hermes® Multimodality image fusion software for co-registration of the images. Co-registration involves determining the optimal linear transformations that will map the co-ordinates of one image to that of the other. The images are co-registered using a landmark-based registration technique in two dimensions as described below. The three metal markers correspond to landmarks in the images. The construction of the mould and binding of the patient's hand prevents movement between acquisition of the delayed bone scan and the X-ray. Typical positioning of the metal markers landmarks can be seen in Fig. 24.3. The metal markers are clearly visible on the X-ray, as are the Co-57 marker points on the bone scan.

24.3.4.1 Advantages and Limitations

Radionuclide wrist registration with X-ray is useful in detecting fractures (Fig. 24.4). Radionuclide wrist registration is an inexpensive method to aid fracture localization in most cases (Fig. 24.5). Radionuclide wrist registration (WRS) has been shown to improve reporter confidence (Mohamed et al. 1997) and influence management (Mohamed et al. 1997; Wraight et al. 1997). However, the technique is cumbersome and time consuming.

24.3.5 Multislice SPECT/CT Imaging of Wrist

The combination of SPECT and CT capabilities into a single device provides accurate localisation and characterisation of abnormalities. SPECT/CT improves specificity and gives greater diagnostic confidence. Using SPECT/CT, it is possible to distinguish between individual carpal bones, a feat which is simply not feasible using only conventional bone scans; the spatial resolution is inadequate.

24.3.6 Imaging Protocol

24.3.6.1 Dual Phase Planar Wrist Scintigraphy

Following the injection of 750 MBq of 99mTc-MDP, both hands are positioned (palm down) on the camera face, and a static image is acquired over 5 min, on a 256×256 matrix. Delayed imaging is then performed at 3–4 h post injection again with both the hands placed palm down on the camera face. Static images in the anterior position are also acquired.

24.3.7 SPECT/CT

CT scan is performed, once the patient is comfortably placed in the required position, and SPECT study is performed after completion of CT scan (Table 24.2).

24.4 Part III: Potential Clinical Applications

24.4.1 Fractures

Radionuclide bone scintigraphy is sensitive in the evaluation of traumatic carpal bone fractures when an X-ray is normal. In the assessment of fractures, Rolfe et al. have suggested that scintigraphy is more reliable after a 48-h time lapse from the original trauma (Rolfe et al. 1981) and slightly longer than this in the elderly. Importantly, increased uptake on a bone scan can often precede any radiological changes in occult fractures; the latter may still be equivocal 2–3 weeks later (Dias et al. 1990). However, accurate localisation of the bone or the sites of fracture are often difficult on a bone scan.

Scaphoid fractures are the most common carpal bone fractures, and the usual mechanism of injury is falling on the outstretched hand. The fracture may involve any part of this bone but are most worrisome when they involve the midsection

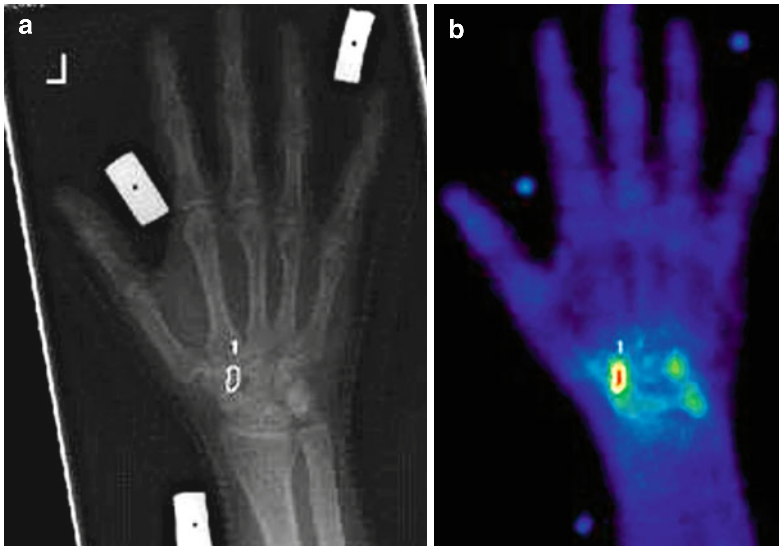

Fig. 24.4 Patient with clinical suspicion of scaphoid fracture (**a**, **b**). WRS demonstrated trapezoid bone fracture/bruising

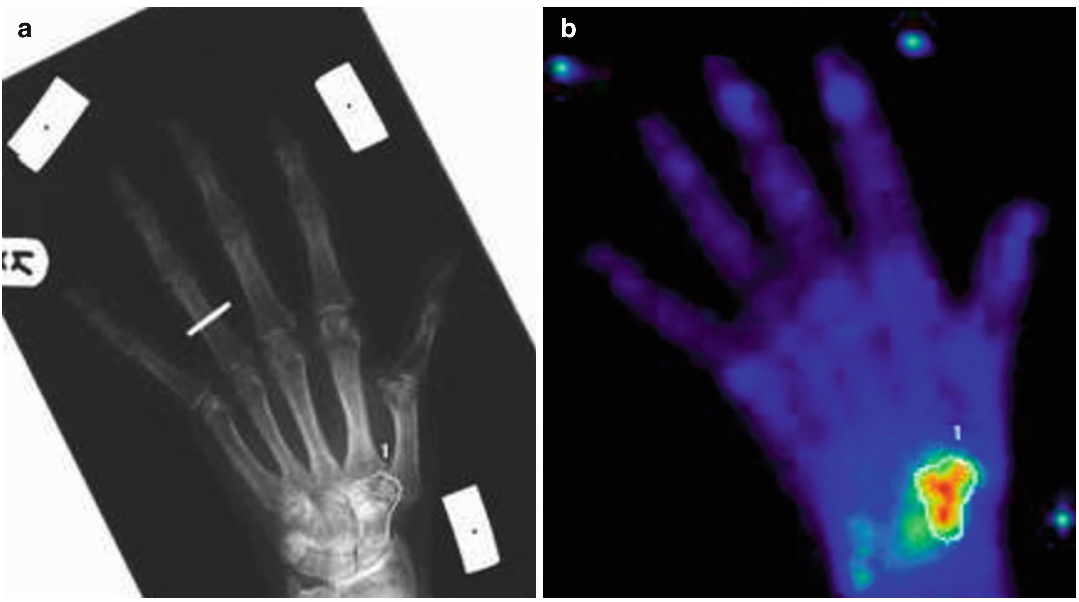

Fig. 24.5 (**a**, **b**) Clinical example of WRS in osteoarthritis defining metabolically active joints

Table 24.2 SPECT/CT imaging of wrist

Patient positioning for SPECT/CT	CT imaging	SPECT imaging
Bilateral wrists SPECT/CT: Patient lies prone with their arms stretched out above their heads towards the centre of the couch (Superman position)	CT scan is performed; once the patient is comfortably placed in the required position, a scout view is carried out to define the CT field	SPECT study is performed after completion of CT scan using the following parameters:
It is important to get the patient as comfortable as possible. Supporting polycarbonate blocks are placed under the hands and wrists and taped firmly to the blocks using micropore	A low-dose CT is used for both hands. Localisation CT is then carried out with voltage settings of 120 keV, current setting of 100 mAs/slice, with slice thickness of 1.5 mm and increment of 0.75 mm. (CT imaging takes approximately 40–60 s)	Low-energy high-resolution, parallel hole collimator
If needed, pillows or foam blocks are placed under the arms to provide further support. The patient's head is turned towards one side, so that they lie as flat as possible, allowing minimal distance from the gamma head	For single wrist, a diagnostic CT is carried out using the following setting of 140 keV, 150 mAs/slice, slice thickness of 0.8 mm and increment of 0.4 mm	Number of projections: 128 with 20 s time per projection and matrix size equivalent to 128 × 128
In order to help patient's comfort further, a pillow or support foam block can be placed under the lower legs or ankles. However, while imaging a single wrist, the patient is made to lie as comfortably as possible in prone position similar to that of bilateral wrists	Diagnostic CT of single wrist is performed because the single wrist is placed in the centre of the couch and hence in the centre of the FOV	The SPECT procedure is the same for both wrists as well as for single wrist (SPECT imaging takes approximately 20–25 minutes)
The wrist being imaged is stretched out above the patient's head. The other wrist is placed under the patient's head in the most comfortable position possible		
The wrist being imaged is placed in the centre of the couch and polycarbonate blocks and supports are used in the same way as for both wrists		

(waist) or proximal pole, as these have a greater risk of complication (Weber and Chao 1978; Goldfarb et al. 2001). Scaphoid fractures are the most common carpal fracture to be misdiagnosed as a simple sprain, and they are often surprisingly pain free despite absence of union in the fracture. However, at a later stage, they may present with secondary degenerative arthritis, and these may become symptomatic after an acute re-injury. These cases pose a diagnostic problem in establishing the cause of persistent pain, particularly if no obvious degenerative changes are visible on plain radiographs but only a non-union is visible. In these scenarios, the surgeon often performs a wrist arthroscopy to identify loss of articular cartilage at the radio-scaphoid articulation. This will determine if a surgical treatment of the non-union or a wrist fusion is likely to cure the wrist pain. SPECT/CT may clarify this in a non-invasive manner in a far more cost-effective manner without the need for a surgical procedure. Additionally, SPECT/CT can be used to assess other carpal fractures, which may be difficult to localise on the conventional planar bone scan (Gnanasegaran et al. 2012). After the scaphoid bone, the most common carpal bone fractures involve the triquetrium and the trapezium and less commonly, the lunate, capitate and hamate bones (Goldfarb et al. 2001).

Common post-traumatic complications of a scaphoid fracture include delayed union (incomplete union after 4 months of cast immobilisation), non-union (non-healed fracture with smooth fibrocartilage covering site) and malunion (i.e. persistent angular deformity). Some degree of malunion occurs in nearly all proximal pole fractures and up to a third of waist fractures (Weber and Chao 1978; Goldfarb et al. 2001; Dobyns and Linscheid 1984). In addition, these fractures may be associated with marked degenerative change (scapholunate-advanced collapse) and gross instability of the wrist (Goldfarb et al. 2001). Fractures of other carpal bones can also become complicated (Goldfarb et al. 2001). Lunate fractures are often associated with Kienbock's disease (avascular necrosis), which can lead to collapse and advanced degenerative change at the wrist, and thus, early diagnosis is critical (Goldfarb et al. 2001; Beckenbaugh et al. 1980).

In the existing literature on this topic, Groves et al. (2005a, b) were able to compare CT with scintigraphy when investigating possible scaphoid injuries. Of the 23 positive bone scans they looked at, only 16 were CT positive (CTs taken on the day of trauma). They considered that the uptake demonstrated on the positive bone scans may imitate the micro-fractures of trabeculae (termed bone bruising). They found that any CT proven fracture showed a much higher uptake background ratio than those scintigraphic scans discordant with CT findings. They concluded that this meant less intense foci of uptake on bone scans may only be indicative of bony bruising as opposed to a fracture, as such. Additionally, since 5–12 % of scaphoid fractures come with additional fractures elsewhere in the wrist (Groves et al. 2005a, b), SPECT/CT can also evaluate other suspicious areas at the same time. All in all, SPECT/CT is able to provide early and accurate diagnoses with far fewer of the equivocal reports yielded by plain X-rays alone (Figs. 24.6–24.11).

24.4.2 Osteoarthritis (OA)

Osteoarthritis can be primary or secondary. The trapeziometacarpal (CMC I) or trapezioscaphoid joints (STT) are commonly affected by primary OA (Dalinka et al. 2000). Secondary OA is commonly referred to as degenerative joint disease and can be a sequela of trauma, infection of crystal arthropathy. It may be difficult to discriminate between existing OA and a post-traumatic fracture on a bone scan. SPECT/CT can narrow down the differential and often be diagnostic (Fig. 24.12). This is perhaps the most important role of SPECT/CT. The ability of hybrid imaging to detect all active pathology with very high sensitivity, combined with the clear demonstration of morphological changes allows the diagnostician to identify culprit pathology (i.e. fracture, scapholunate disruption) and demonstrate the secondary effects of that primary abnormality (Gnanasegaran et al. 2012) (Fig. 24.13). This is therefore a highly powerful tool as it often influences management decisions, and although it may add to the cost of a definitive diagnosis, it is likely to dramatically reduce the overall financial burden of the patient's presentation.

24.4.3 Avascular Necrosis (AVN)

Bony trauma complicated by avascular necrosis is another avenue of possibility for SPECT/CT. The vascular anatomy of the scaphoid and lunate bones predisposes them to post-traumatic avascular necrosis (Goldfarb et al. 2001; Dobyns and Linscheid 1984; Beckenbaugh et al. 1980), and early detection of any fractures can better guide initial management with the aim of reducing the chance of AVN. However, for imaging follow-up, SPECT/CT may be useful in detecting AVN. Early on in its clinical progress, AVN is seen as a photon deficient area on SPECT/CT. Bone SPECT is able to identify AVN before it is radiologically apparent as stage I disease. Stages II and III can be detected using conventional imaging methods, but in cases of Keinboch's disease (stages IIIb and IV), other carpal bones are involved (Goldfarb et al. 2001; Dobyns and Linscheid 1984; Beckenbaugh et al. 1980; Bain and Begg 2006). The use of SPECT/CT in such cases provides a better understanding of disease extent as well as giving information on the vascular supply of the bones. The extent of arthropathy as seen on SPECT/CT, we have found to be a useful surgical guide to modern hand surgeons (Gnanasegaran et al. 2012). For example, if there is little surrounding osteoarthritis in a case of

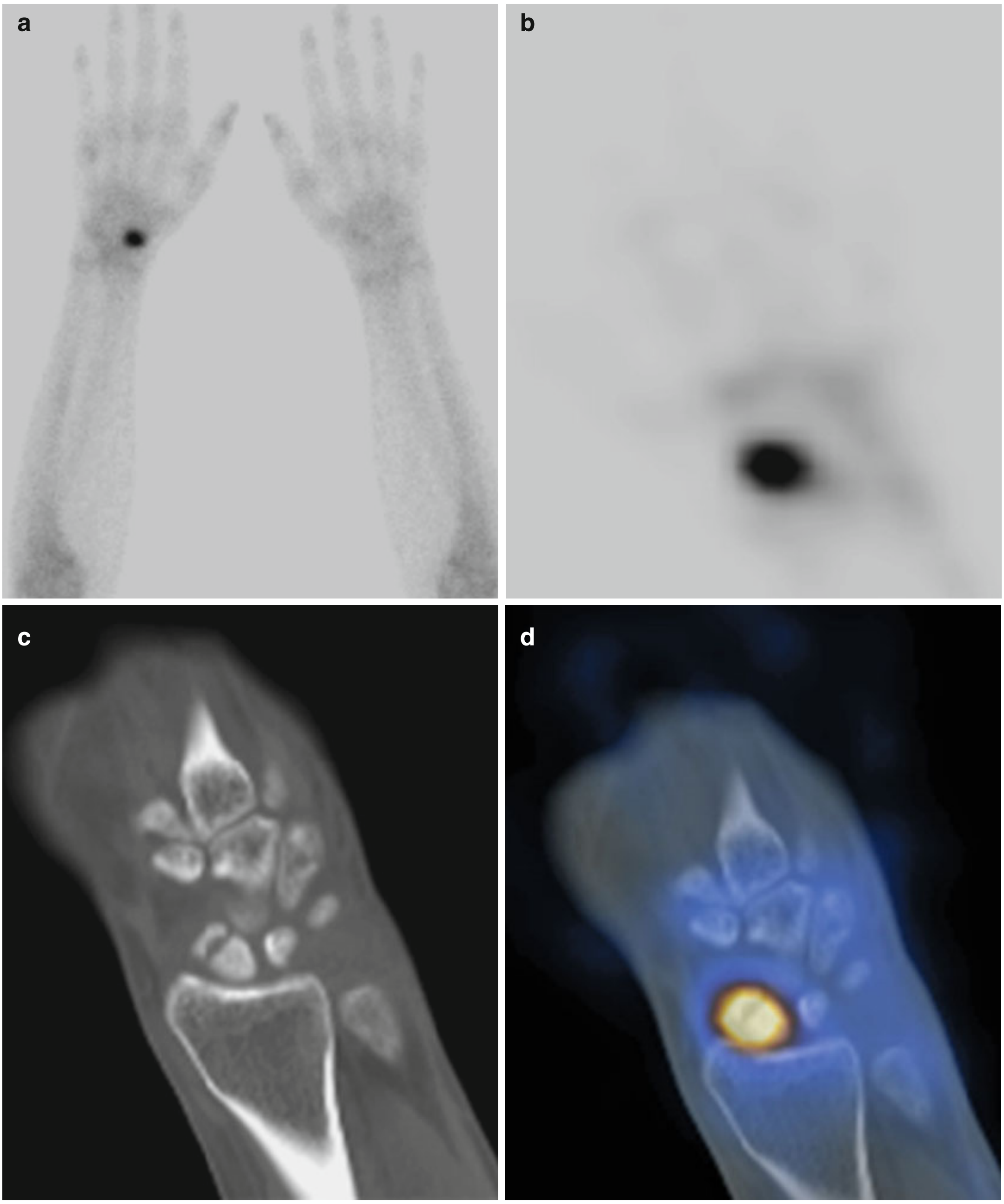

Fig. 24.6 Non-union of fractured scaphoid. Patient fell several months prior to imaging and has complained of pain and stiffness since then (**a**, **b**). Bone scan demonstrated increased uptake in the region of the scaphoid bone, confirmed as non-union by SPECT/CT (**d**). The morphological changes on CT, (**c**) including the degree of bony separation at the scaphoid waist fracture led to internal fixation, to prevent future arthritis, instability and reduced function at the wrist. Earlier diagnosis of a scaphoid fracture is associated with a lower complication rate. Up to one-third of mid-scaphoid fractures demonstrate delayed union or non-union. A second fracture is seen in up to 12 % of patients with scaphoid fractures (not this case), which would be easily identified with SPECT/CT

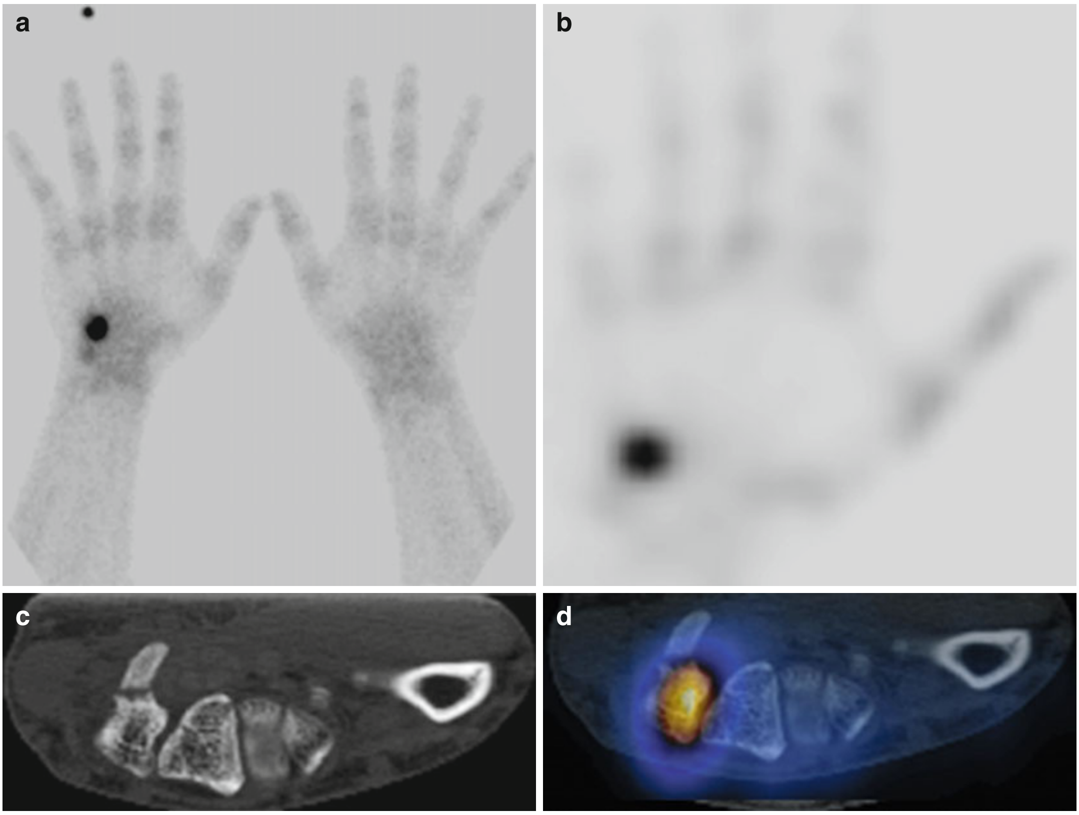

Fig. 24.7 Fractured hook-of-hamate: Patient presented with ongoing wrist pain 2 months after a fall, despite a normal X-ray (not shown). (**a**, **b**) Focal uptake was seen on the planar and SPECT images on the ulnar aspect of the wrist, localised by (**c**, **d**) SPECT/CT to a mildly displaced fracture at the base of the hook of-hamate (type 1 fracture)

lunate AVN, the surgeon may proceed to osteotomy whereas fusion is indicated if a significant degree of osteoarthritis is demonstrated (Bain and Begg 2006).

24.4.3.1 Cyst-Like Lesions

Subchondral cysts are periarticular cystic structures commonly seen in degenerative joint disease, rheumatoid arthritis, crystal arthropathy and AVN and are thought to occur when synovial fluid is forced through a weak point in the articular cartilage. Inflamed cysts can be seen as tracer-avid areas on bone scans, but specificity is limited. SPECT/CT, however, will accurately localise and characterise the lesion and will often identify the source of arthropathy (Gnanasegaran et al. 2012). The well-defined periarticular erosions of gout can have a similar morphological appearance and are usually hot on bone scan. Other lesions that have a cyst-like appearance on other imaging modalities include chondral lesions, which can rarely affect the carpal bones. SPECT/CT will demonstrate whether the lesion is metabolically active and its affect on neighbouring bones and joints (Gnanasegaran et al. 2012) (Fig. 24.14).

24.4.3.2 Wrist Impaction Syndromes

There are various impaction syndromes associated with ulnar-sided wrist pain with the commonest being ulnar impaction syndrome (Cerezal et al. 2002; Friedman and Palmer

Fig. 24.8 Capitate fracture: Patient with history of fall on outstretched hand. Scaphoid fracture. (**a**) The early blood pool and (**b**) delayed image shows a focal area of increased uptake in the left wrist/carpal bones (**c**) on the fused SPECT/CT image focal uptake corresponds to fracture of the capitate bone. SPECT/CT was useful in accurate localisation

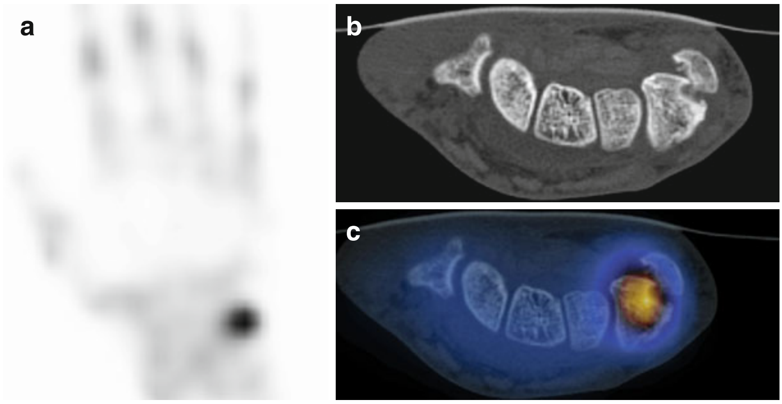

Fig. 24.9 Non-united triquetral fracture. Pain and swelling at the previous site of fracture. (**a**) SPECT image shows increased tracer uptake noted in the region of the left wrist. (**c**) On SPECT/CT the increased uptake corresponds to a pseudarthrosis between the pisiform and triquetral as well as the triquetral fragment (**b**) There is a fracture involving the triquetral and the fracture line is corticated

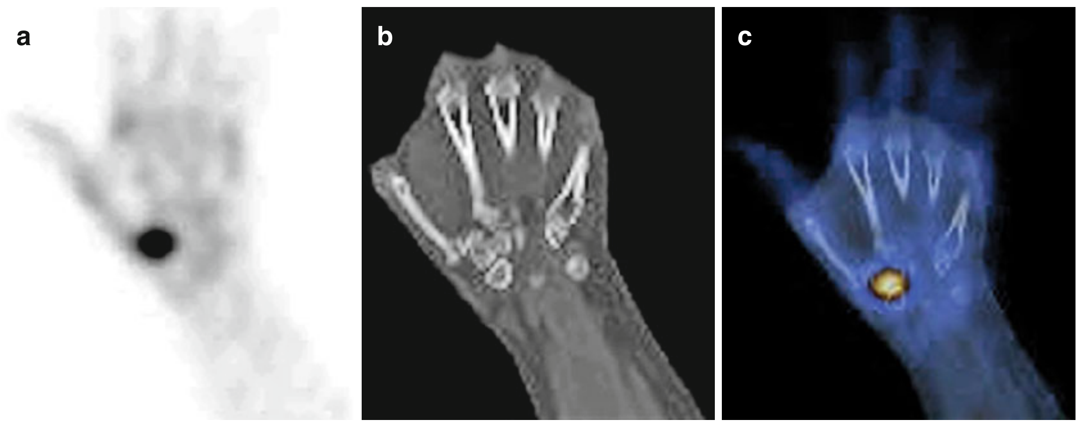

Fig. 24.10 Undisplaced fracture of the left trapezium. Patient with tender left scaphoid tubercle. Fracture of scaphoid tubercle. On the planar (not shown) and (**a**) SPECT images there is focal intense uptake seen in the region of the left scaphoid. On the (**b**) CT and (**c**) fused SPECT/CT images the focal area of uptake in the left wrist corresponds to a fracture of the trapezium adjacent to the joint between the trapezium and trapezoid

1991). Other causes include ulnar impingement syndrome, ulnar-styloid impaction syndrome, ulnocarpal impaction and hamatolunate impingement syndrome (Cerezal et al. 2002; Friedman and Palmer 1991; Hodge et al. 1996; Imaeda et al. 1996; Escobedo et al. 1995). MRI is a useful investigation to assess the structural changes that contribute to ulnocarpal instability and pain (Oneson et al. 1996b) and will demonstrate in exquisite detail the morphological changes of soft tissue (including the triangular fibrocartilagenous complex), the articular surface and the marrow. However, the functional component of SPECT/CT imaging can identify active sites of pathology, and in this regard, it can be considered as complementary to MRI (Gnanasegaran et al. 2012) (Fig. 24.15).

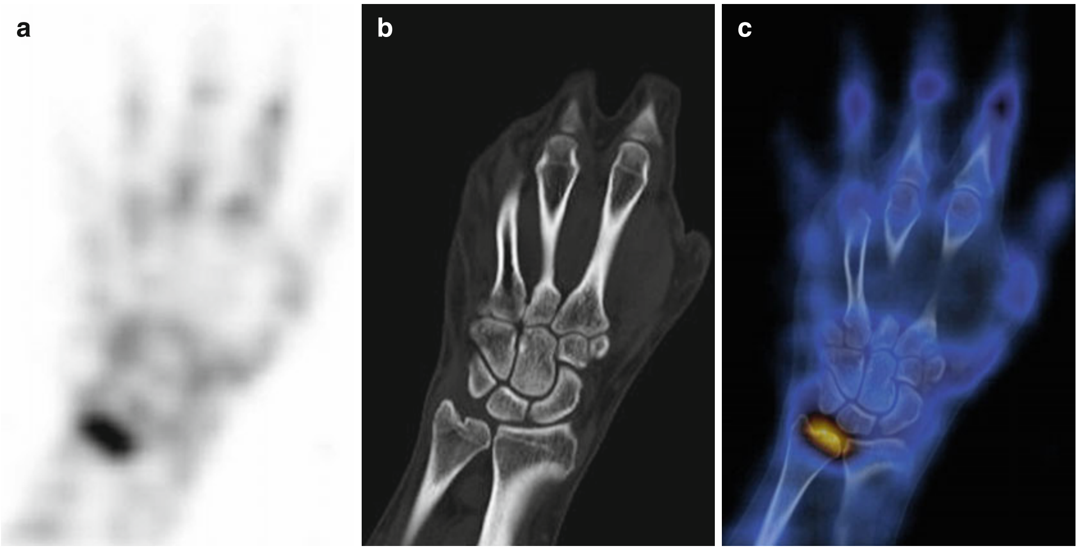

Fig. 24.11 Articular trauma. Pain following sports injury (**a**) SPECT, (**b**) CT and (**c**) fused SPECT/CT. There is significant increased tracer uptake seen associated with the distal right ulna. There is associated cortical/articular irregularity on the CT component

24.4.4 Infection

Early differentiation of soft tissue infection from osteomyelitis is important to ensure appropriate management. Plain X-ray and CT changes of osteomyelitis are often not apparent in early disease, and scintigraphy is often used to determine bony involvement. Typically, the bone scan is hyperaemic in the blood pool and delayed phase within 48–72 h of onset (Van der Wall et al. 2004; Rehm and Aaron 1996). The additional use of an indium-111 or Tc99m-labelled white cell scan often improves specificity (Mariani et al. 2010; Ingui et al. 2007; Filippi and Schillaci 2006). Although the CT may be unremarkable, SPECT/CT will accurately localise the accumulation of white cells to either soft tissue or bone (including periosteum), which may determine the course of management. Often in osteomyelitis however, the CT will have subtle changes, including marked associated soft tissue oedema, small collections, and subtle differences in the CT attenuation of marrow and eventually periosteal reaction and cortical erosions.

24.4.5 Advantages and Limitations

The differential diagnosis of wrist pain is often extensive and accurate localisation and characterisation is of clinical importance in the diagnosis and management of patients with wrist pain. Single photon emission computed tomography (SPECT), despite improved resolution and lesion detection in multiplanar reconstructions, has somewhat limited value in accurate localisation. In general, multislice CT has increased the role of CT in evaluating complicated structures such as the wrist. However, the limitations of musculoskeletal CT include an inability to differentiate active from inactive pathology and limited capabilities with soft tissues.

Dedicated multislice SPECT/CT is combined to enhance localisation and characterisation of bone pathology (Table 24.3). Multislice SPECT/CT scanners were introduced in 1999, with the

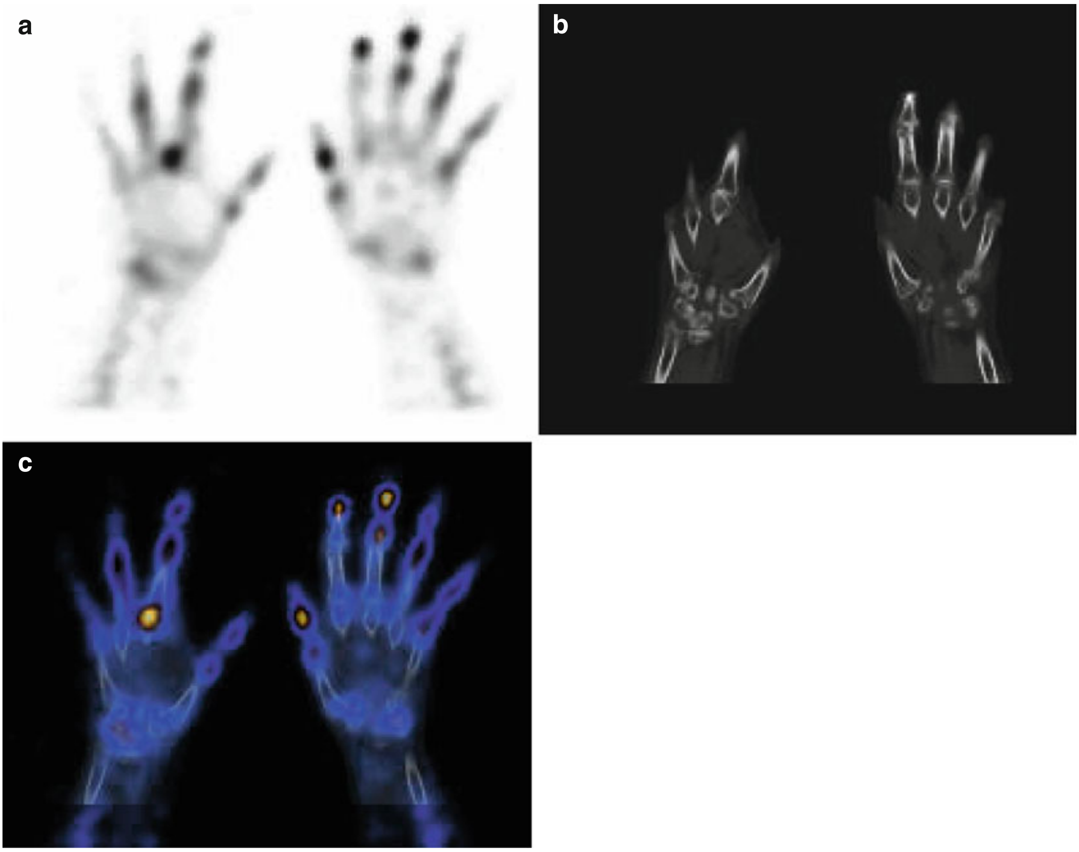

Fig. 24.12 Arthritis: Multiple joint pain: Pain following sports injury (**a**) SPECT, (**b**) CT and (**c**) fused SPECT/CT. There is increased tracer uptake several small bones/joints in the hands

advantage of having both the modalities fused into one machine (hardware fusion) simplifying the whole procedure. Therefore, SPECT/CT provides more information than SPECT or CT alone as a “one stop imaging” (Gnanasegaran et al. 2012). SPECT/CT often confirms the presence of metabolically active secondary degenerative changes due to non-union of carpal bone fractures and will often reduce further need for any invasive wrist arthroscopy. Further, degenerative changes are often overlooked on CT, unless the site of pain corresponds to the CT findings. SPECT/CT may guide the observer to focus on the area of interest, by selectively localising the site of increased tracer uptake (metabolically active), which may correspond to the site of active disease process. SPECT/CT

Table 24.3 Advantages and limitations radionuclide imaging of wrist pain (Gnanasegaran et al. 2012)

Bone scan with X-ray wrist registration	SPECT/CT
Advantages	*Advantages*
Sensitive	Sensitive
Accurate localisation	Specific
Easily available	Localisation
Limitations	Characterisation
Cumbersome technique	Limits or directs further investigations
	One stop imaging
	Limitations
	Limited availability
	Radiation

Fig. 24.13 Degenerative arthropathy following previous fusion. Patient suffered a scaphoid fracture with scapholunate ligamentous disruption 18 months prior to imaging, and was subsequently treated with internal fixation and fusion (**a**). He had been experiencing increasing pain and there was concernfor non-union despite satisfactory plain imaging (**b**). Palmar planar imaging shows moderately increased tracer uptake at several sites within the wrist, but SPECT/CT was required to accurately localise the source's of pain (**c** – **h**). Focal uptake is seen adjacent to a proximal metacarpal screw as well as at the capito-luno-triquetal articulation, suggestive of advanced degenerative arthropathy. Importantly, the fusion of the radius, lunate and capitate was complete. The patient had a single screw removed for some symptomatic relief

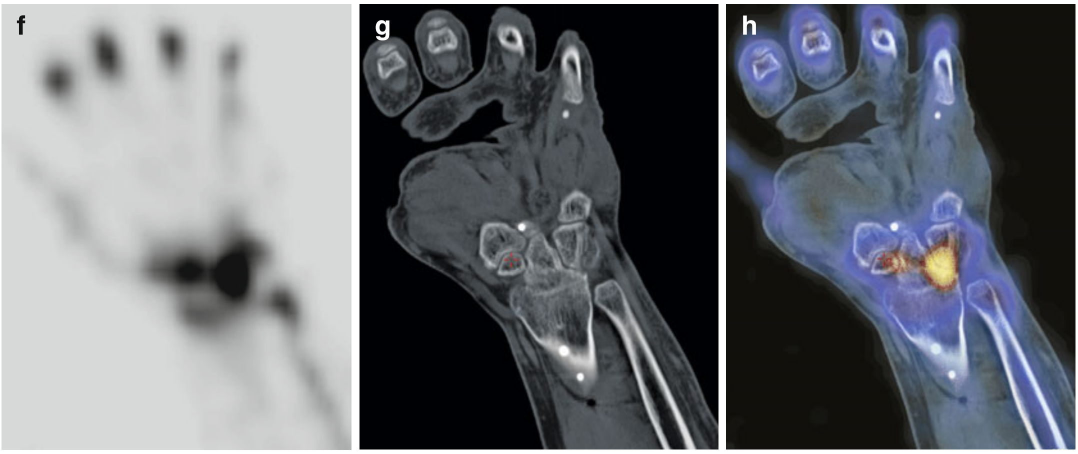

Fig. 24.13 (continued)

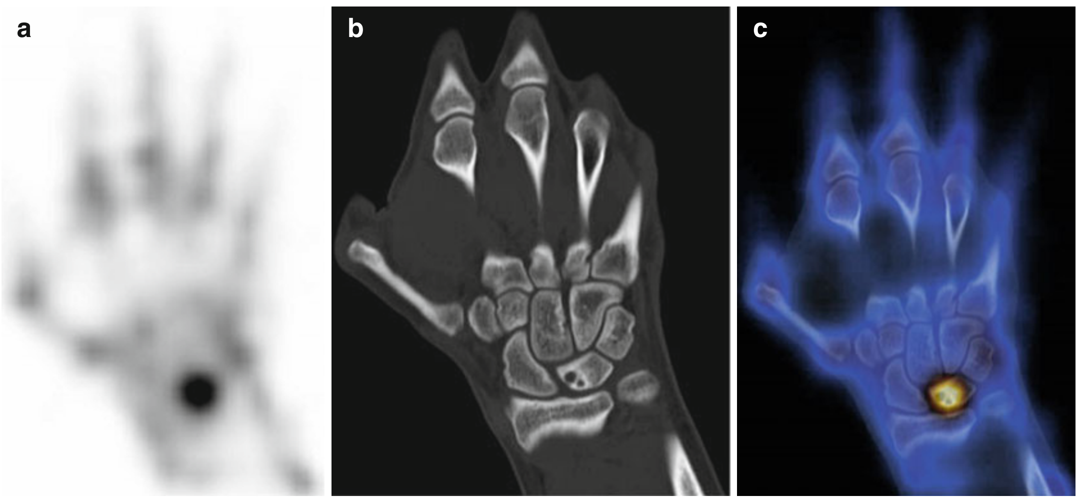

Fig. 24.14 Sub articular cysts with degenerative disease. (**a**) SPECT image shows a focal area of increased tracer uptake uptake corresponds to a large sub articular cyst (radiolunate joint), which shows cortical erosion on the CT and fused SPECT/CT scan (**b**, **c**). The scan appearances are in keeping with degenerative changes involving the radio lunate joint with sub articular cysts within the lunate

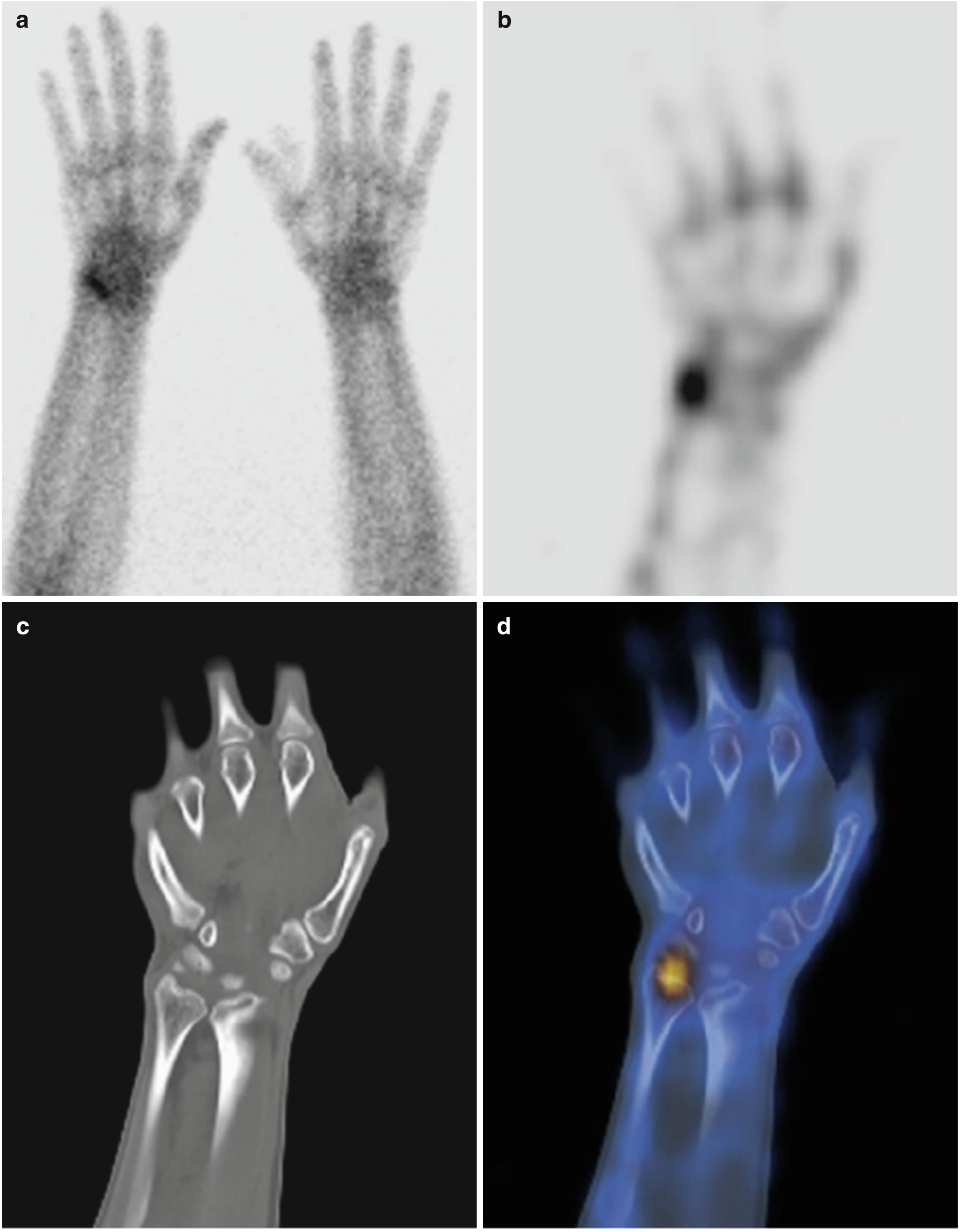

Fig. 24.15 Ulnar abutment syndrome. A man sustained a fractured ulnar styloid 6 years prior to imaging and complains of continued ulna-sided wrist pain. (**a**, **b**) Focal uptake within the ulnar side of the wrist joint on planar imaging is accurately localised by (**d**) SPECT/CT to active pathology on both sides of the ulnar-triquetral articulation, and diagnosed as ulnar-triquetral abutment secondary to non-union of a previously fractured ulna styloid (**c**). This is one of many treatable causes of ulnar sided wrist pain, the majority of which can be differentiated accurately by SPECT/CT

differentiates metabolically active disease causing pain from that of metabolically inactive disease.

Conclusion

Radionuclide imaging plays an important role in the assessment of wrist injuries. However, integration of SPECT and CT provides precise localisation and characterisation of abnormalities. Multislice hybrid SPECT/CT provides improved specificity and diagnostic confidence. It offers the advantage of distinguishing individual carpal bones unlike conventional bone scans. SPECT/CT may be used as a one stop imaging modality in the assessment of wrist injuries.

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