REVIEW ARTICLE

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# Review of imaging of scaphoid fractures

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**Key words**
avascular necrosis, fracture, imaging, non-union, scaphoid.

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Accepted for publication 8 July 2009.

doi: 10.1111/j.1445-2197.2009.05204.x

## Abstract

Scaphoid fractures are the most common fractures of the carpus, accounting for 79% of all carpal fractures. Early diagnosis of scaphoid fractures is imperative owing to potential complications following the fracture, including non-union, avascular necrosis, carpal instability and osteoarthritis. Plain radiography remains the initial imaging modality to assess scaphoid fractures. Magnetic resonance imaging (MRI) is excellent in the detection of clinically suspected, but initially radiographically negative, scaphoid fractures. Cost-effectiveness analysis studies have demonstrated MRI is effective in this setting. Gadolinium enhanced MRI has been shown to be superior to unenhanced MRI in the detection of avascular necrosis. Computerized tomography scan is the preferred modality to assess the intricacies of scaphoid fracture, including fracture location and deformity, as well as union status. This review paper explores the recent advances in imaging of the scaphoid, with reference also to avascular necrosis and non-union following a scaphoid fracture.

## Introduction

Scaphoid fractures are the most common fractures of the carpus, accounting for 79% of all carpal fractures.[1] They are frequently associated with a dorsi-flexion and radial deviation mechanism of injury.[2] Scaphoid fractures are commonly seen in the young and healthy, and are a rare finding in children or the elderly, where a fracture to the distal radius is more frequently seen.[3] Early diagnosis of scaphoid fractures is imperative owing to potential complications following the fracture, including non-union, avascular necrosis, carpal instability and osteoarthritis.

Groves *et al.* conducted a survey where physicians from 105 hospitals on six continents were questioned regarding their departments imaging protocol in cases of suspected scaphoid fracture.[4] All hospitals had access to magnetic resonance imaging (MRI), computerized tomography (CT) and bone scintigraphy. Among the 105 hospitals, no more than 7% shared identical strategies. The most common protocol was four radiographic views repeated at 10–14 days. The use of secondary MRI was the second most common modality.

This article reviews the use of imaging techniques, for suspected and confirmed scaphoid fractures, along with imaging modalities for detecting avascular necrosis and scaphoid fracture non-union.

## Natural history

Seventy per cent of all scaphoid fractures are through the waist of the bone, 20% involve the proximal pole, with the remaining 10% involving the distal pole.[1] In general, the prognosis of distal fractures is often better than that for proximal fractures, because of the retrograde blood supply to the scaphoid.[5] Early and accurate diagnosis is essential to either exclude or confirm the presence of a fracture. Under-treatment may result in significant complications, while over-treatment is associated with increased health-care costs and often results in lost workdays for the immobilized patient.[6]

## Imaging techniques – primary investigation

### Plain radiographs

Plain radiographs remain the standard initial imaging technique of suspected acute scaphoid fractures, although there is considerable

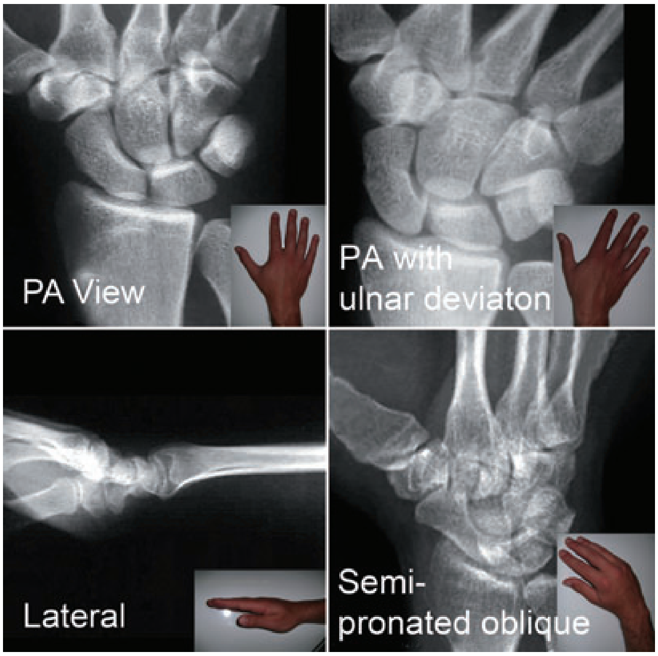


**Fig. 1.** Standard recommended scaphoid x-ray views. Postero-anterior (PA), PA with ulna deviation, lateral and semi-pronated oblique views. Position of hand and wrist relative to x-ray tubing shown with insert showing the x-ray taken.

variability in which images are obtained.[7] The American College of Radiology (ACR) has recommended four views for a suspected scaphoid fracture.[8] These are postero-anterior (PA), lateral, semi-pronated oblique and PA with ulnar deviation and/or cephalad tube angle (Fig. 1).

A meta-analysis of several large series has shown that scaphoid fractures are not identified on initial plain radiographs in 16% of cases.[9] Fractures can take up to 1 to 2 weeks to become evident on plain film.[10]

In 1975, Terry and Ramin described the radiographic sign: 'the scaphoid fat stripe' (they termed the 'navicular' fat stripe) as a useful soft tissue indication of a scaphoid fracture seen as a thin lucent line parallel to the lateral border of the scaphoid bone.[11] Annamalai *et al.* reported only a 50% correlation between MRI confirmed scaphoid fractures and the presence of the scaphoid fat stripe.[12]

## Imaging techniques – secondary investigation

While plain radiography is accepted as the initial imaging modality of a suspected scaphoid fracture, the questions remain: which is the best second-line investigation, if the plain radiographs are normal in a symptomatic patient?

Repeat radiographic examination is the historical standard and a valid investigation in patients with negative initial radiographs but persisting clinical suspicion; however, studies have reported that repeat plain radiographs have a poor inter-observer reliability coefficient (ranging from 18–53%).[10,13–15] Traditionally, this subset of patients were treated with 2 weeks of cast immobilization followed by repeat clinical examination and radiography. Although this remains an accepted treatment option, it may result in an unnecessary immobilization in a plaster cast for an extra 2 weeks, with the subsequent lifestyle, working and dressing restrictions that this entails.

### 1. Other radiographic techniques

There has been much published literature looking at variations in plain radiography to help detect scaphoid fractures. These include the carpal box technique with the use of an alignment box, panoramic radiography and macroradiography.[16–19]

### 2. Ultrasound

**Ultrasound in the therapeutic range (1–3 MHz)**

Historically, this has been used to elicit pain by causing vibration at the interface of the fracture sites. Bedford *et al.* reported initially encouraging results; however, these could not be reproduced.[20–22] This test is now only of historical interest.

**High-spatial resolution sonography (HSRS) (5–15 MHz)**

Several studies have reported their findings with HSRS.[23,24] These studies suggested that scaphoid cortical interruption, an effusion in the radiocarpal joint, and an effusion in the scapho-trapezium-trapezoid joints, are diagnostic of a scaphoid fracture (Fig. 2). The advantages of HSRS as a secondary imaging modality include accessibility, the non-invasive nature, safety, low cost and a short examination time. The uninjured side can also be examined at the same time for comparison. The disadvantages are that it can only assess the dorsal scaphoid waist, possibly missing fractures of the distal radius or other carpal bones. However, the most important clinical factor is the experience of the sonographer and the dynamic nature of this investigation makes it difficult for the treating clinician to interpret the stored images.

### 3. Bone scintigraphy

The advantage of bone scintigraphy in the assessment of acute scaphoid fractures is its high sensitivity (94–100%).[25–27] It can also be performed effectively on patients wearing plaster casts. However, when compared with other imaging modalities, it has a high false positive rate (up to 25%) and a low specificity (varying between 60–95%), due to increased uptake from other traumatic conditions such as scapholunate instability, bone bruises, synovitis and arthritis.[28–34] Bone scanning does not reach maximal predictive power until 72 h following the injury and subsequently in the earliest period, bone scintigraphy may be negative.[35,36] In elderly or debilitated patients, this may be delayed 7–10 days due to a delay in osteoblastic activity.[37]

A negative bone scan, rules out a scaphoid fracture, which is why it had been popular. A positive scan in an otherwise healthy individual diagnoses an injury, but does not diagnose a fracture. A positive scan often requires further investigation, such as a longitudinal CT scan, to confirm a fracture.[38]

**Quantification bone scan**

In an attempt to determine the significance of a hotspot, Groves *et al.* identified scaphoid fractures that were diagnosed on bone scan and

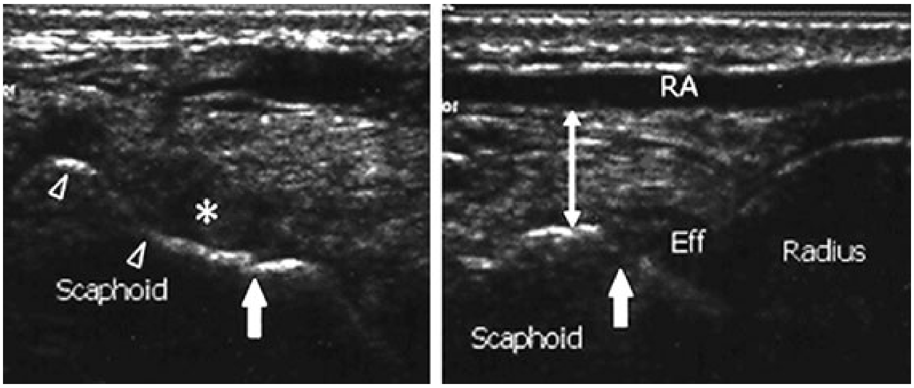


**Fig. 2.** High-spatial resolution ultrasonography (HSRS) in the diagnosis of scaphoid fracture. Longitudinal ultrasound image shown (a) obtained over the palmar aspect of the wrist displaying the scaphoid cortex as a hyperechoic line (open arrowheads). An interruption of the cortex (arrow) corresponds to the fracture line. There is surrounding irregular hyperechoic hematoma (*). A longitudinal image attained over the lateral aspect of the same wrist (b) again shows an interruption of the cortex (arrow), and an effusion within the radiocarpal joint (Eff). There is thickening of the soft tissue (double arrow) with displacement of the radial artery (RA). *(Permission Pending – Fusetti C, Poletti A, Pradel PH* et al. *Diagnosis of occult scaphoid fracture with high spatial resolution sonography: a prospective blind study. J. Trauma. 2005; 59: 677–81. fig. 2a,b).*

performed quantification of $^{99}Tc^{m}$-MDP in these lesions.[39] Overall greater values were found in hot spots that were shown to be the result of a scaphoid fracture, based on CT images, versus other pathology.

## 4. CT

The role of CT imaging of the wrist has been extensively studied.[40–48] Its high resolution, particularly for osseous structures make it ideal to detect occult fractures, to determine the direction of displacement of carpal fractures, and to evaluate fracture healing.[40] Temple *et al.* demonstrated that CT scan is superior to plain radiographs in the identification of fracture displacement.[47]

It is well-recognized that although the resolution of CT is lower than that of MRI scan, its spatial resolution is superior and therefore more able to detect displacement.[41] An expert panel from the ACR has devised a scaling system whereby they award certain imaging modalities a score (range 1–9, with 9 being the highest) for their use in detecting specific pathology.[8] The use of CT scanning of the wrist in suspected acute scaphoid fractures with initially normal plain films has been given an appropriateness criteria score of 4 out of 9.[8] The ACR recommends CT imaging where displacement of the scaphoid fracture fragments is suspected despite normal radiographs.

CT scanning of the scaphoid in the longitudinal axis is now the preferred technique as it provides a greater appreciation of the anatomy and deformity including the humpback deformity.[44,45] The patient lies prone on the CT table with their affected arm above their head, and their wrist in radial deviation and neutral flexion. The scanning plane is then orientated along the axis of the first metacarpal (Fig. 3a). If the correct orientation is obtained, there will be equal portions of the proximal and distal poles of the scaphoid visualized on either side of the capitate. This is the 'target sign' that appropriate orientation has been obtained[44] (Fig. 3b).

Partial volume averaging is a concept relevant to CT scan when the 3D volume is converted to a 2D figure[48] (Fig. 3c). A non-union that passes obliquely through a 'slice' may in fact appear united, as there may be some portion of the bone within the slice that will appear on the 2D image as an incomplete union. This may result in an error of assessment of union status. This effect can be minimized by reducing the width of each slice to 0.5–1.0 mm. Too thin a slice width will unfortunately equate to a longer scanning time and an increased risk of creating movement artefact.[48,49]

CT scan provides the best appreciation of the morphology of the fracture.[1,47,48] It provides a greater appreciation of the scaphoid deformity, including angulation and displacement (Fig. 4). Because of the excellent resolution provided by longitudinal CT scan, fine details such as comminution, sclerosis and orientation are appreciated much more clearly than with any other imaging. The CT scan provides the level of detail such that the surgeon can understand the 'personality of the fracture'.[48]

## 5. MRI

MRI has the distinct advantage in its ability to detect occult fractures and bone bruising of the scaphoid and carpus, as well as any associated soft tissue injuries (Fig. 5). Claustrophobia can be a real problem for the patient and is reported in 1–30% of cases.[50,51]

MRI has been reported to have excellent sensitivity (100%) and specificity (95–100%) for assessment of acute fractures.[9,29,52] Interobserver reliability is generally regarded as good with reported kappa values 0.8 to 0.96.[9,52,53]

# Early MRI for clinical scaphoid fracture

Mack *et al.* followed 56 acutely injured wrists with MRI (1.5T) performed on average 6.6 days after initial normal radiographs.[54] A scaphoid fracture was deemed present if a cortical fracture line and/or a trabecular fracture line was present, displayed by decreased signal intensity on T1 images. The presence of an increased signal intensity around the fracture line on T2 images, representing surrounding oedema is usually seen. Diffuse bone oedema was considered to represent a bone bruise and not a fracture. The use of early MRI, before any 10–14-day repeat radiographs, resulted in a therapeutic consequence in 66.1% ($n = 37$) of cases.

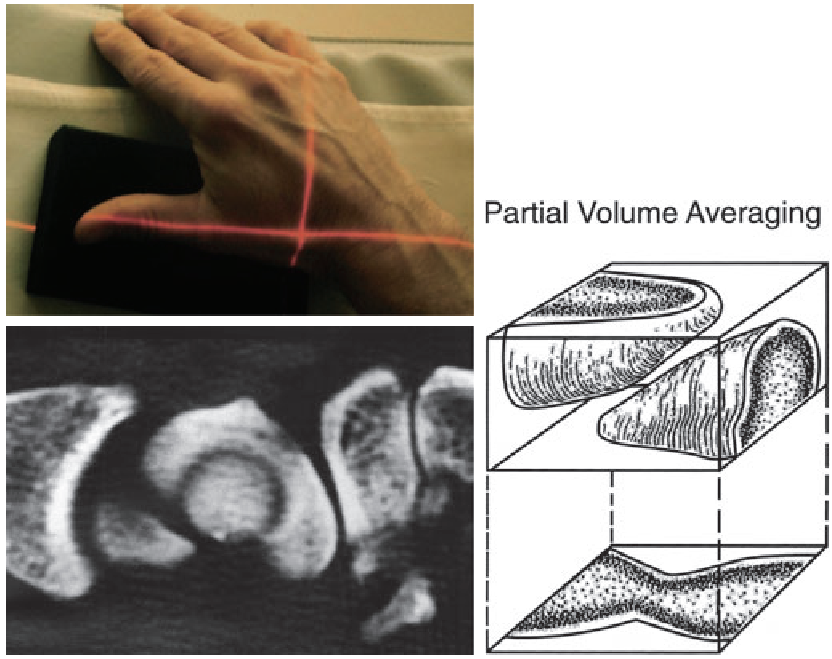


**Fig. 3.** Computerized tomography (CT) scan. Patient lies prone in the CT scanner with the hand above the head and the wrist in radial deviation. The scanning plane is in line with the first metacarpal (a). The 'target sign' is when the head of the capitate lies between the proximal and distal poles of the scaphoid (b). It is objective evidence that the scan is along the longitudinal axis of the scaphoid. Partial volume averaging is demonstrated here where a three-dimensional slice is converted to a two-dimensional image. A non-union that passes obliquely through the 'slice' may appear united (c). *(With kind permission of Springer Science and Business Media – Bain GI, Bennett JD* et al. *Longitudinal computed tomography of the scaphoid: a new technique. Skeletal Radiol. 1995; 24: 271–3. figs. 1–3).*

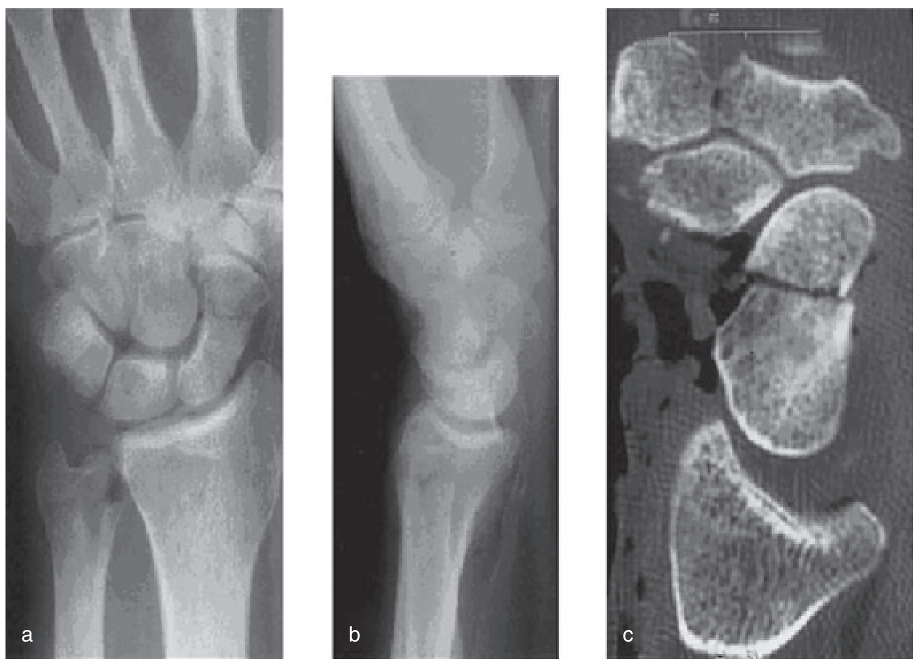


**Fig. 4.** Comparison of x-ray and CT scan demonstrating scaphoid fracture displacement. Images of a scaphoid fracture showing minimal displacement in the plain x-ray PA (a) and lateral (b) views, but a clear view of 1 mm displacement in the sagittal CT scan view (c). *(Reprinted from Temple CLF, Ross DC, Bennett JD* et al.*, Comparison of sagittal computed tomography and plain film radiography in scaphoid fracture model. J. Hand Surg. 2005; 30A: 534–42, with permission from Elsevier).*

Brydie *et al.* conducted a similar study performing MRI within 14 days of injury. A total of 195 patients were included in the study population, all of whom had clinical suspicion of a scaphoid fracture yet negative initial plain radiography.[55] Fifty-one per cent had no abnormality identified, 19% had a scaphoid fracture, 10% had 'bone bruising' and the remaining 20% had various other injuries reported, such as distal radius or capitate fractures. In this study, 80% of patients were immobilized unnecessarily for a suspected scaphoid fracture. As a consequence of early diagnosis, 180 patients (92%) had their management altered from immobilization and fortnightly review to either immediate discharge or immobilization and clinic review appropriate to their particular fracture. Both of these studies suggest that early MRI significantly alters therapeutic decision-making following a scaphoid fracture.

## Cost-effectiveness of early MRI

MRI screening for occult fractures of the hip has been shown to be cost-effective.[56] Several groups have recently looked into the cost-effectiveness of early MRI in comparison to the historically traditional protocol of repeat plain radiographs at 10–14 days for detecting scaphoid fractures.[57–60]

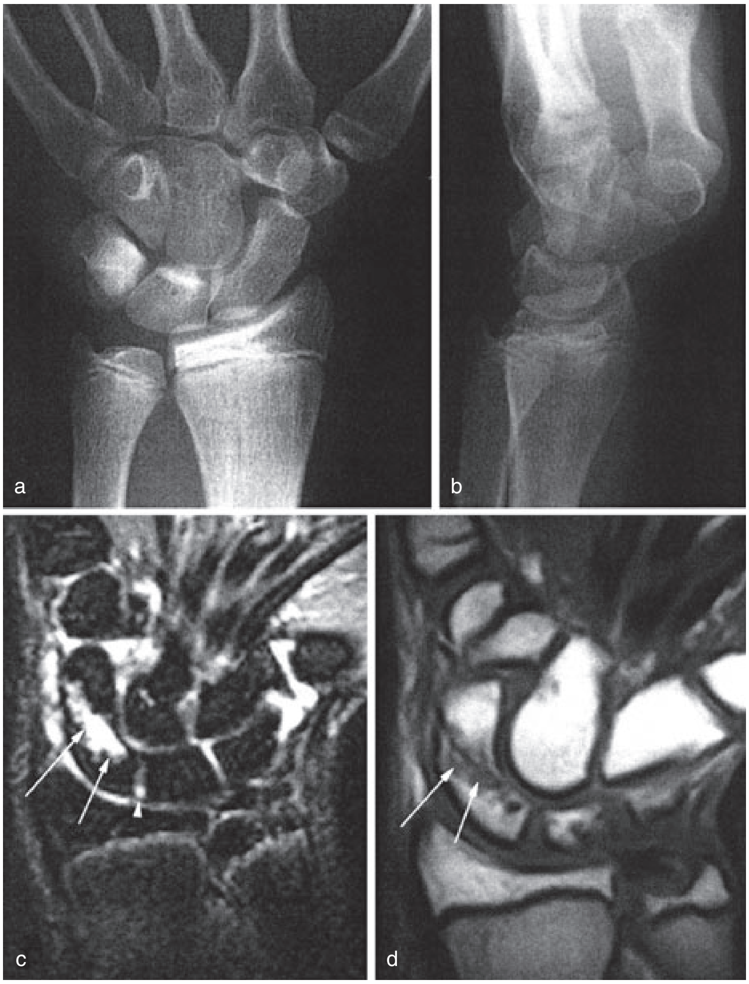


**Fig. 5.** Magnetic resonance imaging (MRI) scan. On plain radiographs a scaphoid fracture is not identified. A non-contrast fat saturated coronal T2-weighted image demonstrates signal alteration of the scaphoid bone (lower left image with arrows) due to the occult scaphoid fracture. The T1-weighted image (lower right) verifies the scaphoid fracture (arrows). The scapholunate ligament is intact (arrow head). *(With kind permission of Springer Science and Business Media – Mack MG, Keim S* et al. *Clinical impact of MRI in acute wrist fractures. Eur. Radiol. 2003; 13: 612–7, fig. 1.)*

Dorsay compared costs for the clinical protocol when using early MRI with traditional cost for follow-up, which include charges for orthopaedic consultation in the emergency department (ED), casting in ED, follow-up orthopaedic appointment in 7–10 days and repeated wrist radiography.[57] The charges (professional and technical) to a patient at this institution (USA) to undergo MRI of the wrist were $770 US dollars. This is compared to an average charge of $527 to patients who underwent the traditional imaging protocol. The authors concluded that when lost productivity and income to the patient are considered, early MRI is favoured at initial presentation. Similar results have been reported in the Australia and New Zealand health-care systems.[58,59]

The ACR issued a score of 8 out of 9 (appropriateness criterion) for the use of early non-contrast MRI as an imaging modality in a suspect acute scaphoid fracture with normal initial radiographs.[8] Potential concerns regarding an increase in demand for MRI scaphoid examination have been discounted by Raby who found no significant increase in requests for acute scaphoid imaging at a busy hospital in Glasgow, Scotland, when their protocol was changed to include immediate MRI.[61]

## Avascular necrosis

The scaphoid receives vascularization from two main branches of the radial artery with dorsal and volar branches entering through distal sections of bone, via numerous small foramina along the spiral groove and dorsal ridge[5] (Fig. 6). Herbert *et al.* have postulated that a small proportion of the proximal poles blood supply comes from the scapholunate ligament.[62]

The gold standard used to detect Avascular necrosis (AVN) has been either surgical inspection of punctate bleeding or intraoperative biopsy and histological analysis.[1]

The use of CT in assessing AVN is controversial, as it is uncertain as to the implication of a radio-dense proximal pole.[63–68] Sclerosis develops only after several weeks and may indicate revascularization with deposition of new bone following an ischaemic episode rather than ongoing AVN.[66] Following the fracture, there is a physiological hyperaemia as part of the healing response. The hyperemia 'washes out' the vascularized components of the carpus, leaving relative sclerosis of the proximal avascular fragment.

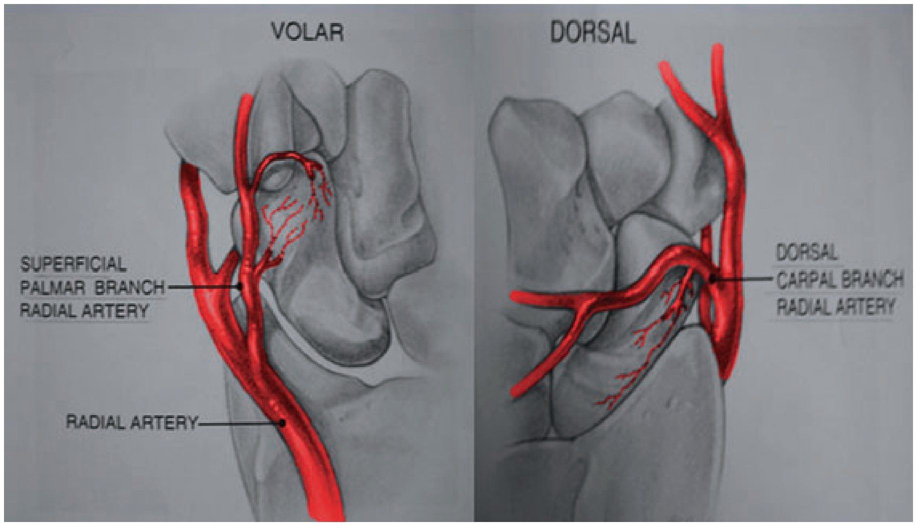


**Fig. 6.** Scaphoid blood supply. The vascular anatomy of the scaphoid bone, demonstrating the retrograde vascularity from the dorsal carpal branch and the superficial carpal branch of the radial artery. (*Reprinted with permission from The Journal of Bone and Joint Surgery, Inc. Taleisnik J, Kelly PJ. The extraosseous and intraosseous blood supply of the scaphoid bone. J. Bone Joint. Surg. Am. 1966; 48: 1125–37).*

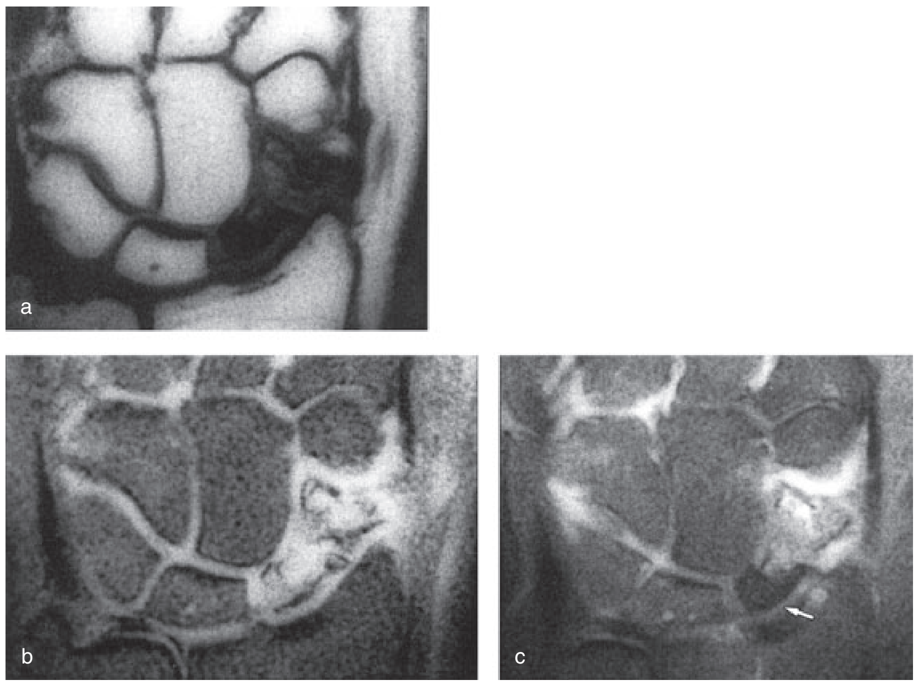


**Fig. 7.** Avascular necrosis of the scaphoid. MRI showing coronal T1-weighted image (a) with low signal intensity of the proximal fragment. T2-weighted, coronal fat-suppressed image (b) showing heterogeneous signal intensity of the proximal fragment. Coronal gadolinium-enhanced fat-suppressed T1-weighted image (c) showing a lack of enhancement (arrow) of the proximal pole of the scaphoid. *(With permission from Lippincott Williams & Wilkins. Cerezal L, Abascal F, Canga A. Usefulness of gadolinium enhanced MR imaging in the evaluation of the vascularity of scaphoid non-unions. American J. Roentology. 2000; 174: 141–9).*

Bone Scintigraphy of the scaphoid is not specific for necrosis and false positives may be obtained, particularly due to synovitis and attempted healing response.[66,69]

Currently, MRI is the best imaging modality for the assessment of avascular necrosis[1,63,70–72] (Fig. 7). Reported sensitivities for unenhanced MRI have ranges from 66% to 100%, while reported specificities have ranged from 42% to 100%.[63,70,71]

Cerezal *et al.* compared gadolinium enhanced MRI to unenhanced MRI, with surgical inspection for punctate bleeding as the gold standard.[72] He reported that unenhanced MRI had a sensitivity of 71%, specificity of 73% and a reliability coefficient of 0.63. Gadolinium enhanced MRI was superior with 85% sensitivity, 95% specificity and a reliability coefficient of 0.85.

## Non-union

Non-union is commonly defined as being present when radiographic signs are consistent with a failure of the fracture to heal (i.e. sclerosis, cyst formation, collapse and bone resorption) or bony union has not occurred over a period of 6 months from the time of fracture.[73] With prompt diagnosis and subsequent treatment, bony union can still be obtained in 94–98% of scaphoid fractures overall; however, proximal pole fractures remain troublesome with non-union rates in this subgroup of 15%.[74–76] A delay in diagnosis effects union rates with 40%–88% scaphoid non-union reported in fractures that are not recognized within 4 weeks from injury.[77,78] The cause of a non-union is multi-factorial and includes a delay in commencement of treatment, inadequate immobilization, displacement of the fracture fragments, instability due to ligamentous injury and inadequate blood supply of the proximal fragment.[5]

CT scan has been widely used in scaphoid non-union for assessing the fracture configuration, bony deformity and any concurrent osteoarthritis. This enables accuracy when planning surgical intervention.[8,42–44,79–83] The images from a longitudinal CT scan provide the best assessment of the location and degree of collapse of the non-union, with the lateral intra-scaphoid angle and the height-to-length ratio helping identify angulation and collapse of the scaphoid.[44,80,81] Bain *et al.* observed that there was greater reliability with the measurement of the height-to-length ratio and dorsal cortical angle, than with the intra-scaphoid angle due to the difficulty of calculating the intra-scaphoid angle.[44,81]

Trumble *et al.* reported that non-unions involving the scaphoid waist are usually associated with significant bone loss and carpal collapse resulting in palmar rotation of the distal pole, which produces dorsal humpback deformity.[79] Moritomo *et al.* and Oka *et al.*, using 3-dimensional CT scanning, independently investigated the effect of scaphoid fracture location on non-union deformity patterns.[82,83] Moritomo *et al.* suggested that the fracture location in scaphoid non-union affected the pattern of deformity.[82] The fracture location was measured based on the anatomical landmark of the dorsal apex of the scaphoid ridge, where the proximal part of the dorsal intercarpal ligament and the dorsal scapholunate interosseous ligament attach. Fractures which occurred distal to the dorsal apex of the ridge developed a humpback deformity. Fractures proximal to this ridge did not. Oka *et al.* showed that with distal fractures (defined as fractures distal to the scaphoid dorsal ridge), a humpback deformity occurred with a 9% volume loss, compared to proximal fractures, where no humpback deformity occurred with only a 1% volume loss.[83] He concluded that with proximal scaphoid fractures, ligamentous attachments (dorsal and volar) remain on the distal fragment, therefore maintaining stability. However, in distal scaphoid fractures, the fracture is beyond the dorsal ligament attachment, and therefore cannot resist flexion forces generated by axial loads, resulting in a humpback deformity.

## Conclusion

Scaphoid imaging has undergone much evolution as technological improvements in modern medicine have been made. Initial plain radiographs remain the first line investigation with four standard views recommended (PA, PA ulnar deviation, lateral and semi-pronated oblique).

If this investigation is positive, the authors recommend CT imaging, regardless of fracture displacement analysis on plain radiographs given CT's superior detection of fracture displacement.

If initial x-rays are negative, and there is a strong suspicion of scaphoid fracture or other injury (the 'acute wrist') then the author recommends MRI scan. This will not only identify a scaphoid fracture, but also other soft tissue injuries that may be present.

The best radiological assessment of AVN at present is MRI with gadolinium enhancement. CT scan is recommended in suspected non-union, both to confirm diagnosis and to assess fracture morphology for subsequent surgical treatment. MRI and CT scan will often be complimentary to each other in scaphoid non-union management.

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