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Diagnosis of suspected scaphoid fractures

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ABSTRACT/TAKE HOME POINTS

- Suspected scaphoid fractures are a diagnostic and therapeutic challenge, despite advances in knowledge and imaging. The risks and restrictions of routine immobilisation and restriction of activities in a young and active population must be weighed against the risks of non-union associated with a missed fracture.
- The prevalence of true fractures amongst suspected fractures is low. This greatly reduces the statistical probability that a positive diagnostic test will correspond with a true fracture, reducing the positive predictive value of an investigation.
- There is no consensus reference standard for a true fracture and thus alternative statistical methods for calculating sensitivity, specificity, positive and negative predictive value are required.
- Clinical prediction rules incorporating a set of demographic and clinical factors may allow stratification of secondary imaging, which could in turn increase the pre-test probability of a scaphoid fracture and improve the diagnostic performance of the sophisticated radiological investigations available.
- Machine learning (ML) derived probability calculators may augment risk stratification, and can improve through self-learning, although these theoretical benefits need further prospective evaluation.
- Convolutional neural networks (CNN) are a form of Artificial Intelligence (AI) that have demonstrated great promise in the recognition of scaphoid fractures on plain radiographs. However, in the more challenging diagnostic scenario of a suspected or so-called “clinical” scaphoid fracture CNNs have not yet proven superior over a diagnosis made by experienced surgeons.

BACKGROUND

Early diagnosis of suspected scaphoid fractures facilitates rapid treatment where indicated. Conversely, the prompt exclusion of suspected fractures limits excessive immobilization and unnecessary further clinical assessments for patients without injury[1–8]. The optimum diagnostic algorithm would ensure that no fractures are missed, although despite extensive research into secondary imaging modalities, a clear and cost-effective diagnostic protocol is yet to be established.

EPIDEMIOLOGY

The scaphoid is the most commonly-injured carpal bone, accounting for 60-80% of all carpal fractures and 10% of all hand fractures[9,10]. Acute fractures of the scaphoid account for 2-3% of all fractures in adults[11], although the quoted incidence varies widely between 1.5 and 121 per 100,000 per year[3,9,10,12–17]. It is possible that this variation arises because large datasets are limited in their ability to distinguish between true and suspected fractures[3,9,10,12,13,15], and the fact that studies investigating *radiographically-confirmed* acute fractures in defined adult populations typically report smaller incidences of 12-39 per 100,000 per year[9,13,16,17]. The mean patient age ranges between 22 and 35 years[3,9,10,12–17]. The male to female ratio is approximately 2.5:1, and males are often younger at the time of injury consistent with a type B fracture distribution curve[3,9,10,12–17].

Scaphoid fractures usually occur as a result of a fall onto the outstretched, hyperextended hand, or during sports[8,9,15,16]. Lower energy injury mechanisms such as a fall from standing height occur more frequently in females, while males are more likely to sustain their fracture after a high-energy injury such as sports or a motor vehicle collision[16]. This may partly explain the younger mean age observed in male patients[16,17]. Football, basketball, cycling and skateboarding have all been associated with an increased risk of fracture, though this varies depending on study origin[15,16]. Scaphoid fractures are also recognised to result from recreational punching, or assault[18,19]. Two studies have reported male sex and sports injuries are risk factors associated with true fractures[8,20].

CLINICAL ASSESSMENT

The primary presenting complaint is usually radial sided wrist pain, with localised tenderness over the scaphoid in the region of the anatomical snuffbox (ASB). It is vital to clarify any history of previous trauma to avoid treating an established non-union as an acute fracture. Plain four-view radiographs are usually obtained as the first-line investigation, although up to 30-40% of scaphoid fractures are not identified by this combination of clinical assessment and imaging[11,21–28]. These patients are said to have a suspected, or so-called "clinical" scaphoid fracture[11]. Suspected fractures are conventionally treated with immobilisation pending repeat radiographic and clinical assessment at 10-14 days following injury. For these cases, the risks and inconvenience associated with immobilisation, namely transient joint stiffness and a delayed return to work and activities[29,30] in a young and active patient cohort, must be balanced against the risks of non-union and arthrosis associated with an untreated scaphoid fracture[31–33]. When interval repeat radiological and clinical examination confirms a fracture, this is referred to as an occult fracture[5,21,26,34–36].

ASB tenderness is one of the most commonly-documented examination findings, but has been reported to have a sensitivity of 90% and a specificity of only 40%, comparable with scaphoid tubercle tenderness with a sensitivity of 87% and specificity of 57%[37]. It has been suggested that the negative predictive value (NPV) of ASB pain on ulnar deviation of the pronated wrist approaches 100%, and that patients without this sign could be safely discharged at presentation[38]. However, at present there is no single sign which is considered to be sensitive or specific enough for the diagnosis of suspected scaphoid fractures (Table 1)[23,27,37,39–43]. The performance of clinical signs improves when used in combination. For example, ASB tenderness, scaphoid tubercle tenderness, and ASB pain on longitudinal compression of the thumb within 24hrs of injury generated a sensitivity of 100% and a specificity of 74% in a prospective study of 215 patients[39].

Alternative clinical signs have been identified as possible predictors of a true fracture. An analysis of ten clinical examination manoeuvres on 41 patients determined that pain on thumb-index finger pinch and ASB pain on forearm pronation were most predictive of a true scaphoid fracture[27]. Duckworth et al. concluded that the best predictors of a true fracture within 72 hours of injury were the presence of ASB pain on ulnar deviation of the wrist and pain on thumb-index finger pinch, with scaphoid tubercle tenderness the most predictive sign two weeks after injury[20]. That study also noted that all patients without ASB pain on ulnar deviation within 72 hours of injury did not have a fracture. A clinical scaphoid score (CSS) has also been developed which combines three examination findings: ASB tenderness with the wrist in ulnar deviation (3 points), scaphoid tubercle tenderness (2 points) and ASB pain with longitudinal thumb compression (1 point)[44]. Utilising MRI findings as the reference standard, 13 occult fractures were identified in 154 patients with normal radiographs, suggesting that patients with a CSS $\geq$4 require an MRI.

IMAGING

Radiographs

Neutral postero-anterior (PA) and lateral radiographs are recommended in the initial assessment of the injured wrist and are useful in assessing carpal alignment and the presence of perilunate fracture-dislocation injuries. However, the efficacy in the detection of acute scaphoid fractures is limited by the projectional overhang of the scaphoid tubercle on the neutral PA view[24,45,46]. "Four-view" scaphoid radiographs are the conventional first-line investigation, but are limited by low inter and intra-rater reliability[47,48], possibly due to overlap of the dorsal lip of the distal radius, or a bent appearance of the scaphoid on the semi-supinated view[24]. As a result, multiple modified views have been suggested to improve diagnostic performance (Table 2)[36,45,46,49].

The 'banana view' described by Ziter refers to an PA view of the wrist in ulnar deviation with the tube angled at 20° to the elbow (Figure 1)[49]. While this view can aid in the identification of scaphoid waist fractures, fractures which are orientated obliquely to the beam may not be well-visualised. The use of a so-called "carpal box" to provide magnified radiographs of the carpus may increase inter-observer agreement in the interpretation of standard four-view radiographs from 36% to 55%[50,51], although this is not routinely utilised. Comparative views of the contralateral uninjured wrist have also been described[52].

Although there is evidence to suggest that radiographs combined with clinical assessment by an experienced surgeon can accurately diagnose all suspected scaphoid fractures within six weeks of injury[24,53], many studies indicate that up to 30-40% of fractures will not be identified on initial assessment[11,21–25,27,28]. However, interval repeat radiographs have been reported to have a low sensitivity, with one study detecting only 50% of occult scaphoid fractures[25].

Tomosynthesis, the generation of cross-sectional images from standard radiographs, has also been used in the diagnosis of scaphoid fractures[54,55]. Proposed benefits include superior diagnostic value compared with conventional radiographs[56], and a recent study reported a positive predictive value (PPV) of 100% and a sensitivity of 67% in 40 cases[57]. It is less sensitive and specific than conventional CT scanning[56], but is associated with a lower radiation dose[58,59]. However, despite promising early results further evaluation and larger-scale feasibility studies will be required before this technique can be introduced in widespread clinical practice.

In the absence of a visible fracture, soft tissue signs may also be detected on plain radiographs. The scaphoid fat pad sign (distortion or loss of adjacent fat stripes over the radial aspect of the scaphoid on the PA view with the wrist in ulnar deviation) and the pronator fat pad/stripe sign (a prominent pronator quadratus fat pad over the volar aspect of the wrist on the lateral view) have been described but have not been found to be reliable[35,60].

The lack of reliability of standard radiographs in diagnosing suspected scaphoid fractures usually leads to immobilisation followed by repeat examination and radiographs 10-14 days following injury[61,62]. The inter-observer variability of this approach decreases more than 2 weeks following injury[48,63–65]. The interval period often leads to a reduction in tenderness and patient apprehension which may result in a more diagnostic clinical examination, but this must be balanced against the risks of immobilisation[29,30].

Ultrasound

Ultrasound is the least effective imaging modality with a sensitivity of 37-93% and a specificity of 61-91%[8,66–69]. Its accuracy is operator and equipment dependent[70], which may partly explain the variation in reported performance characteristics. High spatial resolution sonography is more accurate with a sensitivity of up to 100% and the specificity as high as 91%[5,71], but this may not be widely available. It has been suggested that ultrasound may be most appropriately deployed as a precursor to further imaging modalities in the Emergency Department [72], or when CT and MRI are unavailable[73]. However, other authors have cautioned that a negative ultrasound is not sufficient to exclude a fracture, and that further imaging with CT or MRI would be required for these cases[74]. A recent systematic review highlighted the lack of large clinical trials investigating the use of ultrasound, and called for further research into the accuracy of this modality [75].

Bone Scintigraphy

Despite strong proponents in favour of bone scintigraphy[1,48,76,77], the perceived lack of specificity when compared to CT and MRI has limited the widespread adoption of this modality[78–82]. A recent meta-analysis suggested bone scintigraphy was as sensitive and predictive as MRI for the detection of true fractures, but displayed inferior specificity which raised the possibility of overdiagnosis of fractures[83]. The timing of bone scintigraphy may also influence its diagnostic capabilities: the sensitivity increases with increasing time from the injury, and peaks at 100% at 96 hours[48,76,78,81,84–86]. These limitations, combined with the relatively invasive nature of the investigation may explain why this is the least commonly employed secondary imaging modality in the UK[87].

Computed Tomography (CT)

CT is widely advocated in the investigation of suspected scaphoid fractures[79,88–91], although some authors advise caution when interpreting CT for undisplaced fractures which can be difficult to distinguish from normal vascular markings[92]. In displaced fractures, CT is more useful than MRI in describing the degree of displacement and fracture morphology[62,93]. A previous analysis of 47 patients found CT to be 94.4% sensitive and 100% specific with a NPV of 96.8% and a PPV of 100%, though this study relied on MRI or two-week radiographs as the reference standard[88]. In addition, substantial intra-observer, and moderate[94] to high inter-observer reliability has been reported[95].

The usefulness of this modality is further strengthened by its ability to detect other injuries around the wrist[90,96]. Approximately a third of CT scans performed for suspected scaphoid fractures will demonstrate a separate bony injury[90,96]. In one retrospective study of 84 CT scans for suspected scaphoid fractures performed within two weeks of injury there were 54 scans were normal, while the remaining 30 revealed a bony abnormality of which only 7% were occult scaphoid fractures, 18% were other carpal fractures (triquetrum, capitate, lunate) and 5% were distal radius fractures[96]. Excellent sagittal images can be obtained by manipulating the patient position within the scanner, particularly if the scout beam of the CT gantry is orientated parallel to the long axis of the scaphoid[97].

Cone-beam CT (CBCT) has recently been applied in the diagnosis of scaphoid fractures[98]. This technique can generate high spatial resolution images of the hand and wrist with a lower radiation dose compared with conventional CT[98–100]. The dose can be minimised even further when lead-shielding of organs is undertaken[101]. Recent research has demonstrated that CBCT has superior performance characteristics to repeat plain radiography[95,99,100], but has shown an inferior ability to exclude fractures when compared with MRI[99].

Magnetic Resonance Imaging (MRI)

MRI is generally accepted to be the most accurate investigation, although it may not be readily available in every institution [4,6–8,26,36,82,102–105]. A prospective study of 32 patients with a suspected scaphoid fracture who underwent MRI within 72 hours reported a sensitivity and specificity of 100%, using clinical and radiographic follow-up at six weeks as the reference standard[26]. However, recent research has documented the potential for false-positive scans, with benign abnormalities incorrectly diagnosed as fractures by blinded radiologists [106]. "Bone bruising" (Figure 2) is a common finding on MRI, though the relevance of this is not well-understood in the context of acute fractures[91,107]: in one study, only 2% of cases where bone bruising was observed were subsequently diagnosed as having a true fracture, and 92% of patients were asymptomatic eight weeks later[108].

The low number of true fractures among patients with suspected fractures generates a situation of low prevalence. This can lead to a lower PPV, raising the possibility of over-diagnosis of fractures and the potential for over-treatment. Bayesian formula analysis undertaken by Ring et al. reported a PPV of 88%, suggesting the potential for false-positive diagnosis in around 12% of patients with a suspected fractures[80]. Meta-analysis of this data is presented in Table 3. Therefore, despite favourable performance characteristics, it is difficult to accept MRI as the gold reference standard for the diagnosis of true fractures.

More recently, numerous authors have attempted to quantify the potential cost implications related to routine use of MRI in suspected scaphoid fractures (Figure 3). Aside from healthcare-associated costs, it is important to consider that exclusion of an acute fracture may lead to significant societal cost savings due to early mobilisation and discharge, which may facilitate earlier return to work[109]. Gaebler et al. suggested that the early use of MRI could generate savings of $7,200 per 100,000 people by avoiding unnecessary immobilisation and clinic appointments[26]. This was confirmed by a US based cost-utility analysis which demonstrated that early MRI leads to prompt diagnosis resulting in a lower overall system cost compared to CT and interval clinical assessment[110]. Substantial changes in cost (more than $2000 increase with MRI/CT) and sensitivity (decreased to 25% for CT and 32% for MRI) were required to balance the cost-effectiveness of these advanced modalities. Similar cost-saving implications have been reported in the UK[61,102] and Irish[111] healthcare systems. Most recently, the Scaphoid Magnetic Resonance Imaging in Trauma (SMaRT) prospective randomised controlled trial demonstrated lower costs at six months in patients with suspected scaphoid fractures who underwent immediate MRI in the emergency department, compared with patients who underwent routine immobilisation and clinic review[112].

However, the proposed cost benefit to early MRI has not been universally demonstrated. Prior to publication of the SMaRT trial, two separate randomised controlled trials compared early MRI with routine immobilisation and interval clinical reassessment[102,105]. Patients who underwent MRI and had no evidence of fracture were discharged immediately. No reduction in direct or indirect costs was reported with early MRI. However, less time was required before return to work[105], and higher satisfaction[102] was reported in patients who underwent MRI. Similar findings regarding satisfaction were reported by the SMaRT trial.

CURRENT PRACTICES

There is no currently available imaging modality with perfect diagnostic performance characteristics. A previous meta-analysis suggested that MRI and bone scintigraphy had comparable sensitivity, but that MRI had a higher specificity[82]. A Cochrane review has subsequently suggested that MRI has the highest sensitivity and specificity of the available imaging modalities[83](Table 4).

The United Kingdom's (UK) Royal College of Radiologists concludes that on current evidence bone scintigraphy, CT and MRI are equally valuable in the diagnosis of acute scaphoid fracture[113]. However, this contrasts with guidelines issued by the American College of Radiology which advise the initial use radiographs followed by MRI[114]. There is a widespread variation in imaging protocols reported. In a survey of 116 English hospitals, interval plain radiographs were the most widely used imaging modality for suspected fractures, most commonly undertaken between 10 days and 4 weeks[115]. When further imaging was required, MRI was undertaken in 64%, CT in 27%, and Bone Scintigraph in 9% of cases[115]. A further recent survey found that only 51% of UK healthcare trusts had the capability to offer acute MRI for suspected fractures[87]. An international survey of 105 hospitals in 43 countries worldwide has also been undertaken, and found that only 22% of hospitals had an established imaging protocol for suspected fractures[116].

FUTURE DIRECTIONS

The combination of over-sensitive, non-specific clinical signs and a lack of consensus for a gold standard diagnostic tool leads to the majority of patients receiving more protective immobilisation and investigation than is required for suspected fractures[24,27,37–41]. The potential costs to the healthcare system and the patient due to increased time off work as a result of this are well-documented[1,4,117,118].

The development of gold-standard diagnostic protocols is problematic for two reasons. Firstly, the low prevalence of true fractures amongst suspected fractures lowers the probability that a positive test will correspond with a true fracture as false positives are almost as common as true positives[8–10,22,80,81,92,119]. If a true scaphoid fracture can be expected in 5-20% of patients who present with suspected fractures, and false positives or negatives account for 5-10% of diagnostic test results[8–10,22,80,81,92,119], this low prevalence of true fractures can produce a low PPV of the diagnostic protocol, even when the diagnostic test utilised is both highly sensitive and specific[80,120].

The second problem is the lack of a consensus reference standard for the diagnosis of a true fracture against which diagnostic performance of tests can be consistently evaluated[120,121]. The most frequently used reference standard in the literature is the absence of a fracture on plain radiographs six weeks after injury[53,80,82,92,122], however the integrity of this approach has been called into question[65]. Latent class analysis is a statistical method which may avoid these shortcomings[80,92,122,123]. It is a variation of structural equation modelling that identifies associated factors in patient data and allows evaluation of performance characteristics of diagnostic techniques in conditions without a gold-standard diagnostic method[124]. The technique has recently been applied to the diagnosis of suspected scaphoid fractures[20,125]. These studies reported potentially important differences between the results using traditional formula and latent class analysis, which may permit more representative description of diagnostic performance characteristics.

Clinical Prediction Rules

The low prevalence of suspected fractures and lack of consensus reference standard means that the role of advanced imaging technology remains uncertain. It is probable that there will always be a small probability of missing a true fracture among suspected scaphoid fractures, and the best option could be to stratify higher risk patients towards secondary imaging. Clinical prediction rules aim to increase the prevalence of true fractures among suspected fractures that present for further imaging[80,119], effectively increasing the pre-test probability of an investigation correctly detecting a fracture. Incorporation of a combination of demographic and clinical risk factors predictive of a true scaphoid fracture could allow stratification of high-risk patients to further imaging. This could also reduce the costs associated with potentially unnecessary further imaging.

Two previous studies have investigated the application of clinical prediction rules to the management of suspected scaphoid fractures. The first examined 78 patients and found that reduction in extension strength of greater than 50%, supination strength of ≤10% and the presence of a previous fracture were most predictive of a true fracture on multivariable analysis[81]. A separate multicentre prospective study analysed 223 patients with clinically suspected or radiographically confirmed fractures and found that male gender, sports injury, ASB pain on ulnar deviation of the wrist and pain on thumb-index pinch at presentation, as well as persistent scaphoid tubercle tenderness at two week review were most predictive of a true fracture[20]. This study utilised radiological imaging at six weeks as the reference standard. Another prospective study of 893 patients with acute wrist injury, with 68 patients (7.6%) diagnosed with a scaphoid fracture, was aimed to develop and validate a clinical decision rule.

Mallee et al identified a set of predictors (sex, swelling of the anatomic snuffbox, tenderness in the anatomic snuffbox, painful ulnar deviation and painful axial thumb compression) and weighed these into a prediction tool for risk stratification[126]. Although these studies reported distinct predictors of true fractures, they demonstrated the potential impact of clinical prediction in the diagnosis of suspected scaphoid fractures.

Artificial Intelligence: Machine Learning (ML) derived clinical prediction tools

Artificial intelligence (AI) and machine learning (ML) have been deployed recently to calculate probabilities relating to emergency presentations, survivorship following surgery, and outcomes following spinal surgery[127–132]. ML prediction models differ from classic regression or latent class analysis derived models in their ability to process complex nonlinear relationships and interactions[133,134]. Moreover, ML-derived algorithms are capable of "retraining": adapting and improving in response to prospectively-collected data which can be entered into the model[135]. This may lead to clinical algorithms that rely less on more subjective clinical tests, which could facilitate more accurate assessment and more efficient workflow earlier in the triage process in the Emergency Department[136]. In turn, this could lead to more streamlined referrals for secondary imaging, improving the PPV of these tests.

The aforementioned CSS is an example of a clinical prediction rule that combines three examination findings, but does not account for demographic variables. Another approach is risk stratification with ML-derived models. Such a ML algorithm was trained and tested on combined Edinburgh and Amsterdam datasets: 1) Duckworth et al included 223 patients at their centre with clinical symptoms of a scaphoid fracture and a radiologically visible or occult scaphoid fracture presenting within 72 hours after injury; and 2) Mallee et al enrolled a similar prospective cohort of 235 adult patients in the Amsterdam University Medical Center at five different institutions. This AI application identified age (bimodal), sex (male sex in younger patients; female sex in the elderly), injury mechanism (high versus low energy) and only one clinical examination finding (ASB tenderness on ulnar deviation) to calculate the probability of a scaphoid fracture after wrist trauma. When initiating advanced imaging in patients with negative radiographs, applying a cut-off of the ML-estimated probability of a scaphoid fracture at >10%, the algorithm yielded 100% sensitivity and a 38% specificity. Retrospective application of this algorithm on a prospective cohort of 323 patients undergoing MRI for a suspected or "clinical" scaphoid, the number of patients undergoing advanced imaging would be reduced by 36% without missing a fracture.

This theoretical benefit of a ML-derived clinical prediction tool considering three demographic variables as well as ASB tenderness on ulnar deviation needs to be proven prospectively. Although prospective research is being undertaken, large datasets will be required before the potential impact of this new technology can be fully appreciated.

Convolutional Neural Networks to diagnose scaphoid fractures on radiographs

AI applications in the field of Computer Vision referred to as convolutional neural networks (CNNs) are appealing for the diagnostic challenge of suspected scaphoid fractures. In short, CNNs are complex algorithms similar to interconnected neurons in the brain. CNNs are a form of deep learning (DL), currently utilised for diagnosing clear fractures of the distal radius, proximal humerus, and hip[137]. A CNN learns by repeatedly producing and testing algorithms in iterations) until it has optimized the capability to recognise the assigned feature and has recently been applied to scaphoid fractures[138,139].

Importantly, analogous challenges remain as for studies on diagnostic performance characteristics of CT and MRI: there is no consensus reference standard for a true fracture. Similarly, optimal training and testing of the CNN for recognizing scaphoid fractures on plain radiographs requires a more accurate set of measurements ('gold standard') than the radiographs under review for comparison (a "ground truth"). Langerhuizen et al. reported that their DL algorithm had trouble identifying scaphoid fractures (AUC 0.77, 72% accuracy, 84% sensitivity, 60% specificity) that were obvious to human observers (93% specificity), but accuracy (84%) and sensitivity (76%) did not differ significantly between the algorithm and orthopaedic surgeons. Although the CNN was less specific in diagnosing relatively obvious fractures, it did detect five of six occult scaphoid fractures that were missed by all human observers. The latter potential is being improved with algorithm refinement and may continue to improve with larger datasets. The second recent study on this subject did not demonstrate superior performance of the CNN over experienced surgeons (CNN AUC 0.84; 76% sensitivity and 92% specificity)[138]. Future studies are needed to determine if DL will be useful in suspected scaphoid fractures.

AUTHORS' RECOMMENDATIONS

These are detailed in Table 5.

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TABLES

Table 1: The diagnostic performance characteristics of clinical signs of used in the diagnosis of scaphoid fractures.

Clinical Sign	**Studies (n)**	**Patients (n)**	**Sensitivity (%)**	**Specificity (%)**
Anatomical snuffbox tenderness	8	1,164	87-100	3-98
Pain with axial compression of the thumb	8	961	48-100	22-97
Scaphoid tubercle tenderness	4	879	82-100	17-57
Pain on ulnar deviation	4	394	67-100	17-60
Pain on radial deviation	3	316	67-90	31-42
Reduced range of movement of the thumb	2	412	65-66	38-59
Thumb–index finger pinch	2	264	75-79	44-76

(Table adapted from Table 2 in Mallee WH, Henny EP, van Dijk CN, Kamminga SP, van Enst WA, Kloen P. Clinical diagnostic evaluation for scaphoid fractures: a systematic review and meta-analysis. J Hand Surg Am. 2014 Sep;39(9):1683-1691)

Carpal Fractures and Dislocations. In: Court-Brown CM, McQueen MM, Swiontkowksi M, Ring D, Friedman S, Duckworth AD. Musculoskeletal Trauma in the Elderly. 1st edition. CRC Press; 2016.

Table 2: Additional radiographic views used in the assessment of scaphoid fractures.

Radiologic View	**Advantages**
Ulnar-deviated	Detection of proximal pole fractures
45-degree ulnar oblique (semipronated)	Detection of oblique sulcal, waist (in particular displacement), and tubercle fractures
45-degree radial oblique (semisupinated)	Detection of proximal pole fractures, humpback deformities, and avulsion fractures
Ziter view	Detection of waist fractures as beam at right angles to long axis

Carpal Fractures and Dislocations. In: Tornetta P, Ricci WM, Ostrum RF, McQueen MM, McKee MD, Court-Brown CM. Rockwood and Green's Fractures in Adults. 9th edition. Lippincott Williams & Wilkins; 2019.

Table 3: Diagnostic performance characteristics for imaging modalities as determined by Ring et al. for suspected scaphoid fractures.

Imaging Modality (Number of Studies Assessed)	**Sensitivity (%)**	**Specificity (%)**	**Accuracy (%)**	**PPV**	**NPV**
Ultrasound (*n* = 4)	93	89	92	0.38	0.99
Bone scintigraphy (*n* = 18)	96	89	93	0.39	0.99
CT (*n* = 8)	94	96	98	0.75	0.99
MRI (*n* = 22)	98	99	96	0.88	1.00

Duckworth AD, Ring D, McQueen MM. Assessment of the suspected fracture of the scaphoid. J Bone Joint Surg Br. 2011;93-B(6):713–719.

Table 4: The sensitivity and specificity of imaging modalities as determined by Mallee et al for suspected scaphoid fractures.

Imaging Modality (number of studies)	**Sensitivity (%)**	**Specificity (%)**
Bone scintigraphy (n=6)	99	86
CT (n=4)	72	99
MRI (n=5)	88	100

Carpal Fractures and Dislocations. In: Court-Brown CM, McQueen MM, Swiontkowksi M, Ring D, Friedman S, Duckworth AD. Musculoskeletal Trauma in the Elderly. 1st edition. CRC Press; 2016.

Table 5: Author recommendations based on current best evidence.

Recommendation	Detail
1	The probability of an occult scaphoid fracture can be determined from a combination of patient/injury demographics and clinical examination through the development of clinical prediction rules.
2	A forearm below elbow cast or removable splint can be utilized for lower risk patients with persistent symptoms, followed by conventional interval clinical examination and radiographs at 10-14 days post injury.
3	Secondary imaging (CT or MRI) can be considered to investigate persistent symptoms and where interval examination and radiographs are equivocal, to exclude a fracture and avoid additional immobilization and activity restrictions.
4	High risk patients with an increased pre-test probability of a fracture will likely benefit from early secondary imaging and we would suggest MRI is the optimal modality based on the current available best evidence.

FIGURE LEGENDS

Figure 1: The Ziter's view used as an additional image that demonstrates a fracture of the scaphoid waist.

Carpal Fractures and Dislocations. In: Tornetta P, Ricci WM, Ostrum RF, McQueen MM, McKee MD, Court-Brown CM. Rockwood and Green's Fractures in Adults. 9th edition. Lippincott Williams & Wilkins; 2019.

Figure 2: MRI scan revealing 'bone bruising' of the scaphoid but no true fracture is apparent.

Carpal Fractures and Dislocations. In: Tornetta P, Ricci WM, Ostrum RF, McQueen MM, McKee MD, Court-Brown CM. Rockwood and Green's Fractures in Adults. 9th edition. Lippincott Williams & Wilkins; 2019.

Figure 3: (A) Radiograph revealing no apparent fracture of the scaphoid. (B) MRI scan in the same patient revealing a clear proximal pole scaphoid fracture.