■ INSTRUCTIONAL REVIEW: UPPER LIMB

Assessment of the suspected fracture of the scaphoid

A. D. Duckworth,
D. Ring,
M. M. McQueen

*From the Edinburgh
Orthopaedic Trauma
Unit, Royal
Infirmary of
Edinburgh,
Edinburgh, United
Kingdom*

A suspected fracture of the scaphoid remains difficult to manage despite advances in knowledge and imaging methods. Immobilisation and restriction of activities in a young and active patient must be balanced against the risks of nonunion associated with an undiagnosed and undertreated fracture of the scaphoid.

The assessment of diagnostic tests for a suspected fracture of the scaphoid must take into account two important factors. First, the prevalence of true fractures among suspected fractures is low, which greatly reduces the probability that a positive test will correspond with a true fracture, as false positives are nearly as common as true positives. This situation is accounted for by Bayesian statistics. Secondly, there is no agreed reference standard for a true fracture, which necessitates the need for an alternative method of calculating diagnostic performance characteristics, based upon a statistical method which identifies clinical factors tending to associate (latent classes) in patients with a high probability of fracture.

The most successful diagnostic test to date is MRI, but in low-prevalence situations the positive predictive value of MRI is only 88%, and new data have documented the potential for false positive scans. The best strategy for improving the diagnosis of true fractures among suspected fractures of the scaphoid may well be to develop a clinical prediction rule incorporating a set of demographic and clinical factors which together increase the pre-test probability of a fracture of the scaphoid, in addition to developing increasingly sophisticated radiological tests.

■ A. D. Duckworth, MSc,
MRCSEd, Specialty Registrar
(StR) and Clinical Research
Fellow

■ M. M. McQueen, MD,
FRCSEd(Orth), Professor of
Orthopaedic Trauma
Edinburgh Orthopaedic Trauma
Unit
Royal Infirmary of Edinburgh,
51 Little France Crescent,
Edinburgh EH16 4SU, UK.

■ D. Ring, MD, PhD, Medical
Director and Director of
Research
Department of Orthopaedic
Surgery
Harvard Medical School,
Orthopaedic Hand and Upper
Extremity Service,
Massachusetts General
Hospital, Boston, MA 02114,
USA.

Correspondence should be sent
to Mr A. D. Duckworth; e-mail:
andrew.duckworth@yahoo.co.
uk

©2011 British Editorial Society
of Bone and Joint Surgery
doi:10.1302/0301-620X.93B6.
26506 \$2.00

J Bone Joint Surg [Br]
2011;93-B:713-19.

Received 13 December 2010;
Accepted after revision 1 March
2011

Some patients with a fracture of the scaphoid have normal initial radiographs.¹⁻³ Given the potential for nonunion and degenerative change with a missed fracture,⁴⁻⁶ patients with an injury and clinical signs consistent with a fracture but whose initial radiographs are normal are usually considered to have a 'suspected' fracture.^{2,3,7} Those who are subsequently confirmed as having a fracture, often between 10 and 14 days post injury, are said to have initially had an 'occult' fracture of the scaphoid.^{2,8,9}

A consequence of over-sensitive clinical signs and treating all suspected fractures is that patients often receive unnecessary treatment and imaging.^{7,8,10} This can lead to stiffness of the wrist, costs to the healthcare system and to the patient for time off work, and an inability to play sport.¹¹⁻¹⁴ Previously, improved imaging has been used in an attempt to establish a definitive early diagnosis in order to limit immobilisation and further diagnostic testing.^{11,13-19} However, imaging has proved inadequate because of the low prevalence of

true fractures among suspected fractures of the scaphoid, which magnifies the weaknesses of even the most sensitive and specific diagnostic tests.²⁰⁻²² Furthermore, research is hindered by the lack of a consensus regarding a reference standard for a true fracture.^{20,21,23}

In this paper we describe the demographic and clinical features of a suspected fracture of the scaphoid as well as the merits of the various available diagnostic imaging techniques. We also discuss the potential future directions for research in this area.

Anatomy

The scaphoid is a small, irregular S-shaped tubular bone in the proximal carpal row on the radial aspect of the wrist.¹ It acts as a mid-carpal joint 'bridge' connecting and synchronising the movements of the proximal and distal carpal rows. Over 80% of its surface is covered with articular cartilage that articulates with the radius (proximal/lateral surface), capitate (medial surface), lunate (medial surface) and trapezium/trapezoid (distal surface) bones.

Fig. 1

The effect of disease prevalence on the positive predictive value of diagnostic tests.

The non-articular dorsoradial surface of the scaphoid is the site of its few ligamentous attachments, including the scapholunate interosseous ligament and the intercarpal ligament.²⁴ The short intrinsic ligaments attach the scaphoid to the lunate and merge with the extrinsic ligaments and capsule of the wrist.²⁴ The radioscapaphocapitate ligament acts as a sling across the waist of the scaphoid.²⁴ No tendons attach to the surface of the scaphoid.²⁵

The blood supply is through soft-tissue attachments via two vascular pedicles originating from the scaphoid branches of the radial artery, with the waist of the scaphoid having minimal or no perforating vessels.^{26,27}

Epidemiology and demographic risk factors

The incidence of a fracture of the scaphoid is quoted in the literature to range between 1.5 and 121 per 100 000 persons per year.²⁸⁻³⁰ This wide variation may be due to the use of retrospective data, variations in population subsets, and the limitation of many databases in distinguishing between true and suspected fractures.^{13,28-32} The lower estimates are probably more accurate, given that the estimated incidence of a fracture of the distal radius is 195 per 100 000 persons per year and that fractures of the scaphoid account for approximately 2.4% of all wrist fractures.^{28,33}

The mean age of patients with a fracture of the scaphoid ranges between 25 and 35 years, with a male predominance, which most closely fits a type B (unimodal young male) distribution.^{28,33} In fact, in one study¹⁹ male gender was a predictor of true fracture among suspected fractures.

A fracture of the scaphoid is usually the result of a fall on to the outstretched hand or a sports injury,^{19,28,31} with one study¹⁹ finding that sports injuries are commonly associated with a true fracture. An American study found that sports associated with a high risk of fracture were basket-

ball, cycling and skateboarding, with a link to male gender seen in the majority.²⁸ A fracture of the scaphoid has also been increasingly documented after a punch injury.³⁴

Evaluating diagnostic tests

So far, the dilemma of a suspected fracture of the scaphoid has been approached with the view that if we had a better radiological test, we would not miss any fractures. Unfortunately, this approach has not worked.²¹ The scientific data regarding clinical tests and diagnostic imaging of a suspected fracture of the scaphoid are confusing. The sensitivities and specificities substantially vary between studies and the best diagnostic performance characteristics seem to be reported by advocates of a specific technique.

The calculation of diagnostic performance characteristics such as sensitivity, specificity, positive and negative predictive values, and accuracy, with traditional formulae requires a consensus reference standard for the presence or absence of disease.^{35,36} The images produced by current MRI scanners are so clear that many believe this is the ideal diagnostic test for detecting true fractures. However, it is difficult to test this hypothesis as there is no consensus reference standard for the presence of a true fracture of the scaphoid. Perhaps the most common standard is the absence of a fracture on radiographs six weeks after injury.^{8,20,21,23,37}

Latent class analysis is an alternative statistical method which does not rely on a reference standard. It looks for clinical factors (hidden or latent classes) which associate in patients with a high probability of disease. This technique has been applied to other illnesses with no consensus reference standard, such as carpal tunnel syndrome.³⁸ A recent, as yet unpublished study applied latent class analysis to data from two prospective cohort studies of patients with a suspected fracture of the scaphoid and found small but potentially important differences from the traditional calculations based on a reference standard.³⁹

Another issue that hinders effective diagnosis is the low prevalence of true fractures among patients with a suspected fracture. Previous studies have found that between 5% and 20% of patients who attend the emergency department with a suspected fracture of the scaphoid are ultimately found to have a fracture.^{3,19-22,31,32} Given that false positives and false negatives are between 5% and 10% for most diagnostic tests, this low prevalence of disease leads to low positive predictive values according to Bayes' theorem,⁴⁰ even when the diagnostic test is highly sensitive and specific (Fig. 1).^{21,36} The importance of these two factors, the lack of an agreed reference standard and the low prevalence of a true fracture of the scaphoid among suspected fractures, cannot be overstated. They emphasise that our traditional goal of an all-or-nothing diagnosis of a fracture of the scaphoid may be unreachable, and that it is more appropriate to understand that each individual patient has a probability of a true fracture that rarely if ever reaches zero or 100%. The statistical strategies of latent class

Table I. The sensitivity, specificity, positive predictive value and negative predictive value of clinical signs of a fracture of the scaphoid. (Reproduced from **Gaebler C, McQueen MM.** Carpus fractures and dislocations. In: Buchholz RW, Court-Brown CM, Heckman JD, Tornetta P, eds. *Rockwood and Green's fractures in adults*. Seventh ed. Philadelphia: Lippincott Williams & Wilkins, 2010).

	Sensitivity (%)	PPV* (%)	Specificity (%)	NPV† (%)
ASB‡ tenderness	100	30	19	100
Scaphoid tubercle tenderness	100	34	30	100
Longitudinal thumb compression	100	40	48	100
Reduced thumb movement	66	41	66	85
ASB swelling	61	50	52	58
ASB pain in ulnar deviation/pronation	83	44	17	56
ASB in radial deviation/pronation	70	45	31	56
Pain on thumb/index pinch	48	44	31	41
Scaphoid shift test	66	49	31	69

* PPV, positive predictive value

† NPV, negative predictive value

‡ ASB, anatomical snuffbox

analysis and Bayes' theorem are ideal in this circumstance. They help quantify the 'art' of medicine, meaning the probabilities that healthcare providers work with every day.

It may be helpful to develop a clinical prediction rule that incorporates a checklist of clinical factors, such as gender and tenderness in the anatomical snuffbox, which, when present, increase the pre-test probability of a fracture. Such a rule might better define a population in whom sophisticated imaging would be more appropriate. If the application of the rule can increase the prevalence of a true fracture among suspected fractures, it should lead to better results for diagnostic imaging. Although we need to accept a very small probability of missing a true fracture, there is the potential benefit of greatly reducing the probability of over-diagnosing and over-treating patients with a suspected fracture, whereas relying on sophisticated imaging alone risks over-treatment and a relatively low yield of new fractures identified.

Clinical assessment

A suspected fracture of the scaphoid is characterised by wrist pain with tenderness over the scaphoid after a fall, sports or punch injury, and normal scaphoid-specific radiographs. No single sign has been found to be adequately sensitive or specific (Table I).^{10,41-47} Initial studies in this area examined the sensitivity and specificity of individual clinical signs. Freeland⁴¹ reviewed 246 patients with a suspected fracture of the scaphoid and found that tenderness in the anatomical snuffbox had a sensitivity of 90% and a specificity of 40%, with tenderness of the scaphoid tubercle having a sensitivity of 87% and specificity of 57% for a scaphoid fracture. Powell et al⁴⁴ performed a prospective analysis in 73 patients to determine the sensitivity and specificity of an alternative sign, anatomical snuffbox pain on ulnar deviation of the pronated wrist. They found a negative predictive value of 100% and suggested that patients with a negative test could be safely discharged from the emergency department.

Parvizi et al⁴⁵ examined the effect of combining clinical signs to improve the diagnostic specificity in a prospective study of 215 consecutive patients. They found that the use of one clinical sign in isolation was insufficient for the diagnosis of a fracture, but that a combination of anatomical snuffbox tenderness, tenderness of the scaphoid tubercle and anatomical snuffbox pain on longitudinal compression of the thumb generated a sensitivity of 100% and a specificity of 74%.

More recent studies have looked at other clinical signs as predictors of a fracture. Unay et al¹⁰ reviewed ten physical examination manoeuvres on 41 patients with a suspected fracture of the scaphoid and used MRI to determine the presence of a fracture. They found that pain on thumb-index finger pinch and anatomical snuffbox pain on pronation of the forearm were most suggestive of a bony injury in patients with a confirmed fracture of the scaphoid.

Rhemrev et al²² aimed to develop a clinical prediction rule using multivariate analysis to determine predictors of fracture, thereby potentially increasing the prevalence of a true fracture of the scaphoid in relation to a suspected fracture in order to improve the diagnostic accuracy of radiological tests. In 78 patients with a suspected fracture of the scaphoid they found that a reduction in extension of > 50%, supination strength of ≤ 10% and the history of a previous scaphoid fracture were the most predictive of a true fracture.²² As the tests examined in this study are not widely used, in particular the strength tests which require specific tools, general adoption of this rule is unlikely. However, this paper does demonstrate the potential for a clinical prediction rule to improve the management of a suspected fracture of the scaphoid.

Specific diagnostic imaging techniques

Radiographs. When a fracture of the scaphoid is suspected, neutral posteroanterior and lateral radiographs are insufficient.⁴⁸ Further views suggested to improve the ability to diagnose a scaphoid fracture are:^{8,48} 45° radial oblique

Fig. 2

A Zitter's view of the left scaphoid, showing an undisplaced fracture of the waist.

Fig. 3

A sagittal CT section in the plane of the scaphoid long axis revealing a subtle undisplaced fracture of the waist of the scaphoid. Such fractures appear unicortical and can be difficult to distinguish from other lines, such as vascular channels.

posteroanterior (semi-supinated) to detect proximal pole fractures, humpback deformities and avulsion fractures; 45° ulnar oblique posteroanterior (semi-pronated) to detect oblique sulcal, waist (in particular displaced) and tubercle fractures; ulnar-deviated posteroanterior to detect proximal pole fractures.

Zitter's⁴⁹ view, or the 'banana view', uses a posteroanterior view of the wrist in ulnar deviation with 20° tube angulation to the elbow (Fig. 2). This is a modified view useful for identifying fractures of the waist of the scaphoid. Fractures oblique to the beam, however, are not well identified. Although not routinely used, carpal box views have been shown to increase agreement in the interpretation of the standard four-view scaphoid radiographs from 36% to 55%.^{50,51}

Some studies claim that when clinical and radiological assessment is carried out by experienced staff, all occult fractures of the scaphoid are detected within six weeks.^{7,8} However, more consistently, between 30% and 40% of fractures are not identified on initial assessment and investigation with four-view radiographs.^{1-3,7,8,10,47,52,53} Radiographs have low inter- and intra-observer reliability for the diagnosis of suspected fractures of the scaphoid.^{54,55} Low sensitivity on repeat radiological assessment has also been found, with one study⁵² finding that it only identified 50% of occult scaphoid fractures. Three potential reasons why radiographs of the scaphoid are often misinterpreted were suggested by Barton:⁷ a dark line may be formed by the dorsal lip of the radius overlapping the scaphoid; the presence of a white line formed by the proximal end of the scaphoid tuberosity; and the dorsal ridge of the scaphoid may appear bent on the semi-supinated view.

Scaphoid and pronator fat stripe signs have been demonstrated to be unreliable soft-tissue detectors for the presence of an occult fracture of the scaphoid.⁵⁶ Given this, when

clinical suspicion is present but radiographs are negative, immobilisation in a cast or splint is often recommended, with repeat examination and radiographs performed within 10 to 14 days of injury.

Ultrasound. Although non-invasive and relatively inexpensive, ultrasound examination is operator dependent and has been shown to be ineffective in detecting a true fracture, with a sensitivity ranging between 37% and 93% and a specificity between 61% and 91%.^{19,57,58} Some authors have reported the use of high spatial resolution sonography for the occult fracture of the scaphoid, with the sensitivity rising to 100% and specificity as high as 91%.^{15,59}

Bone scintigraphy. Although there are advocates for bone scintigraphy,^{11,57,60,61} most authors feel that the specificity is too low compared with CT and MRI.^{21,37,62,63} In 43 patients with suspected fracture of the scaphoid, Fowler et al⁶³ found that MRI was more sensitive and specific than bone scintigraphy, using one-year follow-up as the reference standard. However, Beeres et al⁶¹ looked at 100 similar patients and found that bone scintigraphy had a sensitivity of 100% and a specificity of 90%, and concluded that there was no advantage with MRI.

Computed tomography. Some authors advocate the use of CT for the diagnosis of a true fracture among suspected fractures of the scaphoid,^{62,64-67} although some have cautioned against its use for undisplaced fractures.²⁰ Cruickshank et al⁶⁴ looked at 47 patients with a suspected fracture of the scaphoid, using two-week radiographs and/or MRI as the reference standard. They found that early CT was 94.4% sensitive and 100% specific, with a negative predictive value of 96.8% and a positive predictive value of 100%. Furthermore, CT has been shown to be useful in detecting other injuries around

Table II. The sensitivity, specificity, accuracy and average prevalence-adjusted positive predictive value (PPV) and negative predictive value (NPV) for various imaging modalities as determined by Ring and Lozano-Calderón²¹ for a suspected fracture of the scaphoid

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

Table III. The sensitivity and specificity as determined by Yin et al³⁷ of different imaging techniques in the diagnosis of occult fractures to the scaphoid

Imaging modality (number of studies assessed)	Sensitivity (%)	Specificity (%)
Bone scintigraphy (n = 15)	97	89
CT (n = 6)	93	99
MRI (n = 10)	96	99

the wrist when triaging patients with a suspected fracture of the scaphoid.⁶⁶ Ty et al⁶⁶ used CT in 28 patients with a suspected fracture of the scaphoid and found an undisplaced fracture of the distal radius or carpus in 36%.

Adey et al²⁰ used eight observers to evaluate CT scans from 30 patients to determine the intra- and interobserver reliability of CT for the diagnosis of an undisplaced fracture of the scaphoid. Despite substantial intra- and interobserver reliability, they found a notable false positive rate, perhaps due to vascular channels being misinterpreted as unicortical fractures (Fig. 3).

Magnetic resonance imaging. For the suspected fracture of the scaphoid, MRI is arguably the best investigation, although many institutions have limited access to this resource and there are discrepancies regarding its cost-effectiveness.^{9,14,17-19,37,68-70} Gaebler et al⁶⁸ performed a prospective blind study in which an MRI scan was performed within 72 hours of injury in 32 patients in whom a fracture of the scaphoid was clinically suspected but could not be confirmed on conventional radiographs. They used clinical and/or radiological follow-up at six weeks as their reference standard, and concluded that the sensitivity and specificity of MRI were 100%, with potential savings of \$7200 per 100 000 of the population achieved by avoiding unnecessary immobilisation and review.⁶⁸

However, Ring and Lozano-Calderón²¹ performed an analysis of diagnostic tests using an average published prevalence of a scaphoid fracture among suspected fractures of 7% (Table II). Using Bayesian formulae, the negative predictive value for MRI was 0.88, meaning that around 12% of patients with a suspected fracture of the scaphoid and an MRI interpreted as showing a fracture may not actually have a fracture. The potential for false positive MRI scans has been further demonstrated by one recent, as yet unpublished, study of MRI scans in healthy individuals that identified

abnormalities diagnosed as fractures by several blinded radiologists.

Recently, Yin et al³⁷ performed a meta-analysis of 26 studies to assess the prevalence-adjusted diagnostic accuracy of bone scintigraphy, CT and MRI for suspected fractures of the scaphoid. Nine studies used six-week radiological follow-up as their reference standard. Bone scintigraphy and MRI were shown to have comparably high sensitivity rates, although MRI was more specific for confirming a fracture of the scaphoid (Table III). Another recent prospective cohort study⁶⁷ which used the absence of a fracture on six-week radiographs as the reference standard found that CT and MRI have comparable diagnostic performance characteristics for detecting a true fracture among suspected fractures of the scaphoid.

Ultimately, all radiological tests are better at excluding, rather than detecting, a true scaphoid fracture, with Bayes-adjusted negative predictive values of 98% or above for most tests. This is due largely to the low prevalence of true fractures among suspected fractures of the scaphoid, which may change if clinical prediction rules improve our ability to predict who is likely to have a true fracture prior to radiological testing.

Shortcomings of the current data

Current opinion, and the consensus-based guidelines of some professional associations, seems to be based on an overly optimistic assessment of MRI, with recent studies raising concerns about false positive scans. The Royal College of Radiologists concludes that on current evidence bone scintigraphy, CT and MRI are comparable for triaging patients with a suspected acute fracture of the scaphoid.⁷¹ However, the American College of Radiology recommends radiographs and MRI.⁷² Groves et al⁷³ performed an international survey of 105 hospitals worldwide to determine their imaging protocol for a suspected fracture of the scaphoid. They found a notable inconsistency among the hospitals, with only 22% having a fixed protocol. There is no consensus regarding the best management of the suspected fracture of the scaphoid. The authors routinely perform a re-examination with repeat radiographs at two weeks after injury before considering further imaging in the form of CT or MRI.

The current literature consists of small series, usually from advocates of a given technique, with a wide variation in cultural setting and training, inclusion and exclusion

criteria, clinical examination manoeuvres, and a wide range of definitions of a reference standard for a true fracture.

Future directions

Future research should attempt to identify demographic and clinical factors that are predictive of a true acute fracture of the scaphoid. A valid clinical prediction rule would improve the diagnostic performance of more sophisticated imaging by increasing the prevalence of a true fracture among suspected fractures. Given that even the clearest images are subject to misinterpretation (false positives), it may prove impossible to use imaging as a reference standard for a true fracture. Therefore, future research should use latent class analysis to estimate diagnostic performance characteristics.

Although ideally a fracture of the scaphoid would be an all-or-nothing diagnosis, we should accept that we are ultimately dealing with probabilities rather than certainties. The rational and effective management of a fracture of the scaphoid may require us to accept a given negative predictive value of diagnostic testing. In other words, if we cannot reduce the probability of missing a fracture to zero, perhaps 0.5% or lower (negative predictive value of 99.5% or greater) is reasonable and acceptable. It is unlikely that the Bayesian positive predictive value of even the best radiological tests will be better than 90% in the foreseeable future, so our management of the suspected scaphoid fracture should be tempered by an awareness of the potential for false positive diagnoses, particularly as screw fixation becomes an increasingly popular alternative to cast immobilisation.¹⁶

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References

- Gaebler C, McQueen MM. Carpus fractures and dislocations. In: Bucholz RW, Court-Brown CM, Heckman JD, Tornetta P, eds. *Rockwood and Green's fractures in adults*. Seventh ed. Philadelphia: Lippincott Williams & Wilkins, 2010:781-828.
- Ring D, Jupiter JB, Herndon JH. Acute fractures of the scaphoid. *J Am Acad Orthop Surg* 2000;8:225-31.
- Kozin SH. Incidence, mechanism, and natural history of scaphoid fractures. *Hand Clin* 2001;17:515-24.
- Ruby LK, Stinson J, Belsky MR. The natural history of scaphoid non-union: a review of fifty-five cases. *J Bone Joint Surg [Am]* 1985;67-A:428-32.
- Cooney WP. Failure of treatment of ununited fractures of the carpal scaphoid. *J Bone Joint Surg [Am]* 1984;66-A:1145-6.
- Kawamura K, Chung KC. Treatment of scaphoid fractures and nonunions. *J Hand Surg Am* 2008;33:988-97.
- Barton NJ. Twenty questions about scaphoid fractures. *J Hand Surg Br* 1992;17:289-310.
- Gaebler C, Kukla C, Breitenseher MJ, Trattnig S, Vecsei V. Diagnosis of occult scaphoid fractures and other wrist injuries: are repeated clinical examinations and plain radiographs still state of the art? *Langenbecks Arch Surg* 2001;386:150-4.
- Kusano N, Churei Y, Shiraiishi E, Kusano T. Diagnosis of occult carpal scaphoid fracture: a comparison of magnetic resonance imaging and computed tomography techniques. *Tech Hand Up Extrem Surg* 2002;6:119-23.
- Unay K, Gokcen B, Ozkan K, Poyanli O, Eceviz E. Examination tests predictive of bone injury in patients with clinically suspected occult scaphoid fracture. *Injury* 2009;40:1265-8.
- Tiel-van Buul MM, Broekhuizen TH, van Beek EJ, Bossuyt PM. Choosing a strategy for the diagnostic management of suspected scaphoid fracture: a cost-effectiveness analysis. *J Nucl Med* 1995;36:45-8.
- Skirven T, Trope J. Complications of immobilization. *Hand Clin* 1994;10:53-61.
- van der Molen AB, Groothoff JW, Visser GJ, Robinson PH, Eisma WH. Time off work due to scaphoid fractures and other carpal injuries in The Netherlands in the period 1990 to 1993. *J Hand Surg Br* 1999;24:193-8.
- Dorsay TA, Major NM, Helms CA. Cost-effectiveness of immediate MR imaging versus traditional follow-up for revealing radiographically occult scaphoid fractures. *AJR Am J Roentgenol* 2001;177:1257-63.
- Fusetti C, Poletti PA, Pradel PH, et al. Diagnosis of occult scaphoid fracture with high-spatial-resolution sonography: a prospective blind study. *J Trauma* 2005;59:677-81.
- McQueen MM, Gelbke MK, Wakefield A, Will EM, Gaebler C. Percutaneous screw fixation versus conservative treatment for fractures of the waist of the scaphoid: a prospective randomised study. *J Bone Joint Surg [Br]* 2008;90-B:66-71.
- Hansen TB, Petersen RB, Barckman J, Uhre P, Larsen K. Cost-effectiveness of MRI in managing suspected scaphoid fractures. *J Hand Surg Eur Vol* 2009;34:627-30.
- Gooding A, Coates M, Rothwell A. Cost analysis of traditional follow-up protocol versus MRI for radiographically occult scaphoid fractures: a pilot study for the Accident Compensation Corporation. *N Z Med J* 2004;117:U1049.
- Jenkins PJ, Slade K, Huntley JS, Robinson CM. A comparative analysis of the accuracy, diagnostic uncertainty and cost of imaging modalities in suspected scaphoid fractures. *Injury* 2008;39:768-74.
- Adey L, Souer JS, Lozano-Calderón S, et al. Computed tomography of suspected scaphoid fractures. *J Hand Surg Am* 2007;32:61-6.
- Ring D, Lozano-Calderón S. Imaging for suspected scaphoid fracture. *J Hand Surg Am* 2008;33:954-7.
- Rhemrev SJ, Beeres FJ, van Leerdam RH, Hogervorst M, Ring D. Clinical prediction rule for suspected scaphoid fractures: a prospective cohort study. *Injury* 2010; Epub.
- Munk B, Frokjaer J, Larsen CF, et al. Diagnosis of scaphoid fractures: a prospective multicenter study of 1,052 patients with 160 fractures. *Acta Orthop Scand* 1995;66:359-60.
- Taleisnik J. The ligaments of the wrist. *J Hand Surg Am* 1976;1:110-18.
- Linscheid RL. Kinematic considerations of the wrist. *Clin Orthop* 1986;202:27-39.
- Gelberman RH, Panagis JS, Taleisnik J, Baumgaertner M. The arterial anatomy of the human carpus. Part I: the extraosseous vascularity. *J Hand Surg Am* 1983;8:367-75.
- Panagis JS, Gelberman RH, Taleisnik J, Baumgaertner M. The arterial anatomy of the human carpus. Part II: the intraosseous vascularity. *J Hand Surg Am* 1983;8:375-82.
- Van Tassel DC, Owens BD, Wolf JM. Incidence estimates and demographics of scaphoid fracture in the U.S. population. *J Hand Surg Am* 2010;35:1242-5.
- Hove LM. Epidemiology of scaphoid fractures in Bergen, Norway. *Scand J Plast Reconstr Surg Hand Surg* 1999;33:423-6.
- Jonsson BY, Siggeirsdottir K, Mogensen B, Sigvaldason H, Sigursson G. Fracture rate in a population-based sample of men in Reykjavik. *Acta Orthop Scand* 2004;75:195-200.
- Larsen CF, Brøndum V, Skov O. Epidemiology of scaphoid fractures in Odense, Denmark. *Acta Orthop Scand* 1992;63:216-18.
- Wolf JM, Dawson L, Mountcastle SB, Owens BD. The incidence of scaphoid fracture in a military population. *Injury* 2009;40:1316-19.
- Court-Brown CM, Caesar B. Epidemiology of adult fractures: a review. *Injury* 2006;37:691-7.
- Sutton PA, Clifford O, Davis TR. A new mechanism of injury for scaphoid fractures: 'test your strength' punch-bag machines. *J Hand Surg Eur Vol* 2010;35:419-20.
- Altman DG, Bland JM. Diagnostic tests. 1: sensitivity and specificity. *BMJ* 1994;308:1552.
- Altman DG, Bland JM. Diagnostic tests. 2: predictive values. *BMJ* 1994;309:102.
- Yin ZG, Zhang JB, Kan SL, Wang XG. Diagnosing suspected scaphoid fractures: a systematic review and meta-analysis. *Clin Orthop* 2010;468:723-34.
- LaJoie AS, McCabe SJ, Thomas B, Edgell SE. Determining the sensitivity and specificity of common diagnostic tests for carpal tunnel syndrome using latent class analysis. *Plast Reconstr Surg* 2005;116:502-7.
- Buijze GA, Mallee WH, Beeres FJP, et al. Latent class analysis to determine the accuracy of diagnostic tests for suspected scaphoid fractures. *Clin Orthop* 2011; in press.
- Bayes T, Price R. An essay towards solving a problem in the doctrine of chances. *Philosophical Transactions of the Royal Society of London* 1763;53:370-418.
- Freeland P. Scaphoid tubercle tenderness: a better indicator of scaphoid fractures? *Arch Emerg Med* 1989;6:46-50.
- Grover R. Clinical assessment of scaphoid injuries and the detection of fractures. *J Hand Surg Br* 1996;21:341-3.
- Esberger DA. What value the scaphoid compression test? *J Hand Surg Br* 1994;19:748-9.
- Powell JM, Lloyd GJ, Rintoul RF. New clinical test for fracture of the scaphoid. *Can J Surg* 1988;31:237-8.
- Parvizi J, Wayman J, Kelly P, Moran CG. Combining the clinical signs improves diagnosis of scaphoid fractures: a prospective study with follow-up. *J Hand Surg Br* 1998;23:324-7.

46. **Waizenegger M, Barton NJ, Davis TR, Wastie ML.** Clinical signs in scaphoid fractures. *J Hand Surg Br* 1994;19:743-7.
47. **Nguyen Q, Chaudhry S, Sloan R, Bhoora I, Willard C.** The clinical scaphoid fracture: early computed tomography as a practical approach. *Ann R Coll Surg Engl* 2008;90:488-91.
48. **Compson JP.** The anatomy of acute scaphoid fractures: a three-dimensional analysis of patterns. *J Bone Joint Surg [Br]* 1998;80-B:218-24.
49. **Ziter FM Jr.** A modified view of the carpal navicular. *Radiology* 1973;108:706-7.
50. **Roolker W, Tiel-van Buul MM, Ritt MJ, et al.** Experimental evaluation of scaphoid X-series, carpal box radiographs, planar tomography, computed tomography, and magnetic resonance imaging in the diagnosis of scaphoid fracture. *J Trauma* 1997;42:247-53.
51. **Roolker W, Tiel-van Buul MM, Bossuyt PM, et al.** Carpal box radiography in suspected scaphoid fracture. *J Bone Joint Surg [Br]* 1996;78-B:535-9.
52. **Gaebler C, Kukla C, Breitensteher MJ, et al.** Limited diagnostic value of macroradiography in suspected scaphoid fractures. *Acta Orthop Scand* 1998;69:401-3.
53. **Brooks S, Wluka AE, Stuckey S, Cicuttini F.** The management of scaphoid fractures. *J Sci Med Sport* 2005;8:181-9.
54. **Tiel-van Buul MM, van Beek EJ, Broekhuizen AH, et al.** Radiography and scintigraphy of suspected scaphoid fracture: a long-term study in 160 patients. *J Bone Joint Surg [Br]* 1993;75-B:61-5.
55. **Tiel-van Buul MM, van Beek EJ, Borm JJ, et al.** The value of radiographs and bone scintigraphy in suspected scaphoid fracture: a statistical analysis. *J Hand Surg Br* 1993;18:403-6.
56. **Annamalai G, Raby N.** Scaphoid and pronator fat stripes are unreliable soft tissue signs in the detection of radiographically occult fractures. *Clin Radiol* 2003;58:798-800.
57. **Munk B, Bolvig L, Krøner K, et al.** Ultrasound for diagnosis of scaphoid fractures. *J Hand Surg Br* 2000;25:369-71.
58. **Senall JA, Failla JM, Bouffard JA, van Holsbeeck M.** Ultrasound for the early diagnosis of clinically suspected scaphoid fracture. *J Hand Surg Am* 2004;29:400-5.
59. **Herneth AM, Siegmeth A, Bader TR, et al.** Scaphoid fractures: evaluation with high-spatial-resolution US initial results. *Radiology* 2001;220:231-5.
60. **Beeres FJ, Hogervorst M, Rhemrev SJ, den Hollander P, Jukema GN.** A prospective comparison for suspected scaphoid fractures: bone scintigraphy versus clinical outcome. *Injury* 2007;38:769-74.
61. **Beeres FJ, Rhemrev SJ, den Hollander P, et al.** Early magnetic resonance imaging compared with bone scintigraphy in suspected scaphoid fractures. *J Bone Joint Surg [Br]* 2008;90-B:1205-9.
62. **Breederveld RS, Tuinebreijer WE.** Investigation of computed tomographic scan concurrent criterion validity in doubtful scaphoid fracture of the wrist. *J Trauma* 2004;57:851-4.
63. **Fowler C, Sullivan B, Williams LA, et al.** A comparison of bone scintigraphy and MRI in the early diagnosis of the occult scaphoid waist fracture. *Skeletal Radiol* 1998;27:683-7.
64. **Cruickshank J, Meakin A, Breadmore R, et al.** Early computerized tomography accurately determines the presence or absence of scaphoid and other fractures. *Emerg Med Australas* 2007;19:223-8.
65. **You JS, Chung SP, Chung HS, et al.** The usefulness of CT for patients with carpal bone fractures in the emergency department. *Emerg Med J* 2007;24:248-50.
66. **Ty JM, Lozano-Calderón S, Ring D.** Computed tomography for triage of suspected scaphoid fractures. *Hand (NY)* 2008;3:155-8.
67. **Mallee W, Doornberg JM, Ring D, et al.** Comparison of CT and MRI for diagnosis of suspected scaphoid fractures. *J Bone Joint Surg [Am]* 2011;93-A:20-8.
68. **Gaebler C, Kukla C, Breitensteher M, et al.** Magnetic resonance imaging of occult scaphoid fractures. *J Trauma* 1996;41:73-6.
69. **Brydie A, Raby N.** Early MRI in the management of clinical scaphoid fracture. *Br J Radiol* 2003;76:296-300.
70. **Raby N.** Magnetic resonance imaging of suspected scaphoid fractures using a low field dedicated extremity MR system. *Clin Radiol* 2001;76:296-300.
71. **Royal College of Radiologists.** *Making the best use of clinical radiology services guidelines for doctors.* Fifth ed. London: Royal College of Radiologists, 2003.
72. **American College of Radiology.** Expert panel on musculoskeletal imaging, ACR appropriateness criteria. In: Reston VA, ed. *Acute hand and wrist trauma.* Philadelphia: American College of Radiology, 2001:1-7.
73. **Groves AM, Kayani I, Syed R, et al.** An international survey of hospital practice in the imaging of acute scaphoid trauma. *AJR Am J Roentgenol* 2006;187:1453-6.