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Systematic Review of Diagnosis of Clinically Suspected Scaphoid Fractures

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Abstract

Background Scaphoid fracture accounts for approximately 15% of acute wrist fractures. Clinical examination and plain X-rays are commonly used to diagnose the fracture, but this approach may miss up to 16% of fractures in the absence of clear-cut lucent lines on plain radiographs. As such, additional imaging may be required. It is not clear which imaging modality is the best. The goal of this study is to summarize the current literature on scaphoid fractures to evaluate the sensitivity, specificity, and accuracy of four different imaging modalities.

Case Description A systematic-review and meta-analysis was performed. The search term “scaphoid fracture” was used and all prospective articles investigating magnetic resonance imaging (MRI), computed tomography (CT), bone scintigraphy, and ultrasound were included. In total, 2,808 abstracts were reviewed. Of these, 42 articles investigating 51 different diagnostic tools in 2,507 patients were included.

Literature Review The mean age was 34.1 ± 5.7 years, and the overall incidence of scaphoid fractures missed on X-ray and diagnosed on advanced imaging was 21.8%. MRI had the highest sensitivity and specificity for diagnosing scaphoid fractures, which were 94.2 and 97.7%, respectively, followed by CT scan with a sensitivity and specificity at 81.5 and 96.0%, respectively. The sensitivity and specificity of ultrasound were 81.5 and 77.4%, respectively. Significant differences between MRI, bone scintigraphy, CT, and ultrasound were identified.

Clinical Relevance MRI has higher sensitivity and specificity than CT scan, bone scintigraphy, or ultrasound.

Level of Evidence This is a Level II systematic review.

Keywords
- ► diagnostics
- ► fracture
- ► meta-analysis
- ► scaphoid
- ► systematic review

The scaphoid is the most commonly fractured carpal bone.[1] Scaphoid fractures account for approximately 15% of acute wrist injuries that affect predominately young men between 15 and 30 years of age.[2,3] Typical mechanism of injury involves axial loading on an outstretched hand where the forces are transferred through the second metacarpal.

The first scaphoid fracture was described in 1905 by Destot et al following the discovery of radiography.[4] In the following years, fractures were classified into waist, distal, and proximal pole injuries. Among patients with suspected scaphoid fractures, it is estimated that the prevalence of true fractures is only between 5 and 10%.[2] For diagnosis, tenderness on exam at the snuffbox and the volar aspect of the distal tuberosity, as well as scaphoid compression test, in addition to radiographic assessment, are all essential. Because of the difficulty of making this diagnosis and the low healing potential, scaphoid fractures are predisposed to delayed union. Nonunion rates have been reported to be as high as 12%.[5,6]

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In diagnosing scaphoid fractures, the clinical examination is only specific in 74 to 80% of cases with a positive predictive value of 21%.[6] This may vary between the tenderness of the scaphoid tubercle with a sensitivity of 95.23% and specificity of 74.07%, tenderness of the anatomical snuffbox (sensitivity = 85.71% and specificity 29.62%), or a direct compression test (sensitivity = 42.85% and specificity = 29.62%).[7] Radiographic assessment typically includes four views, which include posteroanterior, true lateral, posteroanterior in ulnar deviation, and oblique views. These views are sensitive in 70 to 90% of cases and miss up to 16% of cases, which is why previous studies have recommended advanced imaging modalities.[8–10] Other imaging options include bone scintigraphy, magnetic resonance imaging (MRI), computed tomography (CT), and ultrasound (US). Because of the inconsistency in data and steadily improving imaging quality, an updated systematic review and meta-analysis was performed.[2,10–12] The last reviews published on this topic included studies published up to December 2012.[10,11] Those authors chose similar search criteria for their literature reviews and included between 11[10] and 75 publications,[11] and for 7 US studies.[12] However, these studies concluded that there was no real consensus on the best adjuvant imaging modality for scaphoid fractures, although MRI was generally better at confirming the presence of a scaphoid fracture.

The purpose of this study is to perform a systematic review of the literature concerning the different imaging modalities for diagnosing scaphoid fracture. Additionally, a meta-analysis including studies between 1901 and 2018 was performed.

Materials and Methods

A systematic literature search was performed on August 28, 2018, using the Medline, PubMed, Cochrane, and Google search engine according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[13] The search term "scaphoid fracture" was used because it was thought to be a broad inclusive term. Articles in English, German, and French were included. Articles that evaluated the sensitivity and specificity of different imaging modalities prospectively were included. Articles that had the following criteria were excluded: duplicate results, lack of full access to the original article, retrospective studies, biomechanical studies, case reports, review articles, letters to the editors, or comments. All abstracts were reviewed by two of the authors. In total, 2,818 studies were found based on our search term, including 10 duplicates. Two hundred sixteen abstracts that included the diagnostics of the scaphoid were reviewed. One hundred forty studies were subsequently excluded as these did not meet inclusion criteria, leaving 76 articles for final review. Thirty-four articles were excluded as the full text was not accessible, leaving 42 articles for inclusion in our systematic review (►**Fig. 1**).

Both raw and descriptive data on the demographics, imaging modality, incidence of scaphoid fracture, specificity, sensitivity, as well as positive and negative predictive value were collected. In studies where the raw data was listed, we calculated the sensitivity and specificity separately. Forty of the 42 articles mentioned explicitly that the study was performed prospectively, whereas in two studies we assumed that this was the case.[14,15] Of the 42 articles, 11 studies performed comparisons between different imaging modalities. In total, there are 51 different radiographic analyses, including 16 bone scintigraphy studies, 14 CT studies, 12 MRI studies, and 10 US studies. In all, 2,507 patients were included overall.

For the "gold standard" reference by which to judge whether a scaphoid fracture was actually present, a variety of tests were used. These included a follow-up scaphoid plain radiography in 29 cases ($n = 29/42$) between 2 to > 6 weeks after initial presentation in the clinic which is often described as being the gold standard.[16,17] In the remaining cases either CT ($n = 3$),[14,18,19] MRI scan ($n = 7$), or bone scintigraphy was used ($n = 1$).[20] In plain radiographs, an abnormal lucent line within the scaphoid is considered evidence of fracture. In two studies, the two index tests were used, which are thought to be positive if the findings of two different modalities including clinical findings correspond with each other, either signs of fracture (positive) or absence of a fracture line (negative). These two index tests were applied in CT and compared with US and MRI.[21,22]

Results

A total of 42 studies including 2,507 patients were investigated. In comparison to previous systematic reviews, six additional studies were included.[23–28] Males were affected in 49.2% of cases and the mean age was 34.1 ± 5.7 years. The overall incidence of occult scaphoid fractures was 21.8% (standard deviation [SD] 9.81). Occult scaphoid fractures are defined as wrist pain and scaphoid tenderness with no visible fracture line on X-rays. In 16 publications, bone scintigraphy was investigated. For CT scan, there were 14 publications. Twelve studies compared two different sequences in MRI[26] and there were 10 articles that assessed the sensitivity and specificity of US. A total of 12 studies performed comparisons between two different radiographic modalities. Unfortunately, we were not able to obtain true and false positive values from six studies and only the specificity and sensitivity were presented.[18,23,24,29–31] Because of this absence, the predictive values—positive as well as negative (PPV and NPV)—were not accessible in four studies.[18,29–31]

Sensitivity was found to be highest in MRI at 94.2% (SD 10.7), followed by bone scintigraphy at 92.8% (SD 11.4). All except three studies observed a sensitivity of < 100% for MRI (80 or 83%), which was explained by only a short MRI scanning time of 7 minutes,[22] fibrovascular scar tissue or contrast agent diffusing from adjacent soft tissues,[26] or finally, misinterpretation of bone bruise or vascular channels.[10] Interestingly, US showed equivalent sensitivity (81.5% SD 21.2) to CT at 81.5 (SD 14.0). Statistically, bone scintigraphy ($p = 0.03$) and MRI ($p = 0.02$) have significantly higher sensitivity when compared to CT. For specificity, MRI is highest at 97.7% (SD 4.7), followed by CT scan at 96.0% (SD 4.8) and bone scintigraphy at 90.9% (SD 11.8). US showed a mean specificity of 77.4% (SD 18.5), which was significantly lower than other imaging modalities; compared with MRI ($p = 0.002$), CT ($p = 0.003$) and bone scintigraphy ($p = 0.04$). All sensitivities and specificities including PPVs and

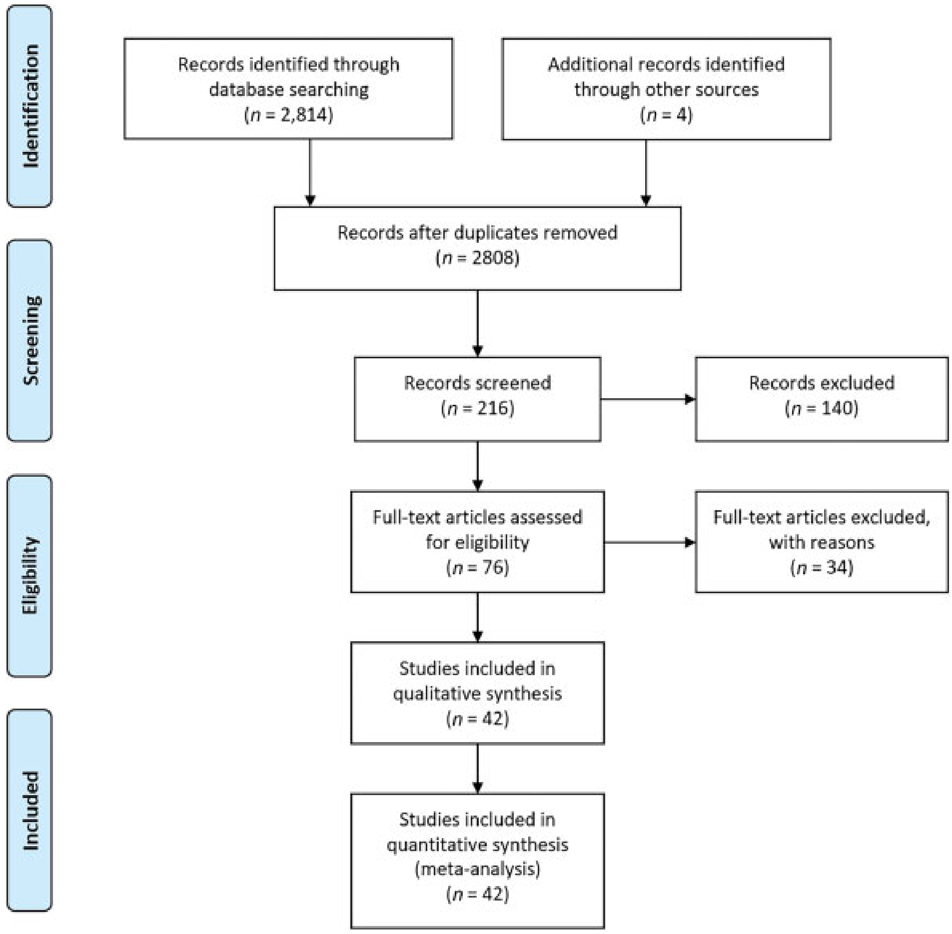

Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2009 flow diagram of included articles.

NPVs are summarized in ►**Table 1**. The individual studies are listed in ►**Table 2**.

Discussion

To avoid scaphoid nonunion and initiate early treatment, prompt and precise diagnosis is essential. If initial plain radiograph imaging appears normal in suspected scaphoid fractures, approximately 21.8% (SD 9.81) will still have a true fracture based on our systematic review. This is an increase of 5.8% compared to earlier publications.[8,9] Therefore, further imaging such as bone scintigraphy, CT, magnetic resonance imaging, and US should be considered in suspected scaphoid fractures without any visible fracture line on plain X-rays.

Six additional publications were included in comparison to the last published systematic reviews, which showed an overall increase in sensitivity for MRI from 88 to 94.2% and CT from 72 to 81.5%.[10] According to our systematic review, the most sensitive and specific adjunctive tool is the MRI at 94.2 and 97.7%, respectively. When considering that 21.8% of scaphoid fractures are missed on initial plain radiograph in four views and the sensitivity of CT scanning is found to be 81.5%, the sensitivity of CT scanning is only slightly better than X-ray. However, the negative predictive value of CT scanning was found to be 94.4 ± 4.8% which means that 94.4% of patients who have no signs of fracture on CT do not actually have a fracture. Although the sensitivity and specificity of CT are lower than that of MRI, it is the only modality which is quick and reliably available in the emergency department.

Table 1 All sensitivities and specificities including positive and negative predictive values

	Number of studies	Number of patients	Sensitivity	Specificity	PPV	NPV
Bone scintigraphy	16	1,133	92.8 ± 11.4	90.9 ± 11.8	72.2 ± 22.6	99.2 ± 2.7
CT	14	838	81.5 ± 14.0	96.0 ± 4.8	83.9 ± 25.2	94.4 ± 4.8
MRI	12	548	94.2 ± 10.7	97.9 ± 4.7	95.3 ± 12.4	98.0 ± 3.1
Ultrasound	10	589	81.5 ± 21.2	77.4 ± 18.5	63.5 ± 26.4	88.8 ± 14.2

Abbreviations: CT, computed tomography; MRI, magnetic resonance imaging; NPV, negative predictive value; PPV, positive predictive value.

Table 2 Overview on the included studies in the systematic review

Authors	No	m/f	Age	Sensitivity	Specificity	PPV	NPV	TP	FP	FN	TN	Incidence	Reference
Bone scan													
Akdemir et al 2004[32]	32	18/14	31	100	100	100	100	8	0	0	24	25	PR
Beeres et al 2008[22]	100	50/50	42	100	90	71	100	20	8	0	72	20	PR, concordance
Breederveld and Tuinebreijer 2004[14]	29	**nr**	nr	78	90	78	90	7	2	2	18	31	CT after 6 weeks
de Zwart et al 2012[33]	159	79/80	41	95	94	68		19	9	1	130	nr	PR
Fowler et al 1998[34]	43	21/22	32	83	95	71		5	2	1	35	14	PR
Groves et al 2005[35]	51	17/34	40.2	100	100	100	100	6	0	0	45	12	PR one case MRI follow-up
Kitsis et al 1998[36]	22	9/13	34	100	95	75	100	3	1	0	18	14	MRI
Murphy et al 1995[37]	99[a]	55/44	36	65	100	65	100	13	7	0	80	13	PR, follow-up BS
Nielsen et al 1983[38]	100[a]	61/39	33	100	52	20	100	11	43	0	47	11	PR
O'Carroll et al 1982[39]	30	21/9	32	100	79	55	100	6	5	0	19	nr	PR
Rhemrev et al 2010[21]	100	51/49	40.8	93	91	62	99	13	8	1	86	nr	PR, concordance
Stordahl A 1984[40]	30	18/12	31	100	100	100	100	9	0	0	19	32	PR
Tiel-van Buul et al 1996[41]	16	11/5	36	71	100	100		5	0	2	9	nr	BS
Tiel-van Buul et al 1993[42]	78	35/43	42	100	98	93	100	14	1	0	45	nr	PR
Tiel-van Buul et al 1993[43]	160	82/78	38.6	100	87	60	100	21	14	0	90	17	PR
Waizenegger et al 1994[44]	84	nr	nr	100	84	37	100	7	12	0	65	8	PR and CT
Total	**1133**			**92.8**	**90.9**	**72.2**	**99.2**	**167**	**112**	**7**	**802**	**17.9**	
CT													
Adey et al 2007[45]	30	19/11	33	85	88							nr	PR
Basha et al 2018[23]	168	104/64	38.81	62.5	97.3	9.9	85.7					37.5	PR
Borel et al 2017[24]	49	31/18	36	94	97	94	97					nr	MRI
Breederveld and Tuinebreijer 2004[14]	29	nr	nr	100	100	100	100	9	0	0	20	31	PR after 6 weeks
Cruickshank et al 2007[46]	47	26/21	nr	94	100	100	96.8	7	0	0	40	15	MRI
de Zwart et al 2012[33]	159	79/80	41	70	99	93	96	14	1	6	138	nr	PR
Groves et al 2005[47]	51	17/34	40.2	100	91	60	100	6	4	0	41	12	PR, one case MRI follow-up
Ilica et al 2011[48]	54	54/0	22	86	100	100	91	14	0	2	39	25.5	MRI follow-up
Mallee et al 2011[25]	34	25/15	nr	67	96	80	93	4	1	2	27	18	PR
Mallee et al 2014[35]	34	nr	nr	67	96	80	93	4	1	2	27	nr	PR
Memarsadeghi et al 2006[49]	29	17/12	34	73	100	100	86	8	0	3	18	nr	PR
Rhemrev et al 2010[21]	100	51/49	40.8	64	99	90	94	9	1	5	85	nr	PR, concordance

Table 2 (*Continued*)

Authors	No	m/f	Age	Sensitivity	Specificity	PPV	NPV	TP	FP	FN	TN	Incidence	Reference
Ty et al 2008[50]	20	12/8	40	97	85	100	100	4	0	0	16	20	PR
Total	**804**			**81.5**	**96**	**83.9**	**94.4**	**79**	**8**	**20**	**451**	**22.7**	
MRI													
Beeres et al 2008[22]	100	50/50	42	80	100	100	95	16	0	4	80	20	PR
Breitenseher et al 1997[51]	42	23/19	30.5	100	100	100	100	14	0	0	28	33	PR
Bretlau et al 1999[52]	52	27/25	44	100	100	100	100	7	0	0	38	16	PR
Fowler et al 1998[53]	43	21/22	32	100	100	100	100	6	0	0	37	14	PR
Gäbler et al 2001[54]	118	74/44	30	100	100	100	100	28	0	0	93	25	PR
Gaebler et al 1996[55]	32	21/11	29.5	100	100							nr	PR
Hunter et al 1997[56]	36	28/8	26	100	86	91	100	10	1	0	19	33	PR 2weeks
Kitsis et al 1998[57]	22	9/13	34	100	100	100	100	3	0	0	19	14	MRI
Kumar et al 2005[58]	22	17/5	27	100	100	100	100	6	0	0	16	27	pr or re-MRI
Larribe et al 2014[59]	18	16/2	30.4	83	100	100	92	5	0	1	12	nr	Histology
Mallee et al 2011[25]	34	25/15	nr	67	89	57	93	4	3	2	25	18	pr
Memarsadeghi et al 2006[60]	29	17/12	34	100	100	100		11	0	0	18	nr	pr
Total	**548**			**94.2**	**97.9**	**95.3**	**98**	**110**	**4**	**7**	**385**	**22.2**	
Ultrasound													
Christiansen et al 1991[27]	103	55/48	31.4	37	61	22	100	10	30	17	46	27	pr
Fusetti et al 2005[18]	24	13/11	42	100	79	56	100					20.8	CT
Hauger et al 2002[61]	54	35/19	26	100	98	83	100	5	1	0	48	9.3	pr or other
Herneth et al 2001[62]	15	7/8	23.5	78	100	100	75	7	0	2	6	38.5	MRI
Hodgkinson et al 1993[31]	78	46/32	36.8	100	74.2							8.3	pr
Jain et al 2018[28]	114	2/1.75	32	79.8	76.7	90.5	57.5	67	7	17	23	nr	MRI
Munk et al 2000[15]	58	31/26	38	50	91	56	90	5	4	5	48	nr	pr
Platon et al 2011[19]	62	29/33	41.2	92	71	46	97	12	0	1	87	21	CT
Senall et al 2004[63]	18	nr	35	78	89	88	80	7	1	2	8	50	pr
Yıldırım et al 2013[64]	63	30/33	39.6	100	34.3	30.3	100	10	23	0	12	22.2	MRI
Total	**589**			**81.5**	**77.4**	**63.5**	**88.8**	**123**	**66**	**44**	**278**	**22.6**	

Abbreviations: nr, not reported; pr, plain radiograph; CT, computed tomography; FN, false negative; FP, false positive; MRI, magnetic resonance imaging; NPV, negative predictive value; PPV, positive predictive value; TN, true negative; TP, true positive.
[a]Bilateral case.

After initial clinical examination, the treating surgeon has to evaluate the necessity for further diagnostic imaging. This may include the pain score using the visual analogue scale in patients with tenderness of the snuffbox which did not show any prognostic factor to diagnose scaphoid fracture (sensitivity = 87% and specificity = 57% for pain scores 7.5 and higher and 75%, respectively, 72 for scores more or equal to 8.5).[66] For clinical examination, the most accurate test is the scaphoid tubercle tenderness that showed no statistically significant difference with MRI results ($p = 0.05$), similar to the scaphoid compression test ($p = 0.05$). For anatomical snuff box tenderness compared to MRI, a statistically significant difference was observed with $p = 0.000$. For sensitivity and specificity, this was highest for scaphoid tubercle tenderness with 95.23% respectively 74.07% for clinical examination, followed by tenderness of the anatomical snuff box and compression with much lower specificity of 29.62% each.[7]

For diagnostic imaging, we found only 13 studies which included 100 or more patients. In addition, the majority of studies on this topic were conducted prior to 2010, which is at risk of being outdated considering the rapid advance of radiographic technology. In total, one study focused on bone scintigraphy, five studies on CT scan, two studies on MRI, and one study on US imaging were published after 2010. Regarding CT, it has been shown that general wrist CT and CT scaphoid sequences (in the corresponding planes) yielded different sensitivity and specificity, favoring the CT sequence formatting specifically for the scaphoid. The sensitivity for CT wrist was 33% with a specificity of 89%, as compared to 67 and 95% for CT scaphoid. For our review, we only included the CT scaphoid sequences.[25] In recent studies, the interests of investigators focused more on the cone beam CT.[23,24] In contrast, similar findings were found on the different MRI sequences. According to Larribe et al, MRI contrast-(gadolinium) enhanced images showed highest sensitivity (83%) and specificity (100%) as compared to unenhanced sequences with 67 and 67%, respectively, which were statistically significant.[26] However, the impact of the MRI magnitude on the resolution of scaphoid fractures stays unclear, as different magnetic field strengths have not been investigated yet.

Timing can also play a critical role in the reported accuracy of the radiographic findings. Kumar et al[65] showed that the sensitivity of MRI within 24 hours after trauma compared to day 10 after initial presentation did not show any difference. However, no other comparable study could be found investigating the timing and accuracy of imaging. Furthermore, a major factor on the sensitivity and specificity of scaphoid fracture can be the experience of the radiologist. For CT scans, the interobserver agreement among four different radiologists for scaphoid fractures was between 7 and 15% with a kappa value of 0.51. This brings up the question that scaphoid fracture may be over- or underdiagnosed because of interobserver viability.[33,67]

In addition, the standard website used for CT radiographs evaluation may have a major impact on the accuracy of scaphoid fracture diagnosis. Mallee et al showed that DICOM viewer has superior diagnostic performance characteristics than static JPEG images. Although no differences in specificity, accuracy, and PPV were observed, the sensitivity and NPV were significantly higher.[68]

Another study assessed the prognostic value of indirect scaphoid fracture signs. Therefore, the pre- and postoperative radiographic interscaphoid carpal alignment was measured, using the radiolunate angle, carpal alignment index, scapholunate, and capitolunate angles. Highest reliability was shown for the radiolunate angle (pre- vs. postoperative measures 16.4 ± 5.4 vs. 8.1 ± 4.4, $p = 0.01$) as well as for the carpal alignment index. For the scapholunate and capitolunate angles, the reliability was less (52.6 ± 8.7 vs. 43.5 ± 8.4, $p = 0.04$; 15.3 ± 9.4 vs. 9.7 ± 7.3, $p = 0.12$); however, it could be used as an alternative tool.[69] The carpal indices would only be abnormal in the presence of scaphoid fracture angulation and/or displacement at the fracture site, in the absence of intracarpal ligamentous injury.

To receive most information of the CT imaging, we would recommend to use scaphoid high-resolution CT in the plane of the scaphoid to catch even small subtle fractures. The timing of the CT scan—early versus delayed imaging—could not be elaborated based on the literature, and therefore it remains unclear. For evaluation DICOM viewer showed superior performance and besides direct fracture signs—presence of a radiolucent fracture line—indirect signs should be used. Therefore, the radiolunate angle as well as carpal alignment index showed to be the most reliable factors that can be supplemented using the scapholunate and capitolunate angles.

As societal costs have increased, clinicians have to focus more on the costs and clinical effectiveness of the individual tools. As MRI, CT scan, and US have become more popular, bone scintigraphy had not been investigated in recent studies. MRI has been shown to be superior to conventional radiography, in its ability to detect the scaphoid fracture and a negative MRI can reduce societal costs of unnecessary immobilization, since a normal MRI essentially rules out a scaphoid fracture.[70] When comparing CT scan with MRI, there is still no consensus, but it is worth noting that most studies support the fact that MRI is better able to detect scaphoid fractures.[71] If an MRI shows a scaphoid fracture, a CT scan should probably still be performed to assess for displacement that, if present, would favor surgical treatment versus cast immobilization.

Based on our findings, we would recommend following diagnostic algorithm with respect to diagnostic imaging (►**Fig. 2**).

Ultrasonography has a lower sensitivity and specificity (81.5 and 77.4%, respectively) compared to MRI, CT, and bone scintigraphy. Although US is not the most accurate, it still has the advantage that it is easily accessible, cheap, and fast. However, this technique is also operator dependent and is not in widespread use for the detection of scaphoid fractures.

To assess scaphoid union during follow-up, plain X-ray showed a high agreement for nonunion after 6 months (kappa = 0.816), although only moderate reliability and accuracy were found for partial and full consolidation (kappa = 0.390 and 0.517). Therefore, CT scanning is probably the most reliable method of assessing scaphoid union as it can demonstrate trabecular healing crossing the fracture site.[72]

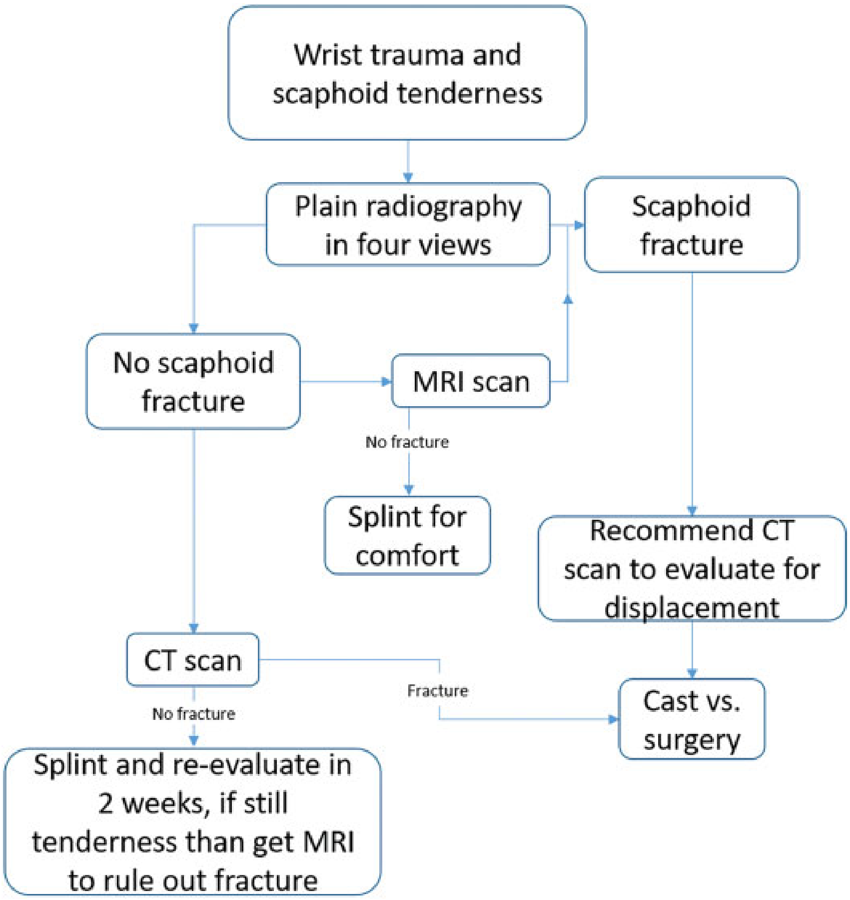

Fig. 2 Diagnostic algorithm for suspected scaphoid fracture. CT, computed tomography; MRI, magnetic resonance imaging.

This systematic review and meta-analysis show that MRI has the highest sensitivity and specificity for detecting scaphoid fractures. CT and US were shown to be significantly lower. However, MRI is more expensive and may not be as readily available as CT, thereby making CT a more pragmatic option for many patients. In comparison to previously published systematic reviews, six additional articles were included. Newer studies incorporating new imaging techniques will need to be studied in order to provide a more up-to-date understanding.

Ethical Approval

We complied with all regulations and IRB guidelines. Internal review board consent is not required as this is a systematic review, which investigates the current literature.

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None.

Conflict of Interest

None declared.

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