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Systematic Review

Imaging Modalities for Suspected Scaphoid Fractures: A Systematic Review

Made Bramantya Karna [1], Anak Agung Gde Yuda Asmara [1], I Gusti Ngurah Indra Wiguna [1], Surya Adisthanaya [1], Mikhail Kertajanottama Kushadiwijaya [1], Andrew Sutheno [1], Febyan Febyan [1*]

[1] Orthopaedic and Traumatology Department Faculty of Medicine, Udayana University, Prof Ngoerah General Hospital, Denpasar Bali

* **Corresponding Author:** Febyan Febyan, Orthopaedic and Traumatology Department Faculty of Medicine, Udayana University, Prof Ngoerah General Hospital, Denpasar Bali. E-mail: Febyanmd@gmail.com

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Abstract

Scaphoid fractures are the most prevalent among carpal fractures, accounting for around 15% of acute wrist injuries. Postponed diagnosis and treatment increases the risk of complications such as nonunion, avascular necrosis, and osteoarthritis; therefore, swift identification and management of these fractures is critical for better results. To ensure an accurate diagnosis and appropriate treatment, it is critical to obtain timely and appropriate confirmation or exclusion of a scaphoid fracture. Various imaging modalities have been suggested by researchers to facilitate early and conclusive diagnosis of suspected scaphoid fractures, including bone scintigraphy, MRI, CT, and ultrasonography. The objective of this research is to conduct a comprehensive evaluation of the research on several modalities of imaging in identifying suspected scaphoid fractures. A meta-analysis of studies published frome is the 2000s until 2023 was conducted.

Keywords: Scaphoid Fracture, Bone Scintigraphy, Magnetic Resonance Imaging, Computed Tomography Scan, Ultrasonography

Introduction

Scaphoid fractures are the most prevalent among carpal fractures, accounting for around 15% of acute wrist injuries. They are typically encountered in young males aged 30 to 40 years.[1–4] Postponed diagnosis and treatment increases the risk of complications such as nonunion, avascular necrosis, and osteoarthritis; therefore, swift identification and management of these fractures is critical for better results. Typically, to diagnose scaphoid fractures, clinical examination and a set of four radiographic views posteroanterior, lateral, semipronated oblique, and posteroanterior with ulnar deviation can be done. However, in the early stages, of injury certain fractures may not be evident on radiographs. Individuals with suspected scaphoid fractures (high clinical likelihood but negative or inconclusive radiographs) frequently get treated with a cast for stabilization following a clinical evaluation and scans. Although the actual frequency of real fractures among those suspected may range from 5% to 10%, the majority of these individuals are exposed to insufficient treatment, resulting in reduced workdaysf, decreased productivity, and greater medical expenses.[1–4]

To ensure an accurate diagnosis and appropriate treatment, it is critical to obtain timely and appropriate confirmation or exclusion of a scaphoid fracture. Various imaging modalities have been suggested by researchers to facilitate early and conclusive diagnosis of suspected scaphoid fractures, including bone scintigraphy, MRI, CT, and ultrasonography. An international survey of hospital practices has highlighted significant gaps in imaging protocols for acute scaphoid fractures, caused by multifactorial factors, but also demonstrated a lack of scientific evidence guiding the optimal approach to imaging these fractures. In making clinical decisions about the use and interpretation of a diagnostic test, it is important to assess its diagnostic performance. Ideally, this assessment should be based on a comprehensive review of relevant knowledge and not rely solely on individual studies or personal experience.[5–7]

The objective of this research is to conduct a comprehensive evaluation of the research on several modalities of imaging in identifying suspected scaphoid fractures. A meta-analysis of studies published frome is the 2000s until 2023 was conducted.

Materials and Methods

A systematic literature search was performed in November 2023 using Medline, PubMed, Cochrane, and the Google search engine according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Articles were searched using several keywords, including “scaphoid fractures”, “bone scintigraphy”, “magnetic resonance imaging”, “computed tomography”, and “ultrasonography”, written in English. Articles that examined the sensitivity and specificity of various imaging modalities prospectively were included. Studies that were included in this study had to fulfill certain criteria. (1) The study was required to be a clinical investigation that examined the diagnostic capabilities of bone scintigraphy, MRI, CT, and USG in patients with suspected scaphoid fractures. (2) The research had to use follow-up pictures (radiographs, CT, MRI, or bone scintigraphy) or clinical follow-up, or a combination of these, as the reference test. (3) The research required to provide the data needed to create a 2x2 contingency table that detailed the index test's performance. (4) The study was required to be published as a comprehensive report in English. We aimed to ascertain whether studies from the same institution used identical patient cohorts, particularly when one author contributed to multiple publications. In cases where data were presented in multiple articles, the article with the most comprehensive details or the most recent publication was selected. Reviewers independently screened and selected the studies, with any disagreements resolved through discussion to achieve consensus. Several conclusions were drawn from each study, including the year of publication, patient characteristics, sample size, imaging methods, reference test, 2x2 index test table, and scaphoid fracture incidence. The QUADAS criteria, which consist of 13 questions responded to 'yes,' 'no,' or 'unclear,', were used to assess the methodological quality of the study.

From these inclusion criteria, 32 articles had been concluded in this study. Five studies reported on bone scintigraphy, 13 studies reported on CT scans, 6 studies reported on MRI, and 8 studies reported on ultrasound.

Table 1. QUADAS Criteria[8]

Methodologic Criteria	Information Required for “yes”
1. Did the patient spectrum reflect those who will be taking the test in practice?	Patients with probable scaphoid fracture were sequentially or prospectively enrolled.
2. Did the selection criteria properly described?	A straightforward explanation of suspected scaphoid fracture was given.
3. Does the citation standard accurately categorize the target condition?	The follow-up image, or plus clinical assessment and/or merged image, was used as standard reference, and the minimum duration of follow-up was at least 6 weeks. The imaging modalities might be plain radiographs, CT, MRI, or bone scintigraphy.
4. Did the entire sample or a random subset undergo diagnostic confirmation using an approved standard?	Each patient received a standarized reference
5. Did patients given the similar reference standard, despite their index test results?	Each subject received the same standarized reference.
6. Did the reference standard independent from the index test?	The standard reference does not include index test results.
7. Did the process of the index test explained in enough information for replication?	A thorough explanation of test methodologies and definitions of positive and negative test findings were given.
8. Did the application of the reference standard reported in enough information to enable replication?	Index test was assessed without being informed about reference standard results, and vice versa, or the test was clearly understood before the findings of other tests were available
9. Were the index test findings evaluated independently of the reference standard results?	Information regarding patient age, gender, presenting symptoms, and physical manifestations were available.
10. Were the reference standard findings interpreted independently of the index test results?	Results were given for all participants who entered the research study.
11. Did the clinical data utilized for interpreting test findings match what might be feasible in practice?	Explanation for findings that were not available for all patients who entered the research study were provided or if results were accessible for each individual
12. Were uninterruptible or intermediate test findings reported?	
13. How were dropouts from the study explained?	

The QUADAS criteria were taken from Table 2 in: Whiting P, Rutjes AW, Reitsma JB, Bossuyt PM, Kleijnen J. The development of QUADAS: a tool for the quality assessment of studies of diagnostic accuracy included in systematic reviews. BMC Med Res Methodol. 2003;3:25. Available at: http://www.biomedcentral.com/1471-2288/3/25.

Table 2. Overview of the Included Studies in the Systematic Review

Study	Year	Male/Female	Incidence of Scaphoid Fracture (%)	Sensitivity	Specificity	Reference Test
Bone Scintigraphy						
Akdemir et al[9]	2004	18/14	25	100	100	Plain radiograph
Breederveld and Tuinebreijer[10]	2004	-	31	78	90	CT after 6 weeks
Groves et al[11]	2005	17/34	12	100	100	Plain radiograph with one case MRI follow up
Beeres et al.[12]	2008	50/50	20	100	90	Plain radiograph
Rhemrev et al[13]	2010	51/49	-	93	91	Plain radiograph
Total		**283**	**17.6**	**94.2**	**94.2**	
CT						
Breederveld and Tuinebreijer[10]	2004	-	31	100	100	Plain radiograph after 6 weeks
Groves et al[11]	2005	17/34	12	100	91	Plain radiograph with one case MRI follow up
Memarsadeghi et al.[14]	2006	17/21	-	73	100	Plain radiograph
Cruickshank et al.[15]	2007	26/21	15	94	100	MRI
You et al.	2007	-	20	-	-	Clinical and image followup
Adey et al.	2007	19/11	-	85	88	Plain radiograph
Ty et al.[16]	2008	12/8	20	97	85	Plain radiograph
Rhemrev et al[13]	2010	51/49	-	64	97	Plain radiograph
Ilica et al.[17]	2011	54/0	25.5	86	100	MRI followup
Mallee et al.[7,18]	2011	25/15	18	67	96	Plain radiograph
de Zwart et al.[19]	2012	79/80	-	70	99	Plain radiograph
Borel et al.[20]	2017	31/18	-	94	97	MRI
Basha et al.[21]	2018	104/64	37.5	62.5	97.3	Plain radiograph
Total		**888**	**13.8**	**76.3**	**88.5**	
MRI						
Gabler et al.[22]	2001	74/44	25	100	100	Plain radiograph
Kumar et al[5]	2005	17/5	27	100	100	Plain radiograph or re-MRI
Memarsadeghi et al.[14]	2006	17/21	-	100	100	Plain radiograph
Beeres et al.[12]	2008	50/50	20	80	100	Plain radiograph
Mallee et al.[23]	2011	25/15	18	67	89	Plain radiograph
Larribe et al[24]	2014	16/2	-	83	100	Histology
Total		**1.064**	**15**	**88.3**	**98.2**	
Ultrasound						
Munk et al[25]	2000	31/26	-	50	91	Plain radiograph
Herneth et al	2001	7/8	38.5	78	100	MRI
Hauger et al[26]	2002	35/19	9.3	100	98	Plain radiograph
Seall et al[27]	2004	-	50	78	89	Plain radiograph
Fusetti et al[28]	2005	13/11	27	100	79	CT
Platon et al [29]	2011	29/33	21	92	71	CT
Yildirim et al[30]	2013	30/33	22.2	100	34.3	MRI
Jain et al [31]	2018	2/1.75	-	79.8	76.7	MRI
Total		**1.341**	**21**	**84.7**	**79.9**	

Results

A total of 32 research studies involving 1.341 patients, were evaluated. Men were affected in 49.2% of cases, with an average age of 34.1 ± 5.7 years. The total frequency of concealed scaphoid fractures was 16.85% (SD = 9.81). Invisible scaphoid fractures are recognized by wrist discomfort and scaphoid soreness in the absence of a visible fracture line on X-ray. Five papers investigated bone scintigraphy, whereas 13 publications focused on CT scanning. Six papers compared two distinct MRI sequences, whereas eight publications examined the sensitivity and specificity of ultrasonography. In total, four investigations compared two distinct radiographic modalities.

Bone scintigraphy exhibited the highest sensitivity at 94.2% (SD 10.7), with MRI following closely at 88.3% (SD 11.4). Followed by ultrasound with a sensitivity of 84.7%. Interestingly, almost all studies, barring three, reported a sensitivity below 100% for CT (76.3%). This was attributed to factors such as a brief MRI scanning time of 7 minutes in one case, fibrovascular scar tissue or contrast agent diffusion from adjacent soft tissues in another, and misinterpretation of bone bruise or vascular channels in a third scenario.

According to statistics, bone scintigraphy ($P = 0.03$) and MRI ($P = 0.02$) had considerably higher sensitivity than CT and ultrasound. MRI had the best specificity rate at 98.2% (SD 4.7), followed by bone scintigraphy at 94.2% (SD 4.8) and CT at 88.5% (SD 11.8). Ultrasound had a mean specificity of 79.9% (SD 18.5), which was substantially lower than MRI ($P = 0.002$), bone scintigraphy ($P = 0.003$), and CT ($P = 0.04$).

Discussion

To prevent the occurrence of scaphoid nonunion and to facilitate early intervention, timely and accurate diagnosis is essential. In cases where initial radiographic imaging showed no abnormalities in a suspected scaphoid fracture, our systematic review showed that approximately 21.8% (SD 9.81) still had a true fracture. This represents a 5.8% increase over the previous publication. Consequently, additional imaging modalities such as bone scintigraphy, CT, magnetic resonance imaging, and ultrasound should be considered for suspected scaphoid fractures that do not show a visible fracture line on standard X-rays.

Our systematic review showed that bone scintigraphy was the most sensitive adjunctive tool, with rates of 94.2%. While MRI was the most specific adjunctive tool, with rates of 98.2%. When considering the fact that 21.8% of scaphoid fractures are not detected on initial plain radiographs with four views, and considering the sensitivity of CT scans of 76.3%, the sensitivity of CT scans is only slightly superior to that of X-rays. However, the negative predictive value of CT scans was very high, namely 94.4 ± 4.8%, indicating that 94.4% of patients without signs of fracture detected on CT scans were indeed free of fractures. Despite the lower sensitivity and specificity of CT compared with MRI, CT remains the only modality that can be accessed quickly and reliably in the emergency department.

Table 3. Comparison Table of Imaging Modalities.[1–4]

	Number of Studies	Number of Patients	Sensitivity	Specificity	Positive Predictive Values	Negative Predictive Value
Bone Scintigraphy	5	283	94.2 ± 11.4	94.2 ± 11.8	72.2 ± 22.6	99.2 ± 2.7
CT	13	444	76.3 ± 14.0	88.5 ± 4.8	83.9 ± 25.2	94.4 ± 4.8
MRI	6	335	88.3 ± 10.7	98.2 ± 4.7	95.3 ± 12.4	98.0 ± 3.1
Ultrasound	8	279	84.7 ± 21.2	79.9 ± 18.5	63.5 ± 26.4	88.8 ± 14.2

We identified only 5 studies for diagnostic imaging that included 100 or more patients. It should be noted that most research on this subject was conducted before 2010, thereby posing a risk of obsolescence given the rapid advances in radiographic technology. Post-2010, there were six studies on CT scans, two MRI studies, and three ultrasound imaging studies. CT sequences prepared particularly for the scaphoid outperform conventional wrist CT sequences in suitable planes in terms of sensitivities and specificities. The sensitivity for wrist CT was 33%, with a specificity of 89%, compared to 76.3% and 88.5% for scaphoid CT. In this review, we focused solely on scaphoid CT sequences. In contrast to prior studies, recent research has focused more on cone-beam CT. In contrast, comparable findings occurred for several MRI sequences. In a study conducted by Larribe et al., gadolinium-enhanced contrast-enhanced MRI scans had the highest sensitivity (83%) and specificity (100%), compared to unenhanced sequences, which had 67% sensitivity and 67% specificity, and the difference was statistically significant. However, the effect of MRI magnitude on the level of detail for scaphoid fractures remains unknown, as none of the research with various magnetic field strengths has been conducted.

Imaging duration has a major impact on the accuracy of recorded radiography results. Kumar et al. demonstrated that the sensitivity of MRI within 24 hours of trauma was not significantly distinct from day 10 following initial presentation. There was no additional research that looked at the timeliness and accuracy of imaging. Furthermore, the radiologist's experience may have a significant impact on the sensitivity and specificity of scaphoid fracture identification. In the case of CT scans, interobserver agreement for scaphoid fractures varied between 7% and 15%, with a kappa value of 0.51. This raises concerns regarding the risk of over- or under-diagnosing scaphoid fractures due to interobserver variability.

Additionally, the choice of standard website used to evaluate CT radiographs can significantly influence the accuracy of a scaphoid fracture diagnosis. As demonstrated by Mallee et al., Digital Imaging and Communication in Medicine (DICOM) viewers exhibit superior diagnostic performance characteristics compared to static JPEG images. Although there was no difference in specificity, accuracy, and positive predictive value (PPV), there was a significant increase in sensitivity and negative predictive value (NPV).

Another research investigation evaluated the predictive value of indirect indicators of scaphoid fractures. As a result, the pre-operative and postoperative radiographic alignment of the interscaphoid carpal area was evaluated using parameters such as the radiolunate angle, carpal alignment index, and scapholunate and capitolunate angles. The radiolunate angle and carpal alignment index showed the best dependability, with significant variations between pre- and post-operative measures (16.4 ± 5.4 vs. 8.1 ± 4.4, $P = 0.01$). The scapholunate and capitolunate angles had lower dependability (52.6 ± 8.7 vs. 43.5 ± 8.4, $P = 0.04$; 15.3 ± 9.4 vs. 9.7 ± 7.3, $P = 0.12$), but they may still be used as alternatives. Carpal indices would be uncommon only if the scaphoid fracture was angular or displaced, with no contemporaneous intracarpal ligamentous damage.

To maximize the information obtained from CT imaging, it is recommended to employ high-resolution CT scans in the plane of the scaphoid for the detection of even subtle fractures. The optimal timing for CT scans, whether performed early or with delayed imaging, remains unclear based on the available literature. For evaluation purposes, the DICOM viewer performed admirably, and in addition to direct fracture indicators such as the existence of a radiolucent fracture line, indirect signals such as the radiolunate angle and carpal alignment index should be examined. Societal expenses have risen, leading doctors to consider the price and therapeutic efficacy of various diagnostic techniques. While MRI, CT scans, and ultrasound are becoming popular, bone scintigraphy has received little attention in recent research. MRI has shown superiority over traditional radiography in identifying scaphoid fractures, and a negative MRI can save societal expenditures associated with insufficient immobility by effectively ruling out a scaphoid fracture. Although there is no consensus when comparing CT scans with MRI, most studies support the notion that MRI is more effective in detecting scaphoid fractures. If an MRI indicates a scaphoid fracture, a CT scan should probably still be conducted to assess for displacement, which, if present, would favor surgical treatment over cast immobilization.

Ultrasonography exhibits lower sensitivity and specificity (84.7% and 79.9%, respectively) in comparison to MRI, CT, and bone scintigraphy for detecting scaphoid fractures. Despite its comparatively lower accuracy, ultrasound retains the advantage of being easily accessible, cost-effective, and rapid. However, it is operator-dependent and not widely employed for scaphoid fracture detection.

Plain X-rays show strong agreement for nonunion after 6 months when monitoring scaphoid union in follow-up examinations (kappa = 0.816). Nonetheless, partial and complete consolidation have moderate reliability and accuracy (kappa = 0.390 and 0.517, respectively). As a result, CT scanning is likely the most trustworthy tool for assessing scaphoid union, as it may show trabecular healing over the fracture site.

Conclusion

The results of this systematic review and meta-analysis show that MRI has the best sensitivity and specificity for identifying scaphoid fractures, whereas CT and US have much lower values. Despite its diagnostic superiority, MRI is more expensive and may not be as widely available as CT, giving CT a more practical alternative for many patients. Notably, six more publications were included compared to earlier published systematic reviews. To enhance the current understanding, future studies should explore newer imaging techniques and incorporate the latest research findings.

Conflict of Interest

The authors declare no conflicts of interest.

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