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The diagnostic characteristics and reliability of radiological methods used in the assessment of scaphoid fracture union

a systematic review

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Aims

To evaluate the diagnostic characteristics and reliability of radiological methods used to assess scaphoid fracture union through a systematic review and meta-analysis.

Methods

MEDLINE, Embase, and the Cochrane Library were searched from inception to June 2022. Any study reporting data on the diagnostic characteristics and/or the reliability of radiological methods assessing scaphoid union was included. Data were extracted and checked for accuracy and completeness by pairs of reviewers. Methodological quality was assessed using the QUADAS-2 tool.

Results

A total of 13 studies were included, which were three assessed radiographs alone, six CT alone, and four radiographs + CT. Diagnostic sensitivity was assessed by CT in three studies (0.78, 0.78, and 0.73) and by radiographs in two studies (0.65, 0.75). Diagnostic specificity was assessed by CT in three studies (0.96, 0.8, 0.4) and by radiographs in two studies (0.67, 0.4). Interobserver reliability was assessed for radiographs by seven studies (two fair, four moderate, and one substantial) and for CT in nine studies (one fair, one moderate, six substantial, and one almost perfect).

Conclusion

There is evidence to support both the use of CT and radiographs in assessing scaphoid fracture union. Although CT appears superior in terms of both its diagnostic characteristics and reliability, further research is necessary to better define the optimal clinical pathways for patients.

Take home message

- There is evidence to support both the use of CT and radiographs in the diagnosis of scaphoid fracture union.
- CT has better diagnostic characteristics and reliability than radiographs.
- Future studies should focus on how best to use CT to improve current pathways of care.

Introduction

Scaphoid fractures are the commonest carpal fracture[1] and account for

Bone & Joint Open

approximately 15% of all acute wrist injuries.[2,3] The negative consequences of nonunion for patients and healthcare providers are significant.[4] Consequently, it is important to be able to diagnose union and nonunion both accurately and reliably. The early diagnosis of union can help to enable early mobilization, reassure patients, and save money for healthcare providers by reducing the need for costly further clinical attendances,[5] while delays in diagnosing nonunion can reduce the chances of surgery achieving union and result in further degenerative change occurring adjacent to the scaphoid.[4,6] The radiological assessment of union continues to pose challenges, due to its unique size, shape, and orientation. To our knowledge, no systematic review has previously attempted to summarize the evidence in this area. The aim of this systematic review of the literature is to answer the following questions relating to the different radiological methods used to assess scaphoid fracture union: 1) what are the diagnostic characteristics of these methods?; and 2) what is the reliability of these methods?

Methods

This systematic review is reported in accordance with the PRISMA statement (Supplementary Table iii).[7] The protocol was developed prospectively, and peer reviewed locally before registration on the PROSPERO database (CRD42022341571).

Data sources and searches

We used the Ovid interface to search two key bibliographic biomedical databases. Searches were run on MEDLINE (1946 to present) and Embase (1974 to present). No date or language limits were applied. We also searched the Cochrane Register of Controlled Trials and the Cochrane Database of Systematic Reviews. The searches were run on 14 June 2022. Sets of synonyms were produced in line with the distinct elements of our research question. There are three major aspects. We therefore selected thesaurus terms and free-text terms for each. Scaphoid was the first, fracture the second, and union or nonunion was the third concept. Synonyms for scaphoid included the MeSH terms scaphoid bone and scaphoid fracture. Synonyms for fracture included break or broken. Synonyms for union or nonunion included heal and malunion.

Inclusion/exclusion criteria

The aim was to include any study reporting on radiological methods assessing scaphoid fracture union. The diagnostic test could include any form of radiological investigation. In terms of the association between diagnosis of union and outcome, only studies that described the diagnostic attributes (such as sensitivity, specificity, accuracy) and/or the reliability of the radiological assessment were included. The search aimed to identify any study relating to scaphoid fractures in adults (aged ≥ 18 years). Articles with the following criteria were excluded: review articles, duplicate results, lack of full access to the original article, articles not available in English, studies not published as a full article such as conference abstracts and letters, and case studies.

Selection of studies

Duplicates were removed and relevant studies identified from the search were imported into Covidence for screening.[8] Studies were independently screened by title and abstract by two authors (WT, GS). The references of all included studies and all relevant review articles on the topic were also reviewed to identify other potential studies for inclusion. This was followed by a full-text evaluation of the selected studies from the first selection step by these authors. Disagreement between the two reviewers was solved by consensus involving a third author (BD).

Data extraction

Two reviewers independently extracted data (WT, GS). Data were extracted using a custom data extraction sheet in Covidence. The custom data extraction sheet was specifically designed to extract data relating to study design, participant characteristics, clinical setting, study design, target condition definition, index test, reference standard, and sample size. If interobserver reliability had been analyzed, Kappa scores were noted. Intraobserver reliability was also reported, if performed. Values ≤ 0 were considered to indicate no agreement, 0.01 to 0.20 none to slight, 0.21 to 0.40 fair, 0.41 to 0.60 moderate, 0.61 to 0.80 substantial, and 0.81 to 1.00 almost perfect agreement. Rossi et al[9] reported correlation between observers (Spearman rank). Furthermore, 2 × 2 data (true positive, false positive, false negative, true negative) with estimates of diagnostic accuracy (sensitivity and specificity) of fracture union and CIs were recorded. Where 2 × 2 data were not provided, it was calculated where sufficient data were provided to enable this. Any inconsistencies between the two reviewers' forms were resolved by consensus discussion. A third reviewer was available for any disagreement that could not be resolved by this initial discussion, but this was not needed.

Risk of bias/quality assessment

Included studies were assessed for risk of bias/quality by two independent raters (GS, WT) using the QUADAS-2 tool.[10] All domains were scored for the studies that had assessed diagnostic characteristics; however, certain domains were not applicable to the studies that had solely assessed reliability.

Statistical analysis

Descriptive analysis was performed for all data relating to the test diagnostic characteristics and reliability to facilitate narrative interpretation and comparison across studies. It was only possible to obtain 2 × 2 data for three of the four studies that assessed diagnostic characteristics. A study by Farracho et al[5] did not provide sufficient data to enable this, and the corresponding author did not respond to our request for further data. As this left one study with 2 × 2 for radiographs and two studies with 2 × 2 data for CT,[11–13] a decision was made that pooling the data for meta-analysis would not be of additional value.

Results

Study selection

This process is shown by Figure 1. In total, 4,297 studies were found based on our search term, including 154 duplicates. Two authors reviewed all the remaining 4,143 abstracts. Of these, 4,040 studies were subsequently excluded as these did not meet the inclusion criteria, leaving 97 articles for final review. Articles were excluded for the following reasons: two as the full text was not accessible, two had the incorrect

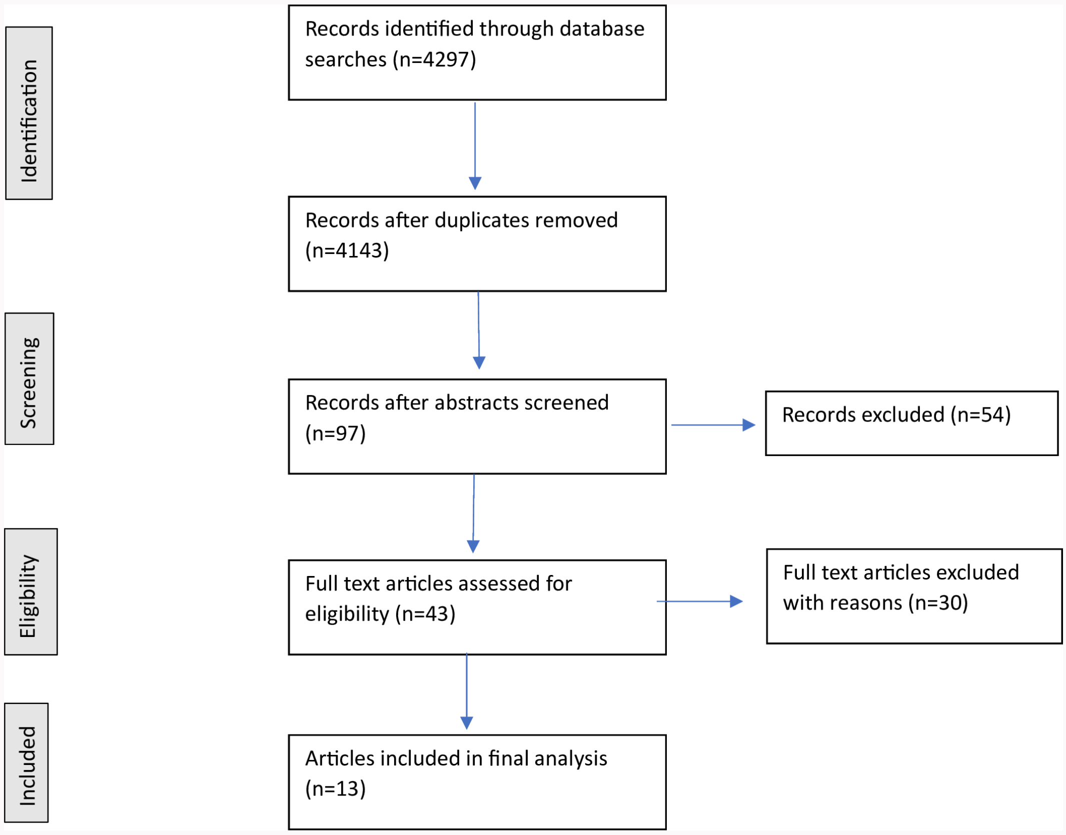

Fig. 1
Study selection process.

patient population, four were conference abstracts, ten were not written in English, and 32 were the incorrect study design or outcome. This left 43 articles, of which only 13 had objective data on the diagnostic characteristics and/or reliability of radiological assessment of scaphoid union for the systematic review.

Study characteristics

Study details, participants, and interventions are described in Table I. The radiological methods used to assess scaphoid union from the 13 studies included radiographs and CT. Conservative treatment in cast with or without thumb immobilization was used in part or as the sole treatment of patients in 11 studies. Treatment also included headless compression screw fixation for the primary treatment of acute fracture[14,15] and in patients for the treatment of nonunion,[15] Russe bone grafting for scaphoid nonunion cases[9], and pulsed electromagnetic stimulation in addition to cast immobilization.[16] The details regarding the radiological assessment of union methods (where provided), the number and details of observers, the details of the union assessment, and reference standard for diagnostic studies are shown in Supplementary Table ii.

Results of included studies

The test diagnostic characteristics (including accuracy, sensitivity, specificity, and positive and negative predictive values) and reliability (inter- and intraobserver) are described in Table II and Supplementary Table i. Four studies included an assessment of test diagnostic characteristics; this included one study involving just radiographs, one using both radiographs and CT, with the other three studies using solely CT scans.[5,11,12]

All 13 studies included an assessment of interobserver agreement. Interobserver agreement was measured using Landis and Koch 1977 Kappa statistics[22] if between two observers, and Kappa Fleiss[23] if among more than two observers in all but two studies.

Sensitivity of CT scans from six to 24 weeks after injury in assessing union was measured at 0.73 by one study[12] and 0.78 by two studies,[5,11] which was slightly better than radiographs, where assessments were made six weeks following injury and measured 0.65[13] and 0.75.[5] The specificity of CT scans varied between 0.4[5] in a study that assessed scans six weeks following injury, compared with them being much better at 0.8 and 0.96[11] in studies that assessed scans from six to 24 weeks after injury; radiographs reported specificity of 0.4[5] and 0.67[13] in studies that only assessed scans at six weeks following injury. Accuracy of CT scan (0.61 to 0.63) was superior to radiographs (0.53 to 0.59) in predicting scaphoid healing at early follow-up (six weeks),[5] and was reported as high (0.84) in a further study assessing CT scan only.[11]

Varying analysis of reliability included: assessment of radiographs or CT scans; assessment of different observers; assessment of differing methods to assess union; and radiographs versus radiographs and CT scans. Only four included an assessment of intraobserver agreement and included results for reading radiographs, CT scans, and a combination of the two.

Overall interobserver reliability was assessed for radiographs by seven studies (two fair, four moderate, and one

Table I. Study details including patients and interventions.

Author, yr	Participants, n	Inclusion criteria	Scaphoid fracture location	Interventions	Comparators	Outcomes	Timepoints
Buijze et al[11]	30	Scaphoid waist fractures (20 known to be united at six months following injury)	Scaphoid waist fractures	Conservatively treated up to six weeks after injury (all 30 patients)	Ten patients had subsequent operative fixation for operatively confirmed nonunion	United or ununited	CT scan performed minimum six weeks after injury
Dias et al[17]	20	Scaphoid waist fractures	Waist fractures	Conservatively treated	Nil	Union and crossing trabeculae	12 weeks post-injury radiography
Dias et al[15]	439	Bicortical fracture of the scaphoid waist on scaphoid radiography < two weeks of presentation July 2013 to September 2017	Bicortical waist of scaphoid fracture < 2-mm step	Percutaneous or ORIF with headless compression screw	Conservative treatment in cast (with or without thumb)	Radiography: United, Almost Partial Probably not Not united CT: United Partial union Not united	Six and 12 weeks Final imaging at 52 weeks (union assessment)
Drijkoningen et al [18]	13	Treated nonoperatively for nondisplaced scaphoid waist fracture	Nondisplaced scaphoid waist fracture	Conservative treatment with cast	Nil	Percentage of bony bridging	Ten to 12 weeks after injury
Farracho et al[5]	52	Scaphoid fracture diagnosis April 2018 to March 2019	Scaphoid fracture	Conservative treatment with cast for six weeks (without thumb)	Nil	Union Nonunion	Six weeks cast then radiography and CT scan, eight weeks clinical review
Geoghegan et al[19]	57	Scaphoid waist fractures visible on radiograph September 2002 to December 2003	Scaphoid waist fracture displaced (17) or undisplaced (43)	Conservative treatment in cast for four weeks (thumb not included)	Nil	United Ununited	Four weeks for CT scan (further scans at eight, 12, and 26 weeks)
Grewal et al[20]	50	Random sampling of acute scaphoid fractures from radiology tertiary centre database 2004 to 2010	Nonoperatively treated scaphoid fractures	Conservative treatment in cast	Nil	United (75% to 100%) Partially united (50% to 75%) Tenuously united (≤ 50%)	CT scan one to 197 days after injury
Hannemann et al[12]	44	Unilateral waist of scaphoid fracture November 2009 to February 2012	Scaphoid waist fracture undisplaced or minimally displaced	Conservatively in short arm cast including the thumb	Nil	Amount of consolidation[21] Union Partial union Nonunion and Union Nonunion	CT six to 24 weeks after injury
Hannemann et al[13]	47	May 2006 to March 2008 unilateral undisplaced waist scaphoid fractures < five days of injury via radiographs or CT	Waist scaphoid fractures	Conservative treatment in cast including thumb	Nil	Union Partial union Nonunion	Six weeks after injury
Hannemann et al[16]	102	January 2010 to December 2011 undisplaced unilateral scaphoid fracture diagnosed < five days of injury via radiography or CT	Herbert A1, A2, B1, and B2 fractures	Conservative treatment in cast with thumb included plus electromagnetic stimulation	Conservative treatment in cast including thumb and placebo	Union Partial union Nonunion	Six, nine, 12, 24, and 52 weeks after diagnosis of the fracture
Matzon et al[14]	32	Scaphoid fracture treated with ORIF or scaphoid nonunion treated with ORIF 2012 to 2018	Proximal, waist and distal pole scaphoid fracture undergoing ORIF	Cannulated headless compression screw fixation	Nil	Healed Partially healed Not healed	Radiography 3.2 months postoperatively (1.3 to 19.5) and CT scan performed 4.5 days after this (1 to 52)
Rossi et al[9]	50	Scaphoid nonunion treated with Russe bone graft 1977 to 1993	Scaphoid waist fracture with nonunion	Russe bone grafts (no fixation) With cast immobilization (long arm then short arm with thumb included for up to 20 weeks)	Nil	Fracture line bridging and degree of lucency both graded 0 to 2	Radiography 2, 3, 4, 5 to 6, 7 to 12, and 13 to 36 months after surgery
Singh et al[21]	100	Scaphoid fractures visible on initial radiography, October 2001 to October 2003	Waist and proximal pole scaphoid fractures	Treated nonoperatively in cast excluding thumb for eight weeks ± four weeks if clinical or radiograph concerns	Nil	United Partially united Nonunion	CT scan at 12 and 18 weeks and if concerns CT after further three months

ORIF, open reduction and internal fixation.

Table II. Data measurements, characteristics, and reliability.

Author, yr	Modality	Diagnostic characteristics	Other	Interobserver reliability (Kappa unless otherwise stated)
Buijze et al[11]	CT	Accuracy 0.84 (95% CI 0.63 to 1.0) Sensitivity 0.78 (95% CI 0.47 to 1.0) Specificity 0.96 (95% CI 0.85 to 1.0) PPV 0.99 (95% CI 0.97 to 1.0) NPV 0.41 (95% CI 0 to 0.84)		0.66
Dias et al[17]	XR	N/A		Fracture union 0.386 Bridging trabeculae 0.104
Dias et al[15]	XR + CT	N/A		XR: 0.724 agreement (95% CI 0.673 to 0.775) 0.769 agreement (95% CI 0.721 to 0.818) 0.684 agreement (95% CI 0.631 to 0.737) CT: 0.896 agreement (95% CI 0.861 to 0.94) 0.841 agreement (95% CI 0.799 to 0.882); 0.915 agreement (95% CI 0.883 to 0.947)
Drijkoningen et al[18]	CT	N/A		0.34 bony bridging 0.31 location bony bridging
Farracho et al[5]	XR + CT	Accuracy XR 0.53 to 0.59; CT 0.61 to 0.63 Sensitivity 0.75 XR and 0.78 CT Specificity 0.4 XR and CT PPV XR PPV = 0.66; CT PPV = 0.67 NPV XR NPV = 0.5; CT NPV = 0.53		Radiologist XR = 0.35 Surgeon XR = 0.956 Both XR = 0.543 Radiologists CBCT = 0.803 Surgeons = 0.803 Both CBCT = 0.641
Geoghegan et al[19]	CT	N/A		0.77
Grewal et al[20]	CT	N/A		Hand surgeon and fellow 0.62 (95% CI 0.44 to 0.80) Hand surgeon and MSK radiologist = 0.8 (95% CI 0.65 to 0.93)
Hannemann et al[12]	CT	Accuracy N/A Sensitivity 0.73 (95% CI 0.66 to 0.79) Specificity 0.8 (95% CI 0.68 to 0.92) PPV N/A NPV N/A	Positive likelihood ratio 3.65 Negative likelihood ratio 0.34 Diagnostic odds ratio 10.9	Overall = 0.576 (95 % CI 0.399 to 0.753) Union = 0.683 Partial union = 0.502 Nonunion = 0.791 Overall union/nonunion = 0.699 (95 % CI 0.529 to 0.870) Union = 0.793 Nonunion = 0.793
Hannemann et al[13]	XR	Accuracy N/A Sensitivity 0.65 (95 % CI 0.54 to 0.75) Specificity 0.67 (95 % CI 0.39 to 0.86) PPV 0.93 (95 % CI 0.83 to 0.97) NPV 0.22 (95 % CI 0.12 to 0.38)		Overall = 0.583 (95 % CI 0.371 to 0.795) No union = 0.816 (95 % CI 0.321 to 0.999) Union = 0.517 (95 % CI 0.077 to 0.999) Partial union = 0.390 (95 % CI 0.048 to 0.832)
Hannemann et al[16]	CT	N/A		Union = 0.683 (95% CI 0.473 to 0.893) Nonunion = 0.791 (95% CI 0.599 to 0.984)
Matzon et al[14]	XR + CT	N/A		Weighted reliability: XR 0.53 (0.42 to 0.63) XR and CT = 0.59 (0.53 to 0.68) for healed vs partially healed vs not healed
Rossi et al[9]	XR	N/A		The scores given by the two observers were significantly correlated, with correlation values ranging from 0.37 to 0.55 (p < 0.001, Spearman rank correlation)
Singh et al[21]	XR + CT	N/A		XR = 0.27

CBCT, cone beam CT; MSK, musculoskeletal; N/A, not available; NPV, negative predictive value; PPV, positive predictive value.

substantial) and for CT in nine studies (one fair, one moderate, six substantial, and one almost perfect). Dichotomizing results as either union or nonunion, rather than including partial union, improved reliability in two studies with kappa score of substantial: 0.699[12] and 0.683.[16] Interestingly, in the sole assessment of the quantity of bony bridging on a CT scan, the kappa score was only fair: 0.34.[18] Interobserver reliability also improved with grade of assessing observer[20] and interpreting both radiographs and CT together. Overall interobserver reliability reported by Dias et al[15] was acceptable agreement (mean 72.6%; 95% CI 63.1 to 81.8) with regards to radiographs and good agreement (mean 88.4%; 95% CI 79.9 to 94.7) regarding CT scans performed at 52 weeks. However, there was no separation of results for those patients managed conservatively or with those treated with open reduction and internal fixation.

Risk of bias/quality assessment

The risk of bias and applicability assessment is shown in Table III. The reference standard used in the study by Farracho et al[5] was short term and consequently felt to be a reason for concern in terms of both risk of bias and applicability.

Discussion

The key findings of this systematic review are that there is some reasonable evidence to support both the use of radiographs and CT in the diagnosis of scaphoid fracture union, but the diagnostic characteristics and reliability of CT appear superior to that of radiographs. A test's performance is improved with higher values of both sensitivity and specificity, with a cumulative value of over 1.5 required for it to be deemed useful.[24] For CT, this value was reached in all but one study,[5] but in neither of the studies that assessed radiographs. The reliability of assessing scaphoid union using CT was also generally superior to that of radiographs, with most studies assessing CT demonstrating substantial reliability versus most demonstrating moderate reliability for radiographs.

It is important that these findings should be considered in the context of the quality and exact nature of imaging obtained. For example, Supplementary Table ii illustrates some of the variability in the nature of the CT scans that were analyzed, with incomplete information provided regarding the type and age of CT scanner used, the thickness and number of the slices obtained, whether the bone window was used (which can help to identify bone edges to calculate proportions of union), and whether multiplanar reconstructions were used. The same is true for plain radiographs, where the number, type, and quality of radiographs assessed showed variation across the relevant papers. Furthermore, the quality of the reference standard used is also clearly of critical importance, with the study by Farracho et al[5] being significantly flawed in using a two-month timepoint in this regard. Notably, this study produced values of specificity of 0.4 for both radiographs and CT, results which should not carry significant weight due to the flawed nature of this reference standard. The timing of imaging is also of critical importance, with it being well recognized that the accuracy of diagnosing union will increase as the time to radiological assessment increases. Differences in the time to imaging may explain some of the observed superiority of CT over radiographs; however, it does not account for the superior reliability as this was observed with equivalent time to follow-up.

Currently in the UK, only 28% of centres use CT scans as their first line in the radiological assessment of scaphoid union.[25] The challenge of confirming scaphoid union, as well as defining when it is appropriate to discontinue immobilization and commence specific activities, is a very important topic due to the potential negative implications of developing a painful scaphoid nonunion. It is made more complex by the heterogeneity of the populations in this systematic review (acute fractures versus treatment of nonunion, and nonoperative versus various forms of operative treatment). For example, internal fixation changes the biomechanics and subsequent physiology of fracture healing, which will influence the way in which union is assessed and interpreted. The role of clinical examination remains unclear, as there is a paucity of evidence in this domain; however, it was not within the scope of this review to ask this question.

The complexities around this topic continue to be researched and discussed, including cadaveric analysis[26] and finite element analysis studies of scaphoid union.[27] The British Society of Surgery for the Hand has recently produced standards for the follow-up of confirmed scaphoid fractures.[28] In addition, it is important to consider that there are some disadvantages to the routine use of CT over radiographs, which include higher costs, less availability, and greater radiation exposure. It should be noted that the radiation exposure of a modern wrist CT is very low indeed.[29] Notably, in the NHS, the estimated cost of a CT is relatively low at GBP £60, which is far lower than the cost of a follow-up clinic appointment.[30]

Limitations of this review include the absence of data in nine studies relating to sensitivity and specificity and thus, positive and negative predictive values. This review included six retrospective articles, five prospective cohort studies, and only two randomized controlled trials, meaning that almost half were subject to potential spectrum bias as the patients were a known cohort prior to analysis being performed. As stated previously, each study has attempted to answer a different question in a different population, as well as the timeframe from injury or operation to imaging varying hugely, from four weeks[19] to 52 weeks.[15] This study heterogeneity is worth acknowledging, but in this context, we feel that it is reasonable to ascribe some meaning to the descriptive trends in the data. Certainly, the optimal patient pathway remains unclear given this heterogeneity, making a strong case for better designed prospective research in this area to define the role of CT with more clarity. It is likely that the optimal pathways would not be homogenous, given that factors such as fracture location (proximal vs distal) and mode of treatment (cast vs acute surgery vs delayed surgery) would likely require different approaches.

The definition of scaphoid union, partial union, or nonunion was not standardized across all papers, although Singh's grading of union was used in several of the studies assessed.[13,14,16,18,21] The dichotomy of healed or not healed (which may or may not be argued as helpful) was used in only three studies.[5,11,19] Fundamentally, union is a process of bridging trabeculae, consolidation, and subsequent remodelling, but defining what can be measured on imaging and when to allow for return to function is the critical question.

There may be more uncertainty in this area than we imagine, in that although in many cases union reliably progresses once a certain degree of partial union has been reached, it may well be that partial union has the potential to regress in certain circumstances. The observers were mostly experts or individuals specifically trained to interpret such imaging, which potentially makes these results only

Table III. Quality assessment for each study.

		Risk of bias				Applicability concerns		
Author, yr	Design	Patient selection	Index test	Reference standard	Flow and timing	Patient selection	Index test	Reference standard
Buijze 2012[11]	Retrospective cohort study	Unclear	Low	Low	Low	Low	Low	Low
Dias et al[17]	Retrospective randomly selected review	Low	N/A	N/A	N/A	Low	Low	N/A
Dias et al[15]	Randomized controlled trial	Low	N/A	N/A	N/A	Low	Low	N/A
Drijkoningen et al[18]	Retrospective review	High	N/A	N/A	N/A	Low	Low	N/A
Farracho et al[5]	Prospective cohort study	Low	Low	High	Low	Low	Low	High
Geoghegan et al[19]	Prospective cohort study	Low	N/A	N/A	N/A	Low	Low	N/A
Grewal et al[20]	Retrospective blinded review	High	N/A	N/A	N/A	Low	Low	N/A
Hannemann et al[12]	Prospective cohort study	Low	Low	Low	Low	Low	Low	Low
Hannemann et al[13]	Prospective cohort study	Low	Low	Low	Low	Low	Low	Low
Hannemann et al[16]	Randomized controlled trial	Low	N/A	N/A	N/A	Low	Low	N/A
Matzon et al[14]	Retrospective review	High	N/A	N/A	N/A	Low	Low	N/A
Rossi et al[9]	Retrospective review	High	N/A	N/A	N/A	Low	Low	N/A
Singh et al[21]	Prospective cohort study	Unclear	N/A	N/A	N/A	Low	Low	N/A

N/A, not available.

generalizable to those with similar levels of experience and training. This is reinforced by the results showing an improved interobserver reliability,[20] with improved grade of assessor. To combat this issue, educating observers in the technique of measuring the area of fracture and the area of trabecular bridging on appropriate CT slices would be a sensible approach to address this. Ultimately, it is arguable that better prospective pragmatic clinical research is needed in this area to test which imaging approach is best.

In conclusion, there is evidence to support both the use of CT and radiographs in assessing scaphoid fracture union, although CT appears to be superior in terms of both its diagnostic characteristics and reliability. These findings are consistent with the trend in current practice towards a greater use of early CT, when the images obtained are of a standardized quality, taken at an appropriate time interval, and interpreted in a consistent way by those suitably trained to do so. Further research is necessary to better define the optimal clinical pathways for patients.

Supplementary material

Tables showing: which studies assessed which particular imaging characteristics; and the asssessment of union methods, observer details, and reference standard. A PRISMA checklist has also been included.

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Data sharing

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