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How Is Scaphoid Malunion Defined: A Systematic Review

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Abstract

Background: Abnormal scaphoid alignment after fracture is used as an indication for fixation. Acceptable alignment after reduction and fixation of scaphoid fractures is not well defined. We systematically reviewed the literature to identify how scaphoid malunion is currently defined and by what parameters. **Methods:** A systematic review was performed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Multiple databases were searched for studies published in the English language that reported on outcomes after scaphoid malunion and included measurements to define malunions. Radiographic scaphoid measurement parameters were collected. Clinical outcome measures recorded included grip strength, wrist range of motion, and patient-reported outcome measures. Study quality was analyzed using the Methodological Index for Non-Randomized Studies (MINORS) criteria. Descriptive summaries of the studies are presented. **Results:** The initial search yielded 1600 articles. Ten articles (161 participants, 93% males, mean age = 28.3 + 6.3 years, mean MINORS score = 10.2 + 1.6) were included and analyzed. Scaphoid malunion was defined if the lateral intrascaphoid angle (LISA) was >45° (3 articles), LISA >35° (1 article), and height to length ratio >0.6 (3 articles). Four out of 5 studies found no significant associations between patient outcomes and degree of scaphoid malunion measured on imaging. **Conclusions:** There is a lack of consensus for defining scaphoid malunion on imaging and absence of correlation between findings on imaging and patient outcomes. Future studies defining scaphoid malunion should be appropriately powered, incorporate measures of intrarater and interrater reliabilities for all reported imaging measurements, and utilize validated patient-reported outcome measures to reflect that malunion is associated with inferior outcomes meaningful to patients.

Keywords: deformity, hand surgery, malunion, patient-reported outcome measures, scaphoid

Introduction

The scaphoid is the most commonly fractured carpal bone, accounting for over 60% of all carpal bone fractures and 11% of all hand fractures.[1-3] Scaphoid fractures have an estimated incidence ranging from 12.4 per 100 000 to 29 per 100 000 and predominantly occur in active young adults.[4,5] Although nondisplaced fractures often heal successfully without surgical treatment, the scaphoid's morphology and poor vasculature predispose certain fracture types, such as displaced fractures, proximal pole fractures, and fractures that encounter delays in treatment, to complications including nonunion and malunion.[6] While the diagnosis and treatment of scaphoid nonunion have been well described in the literature, less is known about scaphoid malunion.[7-12]

In general, a malunion can be defined by a fracture that heals in a malaligned or nonanatomical position. Nonetheless, a clear definition of bony malunion is sometimes difficult to ascertain. For example, the most common complication after distal radius fractures is malunion; yet, a recent review concluded that a standardized definition of distal radius malunion has not yet been established in part because some distal radius malunions are asymptomatic, and therefore perhaps should not be considered "malunions."[13] On the contrary, it is acceptable for humeral shaft fractures to heal with a small degree of angulation, and malunion is not defined for these fractures until greater than 20° of angulation in any plane is identified on imaging.[14-16] Yet the natural history of scaphoid malunion is still relatively unknown.[17] Although some scaphoid mal-

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unions may be asymptomatic, others can result in humpback deformity, which can alter carpal joint mechanics and cause inferior outcomes.[18]

As such, no consensus has been established for defining a scaphoid malunion. There are a variety of measurements that have been utilized in the literature to classify scaphoid malunion on imaging.[19,20] However, these measurements can have interrater and intrarater variabilities, and the degree of deformity may not correlate with clinical outcomes or guide treatment.[19,21] Therefore, the purpose of this investigation was to systematically review the literature to identify how scaphoid malunion is currently defined and by what parameters.

Materials and Methods

This systematic review was registered with PROSPERO (CRD42020200868) on July 24, 2020. Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines were followed.[22] Two authors conducted separate searches of the following medical databases: PubMed, SCOPUS, and Cochrane Central Register of Controlled Trials. The searches were performed on July 24, 2020. The search string used was as follows: (scaphoid[tw] AND (anatom*[tw] OR radiograph*[tw] OR imag*[tw]) AND measur*[tw]) OR (scaphoid[tw] AND malunion[tw]) OR (scaphoid[tw] AND fracture[tw] AND deformity[tw]). Articles published on or after January 1, 1970, were included for screening.

Eligible studies consisted of level I-IV evidence (per Oxford Centre for Evidence-Based Medicine) studies published in the English language that reported on outcomes after scaphoid malunion and included measurements to define malunions. Animal studies, basic science studies, review articles, case reports, book chapters, and technique papers were excluded. In addition, articles reporting on malalignment of nonunions were excluded. Studies with a sample size of less than 5 patients were excluded. In the event of different studies with duplicate (or overlapping) participant populations, the study with the greatest number of participants or greatest clarity of methods and results was included if the participants could not be separated. After removal of duplicates, titles and/or abstracts were screened, and full text articles were further assessed based on inclusion and exclusion criteria by 2 independent reviewers. All references were cross-referenced for inclusion if missed by the initial search. The search results were reviewed for duplicates and the inclusion criteria to determine the articles that were included in the final analysis (Figure 1).

All study, participant, and scaphoid measurement parameters were collected. Study and participant demographic parameters extracted included year of publication, years of participant enrollment, number of participants, sex, age, diagnosis, length of follow-up, and fracture classification. Scaphoid measurement parameters collected included height to length (H/L) ratio, lateral intrascaphoid angle (LISA), dorsal cortical angle (DCA), radiolunate angle (RLA), scapholunate angle (SLA), and capitolunate angle (CLA). Clinical outcome measures recorded included grip strength, wrist range of motion (flexion/extension), and all wrist/upper extremity-specific patient-reported outcome measures (Mayo Wrist Score; Disabilities of the Arm, Shoulder, and Hand [DASH]; Visual Analog Scale [VAS]; and Patient Evaluation Measure [PEM]). Extracted data were cross-checked for accuracy by the 2 reviewers and recorded onto a shared spreadsheet.

The risk of study bias and methodological quality was analyzed using the Methodological Index for Non-Randomized Studies[23] (MINORS), which has been shown to be a reliable and valid assessment of comparative and noncomparative outcome studies. The maximum possible score is 24 points for comparative studies and 16 points for noncomparative studies, with maximum scores representing the highest methodological quality for nonrandomized studies and a low risk of bias. Two authors independently scored the studies, and an interrater reliability (IRR) was calculated using the Cohen's kappa statistic. As the available literature for this review included only level IV studies, pooling of data and meta-analysis was not performed. Thus, descriptive summaries of the studies based on the demographics, scaphoid measurement criteria, cutoff measurements for malunion, fracture characteristics, and outcome data are presented.

Results

The initial search yielded 1600 articles. After removing duplicates, 1001 records were screened for eligibility. Of these, 35 articles underwent full text review, resulting in 10 articles that were included and analyzed[12,20,21,24-30] (Figure 1). All articles were level IV evidence. The MINORS score for studies ranged from 9 to 14, with an average score of 10.2 $\pm$ 1.6 and a kappa value of 0.96, indicating almost perfect interrater agreement. The number of participants per study that were diagnosed with a scaphoid malunion ranged from 5 to 26 for a total of 161 malunion patients (Table 1). All studies included more men than women (93% men). The mean patient age in the studies ranged from 20 to 41 (28.3 $\pm$ 6.3), with a mean follow-up ranging from 12 to 105 months (64.7 $\pm$ 37.0; Table 1).

Scaphoid morphology was characterized and reported based on measurements from computed tomography (CT),[12,21,24-28] trispiral tomography,[20] or radiographs (XR)[29,30] for each study. The LISA was reported in 7 studies,[20,21,24-27,29] and H/L ratio was reported in 5 studies.[12,21,24,25,28] Only 3 studies calculated IRR for H/L[21,28] or LISA[27] measurements, and these ranged from 0.53 to 0.93

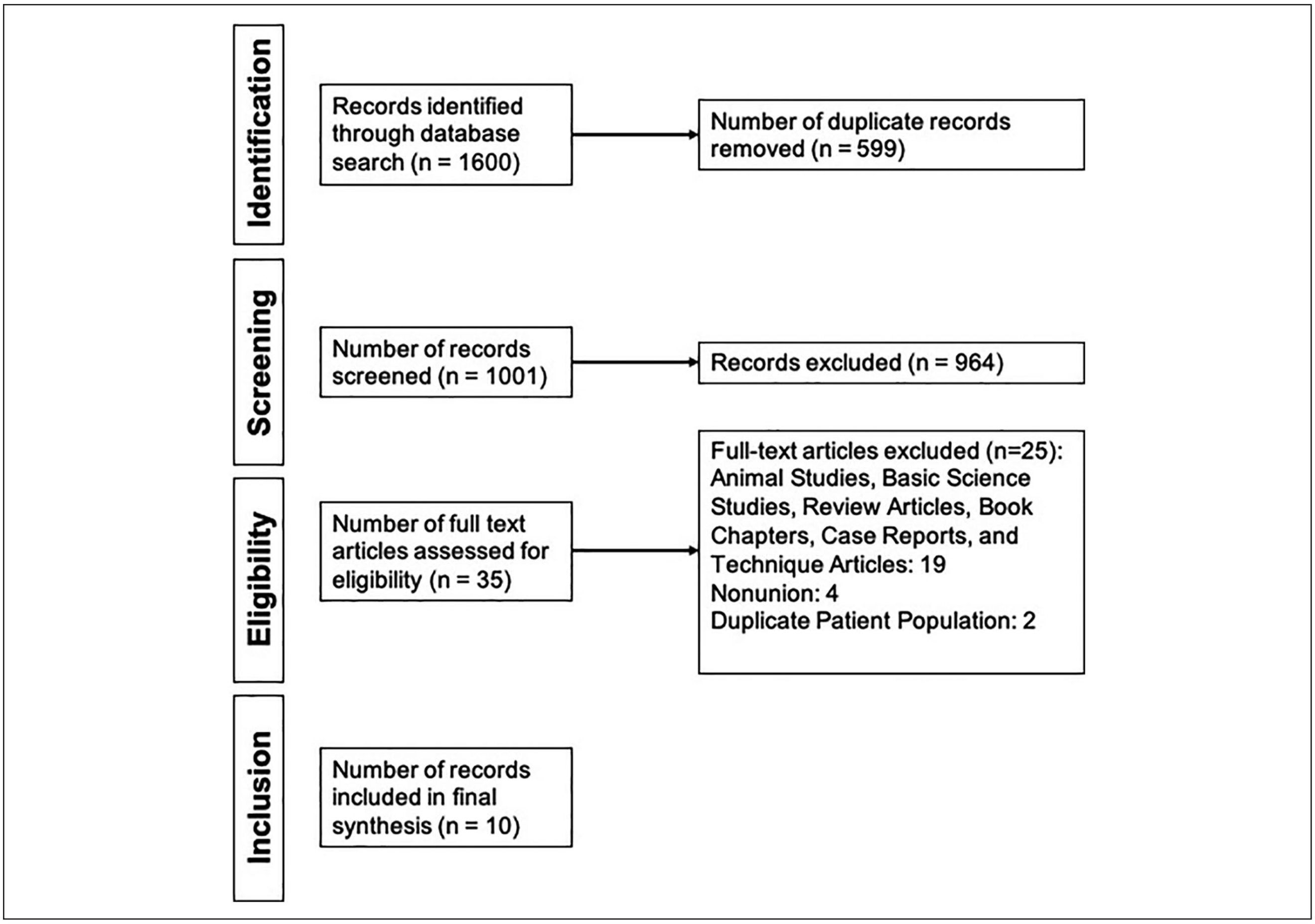

Figure 1. Flow diagram summarizing the literature search, screening, and review.

Table 1. Summary of Study Demographics.

Study	Level of evidence	MINORS	Study time frame	Malunions (n)	Mean age, y (range)	Sex (n)		Mean follow-up, mo (range)
						Male	Female	
Afshar et al[24]	Level IV	10	2008-2015	17	32 (22-45)	17	0	49 (20-75)
Amadio et al[20]	Level IV	10	1976-1984	26	20 (15-34)	26	0	63 (12-124)
El-Karef et al[25]	Level IV	10	NS	13	26 (21-36)	13	0	42 (20-120)
Forward et al[21]	Level IV	14	2001-2003	23	31 (15-61)	NS for malunion group		12 (12-13)
Gillette et al[26]	Level IV	9	1981-2001	17	29 (15-55)	14	3	40 (2.5-140)
Jiranek et al[27]	Level IV	10	1973-1984	13	22 (16-43)	13	0	132 (84-216)
Lee et al[28]	Level IV	10	2004-2008	15	30 (15-46)	14	1	84 (65-110)
Lynch and Linscheid[29]	Level IV	9	1972-1992	5	NS (19-25)	5	0	105 (18-228)
Nakamura et al[30]	Level IV	9	1982-1988	10	24 (13-57)	9	1	32 (12-84)
Seltser et al[17]	Level IV	11	2005-2013	22	41 (16-64)	18	4	88 (53-142)

Note. MINORS = Methodological Index for Non-Randomized Studies; NS = not specified.

(Table 2). Three articles[21,26,27] defined scaphoids as malunited if the LISA was >45°; 1 study[20] classified scaphoid malunions based on a LISA ≥35°; and 3 articles[12,21,28] defined malunion as a scaphoid H/L ratio >0.6. One article[24] considered scaphoids to be malunited if the measurements from imaging (H/L and LISA) were different from the contralateral side, and the remaining 3 studies[25,29,30] did not specify their metrics used to classify

Table 2. Summary of Criteria for Defining Scaphoid Malunion and Measurement Results.

				Measurements				
Study	Fracture location	How authors defined malunion	Imaging modality	H/L, mean ± SD (range)	H/L IRR	LISA (degrees) mean ± SD (range)	LISA IRR	Other, mean ± SD (range)
Afshar et al[24]	Middle 1/3	Measurements different from normal contralateral side	CT	0.74 ± 0.04	NS	34.8 ± 1.4	NS	DCA: 158.3 ± 4.8; APISA: 33.4 ± 0.2
Amadio et al[20]	Middle or proximal 1/3	LISA ≥ 35°	Trispiral tomography	NS	NS	46.7 ± 8.3 (35-69)	NS	RLA: 17.2 ± 11.6; SLA: 61.8 ± 12.1; CLA: 14.2 ± 12.4; APISA: 31.4 ± 9.8
El-Karef et al[25]	Waist	NS	CT	0.62 ± 0.02 (0.58-0.66)	NS	59 ± 6 (53-65)	NS	DCA: 139 (135-143); RLA: 16 (0-20); SLA: 60 (50-85); CLA: 20 (0-30)
Forward et al[21]	Waist	H/L > 0.6, LISA > 45°	CT	0.6 (0.47-0.72)	0.53	35 (6-72)	NS	DCA: 53 (16-78)
Gillette et al[26]	NS	LISA > 45°	CT	NS	NS	58 (55-75)	NS	NS
Jiranek et al[27]	Waist or proximal pole	LISA > 45°	CT	NS	NS	63 (47-87)	0.93	NS
Lee et al[28]	Waist or proximal pole	H/L > 0.6	CT	0.69 (0.6-0.83)	0.83	NS	NS	NS
Lynch and Linscheid[29]	Waist or proximal pole	Subjective, NS	XR	NS	NS	39 (16-43)	NS	RLA: 39 (16-43); SLA: 82 (68-85); CLA: 25 (20-40); APISA: 50 (38-55)
Nakamura et al[30]	Waist or distal 1/3	NS	XR	NS	NS	NS	NS	RLA: –12.7 (–28 to –22); SLA: 68 (38-89)
Seltser et al[17]	Waist, proximal, or distal pole	H/L > 0.6	CT	0.65	NS	NS	NS	NS

Note. H/L = height to length ratio; IRR = interrater reliability; LISA = lateral intrascaphoid angle; CT = computed tomography; XR = radiographs, NS = not specified; DCA = dorsal cortical angle; APISA = anterior-posterior intrascaphoid angle; RLA = radiolunate angle; SLA = scapholunate angle; CLA = capitolunate angle.

malunions (Table 2). Secondary imaging measurements reported included the DCA, APISA (anterior-posterior intrascaphoid angle), RLA, SLA, and CLA. These measurements were not used as a cutoff for malunion.

Outcomes collected were variable, with 4 studies[20,24,26,28] documenting patient-reported outcomes using the Mayo Wrist Score, 2 studies[21,28] with the DASH, and 2 studies[21,28] with the PEM. Grip strength was measured in all but 2[24,26] investigations and was either reported as a percentage of the contralateral side or in kilograms (kg). Four[21,24,26,28] out of 5 studies found no significant associations between patient outcomes and degree of scaphoid malunion measured on imaging, and 1 study[20] reported that increasing LISA was associated with decreased Mayo Wrist Scores (Table 3). Only 1 study[21] completed a sample size estimate prior to comparisons.

Discussion

The present investigation found that the most common measurements used in the literature to define a scaphoid malunion were a LISA of greater than 45° or an H/L ratio of greater than 0.6 based on CT imaging. However, studies rarely reported intrarater reliability or IRR for these measurements, and tools to evaluate patient outcomes varied widely among studies. In addition, all 10 studies included had poor methodologic quality, and only 1 study conducted a power analysis. As such, no consensus definition of scaphoid malunion could be ascertained based on these studies due to the lack of standardization for scaphoid malunion imaging and outcome measurements.

Measurements on imaging have focused on eliciting the degree of scaphoid flexion deformity. The LISA is defined as the angle formed from the intersection of lines that are perpendicular to the proximal and distal scaphoid articular surfaces.[20] Amadio et al[20] first described this measurement technique using trispiral tomography and established a normal LISA range based on measurements of 10 normal scaphoids. Out of 45 patients with healed scaphoid fractures, the authors classified 26 malunions based on a cutoff LISA of greater than 35°. Subsequent studies documenting LISA utilized a cutoff of greater than 45° to define scaphoid malunion.[21,26,27]

The other measurement that was commonly used among studies was the H/L ratio, which is measured by CT, using the most central sagittal slice. To measure the H/L ratio, a volar baseline is drawn, with the height calculated by measuring the maximum height perpendicular to the baseline and the length represented by the distance between the distal and proximal poles along the baseline.[19] Bain et al[19] first introduced the H/L ratio as a method to measure scaphoid humpback deformity on CT, and the authors derived a normal cutoff value of less than 0.6 based on the finding that the mean H/L ratio for normal scaphoids was 0.597 ± 0.042. As such, most of the studies included in the current review that measured H/L ratio used a cutoff value of 0.6 to classify malunions.[12,21,28] Kim et al[31] further investigated the relationship between degree of scaphoid deformity with dorsal intercalated segmental instability (DISI) by correlating the scaphoid H/L ratio with the RLA, and the authors found that DISI can occur if the H/L ratio is greater than 0.73.

Although both the LISA and H/L ratio cutoff values are derived from imaging studies of normal scaphoids, there still exists variability in selecting the central slice and measuring between observers and within observers. In a study examining the intraobserver and interobserver reliabilities for measuring the LISA and H/L ratio on CT, it was found that the H/L ratio had the best intrarater reliability and IRR, whereas the intraobserver and interobserver reliabilities for the LISA were poor.[19] Yet, variations in reliability are seen across the 3 studies in this review that calculated reliability. Jiranek et al[27] reported an interobserver reliability of 0.93 for the LISA, indicating good reliability, although their calculation was based on the percentage of total variability, not with the kappa statistic. Forward et al[21] calculated an IRR of 0.53 and intrarater reliability of 0.65 for the H/L ratio, whereas Lee et al[28] found a higher H/L IRR of 0.83. As the observer reliability differed substantially between studies, subsequent studies on scaphoid malunion imaging should continue to report these reliability measurements.

Little is known about how scaphoid malunion affects wrist joint mechanics and clinical outcomes. In a cadaveric study, Burgess[32] concluded that increased scaphoid angular deformity resulted in loss of wrist extension. However, the majority of studies included in the present review did not find significant differences in wrist range of motion between scaphoid malunion and normal union groups.[12,21,28] Similarly, no relationship between grip strength and H/L ratio was reported.[12,21,28] Due to the lack of sample size calculations, it is unknown if these relationships hold true, or if the studies were adequately powered to detect differences in clinically significant functional or patient-reported outcomes.

Chambers et al[33] recently conducted a computational simulation of scaphoid malunions with varying degrees of distal pole angulation and found that greater deformity was associated with a significantly increased amount of radioscaphoid joint contact. However, the clinical manifestations of the increased joint contact have not been determined. It has been hypothesized that the altered carpal mechanics due to scaphoid malunion humpback deformity can lead to posttraumatic osteoarthritis and decreased outcomes. Amadio et al[20] found that 54% of patients with a LISA $>$ 45° had radiographic evidence of posttraumatic osteoarthritis, compared with only 22% whose scaphoid fractures healed without malunion. Furthermore, significantly fewer patients with scaphoid malunion had satisfactory patient-reported outcomes as measured by the Mayo Wrist Score compared with patients with normal scaphoid union.

Table 3. Overview of Patient-Reported Outcomes and Functional Outcomes After Scaphoid Malunion Reported by Each Study.

	Patient-reported outcomes, mean + SD (range)		Functional outcomes, mean (range)			
			Grip strength			
Study	Upper extremity/Hand questionnaires	VAS	% contralateral	kg	Wrist flexion (degrees)	Wrist extension (degrees)
Afshar et al[24]	Mayo: 83 + 4	0 (0-7)	NS	NS	NS	NS
Amadio et al[20]	Mayo: 80.4 + 14.1[a]	NS	76 (24-132)	NS	NS	NS
El-Karef et al[25]	NS	NS	47 (32-73)	19 (13-30)	NS	NS
Forward et al[21]	DASH: 5 (1-10); PEM: 7 (3-12)	0 (0-2)[a] out of 6	95 (88-100)	NS	NS	74 (70-79)
Gillette et al[26]	Mayo: 55.3 (25-85)	NS	NS	NS	NS	NS
Jiranek et al[27]	Subjective rating scale: 85 (26-100)	NS	76 (65-100)	NS	NS	NS
Lee et al[28]	Mayo: 90.3 (70-100); DASH: 2.8 (0-6.9); PEM: 17.5 (14-32)	1.2 (0-4)	99 (65-110)	45.8 (35-52)	72.3 (60-80)	67 (45-75)
Lynch and Linscheid[29]	NS	NS	NS	16 (14-35)	47 (25-85)	35 (25-47)
Nakamura et al[30]	NS	NS	NS	24.6 (15-47)	Flexion-extension: 98.3 (42-171)	
Seltser et al[17]	NS	NS	94	41.7 (17.3-61.6)	63.4 (20-90)	61.9 (25-84)

Note. VAS = Visual Analog Scale; kg = kilograms; Mayo = Mayo Wrist Score; NS = not specified; DASH = Disabilities of the Arm, Shoulder, and Hand; PEM = Patient Evaluation Measure.
[a]Significant difference between normal scaphoid outcomes.

Seltser et al[12] recently reported that nearly half of patients with scaphoid malunion had evidence of early arthritis on CT, although no differences were detected in patient-reported outcomes compared with the unaffected side. Most other studies have not found correlations between degree of malunion and patient outcomes.[21,24,26,28] Outcome measures varied and future studies should strive to use more standardized, validating outcome measures that focus on patient-reported outcomes or outcomes that matter to patients.

There are several limitations noted among the studies included in this review. The study design resulted in the analysis of relatively few studies (10 studies) and few patients (161 patients). All of the articles included in this review were level IV, limiting the strength of the conclusions. The study methodological quality, as assessed by the MINORS, was poor on average. These limitations reflect the underlying limitations of the literature on this topic with no comparative studies. Due to the variability in reporting of type of measurement and type of patient-reported outcome used in each study, comparisons of these data could not be made. In addition, no studies examined malunion following proximal pole scaphoid fracture exclusively, as most malunions in the included studies occurred after scaphoid waist fractures. As such, we did not subdivide malunions by fracture classification type, although there may be differences in malunion measurement on imaging based on the fracture location. Furthermore, studies were only included if they reported quantitative measurements on imaging to guide diagnosis of scaphoid malunions. Acceptable parameters for fracture displacement can be guided by evidence that identifies a threshold of displacement that may lead to function limitations. For example, humeral shaft, clavicular, distal ulna, and boxer's fractures have evidence to guide their treatment based on measures supporting limitations secondary to displacement. The clinical implication of a bone healing in a nonanatomic position, or "malunion," varies by bone and the clinical scenario. For example, shortening, loss of volar angulation, and loss of radial inclination in distal radius fractures may lead to functional deficits in an active 20-year-old, but not in an infirm 65-year-old. As such, there is potential for malunion to be defined based on patient outcomes rather than solely relying on imaging measurements.

The results of this study show the lack of consensus for defining scaphoid malunion on imaging and absence of correlation between findings on imaging and patient outcomes. While we cannot comment on which modality, imaging parameters, and so on are superior to measure scaphoid malunion (as head-to-head studies are limited), this lack of consensus may be improved upon with further investigation and standardization of malunion measurement. For example, investigators could evaluate LISA and H/L at 6 months as continuous variables using CT scans and correlate this or find a threshold after which Quick Disabilities of the Arm, Shoulder, and Hand (QuickDASH) scores reach a minimal clinically important difference from preinjury to postinjury or surgery. The authors recommend that future studies of scaphoid malunion should be appropriately powered, incorporate measures of intrarater reliability and IRR for all reported imaging measurements, and utilize validated patient-reported outcome measures to assess whether fracture displacement or angulation is associated with outcomes meaningful to patients.

Authors' Note

The content of this work is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health (NIH) or the Orthopaedic Research and Education Foundation (OREF).

Ethical Approval

The authors have complied with the ethical standards as detailed in "Instructions to the Author" set forth by *HAND*.

Statement of Human and Animal Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

Statement of Informed Consent

Informed consent was not obtained from patients given the nature of this investigation.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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