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Scaphoid fractures: anatomy, diagnosis and treatment

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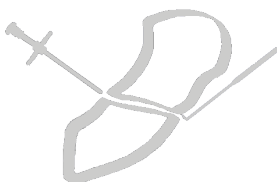
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Chapter

6

Diagnostic performance of radiographs and computed tomography for displacement and instability of acute scaphoid waist fractures

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J Bone Joint Surg-Am., in press.

Abstract

Background Fracture displacement is the most important factor associated with nonunion of a scaphoid waist fracture. We evaluated the performance characteristics of radiographs and computed tomography (CT) in diagnosing intra-operative displacement and instability of scaphoid waist fractures using wrist arthroscopy as the reference standard.

Methods During a 6-year period (2004-2010) at two institutions, 44 adult patients with a scaphoid waist fracture underwent arthroscopy-assisted operative fracture treatment a mean of 9 days after injury (range, 2 to 22 days). Subjects included all of those with radiographically displaced scaphoid fractures and a selection of nondisplaced scaphoid fractures (patients who preferred to avoid cast immobilization or who were randomized to this treatment as part of another study). All patients had pre-operative radiographs and CT. Arthroscopy with up to 5kg of traction was the reference standard for fracture displacement (fragments out of position) and instability (fragments could be moved out of position with gentle manipulation).

Results The reference standard (arthroscopy) diagnosed 22 displaced fractures (all unstable) and 22 nondisplaced fractures (7 unstable). Displacement was diagnosed on radiographs in 11 patients (25%) and on CT in 20 (45%). The sensitivity, specificity, and accuracy for diagnosing intra-operative displacement were 45%, 95%, and 70%, respectively, for radiographs and 77%, 86%, and 82%, respectively, for CT. The sensitivity, specificity, and accuracy for diagnosing intra-operative instability were 34%, 93%, and 55%, respectively, for radiographs and 62%, 87%, and 70%, respectively, for CT. Assuming a 10% prevalence of fracture displacement and instability among all scaphoid waist fractures, the positive and negative predictive values for displacement were 53% and 16%-->94% respectively for radiographs, and 39% and 30%-->97% for CT, and for instability were 36% and 14%-->93% respectively for radiographs, and 34% and 20% for CT.

Conclusions Radiographs and CT scans cannot be relied upon to accurately diagnose intra-operative fracture displacement or instability, compared with arthroscopic examination. The influence of intra-operative instability on a radiologically nondisplaced fracture with regard to the risk of nonunion is currently unknown.

Introduction

Factors associated with nonunion of a scaphoid waist fracture include delay in diagnosis and treatment and—importantly—fracture displacement.¹⁻⁵ Some studies have used radiological techniques to diagnose displacement, but none have used direct intraoperative visualization.¹⁻⁴ We set out to study whether radiological displacement corresponds with fracture instability,^{6,7} as suggested by the classification of Herbert and Fisher which considers complete fractures of the waist as unstable (type B) and incomplete “crack” fractures of the waist as stable (type A).⁸ The fracture pattern influences stability (comminuted fractures are unstable) but the orientation of the fracture (oblique vs. transverse) does not.⁸

The addition of arthroscopy to percutaneous screw fixation allows for assessment of both malalignment (displacement) and movability of the fracture (instability), visualization of fracture reduction and screw implantation, and evaluation of concurrent ligament injuries.⁹⁻¹¹ Arthroscopy is presumed to provide the reference standard for the diagnosis of displacement and instability.^{12,13}

This prospective study evaluated the sensitivity, specificity and accuracy as well as prevalence-adjusted positive predictive value (PPV) and negative predictive value (NPV) of radiographs and computed tomography in diagnosing intra-operative displacement and instability of scaphoid waist fractures using arthroscopy as the reference standard. We tested the null hypothesis that the diagnostic performance characteristics of radiographs and computed tomography are equal to each other.

Materials and Methods

This study was designed and reported according to the QUADAS (Quality Assessment of Diagnostic Accuracy Studies) guidelines¹⁴ (Table 1). Our respective Institutional Review Boards approved the study and all patients gave written informed consent.

Patients

During a 3-year period (2004-2007) at one institution (Skåne University Hospital, Malmö, Sweden) and a 4-year period (2006-2010) at the other institution (Massachusetts General Hospital, Boston, USA), all adult patients (age 18 years or greater) with an isolated fracture of the scaphoid (irrespective of fracture displacement and location), without a history of trauma to the affected wrist prior to the event leading to the diagnosis of a scaphoid fracture who elected operative treatment were invited to enroll in a prospective scaphoid study and were asked for permission to enter their data in a prospective database. The prospective cohort of operated patients consisted of all radiologically displaced scaphoid fractures (based on radiographs and CT) and a selection



TABLE 1 QUADAS* guidelines	
Characteristic	Motivation
1. Was the spectrum of patients representative of the patients who will receive the test in practice?	No. We included patients who elected surgical treatment based on a doctor's recommendation (displaced fractures) or personal preference in order avoid cast immobilization. Therefore, there are relatively more patients with a displaced fracture in this cohort.
2. Were selection criteria clearly described?	Yes.
3. Is the reference standard likely to correctly classify the target condition?	Yes. Even though there is no gold standard, arthroscopy is arguably the most accurate reference standard available.
4. Is the time period between reference standard and index test short enough to be reasonably sure that the target condition did not change between the two tests?	Yes. On average there was less than a week time between the radiographic tests and the arthroscopy. During this period, the wrist was immobilized in a thumb-spica cast.
5. Did the whole sample or a random selection of the sample receive verification using a reference standard of diagnosis?	Yes.
6. Did patients receive the same reference standard regardless of the index result?	Yes.
7. Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)?	Yes.
8. Was the execution of the index test described in sufficient detail to permit replication of the test?	Yes.
9. Was the execution of the reference standard described in sufficient detail to permit its replication?	Yes.
10. Were the index test results interpreted without knowledge of the results of the reference standard?	Yes.
11. Were the reference standard results interpreted without knowledge of the results of the index test?	No. The treating physician had knowledge of the index test results during arthroscopy.
12. Were the same clinical data available when test results were interpreted as would be available when the test is used in practice?	Yes.
13. Were uninterpretable/intermediate test results reported?	Not applicable. There were no uninterpretable test results.
14. Were withdrawals from the study explained?	Yes. Under exclusion criteria.

*This study was reported according to the QUADAS (Quality Assessment of Diagnostic Accuracy Studies) guidelines

of nondisplaced scaphoid fractures based on preference to avoid cast immobilization (both institutions) or on randomization as part of another study (one institution). For purposes of this diagnostic study, we excluded patients with fractures of the proximal or distal third of the scaphoid or any associated ipsilateral perilunate injuries apparent on radiographs, and patients with a surgical delay of more than 4 weeks after injury.

Fifty-eight patients (Malmö n=43 patients, Boston n=15 patients) gave permission to enter their data in the prospective database at one of the two institutions. Fourteen patients from this database were excluded from this study because they had a fracture of either the proximal or distal third of the scaphoid (6 patients), had a surgical delay of more than 4 weeks (7 patients), or did not have computed tomography (1 patient). Forty-four patients were treated by arthroscopy-assisted surgery within a mean of 9 days after injury (range, 2 to 22 days) and had pre-operative radiographs and computed tomography. There were 32 males and 12 females, with a mean age of 34 years (range, 18 to 68 years).

Imaging Protocols

Radiographs of the wrist were obtained with at least 4 views of the scaphoid: posteroanterior, lateral, posteroanterior with ulnar deviation, and oblique with 45° of pronation. Scaphopisocapitate alignment was not controlled in this study.¹⁵ Additionally, all patients had computed tomography of the wrist with reconstructions in the coronal and sagittal planes defined by the long axis of the scaphoid. All radiological examinations were evaluated by a musculoskeletal radiologist and the treating physician in order to reach consensus on fracture location (proximal, middle, or distal third of the bone), and displacement (either gapping and/or translation >1mm or dorsal tilting of the lunate of >15° with respect to the radius on a true lateral radiograph with the third metacarpal parallel to the radius).¹⁶ On static imaging (radiographs and CT), nondisplaced fractures were defined as stable and displaced fractures as unstable.^{6,7}

Surgical procedure

Arthroscopy was performed under brachial plexus block or general anesthesia with a tourniquet on the upper arm and the hand in a vertical traction tower. Using finger traps on the index and long fingers, up to 5 kg of traction was applied. A 1.9-mm or 2.7-mm arthroscope was used, sometimes in combination with a motorized shaver to clear the joint of blood, debris, and synovitis. At one institution, the standard 3–4 and 4–5 intercompartmental portals and the 6R (radial) and 6U (ulnar) on each side of the sixth compartment were used in the radiocarpal joint and at the other just the 3-4 portal was used because the scaphoid fracture can rarely be seen in the radiocarpal joint. In the midcarpal joint, the standard radial and ulnar portals were used and,



in some cases, supplemented with the scaphotrapeziotrapezoid joint portal; no volar portals were used. A small image intensifier was used in all procedures. The surgical procedures were performed by one surgeon in one institution and 3 surgeons in the other institution.

Data from both institutions were collected in prospective cohort studies where the following definitions were consistently applied. During operative visualization of the fracture, static malalignment (gapping, translation, angulation of the fracture) was defined as intra-operative displacement. Intra-operative instability was diagnosed if there was movement of the fracture fragments with gentle manipulation of the bone by applying external pressure on the proximal or the distal pole of the scaphoid, by deviating the wrist in radial and ulnar direction, or by inserting a probe between the fracture fragments (Figures 1 and 2). In other words, a fracture was diagnosed as displaced when the fragments were out of position, and a fracture was diagnosed as unstable when the fragments could be moved out of position.

Statistical analysis

The sensitivity, specificity, and accuracy for the diagnosis of intra-operative displacement and instability of scaphoid waist fractures with radiographs and with CT were calculated according to standard formulas with 95% confidence intervals constructed with use of Pratt's normal approximation method for binomial proportions.¹⁷ The significance of differences was evaluated with use of the McNemar's test for paired binary data for each imaging modality.¹⁸ The positive predictive value (PPV) and negative predictive value were determined with use of Bayes' theorem, which requires an a priori estimate of the prevalence (pretest probability) of the presence of scaphoid fractures.¹⁹ The predictive values of any imaging modality depend critically on the prevalence of the characteristic in the patients being tested; hence the use of the appropriate Bayesian analysis is important. For the determination of positive and negative predictive values, we estimated an average prevalence of 10% of fracture displacement and instability among all scaphoid waist fractures.²⁰ The positive predictive value was calculated as: $[\text{sensitivity} \times \text{prevalence}] / [(\text{sensitivity} \times \text{prevalence}) + (1 - \text{specificity}) \times (1 - \text{prevalence})]$, and the negative predictive value was calculated as: $[\text{specificity} \times (1 - \text{prevalence})] / [\text{specificity} \times (1 - \text{prevalence}) + (1 - \text{sensitivity}) \times \text{prevalence}]$.^{19,21}

Statistical analysis and power analysis were performed to establish the number of patients required for comparing diagnostic performance characteristics (sensitivity, specificity, accuracy, positive predictive value, and negative predictive value) between radiographs and computed tomography. Using McNemar's test of equality of paired proportions,²² a sample size of 37 patients provided 90% power ($\alpha = 0.05$, $\beta = 0.10$) to detect significant differences in proportions of 20% in each performance characteristic

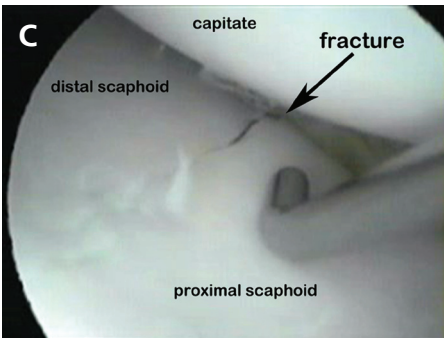
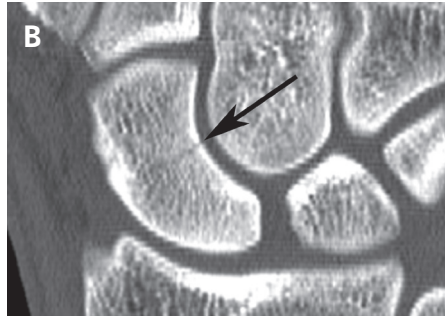
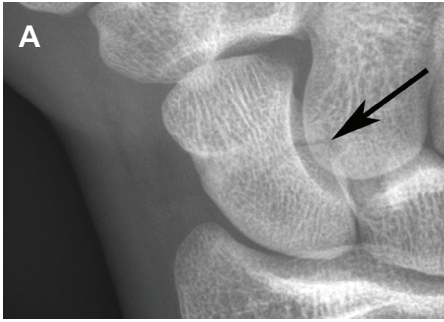


Figure 1. **A** Radiograph showing a nondisplaced scaphoid waist fracture (arrow). **B** CT reconstruction in the coronal plane of the long axis of the scaphoid showing the same nondisplaced scaphoid waist fracture (arrow). **C** Arthroscopic image of the same wrist showing an intra-operatively nondisplaced and stable fracture (arrow). The tip of the probe is gently pressed against the proximal fragment.

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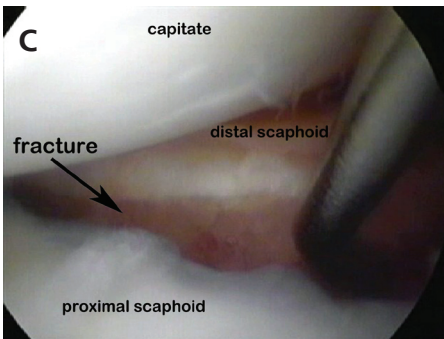



Figure 2. **A** Radiograph showing a nondisplaced scaphoid waist fracture (arrow). **B** CT reconstruction in the coronal plane of the long axis of the scaphoid showing the same nondisplaced scaphoid waist fracture (arrow). **C** Arthroscopic image of the same wrist showing an intra-operatively nondisplaced and unstable fracture (arrow). The tip of the probe is gently pressed against the distal fragment to open up the fracture gap.

between the two imaging protocols with use of a two-sided significance at the level of 0.05.

Source of Funding

Financial support was received from the Netherlands Organisation for Scientific Research (NWO) and by grants from Region Skåne and Skåne University Hospital Foundation, Sweden.

Results

According to the reference standard (arthroscopy), 22 fractures were intra-operatively displaced and 29 were intra-operatively unstable (50% and 66% of all fractures, respectively). Displacement was diagnosed on radiographs in 11 patients (25%) and on CT scans in 20 patients (45%). The performance characteristics of radiographs and CT for the diagnosis of intra-operative displacement of a scaphoid waist fracture are summarized in Tables 2 and 3 and for intra-operative instability in Tables 4 and 5. CT was significantly more accurate than radiographs at determining intra-operative fracture displacement ($p < 0.05$) and instability ($p < 0.05$).

Among the intra-operatively stable fractures there was one partial fracture (i.e. not completely through the circumference of the scaphoid). Of the 29 intra-operatively unstable fractures, 7 fractures were intra-operatively nondisplaced and appeared stable before provocation of inter-fragmentary motion. All of these 7 fractures were considered nondisplaced on radiographs and all but one fracture was considered nondisplaced on CT. All intra-operatively displaced fractures were unstable.

Discussion

During the arthroscopic evaluation of scaphoid waist fractures, we found that radiographs and computed tomography did not accurately identify fracture displacement and instability found on arthroscopic evaluation. Our null hypothesis that radiographs and CT have the same performance characteristics for diagnosing intra-operative displacement and instability assessed by arthroscopy was rejected as CT proved significantly more accurate.

The findings of the present study should be interpreted in light of several potential shortcomings. First, there was the effect of selection bias for inclusion/exclusion of patients (spectrum bias) as radiographically displaced fractures were over represented compared to most series (50% vs. 10-30%).^{2-4,20} Second, the arthroscopic procedure typically uses up to 5 kilograms of traction on two digits using finger traps. The effect

TABLE 2. Results of displacement on radiographs compared to the reference standard (arthroscopy) for fracture displacement.

	Radiographs		Total
	Displacement	No displacement	
Displaced fracture	10	12	22
Arthroscopy			
Non-displaced fracture	1	21	22
Total	11	33	44
Diagnostic Performance Characteristics			
Sensitivity:	$10 / 10 + 12 = 45\%^*$		
*The proportion of patients with a displaced scaphoid fracture according to the reference standard (arthroscopy) classified as having a displaced scaphoid fracture on radiographs (true positives)			
Specificity:	$21 / 21 + 1 = 95\%^{**}$		
**The proportion of patients with a non-displaced scaphoid fracture according to the reference standard (arthroscopy) classified as having a non-displaced scaphoid fracture on radiographs (true negatives)			
Accuracy:	$10 + 21 / 10 + 12 + 1 + 21 = 70\%^{***}$		
***The proportion of patients who are correctly classified on radiographs			
Positive Predictive Value (PPV)	$10 / 10 + 1 = 91\%^\dagger$		
\dagger The probability that a patient with a displaced scaphoid fracture on radiographs has a displaced scaphoid fracture			
PPV accounting for prevalence and incidence: $[45\% \times 10\%] / [(45\% \times 10\%) + (100\% - 95\%) \times (100\% - 10\%)] = 53\%$			
Negative Predictive Value (NPV)	$21 / 21 + 12 = 64\%^{\dagger\dagger}$		
$\dagger\dagger$ The probability that a patient with non-displaced scaphoid fracture on radiographs has a non-displaced scaphoid fracture			
NPV accounting for prevalence and incidence: $[95\% \times (100\% - 10\%)] / [95\% \times (100\% - 10\%) + (100\% - 45\%) \times 10\%] = 94\%$			

of this traction on fracture alignment and instability are unknown, but it might have a small risk of destabilizing the fracture. In other words, there may be a subset of nondisplaced fractures that although stable when not manipulated, are potentially unstable when manipulated during arthroscopy and are therefore classified as unstable by our criteria. The results pertain only to our specific definition of instability. Third, all of the intra-operative diagnoses are somewhat subjective with an inherent risk of limited reliability and furthermore, they were performed by four different surgeons in two centers. Although instability was defined, the validity of this definition is open to debate because of the use of qualitative terms like “gentle” and “external pressure” which are, in themselves, hard to define. Finally, if arthroscopy is more accurate than imaging, then the usefulness of imaging is appropriately estimated by this analysis.



TABLE 3 Results of displacement on CT compared to the reference standard (arthroscopy) for fracture displacement.			
	CT		Total
	Displacement	No displacement	
Displaced fracture	17	5	22
Arthroscopy			
Non-displaced fracture	3	19	22
Total	20	24	44
Diagnostic Performance Characteristics			
Sensitivity:	17 / 17 + 5 = 77%*		
*The proportion of patients with a displaced scaphoid fracture according to the reference standard (arthroscopy) classified as having a displaced scaphoid fracture on CT (true positives)			
Specificity:	19 / 19 + 3 = 86%**		
** The proportion of patients with a non-displaced scaphoid fracture according to the reference standard (arthroscopy) classified as having a non-displaced scaphoid fracture on CT (true negatives)			
Accuracy:	17 + 19 / 17 + 19 + 5 + 3 = 82%***		
***The proportion of patients correctly classified on CT			
Positive Predictive Value (PPV)	17 / 17 + 3 = 85% †		
† The probability that a patient with a displaced scaphoid fracture on CT has an displaced scaphoid fracture			
PPV accounting for prevalence and incidence: $[77\% \times 10\%] / [(77\% \times 10\%) + (100\% - 86\%) \times (100\% - 10\%)] = \mathbf{39\%}$			
Negative Predictive Value (NPV)	19 / 19 + 5 = 79% ††		
†† The probability that a patient with non-displaced scaphoid fracture on CT has a non-displaced scaphoid fracture			
NPV accounting for prevalence and incidence: $[86\% \times (100\% - 10\%)] / [86\% \times (100\% - 10\%) + (100\% - 77\%) \times 10\%] = \mathbf{97\%}$			

For displacement and instability, it's unclear what will be a better reference standard than direct inspection and manipulation, but our data should be interpreted in light of the fact that arthroscopy may not be a perfect reference standard. For example, there was an excluded nondisplaced distal third fracture that did not disrupt the cartilage and was not detectable by arthroscopy. In addition, the manipulation necessary to distract the joint and enter the wrist may change the fracture. The imperfection of the reference standard and the spectrum bias may both overstate the gap between radiological displacement and intra-operative instability.

In the current study, radiographs and CT scans were much more specific than they were sensitive. Nonetheless, the positive predictive values of both modalities are low and the negative predictive values of both modalities are high, primarily because the prevalence of displaced fractures among all scaphoid fractures is low.¹⁻⁴ These

TABLE 4 Results of displacement on radiographs compared to the arthroscopic reference standard for fracture instability.

	Radiographs		Total
	Displacement	No displacement	
Unstable fracture	10	19	29
Arthroscopy			
Stable fracture	1	14	15
Total	11	33	44
Diagnostic Performance Characteristics			
Sensitivity:	10 / 10 + 19 = 34%*		
*The proportion of patients with an unstable scaphoid fracture according to the reference standard (arthroscopy) classified as having a displaced scaphoid fracture on radiographs (true positives)			
Specificity:	14 / 1 + 14 = 93%**		
**The proportion of patients with a stable scaphoid fracture according to the reference standard (arthroscopy) classified as having a non-displaced scaphoid fracture on radiographs (true negatives)			
Accuracy:	10 + 14 / 10 + 19 + 1 + 14 = 55%***		
***The proportion of patients who are correctly classified on radiographs			
Positive Predictive Value (PPV)	10 / 10 + 1 = 91% †		
† The probability that a patient with a displaced scaphoid fracture on radiographs has an unstable scaphoid fracture			
PPV accounting for prevalence and incidence: $[34\% \times 10\%] / [(34\% \times 10\%) + (100\% - 93\%) \times (100\% - 10\%)] = \mathbf{36\%}$			
Negative Predictive Value (NPV)	14 / 14 + 19 = 42% ††		
††The probability that a patient with non-displaced scaphoid fracture on radiographs has a stable scaphoid fracture			
NPV accounting for prevalence and incidence: $[93\% \times (100\% - 10\%)] / [93\% \times (100\% - 10\%) + (100\% - 34\%) \times 10\%] = \mathbf{93\%}$			

predictive values mean that test results do not provide certainties in clinical practice, and we need to discuss the probability rather than the certainty of displacement with our patients.

Several studies have addressed instability among scaphoid nonunions.²³⁻²⁶ One study showed a relationship between the location of the nonunion and instability of the fragments.²⁵ To our knowledge, no previous clinical study has investigated arthroscopically the potential instability of an acute scaphoid fracture, which can only be diagnosed with dynamic imaging studies or with intra-operative visualization. The present study shows that intra-operatively all displaced fractures were unstable. It also shows that 7 of 19 false negative radiographic diagnoses of instability (37% nondisplaced fractures on radiographs which were arthroscopically unstable) and 6 of 11 false negative CT diagnoses of instability (55%; nondisplaced fractures on



TABLE 5 Results of displacement on CT compared to the reference standard (arthroscopy) for fracture instability			
	CT		Total
	Displacement	No displacement	
Unstable fracture	18	11	29
Arthroscopy			
Stable fracture	2	13	15
Total	20	24	44
Diagnostic Performance Characteristics			
Sensitivity:	18 / 18 + 11 = 62%*		
*The proportion of patients with an unstable scaphoid fracture according to the reference standard (arthroscopy) classified as having a displaced scaphoid fracture on CT (true positives)			
Specificity:	13 / 13 + 2 = 87%**		
** The proportion of patients with a stable scaphoid fracture according to the reference standard (arthroscopy) classified as having a non-displaced scaphoid fracture on CT (true negatives)			
Accuracy:	18 + 13 / 18 + 11 + 2 + 13 = 70%***		
***The proportion of patients correctly classified on CT			
Positive Predictive Value (PPV)	18 / 18 + 2 = 90% †		
† The probability that a patient with a displaced scaphoid fracture on CT has an unstable scaphoid fracture			
PPV accounting for prevalence and incidence: $[62\% \times 10\%] / [(62\% \times 10\%) + (100\% - 87\%) \times (100\% - 10\%)] = \mathbf{34\%}$			
Negative Predictive Value (NPV)	13 / 13 + 11 = 54% ††		
†† The probability that a patient with non-displaced scaphoid fracture on CT has a stable scaphoid fracture			
NPV accounting for prevalence and incidence: $[87\% \times (100\% - 10\%)] / [87\% \times (100\% - 10\%) + (100\% - 62\%) \times 10\%] = \mathbf{95\%}$			

CT which were arthroscopically unstable) showed no malalignment of the fracture upon introduction of the arthroscope but were unstable upon probing. In other words, scaphoid fractures can be statically nondisplaced in neutral wrist position but dynamically displaceable when the fragments are gently manipulated and with 5kg distraction force applied.

These findings raise new questions regarding the concepts of displacement and instability of acute scaphoid fractures. The data suggest that we should no longer use the terms nondisplaced (defined by alignment on radiography, CT, and even intra-operative visualization) and stable interchangeably.^{7,27-30} Among patients in this cohort with arthroscopically unstable fractures only 62% had malalignment on CT. The influence of fracture instability on the risk of nonunion is currently unknown. If previous studies of conservative treatment for radiographically nondisplaced acute scaphoid

waist fractures had similar percentages of unstable fractures, then one would assume that the majority of unstable fractures heal.^{27,31-33} On the other hand, our data set is subject to spectrum bias and an alternative explanation is that the approximately 10% nonunions observed in prior series represent the subset of patients with malalignment or instability, which may have much higher rates of healing problems.

Considered in the light of the study's shortcomings, we conclude that radiographs or CT scans do not accurately diagnose intra-operative fracture displacement and instability of acute scaphoid waist fractures. We do not feel this study should alter management. Only a study that demonstrates improved outcomes with routine CT or arthroscopy should change management. This study advances understanding of scaphoid fractures and helps clarify the questions we need to ask to optimize management. About 5-10% of scaphoid waist fractures are displaced.²⁰ This study shows that CT and arthroscopy better define the probability that there is displacement or instability. We do not know if instability of a fracture that is not displaced on radiographs is associated with adverse outcomes, nor do we know if routine CT or arthroscopy improves management. Fracture displacement is a known risk factor for nonunion, but additional research is necessary to determine the relationship between fracture instability and nonunion.



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