

# Computed Tomography of Suspected Scaphoid Fractures

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**Purpose:** Computed tomography (CT) can be used to triage suspected scaphoid fractures. This study assessed intraobserver and interobserver reliability and positive and negative predictive values of CT for the diagnosis of a nondisplaced scaphoid fracture.

**Methods:** Eight observers evaluated CT scans from 30 patients (13 with nondisplaced scaphoid fractures, 17 with no scaphoid fractures) for the presence or absence of a fracture. Five observers evaluated the scans a second time. Statistical analyses included intraobserver and interobserver reliability and diagnostic characteristics.

**Results:** Computed tomography had substantial intraobserver and interobserver reliability for the diagnosis of a nondisplaced scaphoid fracture. The average sensitivity, specificity, and accuracy of CT for a nondisplaced scaphoid fracture were 89%, 91%, and 90% for the first round and 97%, 85%, and 88% for the second round of observations, respectively. Based on an estimated prevalence of 5% true fractures among patients with suspected scaphoid fractures, the average positive predictive value for the detection of radiographically occult scaphoid fractures with tomography of the wrist was 0.28. The average negative predictive value was 0.99.

**Conclusions:** Computed tomography should be used with caution for triage of nondisplaced scaphoid fractures because false-positive results occur, perhaps from misinterpretation of vascular foraminae or other normal lines in the scaphoid. Given the relative infrequency of true fractures among patients with suspected scaphoid fractures, CT is better for ruling out a fracture than for ruling one in. (*J Hand Surg* 2007;32A:61–66. Copyright © 2007 by the American Society for Surgery of the Hand.)

**Key words:** Suspected scaphoid fracture, diagnosis, computed tomography.

Radiographically occult scaphoid fractures can fail to unite if not protected adequately.<sup>1–4</sup> The alternatives for the investigation of suspected scaphoid fractures include repeat examination and radiographs 2 weeks after injury,<sup>5</sup> bone scan,<sup>6</sup> magnetic resonance imaging (MRI),<sup>7</sup> and computed tomography (CT); however, the data regarding CT are quite limited.<sup>1,8–11</sup> Computed tomography is used in many centers, particularly in Europe, and is appealing because it is less costly and more readily available than MRI. This study was designed to assess intraobserver and interobserver reliability and positive predictive values (PPVs) and negative predictive values (NPVs) of CT for the diagnosis of a nondisplaced scaphoid fracture.

## Materials and Methods

Computed tomography scans of the scaphoid were obtained in 30 patients as part of 1 of 2 institutional review board–approved protocols. Computed tomography scans of the scaphoid were obtained for 13 patients with radiographically visible fractures enrolled in a clinical trial of surgical versus nonsurgical treatment of nondisplaced fractures of the scaphoid waist. These 13 CT scans confirmed nondisplaced scaphoid waist fractures. Computed tomography scans of the scaphoid obtained in 17 patients with radial-sided wrist pain and tenderness after a fall onto the outstretched hand were obtained from a prospective cohort study of patients with suspected scaphoid

fractures. These 17 patients had normal radiographs of the scaphoid both at the time of the injury and 6 weeks after the injury, and their CT scans therefore were defined as documenting that the scaphoids were not fractured. There were 19 men and 11 women with an average age of 33 years (range, 19–57 y). None of these patients had MRI scans performed of the scaphoid.

The CT scans were obtained with a scanner (GE Lightspeed Qx/i CT Scanner; GE Medical Systems, Pewaukee, WI), using the technique described by Sanders.<sup>8</sup> According to this technique, the patient lies prone on the table with the arm overhead and the forearm crossing the gantry of the CT unit at a 45° angle. The hand was placed flat on the table, with the wrist in neutral flexion and neutral radial-ulnar deviation. Scout images were obtained to ensure that the scanning plane corresponded with the long axis of the scaphoid. We defined sagittal plane images of the scaphoid as scans that provided a lateral view of the scaphoid bone as defined by the central longitudinal axis of the scaphoid. Coronal plane images—defined as images that provided a posteroanterior view of the scaphoid in the anatomic plane and in line with the axis of the scaphoid—were obtained by supinating the forearm 90°, keeping the wrist in a neutral position. Images of 1.2-mm thickness were obtained with 1.2-mm spacing between the images (no overlap).

Thirteen patients had fractures of the scaphoid that were visible on radiographs. These fractures were defined as nondisplaced based on both radiographic (<1 mm gap or translation and <15° dorsal tilt of the lunate on a lateral radiograph)<sup>1,12,13</sup> and CT criteria (<1 mm gap at any point in the fracture and little or no angular deformity at the fracture site)<sup>1</sup> according to the interpretation of the surgeon and musculoskeletal radiologist who cared for the patient.

Seventeen patients were defined as not having a scaphoid fracture. All 17 patients had been diagnosed originally with a suspected scaphoid fracture based on history, signs, and symptoms. In addition to normal radiographs, including oblique and ulnar deviation views of the scaphoid, these patients had a CT interpreted as showing no scaphoid fracture by the treating surgeon and the radiologist. Six patients had fractures other than the scaphoid that were not apparent on radiographs but were diagnosed on CT, including 3 with distal radius fractures and one each of the trapezium, capitate, or triquetrum fracture. A physical examination and radiographs of the scaphoid obtained 6 weeks after injury also were normal. Normal radiographs at 6 weeks have been used as a

gold standard for absence of a scaphoid fracture in prior studies.<sup>8,13–16</sup> These patients were defined as not having a scaphoid fracture.

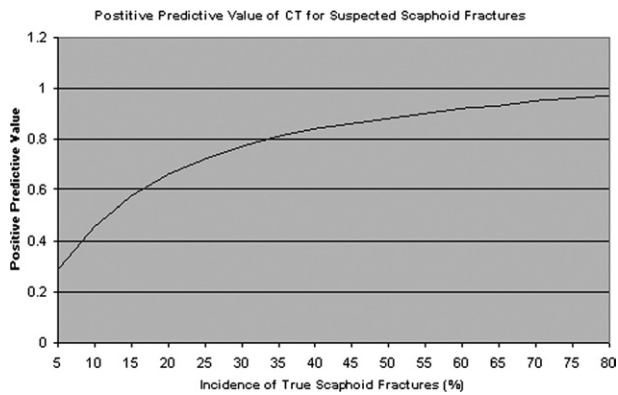
The 30 CT scans were interpreted by 8 physicians: 7 surgeons with specific training in surgery of the hand and wrist and 1 musculoskeletal radiologist. The observers were asked to comment on the presence or absence of a scaphoid fracture and also were asked to comment on any other abnormalities they saw on the scan. Five observers (1 musculoskeletal radiologist and 4 hand surgeons) reinterpreted the scans a second time 3 to 6 months after their initial reading to assess intraobserver reliability.

### Statistical Analysis

The  $\kappa$  statistic was used as a chance-corrected parameter for agreement measurement. The strength of agreement was interpreted according to Landis and Koch<sup>17</sup> benchmarks with 95% confidence intervals (CIs) providing the range of expected values for our study population.<sup>18</sup> Intraobserver reliability was assessed in the 5 observers who completed 2 sets of observations. Intraobserver reliability was tested for the first and second observation (8 and 5 observers, respectively). The determination of interobserver reliability was based on a measure of multirater  $\kappa$ ,<sup>17</sup> and compared agreement among pairs of observers and a test of the null hypothesis of a 0 population value for  $\kappa$ .<sup>19</sup>

Sensitivity, specificity, and accuracy were calculated using standard formulas and then averaged for all observers. Radiographs of the scaphoid taken 6 weeks after injury were used as the gold standard for comparison. We calculated 2-sided 95% CIs for sensitivity and specificity using the normal approximation method to the binomial distribution.<sup>18</sup> The basis for this approach is the central limit theorem and the idea is to define the interval that will contain the true parameter for 95% of all random variables that could have been obtained from the reference population.<sup>20</sup>

The rate of true fractures among patients with suspected scaphoid fractures at our institution was estimated at 5% based on data from previously published studies.<sup>21–32</sup> By using this estimate, we calculated PPVs and NPVs using Bayes' theorem. We also calculated the PPV over a range of possible prevalence levels (Fig. 1). The PPV is the probability of a patient having a radiographically occult scaphoid fracture when there is a positive result on the CT scan for fractures, whereas the NPV is the possibility of not having the described condition when there is a negative result on the CT scan. Predictive values



**Figure 1.** The range of possible PPVs according to potential levels of prevalence of true scaphoid fractures among suspected fractures.

were calculated with the following formulas, which include an estimate of prevalence.<sup>33</sup> The PPV was calculated as follows:  $(\text{sensitivity} \times \text{prevalence}) \div [(\text{sensitivity} \times \text{prevalence}) + (1 - \text{specificity}) \times (1 - \text{prevalence})]$ . The NPV was calculated as follows:  $\text{specificity} \times (1 - \text{prevalence}) \div [(1 - \text{sensitivity}) \times (\text{prevalence} + \text{specificity}) \times (1 - \text{prevalence})]$ .

Statistical analysis was performed using statistical software (SPSS statistical package, version 10.0; SPSS Inc., Chicago, IL). A power analysis was conducted to establish the number of observations required. A sample size of 30 scaphoid images evaluated by each of 5 surgeons yielded 150 cases for CT scan assessment and would provide 80% power ( $\alpha = 0.05$ ,  $\beta = 0.20$ ) to detect significant differences of 10% in each performance characteristic (sensitivity, specificity, accuracy, PPV, NPV) between the 2 observations using chi-square analysis (nQuery Advisor, version 6.0; Statistical Solutions, Saugus, MA). The criterion for statistical significance was defined

**Table 1. Intraobserver Reliability for the Detection of Nondisplaced Scaphoid Fractures Assessed by CT Scan**

Observer	Averages	Level of Agreement*
1	0.46	Moderate
2	0.93	Almost perfect
3	0.70	Substantial
4	1.00	Perfect
5	0.69	Substantial
Average	0.79 (0.73–0.83)†	Substantial

\*Based on the benchmarks of Landis and Koch<sup>17</sup> for interpreting the strength of the  $\kappa$  statistic.  
†95% CI,  $p < .01$ .

**Table 2. Interobserver Reliability for the Detection of Nondisplaced Scaphoid Fractures Assessed by CT Scan**

Round	Averages	Level of Agreement*
First	0.70 (0.63–0.75)†	Substantial
Second	0.62 (0.53–0.69)†	Substantial
Average	0.66 (0.58–0.72)†	Substantial

\*Based on the benchmarks of Landis and Koch<sup>17</sup> for interpreting the strength of the  $\kappa$  statistic.  
†95% CI,  $p < .01$ .

as a  $p$  value of less than .01 (2-tailed) to protect against type I errors caused by multiple group comparisons.

## Results

The intraobserver reliability for CT interpretations was excellent with an average  $\kappa$  value of 0.79 (95% CI, 0.73–0.83,  $p < .01$ ) (Table 1). The interobserver agreement for the first round of interpretations was substantial with an average  $\kappa$  value of 0.70 (95% CI, 0.63–0.75,  $p < .01$ ) and also was substantial for the second round of interpretations with an average  $\kappa$  value of 0.62 (95% CI, 0.53–0.69,  $p < .01$ ) (Table 2).

The sensitivity of CT for the detection of a nondisplaced fracture was 89% (95% CI, 84% to 92%) for the first round of interpretations and 97% (95% CI, 93% to 99%) for the second round of interpretations. The specificity was 91% (95% CI, 86% to 94%) for the first round of interpretations and 85% (95% CI, 77% to 89%) for the second round of interpretations. Accuracy averaged 89% (95% CI, 89% to 92%) on the first assessment and 88% (95% CI, 82% to 91%) during the second (Table 3).

The PPV for the detection of radiographically occult scaphoid fractures with tomography of the wrist was 0.28 (95% CI, 0.23–0.32); the NPV was 0.99 (95% CI, 0.97–0.99). The PPV would not approach 90% unless the incidence of true fractures among suspected scaphoid fractures was approximately 55% (Fig. 1).

## Discussion

Computed tomography has been recommended as an accurate, reliable, readily available, and relatively cost-effective way of diagnosing scaphoid fractures.<sup>1,9</sup> The CT scan was shown to be 100% sensitive and specific in the detection of scaphoid fractures in 2 studies.<sup>10,11</sup> Our study did not support this

**Table 3. Diagnostic Performance Characteristics by Observer When Using CT Scan for the Diagnosis of Nondisplaced Scaphoid Fractures**

Observer	First Round			Second Round		
	Sensitivity	Specificity	Accuracy	Sensitivity	Specificity	Accuracy
1	91%	89%	90%	100%	68%	73%
2	93%	100%	97%	100%	100%	100%
3	83%	83%	83%	100%	77%	83%
4	100%	85%	90%	100%	85%	90%
5	80%	93%	87%	86%	94%	90%
6	86%	94%	90%	—	—	—
7	81%	100%	90%	—	—	—
8	100%	85%	90%	—	—	—
Average*	89% (84% to 92%)	91% (86% to 94%)	89% (89% to 92%)	97% (93% to 99%)	85% (77% to 89%)	88% (82% to 91%)

\*Ranges of values shown in parentheses represent 95% CIs determined by the normal approximation method.

same level of diagnostic accuracy. Breederveld and Tuinebreijer<sup>10</sup> studied only suspected scaphoid fractures and had fewer fractures overall (7 of 29). Roolker et al<sup>11</sup> studied cadaveric specimens in which they recreated scaphoid fractures. The sample size used by Roolker et al<sup>11</sup> also was particularly small—only 8 wrists. In our opinion, the greater number of patients, observations, and true fractures make our data more representative and more reliable.

The diagnostic inaccuracy in our study may have arisen from misinterpretation of the vascular foramina as fractures. This is possible because nondisplaced fractures—particularly unicortical fractures—can be subtle on CT. In addition, CT images have a thickness of about 1 mm, which may cause some blurring of the fracture site owing to averaging, particularly if the plane of the image is oblique to the plane of the fracture.

A weakness of this study was a lack of definitive gold standards for the presence or absence of a scaphoid fracture and for displacement or instability of a scaphoid fracture. The commonly used gold standard for the presence or absence of a scaphoid fracture (evidence of a fracture on radiographs of the scaphoid 6 weeks after injury) has obvious shortcomings in that we do not know how well this test detects scaphoid fractures. This is important when considering our control group because we used a convenience sample of patients who had scaphoid-specific CT for a suspected scaphoid fracture and were diagnosed as not having a scaphoid fracture. It might have been better to use a group of normal volunteers, that is, people with no history of a wrist injury.

By using similar gold standards, MRI scanning has been shown to have 95% to 100% sensitivity and specificity in multiple studies.<sup>7,34,35</sup> Magnetic reso-

nance imaging is limited because it is not readily available in most settings and it is relatively expensive. In addition, studies have focused on specificity and sensitivity instead of accuracy and predictive values, which may be more meaningful diagnostic performance characteristics.

Scaphoid fractures are notorious and most physicians are trained to be vigilant and not overlook this fracture, particularly in young active individuals who fall on an outstretched hand. There is a degree of anxiety associated with the potential for missing these fractures because it is well known that they can be radiographically occult and yet still be problematic. As a result, patients diagnosed with a potential radiographically occult fracture are relatively unlikely to have a true fracture. We would estimate about 1 in 10 to 20 patients (5% to 10%) diagnosed with a radiographically occult scaphoid fracture actually have a fracture, based on published studies: Larsen et al, 7%; Hauger et al, 9% (range, 3.7% to 27%); and Staniforth et al, 7%.<sup>21–32,36–38</sup>

The low prevalence of scaphoid fractures affects the diagnostic characteristics of CT. Because a true fracture is unlikely, the inadequacies of CT are magnified. In other words, the ratio of false-positive to true-positive diagnoses of a scaphoid fracture is weighted in favor of false positives when true positives are less likely. This is apparent in the PPVs. A CT scan interpreted as showing a fracture is indicative of an actual fracture in 28% of patients, with the remaining patients having a false-positive result. On the other hand, a negative test indicates a nonfractured scaphoid in 99% of patients. In other words, CT is much better for ruling out a scaphoid fracture than for ruling one in.

If neither radiographs nor CT scan show evidence

of a fracture then a fracture is unlikely. On the other hand, identification of a fracture on CT may not be definitive evidence of a true fracture. Additional radiologic testing such as MRI or diagnostic wrist arthroscopy to evaluate acute nondisplaced fractures was not evaluated in this study. It is unclear whether additional diagnostic radiologic testing such as MRI, or diagnostic surgery such as wrist arthroscopy, is merited in this circumstance to address the potential for overtreatment (either unnecessary cast immobilization or unnecessary surgical fixation).<sup>34</sup>

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