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Computed tomography for suspected scaphoid fractures: comparison of reformations in the plane of the wrist versus the long axis of the scaphoid

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Abstract
Background Definitive diagnosis of occult scaphoid fractures remains difficult. We tested the null hypothesis that, for diagnosis of true fractures among suspected scaphoid fractures, computed tomography (CT) reformations along the long axis of the scaphoid have the same accuracy as reformations made relative to the anatomical planes of the wrist.
Methods In a prospective trial, 34 patients with a suspected scaphoid fracture underwent CT scanning within 10 days after trauma. CT reformations along the long axis of the scaphoid (CT-scaphoid) and along planes relative to the wrist (CT-wrist) were made. We used radiographs obtained 6 weeks after injury as the reference standard for a true fracture. A blinded panel including two surgeons and one radiologist came to a consensus diagnosis for each reformation plane.
Results The reference standard showed six fractures of the scaphoid (prevalence, 18 %). Using CT-wrist, a scaphoid fracture was diagnosed in five patients (15 %), with three false positive, four false negative and two true positive diagnoses. Using CT-scaphoid, a scaphoid fracture was diagnosed in five patients (15 %), with one false positive, two false negative and four true positive results. Sensitivity, specificity and accuracy were 33, 89 and 79 % for CT-wrist and 67, 96 and 91 % for CT-scaphoid, respectively. This resulted in positive predictive values of 36 % for CT-wrist and 76 % for CT-scaphoid. Negative predictive values were 87 % for CT-wrist and 94 % for CT-scaphoid. No significant differences were found with the number of patients available.
Conclusions For diagnosis of true fractures among suspected scaphoid fractures, the diagnostic performance characteristics of CT scans reformatted along the long axis of the scaphoid were better than CT scans in the planes of the wrist, but the differences were not significant.

Keywords Computed tomography · Suspected scaphoid · Fracture · Diagnostics · Reformations

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Introduction

There is no consensus regarding the best diagnostic strategy for patients with suspected scaphoid fractures, defined as patients with scaphoid tenderness after a fall and normal scaphoid radiographs [10, 14]. When computed tomography (CT) is used to image the scaphoid for fracture diagnosis or to measure alignment, reformations made along the long axis of

the scaphoid are often recommended [1, 8, 13, 15, 16]. While these reformations have been adopted by experts in the field [3, 13], our sense is that they are not used consistently in all hospitals. We tested the null hypothesis that reformations in planes defined by the long axis of the scaphoid and reformations made in the anatomic planes of the wrist have comparable accuracy for diagnosing true fractures among suspected fractures of the scaphoid.

Patients and Methods

The QUADAS guidelines [17] were used to design the primary study which was approved by our Institutional Review Board.

Patients

This study used a convenience sample of data from a prospective cohort comparing CT and MRI [9]. Forty consecutive patients with a clinically suspected scaphoid fracture but normal initial radiographs in four views were enrolled. An attending trauma or orthopedic surgeon and a musculoskeletal radiologist evaluated the radiographs. Further criteria for inclusion in the study were a minimum age of 18 years, wrist trauma within the previous 24 h and snuffbox tenderness on palpation and when longitudinally compressing the thumb [5]. Exclusion criteria were prior scaphoid fracture, rheumatoid arthritis and dementia. Six patients were lost to follow-up and excluded from this comparison.

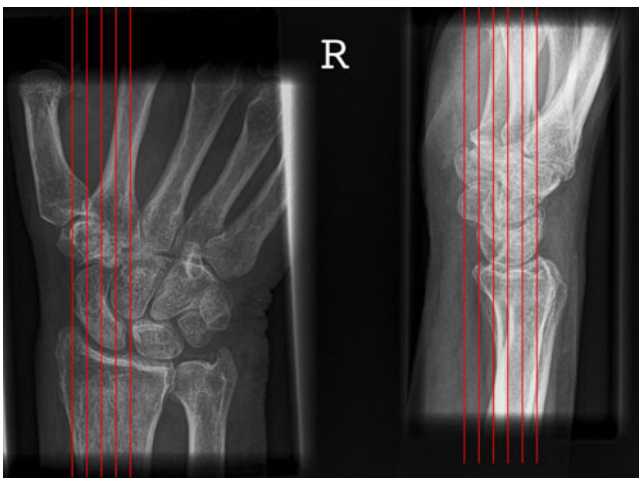

Fig. 1 Planes of the wrist on PA and lateral radiographs, respectively. The *red lines* represent the plane of the wrist in which the scans are reformatted

Imaging

CT Protocol

CT scans were obtained an average of 3.6 days after injury (range, 0–10 days) using a Brilliance CT scanner (64 slice, Philips medical System, Eindhoven, The Netherlands) from the distal radioulnar joint to the proximal 1/3 of the metacarpal bones. We used a high-resolution sequence with 0.5 mm slice thickness. Acquired volumetric data were reformatted into axial, coronal and sagittal scans in the anatomical planes of the wrist (CT-wrist) [10] (Figs. 1 and 2a). In addition, sagittal and coronal reformations along the central longitudinal axis of the scaphoid (CT scaphoid) were made [1, 8, 15] (Figs. 2b and 3).

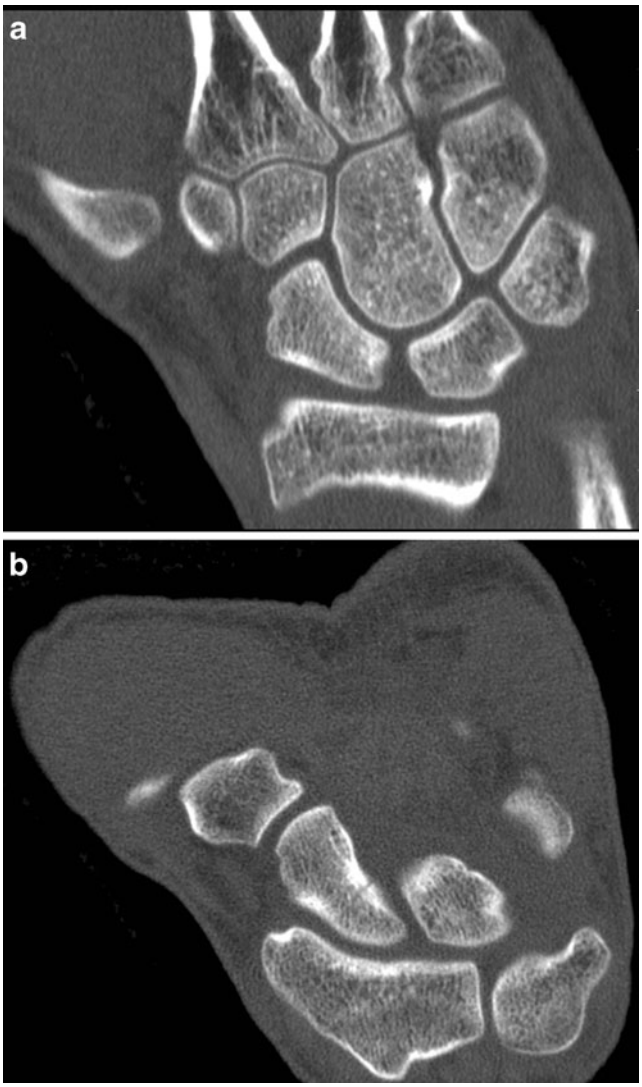

Fig. 2 **a** No fracture line visible on CT scan reformatted in the plane of the wrist (CT-wrist). **b** The same patient did show a fracture on CT scan reformatted along the long axis of the scaphoid (CT-scaphoid)

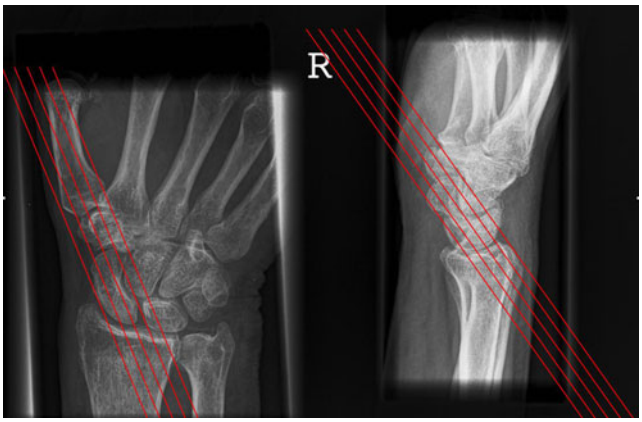

Fig. 3 The longitudinal axis of the scaphoid on PA and lateral radiographs, respectively. The *red lines* represent the long axis of the scaphoid in which the scans are reformatted

Reference Standard

Six weeks after the initial injury, the same radiographs in four standard scaphoid views were repeated. This is one of the most commonly used reference standards in the study of suspected scaphoid fractures [14]. An abnormal lucent line within the scaphoid and/or a disruption of the cortex was considered evidence of a fracture [10].

Diagnosis of Fracture

CT-wrist, CT-scaphoid and the reference standard were separated into three rounds and presented to a panel of observers which consisted of an attending musculoskeletal radiologist, and two attending surgeons. The panel evaluated the images for the presence of a scaphoid fracture to reach a consensus opinion. The images were blinded and randomly ordered with a 4-week interval between evaluations to limit recall of the images. In the first round, the panel examined the initial radiographs and CT reformation relative to the wrist; in the second round, they examined the initial radiographs and the CT with scaphoid axis reformations; and in the third round, they evaluated the initial radiographs and the 6-week post-injury radiographs. In each round, the panel was blinded to the results of the other imaging modalities.

Criteria for a fracture on CT images were according to the protocol of Memarsadeghi et al. [10]; the presence of a sharp lucent line within the trabecular bone pattern, a break in the continuity of the cortex, a sharp step in the cortex, or a dislocation of bone fragments.

Statistical Analysis

Using standard formulas, we calculated sensitivity, specificity and accuracy for the detection of a scaphoid fracture with CT-wrist and with CT-scaphoid (Table 1). The positive predictive value (PPV) and negative predictive value (NPV) were determined with use of Bayes' theorem [1, 2]. We estimated the prevalence of true scaphoid fractures as 16 % in our center for the purpose of these calculations [6]. Ninety-five percent confidence intervals were calculated with use of Pratt's normal approximation method for binomial proportions.

The McNemar test for paired binary data was used to test for significant differences between scanning planes [7]. For

Table 1 Results of computed tomography imaging compared to the 6 week follow-up reference radiographs

CT-WRIST versus CT-SCAPHOID 4x4								
		CT-wrist				CT-scaphoid		
		Scaphoid Fracture	No scaphoid fracture	Total		Scaphoid Fracture	No scaphoid fracture	Total
Reference Standard	Scaphoid fracture	2	4	6	Scaphoid fracture	4	2	6
	No scaphoid fracture	3	25	28	No scaphoid fracture	1	27	28
	Total	5	29	34	Total	5	29	34
Sensitivity	2 / 2 + 4 = **33%**[a]				4 / 4 + 2 = **67%**[a]			
Specificity	25 / 3 + 25 = **89%**[b]				27 / 1 + 27 = **96%**[b]			
Accuracy	2 + 25 / 2 + 4 + 3 + 25 = **79%**[c]				4 + 27 / 4 + 2 + 1 + 27 = **91%**[c]			
PPV[d]	33% x 16% / (33% x 16%) + [(1 – 89) x (1 – 16%)] = **36%**				67% x 16% / (67% x 16%) + [(1 – 96) x (1 – 16%)] = **76%**			
NPV[d]	89% x (1 – 16%) / [(1 – 33%) x 16%] + [89% x (1 – 16%] = **87%**				96% x (1 – 16%) / [(1 – 67%) x 16%] + [96% x (1 – 16%] = **94%**			

[a] The proportion of patients with a scaphoid fracture according to the reference standard classified as having a positive CT (true positives)

[b] The proportion of patients with no scaphoid fracture according to the reference standard classified as having a negative CT (true negative)

[c] The proportion of patients who are correctly classified by CT

[d] Accounting for prevalence and incidence

the original study, a sample size of 32 patients provided 80 % power (α=0.05, β=0.20) to detect significant differences of 20 % in diagnostic performance characteristics between MRI and CT. Post hoc power analysis was performed to calculate if we could reach the same power for this specific study question.

According to post hoc power analysis, 133 patients would be needed to achieve 80 % power to show statistical significance of the differences noted.

Results

Reference Standard

The scaphoid specific radiographs obtained 6 weeks after injury showed a fracture of the wrist in ten patients (29 %), of whom six (18 %) patients had a fracture of the scaphoid (five waist and one distal pole) and the other fractures were located in the triquetrum (two patients), the capitate (one patient) and the distal radius (one patient). No patients were diagnosed with multiple fractures.

CT-wrist

With CT reformations in planes relative to the wrist, 13 patients were diagnosed with 17 fractures (Table 1). Fractures to bones other than the scaphoid diagnosed on CT-wrist included a lunate fracture in one, triquetrum fracture in four, trapezium fracture in one, trapezoid fracture in one, capitate fracture in one, hamate fracture in one, distal radius fracture in two and small finger metacarpal fracture in one. Two patients were diagnosed with other fractures along with the scaphoid fracture (distal radius in one and triquetrum in one). In one patient, the trapezium, trapezoid and capitate were fractured. Fracture of the scaphoid was diagnosed in five patients (four waist and one proximal pole). There were two true positive, three false positive and four false negative results according to the reference standard. We calculated a sensitivity of 33 % (95 % confidence interval=11–60 %) and a specificity of 89 % (95 % CI=84–95 %) with an accuracy of 79 % in depicting scaphoid fractures. The prevalence-adjusted PPV was 36 % (95 % CI=11–69 %) and prevalence-adjusted NPV was 87 % (95 % CI=83–93 %).

CT-scaphoid

With CT reformations in planes defined by the long axis of the scaphoid, 17 patients were diagnosed with 20 fractures (Table 1). Fractures to bones other than the scaphoid diagnosed on CT-scaphoid included a lunate fracture in two, triquetrum fracture in four, trapezium fracture in one, capitate fracture in one, hamate fracture in one, distal radius fracture in four and small finger metacarpal fracture in two. One patient was diagnosed with a distal radius fracture along with a fractured scaphoid. One fractured both the small finger metacarpal and triquetrum and one fractured the trapezium and capitate. Fracture of the scaphoid was diagnosed in five patients (four waist and one proximal pole). There were four true positive, one false positive and two false negative results according to the reference standard. We calculated a sensitivity of 67 % (95 % confidence interval=36–80 %) and a specificity of 96 % (95 % CI=90–99 %) with an accuracy of 91 % in depicting scaphoid fractures. The prevalence (16 %)-adjusted PPV was 76 % (95 % CI=39–94 %) and prevalence-adjusted NPV was 94 % (95 % CI=88–97 %).

Statistical Analysis

According to the McNemar's test of equality of paired proportions [11], we could not detect a significant difference between CT-wrist and CT scaphoid with the number of patients available.

Discussion

Our null hypothesis that CT-wrist and CT-scaphoid have comparable accuracy (79 vs. 91 %, respectively) is confirmed, at least with the number of scans available. With a larger sample, the substantial differences between PPV (CT-wrist (36 %) and CT-scaphoid (76 %)) and sensitivity (CT-wrist (33 %) and CT-scaphoid (67 %)) might reach statistical significance.

The study of diagnostic performance characteristics of tests for diagnosing true fractures among scaphoid fractures is hindered by the lack of a consensus reference standard for a true fracture [1, 12]. We used one of the more common reference standards (6-week post-injury radiographs), but none of the proposed standards (including MRI, which is subject to false positives) [9] are satisfactory. It is conceivable that we will never have a consensus reference standard. We may need to use alternative statistical techniques such as latent class analysis, which relies on associations of specific factors (unobserved or latent classes) rather than a reference standard to estimate diagnostic performance characteristics. Preliminary data from this paper were provided for a study of latent class analysis [4]. The numbers changed slightly after all three observers completed the evaluations.

This study should be interpreted in light of several actual or potential shortcomings. First, this was a retrospective analysis of CT scans obtained as part of a prospective study designed to test a different primary study question. This represents a sample of convenience, which offered a prime opportunity to evaluate this issue. Therefore, the comparison of the reformations must be interpreted as a pilot experiment, since the study was not designed or powered to answer this question and showed to be underpowered. This is particularly

important given the low prevalence of true fractures among suspected fractures. The differences we observed are substantial and likely would be statistically significant in a larger study.

Conclusion

Computed tomography reformatted along the long axis of the scaphoid is statistically comparable to CT scans in the planes of the wrist for diagnosis of suspected scaphoid fractures although the diagnostic performance characteristics were notably better for CT in the plane of the scaphoid. We encourage further study with larger numbers to test our clinical impression that CT-scaphoid might reach significant superiority over CT-wrist.

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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. Written informed consent was obtained from all patients for being included in the study.

Conflict of interest statement There were no financial or personal relationships with other people or organizations that could inappropriately influence this work. The authors declare that they have no conflict of interest.

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