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Clinical Research

What Is the Diagnostic Performance of Conventional Radiographs and Clinical Reassessment Compared With HR-pQCT Scaphoid Fracture Diagnosis?

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Abstract

Background Conventional radiographs and clinical reassessment are considered guides in managing clinically suspected scaphoid fractures. This is a unique study as it assessed the value of conventional radiographs and clinical reassessment in a cohort of patients, all of whom underwent additional imaging, regardless of the outcome of conventional radiographs and clinical reassessment.

Questions/purposes (1) What is the diagnostic performance of conventional radiographs in patients with a clinically suspected scaphoid fracture compared with high-resolution peripheral quantitative CT (HR-pQCT)? (2) What is the diagnostic performance of clinical reassessment in patients with a clinically suspected scaphoid fracture compared with HR-pQCT? (3) What is the diagnostic performance of conventional radiographs and

clinical reassessment combined compared with HR-pQCT?

Methods Between December 2017 and October 2018, 162 patients with a clinically suspected scaphoid fracture presented to the emergency department (ED). Forty-six patients were excluded and another 25 were not willing or able to participate, which resulted in 91 included patients. All patients underwent conventional radiography in the ED and clinical reassessment 7 to 14 days later, together with CT and HR-pQCT. The diagnostic performance characteristics and accuracy of conventional radiographs and clinical reassessment were compared with those of HR-pQCT for the diagnosis of fractures since this was proven to be superior to CT scaphoid fracture detection. The cohort included 45 men and 46 women with a median (IQR) age of 52 years (29 to 67). Twenty-four patients with a median age of 44 years (35 to 65) were diagnosed with a scaphoid fracture on HR-pQCT.

Results When compared with HR-pQCT, conventional radiographs alone had a sensitivity of 67% (95% CI 45% to 84%), specificity of 85% (95% CI 74% to 93%), positive predictive value (PPV) of 62% (95% CI 46% to 75%), negative predictive value (NPV) of 88% (95% CI 80% to 93%), and a positive and negative likelihood ratio (LR) of 4.5 (95% CI 2.4 to 8.5) and 0.4 (95% CI 0.2 to 0.7), respectively. Compared with HR-pQCT, clinical reassessment alone resulted in a sensitivity of 58% (95% CI 37% to 78%), specificity of 42% (95% CI 30% to 54%), PPV of 26% (95% CI 19% to 35%), NPV of 74% (95% CI 62% to 83%), as well as a positive and negative LR of 1.0 (95% CI 0.7 to 1.5) and 1.0 (95% CI 0.6 to 1.7), respectively. Combining clinical examination with

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conventional radiography produced a sensitivity of 50% (95% CI 29% to 71%), specificity of 91% (95% CI 82% to 97%), PPV of 67% (95% CI 46% to 83%), NPV of 84% (95% CI 77% to 88%), as well as a positive and negative LR of 5.6 (95% CI 2.4 to 13.2) and 0.6 (95% CI 0.4 to 0.8), respectively.

Conclusion The accuracy of conventional radiographs (80% compared with HR-pQCT) and clinical reassessment (46% compared with HR-pQCT) indicate that the value of clinical reassessment is limited in diagnosing scaphoid fractures and cannot be considered directive in managing scaphoid fractures. The combination of conventional radiographs and clinical reassessment does not increase the accuracy of these diagnostic tests compared with the accuracy of conventional radiographs alone and is therefore also limited in diagnosing scaphoid fractures.

Level of Evidence Level II, diagnostic study.

Introduction

Diagnosing scaphoid fractures is challenging because of the unique shape, size, and orientation of this carpal bone. Various imaging techniques have been suggested for the improvement of diagnosis. Currently, CT, MRI, and bone scintigraphy (BS) are the most frequently used imaging techniques, but they all have limitations [1, 8, 10, 12, 20, 21, 24, 26, 30, 32, 36, 38, 45-47, 50]. Because of varying diagnostic performance results, no true reference standard exists regarding the preferred imaging technique.

Clinical suspicion is most often based on tenderness in the anatomic snuffbox after a fall on an outstretched

hand [22, 23]. Conventional radiography is performed at the emergency department (ED) but is insufficient to exclude a scaphoid fracture because 20% to 40% of patients with normal initial radiographic findings have a fracture on additional imaging, according to existing studies [3, 14, 23-25, 29]. Therefore, regardless of the outcome of conventional radiography, patients with a clinically suspected scaphoid fracture are immobilized with a cast and reassessed within 1 to 2 weeks. If a scaphoid fracture is still suspected at the patient's clinical reassessment, additional imaging is performed to obtain a definite diagnosis [5, 9, 33, 46].

This is a unique study as it assessed the value of conventional radiographs and clinical reassessment in a cohort of patients subjected to additional imaging, regardless of the outcome of conventional radiographs and clinical reassessment. High-resolution peripheral quantitative CT (HR-pQCT), a novel imaging technique that allows an assessment of the microstructure of cortical and trabecular bone at the distal radius and tibia, has recently been introduced [11, 13, 17-19, 31, 39]. Because there is no consensus regarding the reference imaging technique for diagnosing scaphoid fractures, we have studied HR-pQCT as a diagnostic tool and have shown that it is feasible [7, 16] and superior [15] to CT for detecting fractures in patients with a clinically suspected scaphoid fracture. Therefore, we compared the results of conventional radiographs and clinical reassessment with HR-pQCT in this study.

In this study, we asked: (1) What is the diagnostic performance of conventional radiographs in patients with a clinically suspected scaphoid fracture compared with HR-pQCT? (2) What is the diagnostic performance of clinical

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reassessment in patients with a clinically suspected scaphoid fracture compared with HR-pQCT? (3) What is the diagnostic performance of conventional radiographs and clinical reassessment combined compared with HR-pQCT?

Patients and Methods

Study Population and Design

In this prospective study, all patients 18 years or older with a clinically suspected scaphoid fracture who presented to the ED between December 2017 and October 2018 within 1 week after trauma were eligible for study participation. This yielded a total of 162 patients, of which 46 were excluded based on age younger than 18 years, mental disability, trauma more than 7 days before, or a previous scaphoid fracture. Another 25 patients were eligible but not willing or able to participate, resulting in 91 included patients (Fig. 1).

At the ED, conventional radiographs were obtained in four views: posteroanterior, true lateral, semipronated oblique, and posteroanterior with the wrist in ulnar deviation. Conventional radiographs were assessed by an experienced team of radiologists. Independent of the outcome of these radiography findings, cast immobilization was applied and patients received written study information from their treating physician in the ED. Standard outpatient visits were planned within 7 to 14 days after trauma (for patients for whom nonoperative treatment was appropriate) according to current clinical practice. If patients were eligible and willing to participate, informed consent was obtained during this visit, followed by a clinical examination and questionnaires, including pain and functioning scores, medical history, smoking status, alcohol use, medications, dominant hand, and trauma mechanism.

A surgical resident (AMD) conducted clinical reassessment and classified a finding as positive if at least one of the following was present: anatomic snuffbox tenderness, scaphoid tubercle tenderness, or axial compression pain on the thumb (with the thumb in extension and

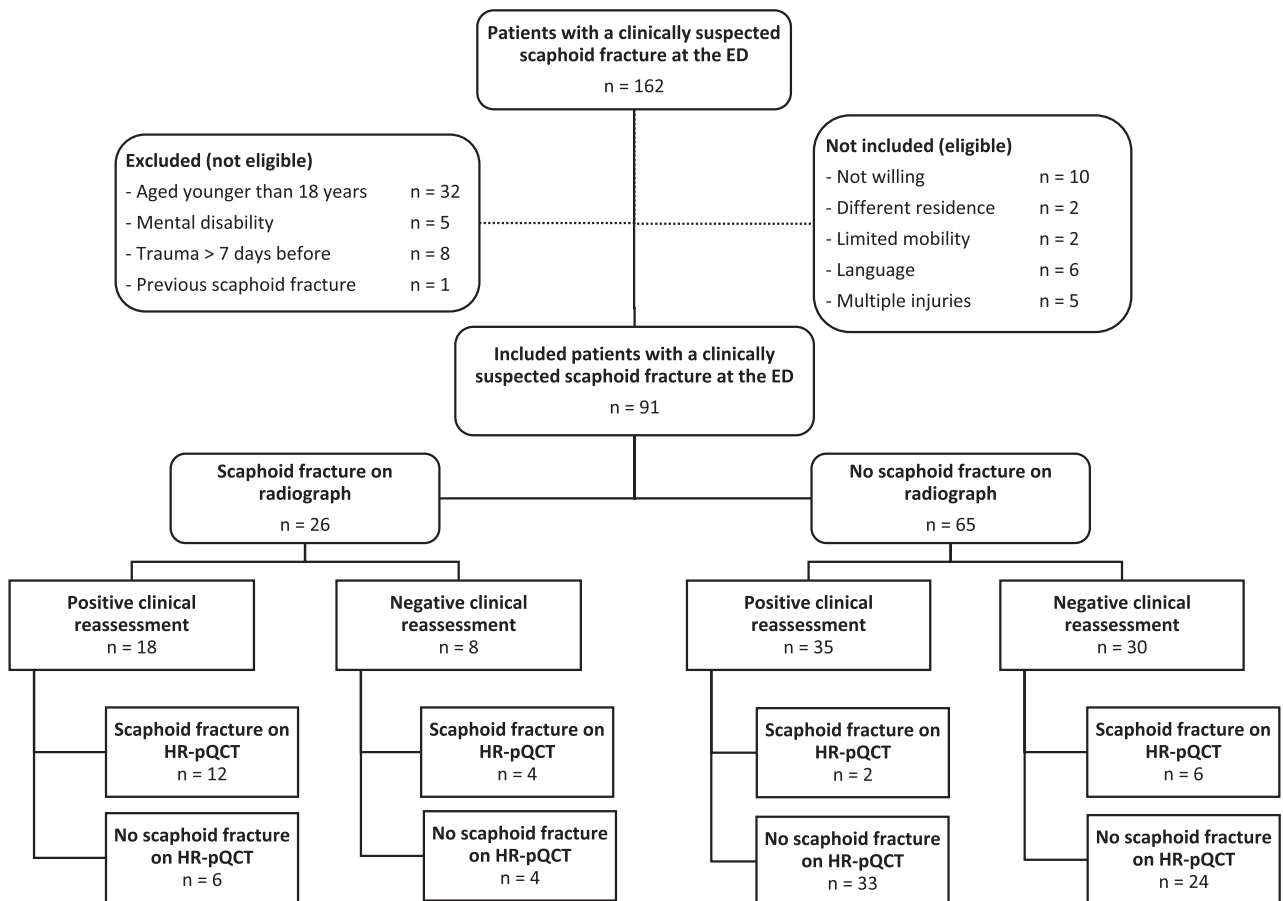


Fig. 1 This flowchart shows the patient selection, inclusion criteria, and results of this study.

abduction). This clinical workup was in accordance with regional treatment protocols and published studies [5, 9, 33, 46]. Conventional CT and HR-pQCT scanning of the scaphoid bone region was conducted on the same day, regardless of the outcome of clinical reassessment. As there is currently no true reference standard available, we compared the results of conventional radiographs and clinical reassessment to HR-pQCT because this technique was superior to conventional CT in our previously conducted study [15]. The radiologist and trauma surgeon assessing the CT and HR-pQCT were blinded to the other's assessment of the patients as well as to their clinical data.

Primary and Secondary Study Outcomes

Our primary study goal was to assess the diagnostic performance of conventional radiographs and clinical reassessment compared with HR-pQCT. We obtained conventional radiographs at initial presentation of all patients and conducted clinical reassessment at the outpatient clinic and compared this with the results of our chosen gold standard, HR-pQCT. Our secondary study goal was to assess the diagnostic performance of conventional radiographs and clinical reassessment combined compared with HR-pQCT. We combined the data and classified it as positive if a scaphoid fracture was seen on conventional radiographs and clinical reassessment was positive; we classified it as negative if there was no scaphoid fracture on conventional radiographs or clinical reassessment was negative.

Patient Characteristics

The median (IQR) age in our cohort, which consisted of 45 men and 46 women, was 52 years (29 to 67). The presence of a scaphoid fracture was suggested on the conventional radiographs of 29% (26 of 91) of patients, and 58% (53 of 91) of patients had clinical suspicion of a scaphoid fracture at reassessment. Overall, a scaphoid fracture was diagnosed in 26% (24 of 91) on HR-pQCT.

The median (IQR) age was lower in patients with a scaphoid fracture on HR-pQCT (44 years [35 to 65]) than in those without a scaphoid fracture (65 years [52 to 74]; $p = 0.001$). Fifteen of 24 patients with a scaphoid fracture on HR-pQCT were men.

HR-pQCT

HR-pQCT (XtremeCT II; Scanco Medical AG) scanning of the scaphoid bone was performed on a 30.6-mm region of the wrist (three consecutive 10.2-mm stacks with an isotropic voxel size of 0.061 mm), with a reference line at

the longitudinal sagittal ridge between the scaphoid bone and lunate fossa at the articular surface of the distal radius. The standard protocol of the distal radius, with an isotropic voxel size of 0.061 mm, was adapted to three consecutive stacks (30.6 mm) to cover the entire scaphoid [37, 42, 43].

All scanning was conducted with the wrist in a synthetic cast with a removable cast around the thumb, which was only applied during the HR-pQCT procedure for added stability. The patient's forearm was placed in an anatomically shaped motion-restraining holder to obtain a standardized position. Detailed information regarding the scanning procedures, image reconstruction, and fracture assessment was described previously [7, 15].

Ethical Approval

This study was approved by our medical ethics committee (NL 62476.068.17) and was conducted according to the principles of the Declaration of Helsinki and in accordance with the Medical Research Involving Human Subjects Act.

Statistical Analysis

We analyzed data using IBM SPSS Statistics, version 25.0 (IBM Corp). Categorical data are presented as frequencies with a percentage. Data distributions were tested with Q-Q plots and a Kolmogorov-Smirnov analysis. Normally distributed data have been presented as the mean and SD; nonnormally distributed data have been presented as the median and IQR. We used chi-square tests to analyze differences in patient characteristics between patients with a scaphoid fracture and those without a scaphoid fracture on HR-pQCT. The level of significance was set at $\alpha = 0.05$. The diagnostic performance characteristics of conventional radiographs and clinical reassessment, including sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV), positive and negative likelihood ratio (LR), and accuracy were calculated using MedCalc, Clinical Online Calculator, diagnostic test evaluation calculator (MedCalc Software Ltd) compared with HR-pQCT.

Results

Conventional Radiographs

We found a sensitivity of 67% (95% CI 45% to 84%), specificity of 85% (95% CI 74% to 93%), PPV of 62% (95% CI 46% to 75%), NPV of 88% (95% CI 80% to 93%), as well as a positive and negative LR of 4.5 (95% CI 2.4 to 8.5) and 0.4 (95% CI 0.2 to 0.7), respectively, for conventional radiographs compared with HR-pQCT scaphoid

Table 1. Diagnostic performance characteristics of conventional radiographs at the ED and outpatient clinical reassessment 7 to 14 days later using HR-pQCT diagnosis as reference (scaphoid fracture vs no scaphoid fracture)

Diagnostic performance characteristic	Sensitivity	Specificity	PPV	NPV	Positive LR	Negative LR	AUC (95% CI)	p value
Radiograph vs HR-pQCT	67%	85%	62%	88%	4.5	0.4	0.76 (0.64-0.88)	< 0.001
Clinical reassessment vs HR-pQCT	58%	42%	26%	74%	1.0	1.0	0.50 (0.37-0.64)	0.99
Radiograph and clinical reassessment vs HR-pQCT	50%	91%	67%	84%	5.6	0.6	0.71 (0.57-0.84)	0.003

AUC = area under the curve.

fracture diagnosis (Table 1). Eight of 24 patients with scaphoid fractures diagnosed with HR-pQCT did not have a scaphoid fracture on conventional radiographs, and 10 patients were diagnosed with a scaphoid fracture on conventional radiographs, although they appeared to have no fracture on HR-pQCT.

Clinical Reassessment

We found a sensitivity of 58% (95% CI 37% to 78%), specificity of 42% (95% CI 30% to 54%), PPV of 26% (95% CI 19% to 35%), NPV of 74% (95% CI 62% to 83%), as well as a positive and negative LR of 1.0 (95% CI 0.7 to 1.5) and 1.0 (95% CI 0.6 to 1.7), respectively (Table 1). Clinical reassessment results were negative in 10 of 24 patients with a scaphoid fracture on HR-pQCT and positive in 39 patients without a scaphoid fracture on HR-pQCT. Of 39 patients with a positive clinical reassessment result without a scaphoid fracture on HR-pQCT, nine had a diagnosis of a nondisplaced fracture of one of the other carpal bones, and two had a fracture of the distal radius.

Conventional Radiographs and Clinical Reassessment Combined

The combination of conventional radiographs and clinical reassessment resulted in the following diagnostic performance characteristics compared with HR-pQCT: sensitivity of 50% (95% CI 29% to 71%), specificity of 91% (95% CI 82% to 97%), PPV of 67% (95% CI 46% to 83%), NPV of 84% (95% CI 77% to 88%), as well as a positive and negative LR of 5.6 (95% CI 2.4 to 13.2) and 0.6 (95% CI 0.4 to 0.8), respectively (Table 1).

Discussion

The unique shape, size, and orientation of the carpal bone makes diagnosing scaphoid fractures a challenge. Further, the varied diagnostic performance of the most commonly

used imaging techniques—CT, MRI, and BS—results in the absence of a true reference standard.

Conventional radiography performed in the ED often falls short when diagnosing scaphoid fractures: 20% to 40% of patients with normal initial radiographic findings are found to have a fracture on additional imaging [3, 14, 23-25, 29]. Consequently, regardless of imaging results, patients with a clinically suspected scaphoid fracture are immobilized with a cast and reassessed within 1 to 2 weeks. If a scaphoid fracture is still suspected at the clinical reassessment, additional imaging is performed to obtain a definite diagnosis [5, 9, 33, 46].

In our study, we evaluated the diagnostic performance of conventional radiographs and clinical reassessment in a cohort of patients with clinically suspected scaphoid fractures. We found that clinical reassessment had limited value in diagnosing scaphoid fractures, and it cannot be considered directive in managing these injuries. Further, combining conventional radiographs and clinical reassessment does not increase the accuracy of these diagnostic tests compared with the accuracy of conventional radiographs alone; therefore, they are also limited in diagnosing scaphoid fractures.

Limitations

This study is limited because HR-pQCT is not yet readily available in a hospital setting because it is exclusively used as research tool. As the patients in our study were selected from a group of consecutive patients from the ED who all underwent HR-pQCT, we are convinced that this does not affect our results. Although this limited availability may complicate research involving the HR-pQCT in the near future, implementation in a hospital setting will follow in the upcoming years, and thereby this limitation will be overcome. Furthermore, other fractures were detected on additional imaging. The presence of fractures (other than scaphoid fractures) may influence the clinical assessment findings since patients might experience pain as a result of this other fracture interfering with the assessment for scaphoid fractures, as known from previously conducted

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studies [12, 28, 29]. In our study, other nondisplaced carpal fractures or distal radius fractures were present in 11 of 39 patients with positive clinical reassessment results (without a scaphoid fracture on HR-pQCT). Third, given that there were only 24 patients with a scaphoid fracture, the 95% CIs of mainly the sensitivity and PPV rates were wider, and therefore, the uncertainty is greater for those values. However, we believe there is still enough perspective to make decisions about the utility of these diagnostics.

Conventional Radiographs

Conventional radiographs can be helpful to diagnose other fractures but are insufficient to diagnose scaphoid fractures without any additional imaging. Although the value of conventional radiographs has been studied frequently in the past [2, 4, 8, 10], comparing the results is difficult because of variation in the reference standard that was used. Overall, 20% to 40% of scaphoid fractures are initially occult on conventional radiographs [25, 38, 40, 48]. This is similar to the 33% proportion we found compared with HR-pQCT in our study. Because initially occult fractures are the focus of most studies, patients with positive conventional radiographic findings are not considered. This results in the absence of adequate diagnostic performance characteristics regarding false-positive radiographic diagnoses. If these patients were thought to have a scaphoid fracture without additional imaging, they would be immobilized unnecessarily, resulting in concurrent physical and socioeconomic consequences. In our opinion, the suggestion of a scaphoid fracture on conventional radiographs in the ED justifies early second-line imaging to confirm the diagnosis and assess the anatomic position of the fracture to rule out displacement or proximal pole localization or to reject the diagnosis of a scaphoid fracture. However, studies have used repeated conventional radiographs, an unreliable method, as the reference standard [32, 50].

Clinical Reassessment

The diagnostic accuracy of a clinical assessment for detecting suspected scaphoid fractures is limited. A large number of physical examination tests have been described to support diagnosing scaphoid fractures. The most common tests evaluate for tenderness in the anatomic snuffbox, scaphoid tubercle tenderness, and axial compression pain of the thumb [6, 12, 27, 34]. In a systematic review and meta-analysis [34], sensitivity ranges appeared to be relatively high, whereas specificity results were poor for tenderness in the anatomic snuffbox and axial compression on

the thumb. We think that in contrast to Unay et al. [49], the focus of a clinical assessment should be to minimize missed scaphoid fractures instead of preventing unnecessary additional imaging. In our study, we combined the diagnostic findings and classified patients as having positive findings if at least one of these findings was positive at clinical reassessment. Despite this low threshold, we identified more missed diagnoses ($n = 10$) compared with HR-pQCT if patients with negative clinical examination findings did not receive additional imaging.

Conventional Radiographs and Clinical Reassessment Combined

The combination of conventional radiographs and clinical reassessment does not increase the accuracy of these diagnostic tests compared with the accuracy of conventional radiographs alone. Some studies combined clinical tests or developed a clinical decision rule to increase the post-test fracture probability [6, 23, 35, 41, 44]. However, the proportion for predicting a true fracture remains relatively low (40%) [23], and implementation in daily practice is not always feasible because of the extensiveness and difficulty of the tests that are used [44]. Tenderness in the anatomic snuffbox is the most sensitive clinical diagnostic test but is insufficient to safely rule out a scaphoid fracture.

Conclusion

Based on our study results and the results of a previously mentioned review [34] with varying and disappointing diagnostic performance values, we conclude that clinical assessment is an inadequate indicator of the presence or absence of scaphoid fractures. We acknowledge that clinical investigation remains important in daily practice and that part of this assessment is useful; however, deciding to dismiss a patient from further follow-up with a 33% (HR-pQCT) chance of having a scaphoid fracture is not desirable. Therefore, clinical assessment alone cannot be considered directive in managing scaphoid fractures. The combination of conventional radiographs and clinical reassessment does not increase the accuracy of these diagnostic tests compared with the accuracy of conventional radiographs alone and is therefore also limited in diagnosing scaphoid fractures. Given that clinical reassessment is only 50% accurate, we suggest that additional imaging should not be conducted in addition to or based upon clinical reassessment but should rather immediately replace the current clinical reassessment. By introducing early additional imaging (high-resolution CT) in all patients instead of decision making (including the decision to perform imaging) based on clinical reassessment, the time

to definite diagnosis will be accelerated and decisions on treatment can be made more reliably.

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