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Time is Bone: Streamlining the Diagnostic Pathway of Suspected Scaphoid Fractures with Cone-Beam CT

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Abstract

Background: Scaphoid fractures present a significant diagnostic challenge in emergency departments. Conventional radiography frequently misses occult fractures, leading to either delayed diagnoses with severe complications or unnecessary, prolonged cast immobilization for healthy patients. While Magnetic Resonance Imaging (MRI) remains the gold standard, its high cost and

limited availability restrict its routine use in acute settings. Cone-Beam Computed Tomography (CBCT) has emerged as a promising, accessible 3D imaging alternative.

Objective: To evaluate the diagnostic accuracy of CBCT for suspected scaphoid fractures and assess its clinical utility regarding radiation dose and the optimization of the diagnostic pathway.

Methods: A systematic review of PubMed, Europe PMC, and Cochrane databases was conducted up to March 2026. The review included original clinical studies providing quantitative data on the diagnostic performance of CBCT for scaphoid fractures in adult patients.

Results: Six studies comprising 335 patients (106 with confirmed fractures) met the inclusion criteria. CBCT demonstrated high diagnostic validity, with sensitivity ranging from 88.9% to 100% and specificity between 96% and 100%. The median effective radiation dose (3.65–4.3 μSv) was significantly lower than that of standard multi-detector computed tomography (MDCT). Implementing early CBCT protocols reduced the median time to definitive diagnosis from 16.5 to 2.0 days, enabling 94.1% of patients to receive a conclusive diagnosis within 48 hours and reducing unnecessary fracture clinic attendances by 71.9%. **Conclusions:** CBCT provides diagnostic accuracy comparable to MRI with a highly favorable radiation safety profile. Integrating CBCT into routine clinical protocols for acute wrist trauma safely accelerates the diagnostic pathway, optimizes healthcare resources, and protects patients from unwarranted immobilization.

Key words: scaphoid fracture; cone-beam computed tomography; diagnostic imaging; wrist injuries

INTRODUCTION

Hand injuries are among the most common reasons for patients present to emergency departments, and the scaphoid is the most frequently fractured carpal bone [1,2,22]. What makes scaphoid fractures especially tricky is the bone's unique anatomy and blood supply — when diagnosis is delayed, patients face a real risk of serious complications, including delayed union, post-traumatic arthritis, and avascular necrosis [3]. At the same time, putting every patient with a wrist injury in a cast "just in case" is far from harmless: unnecessary immobilization leads to stiffness, prolonged rehabilitation, and significant time off work [4]. Furthermore, a recent multicenter randomized controlled trial demonstrated that in patients with suspected scaphoid fractures and normal initial radiographs, using a short-term bandage instead of a two-week cast immobilization results in noninferior functional outcomes. Patients in the bandaging group exhibited a better wrist range of motion at two weeks and

reported higher treatment satisfaction compared to the casting group, suggesting that routine rigid immobilization can be safely avoided. Nevertheless, reassessment after 2 weeks is required [21]. This is why getting the diagnosis right, and doing so quickly, genuinely matters.

Diagnosing scaphoid fractures is not always straightforward. Clinically, certain signs — such as anatomical snuff box (ASB) tenderness within 72 hours of injury — can raise suspicion [5], but clinical findings alone are rarely enough to confirm or rule out a fracture. Further radiological investigation is essential to implement appropriate treatment.

Relying only on conventional radiography carries a high risk of incorrect diagnosis. Studies prove that adding additional tools in the diagnostic process, final treatment can be changed even in 31,5% cases. As indicated by a systematic review, nearly 22% of patients with normal initial radiographs have an occult scaphoid fracture [6]. These missed diagnoses are a leading cause of delayed treatment and, under certain circumstances, nonunion - making the case for more advanced cross-sectional imaging hard to ignore.

One of the diagnostic tools involves using ultrasonography(USG). A systematic review demonstrated that ultrasound could diagnose radiographically occult fractures with a pooled sensitivity of 84.75% and a specificity of 85.5%. Due to its low cost and wide availability, USG serves as a valuable and more cost-effective initial screening tool compared to empiric cast immobilization. However, because its diagnostic accuracy is not absolute, USG cannot definitively rule out occult injuries or completely obviate the need for advanced cross-sectional imaging. Therefore, while USG represents a practical adjunct, there remains a clear clinical need for a more precise 3D imaging modality to resolve equivocal cases and establish a definitive diagnosis.

Another diagnostic tool is MRI (Magnetic Resonance Imaging). Recent systematic review shows that early use of MRI for suspected scaphoid fractures is more precise and cost-effective than standard care. Despite its high sensitivity and specificity, MRI is not routinely used in emergency departments due to institutional constraints, limited equipment availability, and considerable initial costs [7]. As a result, alternative 3D imaging modalities, such as cone-beam computed tomography (CBCT), are being considered for their potential to achieve high diagnostic accuracy, improve accessibility, and shorten examination times.

CBCT works in a different way than conventional multidetectorial computer tomography (MDCT). MDCT relies on fan-beam geometry and requires the patient to advance through a rotating scanner, while CBCT utilizes a cone-shaped X-ray beam and a 2D digital flat-panel detector. This technological configuration allows for the acquisition of complete 3D volumetric data of the specific area of interest in a single, short rotation.[17]

The aim of this study is to assess the accuracy of CBCT in the diagnostic process of scaphoid bone fracture and determine whether it is recommended for routine clinical implementation.

Materials and Methods

To identify relevant studies, three independent databases were searched from inception to 15.03.2026: PubMed, Europe PMC, and Cochrane, using a combination of keywords related to the scaphoid bone, injuries, and cone-beam computed tomography (CBCT) technology. The exclusion criteria were studies published more than 10 years ago, participants under 18 years of age, secondary research, non-original articles such as systematic reviews, meta-analyses, case reports, small case series (<10 patients), letters to the editor, and expert commentaries. Furthermore, non-clinical research, including cadaveric, animal, and in vitro studies, were excluded. Finally, publications from which precise quantitative data regarding the diagnostic performance of CBCT for scaphoid fractures could not be extracted were also omitted. All patients included in the study underwent radiographs and CBCT.

Results

Characteristics of included studies

We have collected 6 studies on implementing CBCT in the diagnostic evaluation of scaphoid fractures. Totally, we gathered 335 patients, 106 of whom were diagnosed with scaphoid fractures. The review included both prospective [10,13] and retrospective studies [8,11,12]. Magnetic resonance imaging (MRI)[8,12,13], surgical reports [11], and long-term clinical follow-up [8] were used as the reference standard in the studies. Radiographic images and CBCT scans were evaluated by independent specialists (usually 2, in one case 4[12]). One study was included to demonstrate the feasibility of implementing a rapid diagnostic pathway.[15]

Diagnostic effectiveness

The results of the analyzed studies suggest the very high diagnostic validity of CBCT technology. The sensitivity of CBCT in detecting scaphoid fractures ranged from 88.9% to 100%. The specificity of the method, in studies where it could be accurately determined [11,12,13], ranged from 96% to 100%. In a prospective study by Borel et al. (2017) [13], CBCT findings were verified against reference MRI scans within an average of 4.1 days post-injury. The sensitivity for occult fractures reached 94%, and the specificity was 97%. Furthermore, a large retrospective analysis by Neubauer et al. (2018) [12], involving a cohort of 102 patients, reported a sensitivity of 93% ($p=0.019$) and a specificity of 96% ($p< 0.001$), showing a statistically significant superiority of CBCT over standard radiography.

Radiation dose

The median effective dose for CBCT scans was between 4.3 and 3,65 μSv. Although this dose is slightly higher than that of conventional radiography (0.2 μSv), it remains significantly lower than in standard multi-detector computed tomography (MDCT). [8,11]

Optimization of Time to Diagnosis and Clinical Pathway

One of the key benefits observed in the reviewed research was the shortened timeframe required to make an accurate diagnosis. We have choosen researches, in which CBCT was performed urgently — either on the same day as an inconclusive radiograph [8,11] or within a few days [10,12,13]. Early access to CBCT allowed 94.1% of patients to receive a definitive diagnosis within 2 days of injury. This refinement can make a significant difference in practice: protecting patients without fractures from unnecessary immobilization and allowing those with confirmed fractures to be treated with urgent and well-based diagnosis.

Moreover, in another study, the clinical utility of hastening this process is additionally underscored by a recent interventional before-and-after study by Flanagan et al. (2025), which evaluated a new ambulatory CBCT pathway for suspected scaphoid fractures in the emergency department. The implementation of this dedicated pathway reduced the median time from patient presentation to CBCT imaging, starting from 16.5 days to merely 2.0 days. Consequently, the proportion of patients receiving definitive imaging within 7 days increased significantly from 11.1% to 91.8%. This rapid access to CBCT led to a 71.9% reduction in unnecessary fracture clinic attendances, demonstrating that early CBCT not only expedites patient care but also notably optimizes healthcare resource application.[15]

Discussion

The clinical management of suspected scaphoid fractures relies heavily on accurate imaging, and the use of CBCT has been shown to markedly increase clinicians' diagnostic confidence [12]. More than only confirming or ruling out fractures, CBCT actively influences therapeutic decision-making. Current literature demonstrates that undetected scaphoid fractures on initial plain radiographs can be reclassified as surgical cases following a CBCT scan, thereby ensuring necessary operative interventions or, conversely, sparing patients from unwarranted surgery [12]. However, although highly effective, CBCT is not an infallible diagnostic tool, as it may occasionally fail to identify specific fractures that are subsequently detected on MRI [8].

Despite these occasional misses, CBCT’s greatest strength lies in how dramatically it can accelerate the diagnostic pathway. Rapid scanning protocols have enabled a definitive diagnosis in 94.1% of patients within just two days [10] — sparing those without fractures from weeks of unnecessary immobilization and allowing immediate rehabilitation. Beyond the scaphoid itself, 3D imaging frequently uncovers additional injuries: CBCT routinely detects occult fractures in adjacent structures — particularly the trapezium and radial styloid — that were completely invisible on initial X-rays [11,15]. Advanced extremity imaging modalities like HR-pQCT take this even further, identifying 60% more scaphoid fractures than standard MDCT in trauma patients [9].

Importantly, this augmented diagnostic capability is achieved while maintaining highly favorable radiation safety profiles. The specific design of CBCT and HR-pQCT scanners enables effective physical shielding of radiation-sensitive organs, significantly reducing the patient's effective dose (e.g., to as low as 15 μSv in HR-pQCT) [9, 12].

Notwithstanding these significant advantages, CBCT technology shows distinct technical limitations. While it excels at visualizing cortical disruptions, it struggles with trabecular fractures, which can occasionally go undetected [13]. Additionally, the required acquisition time of approximately 15 seconds makes CBCT inherently more susceptible to patient motion artifacts compared to standard, faster MDCT scanners [13].

Given these constraints, MRI still holds a strong position in the management of suspected scaphoid fractures. According to Tiago Rua et al., while MRI demands a higher upfront investment, it generates overall financial savings by cutting downstream costs — unnecessary follow-up visits, repeat imaging, and avoidable surgeries. In economic terms, MRI dominated the standard of care: it was both cheaper and more effective in terms of patient quality of life [16].

Another diagnostic tool, which appears above the horizon, is AI assistance in the diagnostic process. Recent meta-analysis of 26 studies shows that sensitivity with AI can achieve 87% in comparison to 77% without additional help and specificity 92% in comparison to 88%. [19]

Deep learning models seem to be helpful in the primary diagnostic process. Some studies suggest that, from an economic perspective, implementing deep learning models to assist clinicians in the diagnostic process (as an adjunct, not a substitute) may prove beneficial and significantly reduce incurred costs in the long term [23]. Nevertheless, there are cases where more accurate diagnosis is needed to dispel doubts. Although AI models may seem appealing, implementing such assistance may also have a negative influence on diagnosis. Due to incoherent imaging parameters and environments radiograms may differ in image quality, detail, contrast, clarity, or film darkness such tool might lead to misdiagnosis, even if performed in one hospital [18]

Finally, evaluating the true clinical efficacy of CBCT is complicated by several methodological limitations within the current literature. First, selection bias is highly prevalent in retrospective cohorts. Strict inclusion criteria often limit study populations to patients with ambiguous initial radiographs, potentially artificially inflating the "problem-solving" value of CBCT while diminishing the statistical performance of standard X-rays [12]. Second, the lack of a universal reference standard heavily impacts the reported metrics. By using surgical reports as the confirmation method rather than systematic MRI confirmation, studies restrict their cohorts to patients requiring operative intervention, which results in a significant inclusion bias and eliminates healthy control groups. Hence, the reported 100% diagnostic performance often reflects only sensitivity and precludes the calculation of specificity [11]. The absence of confirmatory MRI in other studies similarly prevents definitive

validation of both parameters [10]. Lastly, delayed imaging methods present a major confounding variable. In one noteworthy study, the median time from initial radiography to CBCT was 15 days, during which patients were immobilized in casts. The authors appropriately concede that minor, non-displaced fractures could have healed prior to the scan, significantly undermining the credibility of the findings [14]. Given these methodological constraints, future prospective studies are vital to fully establish and standardize the clinical utility of CBCT.

Conclusions

In conclusion, Cone Beam Computed Tomography (CBCT) demonstrates more accurate diagnostic performance for suspected scaphoid fractures, offering sensitivity and specificity more similar to MRI while providing a significantly lower radiation dose than standard MDCT. The implementation of early CBCT imaging relevantly improves the clinical pathway, reducing the time for definitive diagnosis and preventing weeks of unnecessary cast immobilization for patients without fractures. While MRI remains a highly cost-effective gold standard for definitive evaluation, its limited availability in sudden injury makes CBCT an accessible, rapid, and safe alternative in emergency departments. Therefore, integrating CBCT into routine clinical diagnostic protocols for acute wrist trauma is highly recommended, although further large-scale prospective studies are appropriate to fully standardize these clinical pathways.

Disclosure

Authors' contribution

Conceptualization MM and MZ;
Methodology: AB and JA;
Software: BC and AO;
Validation: ZG, PK and AG;
Formal analysis: MM;
Investigation: MZ and AG;
Resources: AB and PK;
Data curation: ZG;
Writing – original draft: JA and MZ;
Writing - review and editing: AB, ZC and AM;
Visualization: AG and AM;
Supervision: AB and MM;
Project administration: MM;

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AI (Google Gemini) was for additional linguistic refinement of the research manuscript, ensuring proper English grammar, style, and clarity in the presentation of results. It is important to emphasize that all AI tools were used strictly as assistive instruments under human supervision. The final interpretation of results, classification of errors, and conclusions were determined by human experts in clinical medicine and formal logic. The AI tools served primarily to enhance efficiency in data processing, pattern recognition, and linguistic refinement, rather than replacing human judgment in the analytical process.

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