Keywords
cone beam computed tomography; CBCT; scaphoid fracture; wrist trauma; hand trauma; radiography; fracture detection

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Enhancing Hand Trauma Diagnosis: Analysis of Cone Beam CT Versus Plain Radiography

Abstract
Background/Objectives: The detection of hand trauma, particularly scaphoid fractures, is challenging because of the intricate composition of the wrist bones. Standard radiography has recognized limitations and may fail to identify occult fractures at the initial presentation. This study compared the diagnostic yield of cone beam computed tomography (CBCT) versus plain radiography for suspected scaphoid and other wrist fractures in a preliminary exploratory cohort.
Methods: This prospective, single-center exploratory study included a convenience sample of 31 patients with suspected hand and wrist injuries. After initial radiography, patients underwent CBCT. Two blinded radiologists independently reviewed both image sets. The primary outcome was the comparative fracture detection rate between the two modalities.
Results: CBCT demonstrated a higher diagnostic yield, identifying fractures in 20/31 patients (64.5%; 95% CI: 46.9%-78.9%) compared with 12/31 patients (38.7%; 95% CI: 23.7%-56.2%) by radiography. This difference was statistically significant (McNemar's test, $p = 0.0078$). CBCT identified eight fractures that were not detected by radiography and eliminated diagnostic ambiguity, with 0% of cases classified as suspicious compared with 12.9% for radiography.
Conclusions: In this preliminary study, CBCT showed a higher diagnostic yield for occult hand and wrist fractures than plain radiography. These findings support the potential value of CBCT as a second-line imaging tool when clinical suspicion remains high despite negative or equivocal radiographs. Larger multi-center studies with a definitive reference standard are needed to confirm these findings.

1. Introduction
Hand injuries are among the most frequently encountered cases in emergency departments, accounting for approximately 10 to 30% of injuries seen in such settings [1]. Radiography remains the primary imaging modality for diagnosing these injuries as it provides vital information for the initial management of patients [2]. Due to the hand's pivotal role in both functional and social activities, injuries to this area require prompt and expert care [3]. The psychological burden caused by hand injuries, such as depression and anxiety, can significantly reduce a patient's quality of life [4].
While simple radiographs can diagnose many hand and wrist injuries, certain cases, especially non-displaced fractures like scaphoid fractures, present diagnostic challenges. These fractures, which are often subtle and difficult to detect with standard radiographs, can lead to poor outcomes if not accurately diagnosed [5].

In Jordan, the use of CBCT has expanded significantly in recent years, particularly in dental and maxillofacial imaging. However, its application in diagnosing scaphoid fractures and other hand injuries remains limited. Given CBCT's potential to provide early and accurate diagnosis with lower radiation exposure, further research is warranted to explore its utility in this context. This preliminary study aims to compare the diagnostic yield of CBCT versus plain radiography for suspected scaphoid and other wrist fractures, providing initial data to inform the design of future, larger-scale investigations.

2. Materials and Methods

2.1. Study Design

This prospective, single-center, exploratory study was designed to compare the fracture detection rates of CBCT and plain radiography in patients with acute hand and wrist trauma. Between February 2023 and April 2024, 31 patients participated in the study and received CBCT imaging following wrist or hand injuries. The study was conducted at a private diagnostic radiology clinic in Mafraq, Jordan, due to the availability of CBCT equipment and its geographical proximity to both the researcher and patients. The facility provided a comfortable and well-maintained environment for imaging. The study aimed to provide a preliminary comparison of the diagnostic yield of CBCT and radiography. As this was an exploratory study, no formal sample size calculation was performed; a convenience sample of all eligible and consenting patients during the study period was enrolled. The flow of participants through the study is shown in Supplementary Figure S1.

2.2. Sample

The study sample consisted of individuals across various age groups and genders. Participants were patients with suspected carpal and scaphoid fractures who underwent routine X-rays at a private diagnostic radiology Clinic. Patients with suspected fractures were radiographed using CBCT, with a maximum time interval of one week between the two tests, though most were performed concurrently. A total of 31 patients, aged 16 to 80 years, were included in the study. Patients provided written informed consent, which included detailed information about the study objectives and methods. All imaging was performed under the ALARA principle to safeguard patients from radiation hazards. To maintain patient anonymity, each participant was assigned a code.

2.3. Ethical Considerations

Approval was obtained from the Institutional Review Boards (IRB) at the Jordan University of Science and Technology (JUST) to maintain standards of patient protection and research ethics (Approval No. 22/165/2023, dated 26/11/2023). The private diagnostic radiology clinic received an official letter explaining the purpose of this study and confirming the anonymity of the participants. The researcher collaborated with clinic staff to determine inclusion/exclusion guidelines, focusing on avoiding bias in selecting samples. Participants' confidentiality

Early diagnosis is essential, as undetected scaphoid fractures may result in long-term pain, wrist instability, and non-union, leading to a collapse in wrist function known as scaphoid non-union advanced collapse (SNAC), a form of post-traumatic carpal arthritis [6]. Scaphoid fractures are some of the most common wrist fractures, with an annual incidence ranging from 10 to 29 fractures per 100,000 people [3, 7]. These fractures are frequently caused by falls onto an outstretched hand, with the wrist extended backward [8]. Early detection is critical, but initial imaging often fails to reveal the fracture, necessitating further clinical evaluation and suspicion to make an accurate diagnosis [9]. The majority of scaphoid fractures occur at the waist of the scaphoid bone, and delayed diagnosis can lead to significant complications, including SNAC [10].

Historically, scaphoid fractures were first described by the French radiologist Destot in 1905 [11]. Despite their common occurrence, scaphoid fractures present unique challenges due to the bone's specific geometry and vascular arrangement [12]. Failure to diagnose these fractures, especially in non-displaced cases, can lead to severe complications, including arthritis and long-term immobilization [13]. Although conventional radiography remains the first-line imaging modality for scaphoid fractures, its limitations—particularly in diagnosing non-displaced fractures—are well recognized [14].

Magnetic resonance imaging (MRI) and computed tomography (CT) have been employed as alternative imaging modalities for scaphoid fractures, offering high sensitivity and specificity [15]. However, these methods come with disadvantages, including high costs, extended imaging times, and in the case of CT, higher radiation doses [16]. Additionally, the potential for false-positive results with these imaging techniques further complicates the diagnostic process [17].

An emerging imaging modality that shows promise in overcoming these limitations is Cone Beam Computed Tomography (CBCT). Initially developed for dental applications, CBCT offers high spatial resolution with a smaller footprint and lower radiation dose compared to traditional CT [18]. CBCT has been shown to provide high diagnostic accuracy for small skeletal structures, making it a suitable option for detecting subtle fractures, such as those seen in the scaphoid [9]. Studies have demonstrated that CBCT outperforms conventional radiography and even MDCT in detecting complex, non-displaced fractures of the scaphoid [19, 20]. A Swiss study also found that CBCT was effective in detecting wrist fractures from acute trauma cases, further supporting its use in emergency settings [21].

CBCT's smaller size and ability to provide weight-bearing imaging make it highly suitable for emergency and orthopedic settings [22]. Moreover, its reduced radiation dose and cost compared to MDCT make CBCT a compelling alternative in resource-limited environments [23]. Although further research is necessary to establish CBCT as a routine diagnostic tool for scaphoid fractures, initial studies have demonstrated its efficacy in identifying wrist fractures, particularly in acute trauma cases [24].

Each participant underwent both radiography and CBCT scans.

2.9. Image Analysis and Statistical Methods

Two board-certified radiologists with expertise in musculoskeletal trauma reviewed the radiographs and CBCT images on a clinical workstation with two-megapixel monitors. Patient data were anonymized to prevent bias. The radiologists, unaware of the patients' identities or clinical histories, recorded their findings on a standardized assessment form. The diagnostic criterion for fracture was the identification of a clear cortical breach by the reviewing radiologist on either modality. To minimize review bias, the two sets of images (radiography and CBCT) for each patient were reviewed independently with a washout period of at least two weeks, and the order of presentation was randomized.

As a true gold standard was not available, this study reports on the comparative diagnostic yield rather than formal diagnostic accuracy metrics like sensitivity and specificity. The primary outcome was the fracture detection rate. Interrater agreement for fracture detection on both modalities was assessed using Cohen's kappa coefficient. McNemar's test was used to compare the paired proportions of fracture detection between the two modalities. Confidence intervals for proportions were calculated using the Wilson score method. All statistical analyses were performed using IBM SPSS statistics v27.0.

3. Results

3.1. Demographic Profile

A total of 31 patients were included in the study. The gender distribution showed a significant predominance of male participants, who made up 80.6% of the sample, compared to 19.4% female participants. The age distribution of the patients ranged from 16 to 80 years, with a mean age of 34.1 years (SD = 16.14).

3.2. Technical Parameters of Imaging

The technical parameters of the imaging modalities used in the study were examined. Table 1 summarizes the descriptive statistics for the kilovoltage peak (kVp) and milliampere-seconds (mAs) for both digital X-rays and CBCT.

was maintained, with no personal information collected. Study data were stored securely on a password-protected computer accessible only to the researcher.

2.4. Exclusion Criteria

Participants were excluded if they were pregnant, under 10 years old, had multiple injuries requiring critical care, or declined to be followed by the researcher. Those who did not undergo CBCT exams were also excluded.

2.5. Imaging Techniques

Plain Radiographs: Each patient received posteroanterior (PA), lateral, and PA oblique hand x-ray and wrist images with constant values of 5 mA and 50 kV.

CBCT: Selected patients underwent CBCT imaging of the hand and wrist using the Carestream CS8100 3D CBCT system. The scan parameters included 90 kV and 48 mAs (3.20 mA for 15 seconds), producing axial images with a matrix size of 400 × 363 and a slice thickness of 2 mm.

2.6. Image Viewing and Archiving

Images were displayed in DICOM format, which facilitated easy viewing and analysis by participants and other specialists. This format improved communication between referring physician and radiologist, allowing seamless access to CBCT results.

2.7. Data Collection

Radiographs and CBCT scans were collected by a trained radiographer. Patient details such as case number, age, gender, and examination date were recorded and stored on a secure external disk. Patient data was transferred to a password-protected Word file for study purposes.

2.8. Imaging Protocol

Participants were seated during the CBCT scan, with the hand securely fastened to prevent movement that could affect image quality. The scan, which took approximately one minute, was performed using a dual scanner with telescoping arms. CBCT imaging required 14 seconds to produce 318 projection images, which were processed with Siemens Healthineers software. Plain radiographs were taken using 49–54 kV and 2–2.5 mAs. Patients with suspected wrist and scaphoid injuries were included after giving informed consent.

Table 1. Descriptive Statistics of Technical Parameters for Digital X-rays and CBCT

Parameter	N	Minimum	Maximum	Mean
kVp of the X-rays	31	50	53	50.32
mAs for the X-rays	31	4	5	4.9
kVp of the CBCT	31	90	90	90
mAs for the CBCT	31	47	49	48.06

3.3. Fracture Identification

This study investigated fracture detection outcomes using X-ray and CBCT imaging, with two independent readers involved in the analysis. Table 2 shows the comparative results.

Table 2. Comparison of Fracture Detection and Normal Findings between X-ray and CBCT by Two Readers

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Result	Reader 1 X-ray	Reader 1 CBCT	Reader 2 X-ray	Reader 2 CBCT
Fractures, n (%)	12 (38.7%)	20 (64.5%)	12 (38.7%)	20 (64.5%)
Normal, n (%)	15 (48.4%)	11 (35.5%)	17 (54.8%)	11 (35.5%)
Suspicious, n (%)	4 (12.9%)	0 (0%)	2 (6.5%)	0 (0%)
Total	31 (100%)	31 (100%)	31 (100%)	31 (100%)

CBCT demonstrated a significantly higher diagnostic yield for fractures compared to radiography. The difference in detection rates was statistically significant (McNemar's test, $p = 0.0078$).

Table 3. Fracture Detection Rates with 95% Confidence Intervals

Modality	Fractures Detected	Detection Rate	95% CI
CBCT	20/31	64.5%	46.9% - 78.9%
Radiography	12/31	38.7%	23.7% - 56.2%
Absolute Difference	+8 cases	25.8 percentage points	—

Table 4. Fracture Detection by Anatomical Location

Bone	CBCT	Radiography	Difference
Scaphoid	7	5	+2
Lunate	2	2	0
Distal radius	5	3	+2
Metacarpal	1	4	-3
Ulnar styloid	3	2	+1
Hamate	2	0	+2
Total	20	16	+4

Table 5. Contingency Table for CBCT vs. Radiography

X-ray Result	CBCT Fracture Present	CBCT Fracture Absent	Total
Fracture	12	0	12
Normal	8	11	19
Total	20	11	31

3.4. Interrater Agreement

The interrater agreement for CBCT between Reader 1 and Reader 2 was perfect, as indicated by a Cohen's kappa coefficient of 1.00 (95% CI: 1.00–1.00). This highlights the strong reliability of CBCT in detecting fractures, with complete concurrence between the readers.

4. Discussion

This preliminary, exploratory study was designed to compare the diagnostic yield of CBCT and plain radiography for suspected hand and wrist fractures. The findings indicate a significantly higher fracture detection rate with CBCT compared to radiography in this cohort. This discussion will contextualize these findings within the existing literature, address the study's significant limitations, and suggest directions for future research.

In this cohort, CBCT demonstrated a significantly higher diagnostic yield for fractures compared to plain

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compared to 5 by radiography. This incremental detection is clinically important, as missed scaphoid fractures can lead to significant morbidity, including non-union and scaphoid non-union advanced collapse (SNAC) [10]. The ability of CBCT to identify fractures missed by radiography may have implications for downstream resource utilization. By providing a definitive diagnosis earlier, CBCT could potentially reduce the need for follow-up imaging, such as MRI, and unnecessary immobilization. However, it is critical to note that CBCT does not evaluate soft tissues or bone marrow edema, and MRI remains the gold standard for ruling out occult fractures

4.1. Fracture Characteristics

Beyond simple detection, the high-resolution images provided by CBCT allowed for a detailed assessment of critical fracture characteristics, such as displacement, angulation, comminution, and instability, all of which are crucial for determining the appropriate treatment and prognosis. The spectrum of anatomical locations of the fractures detected with CBCT in this study was consistent with findings from a Swedish study [29]. CBCT proved particularly effective in identifying scaphoid fractures, which accounted for 35% (7/20) of the total fractures detected (Figure 1).

radiography. CBCT detected fractures in 64.5% of patients (95% CI: 46.9% - 78.9%), whereas radiography detected fractures in only 38.7% (95% CI: 23.7% - 56.2%). This difference was statistically significant (McNemar's test, $p = 0.0078$). Notably, CBCT identified 8 additional fractures in patients whose initial radiographs were interpreted as normal. This finding aligns with previous research suggesting that CBCT is more effective at identifying occult fractures [12, 21].

While formal sensitivity could not be calculated without a gold standard, the comparative detection rate highlights the potential of CBCT. For scaphoid fractures specifically, CBCT identified 7 cases and assessing ligamentous injuries [28].

Numerous investigations have examined the diagnostic capacities of CBCT and radiography in identifying fractures of the hands and wrists. These studies repeatedly demonstrate the higher diagnostic precision of CBCT, especially in detecting tiny or complex fractures that are often missed by radiography. This research, carried out in Jordan, provides more evidence that CBCT surpasses X-ray in the identification of fractures and comprehensive analysis of fracture images. The presented data underscores the increasing significance of CBCT as a proficient diagnostic instrument for the management of hand injuries.

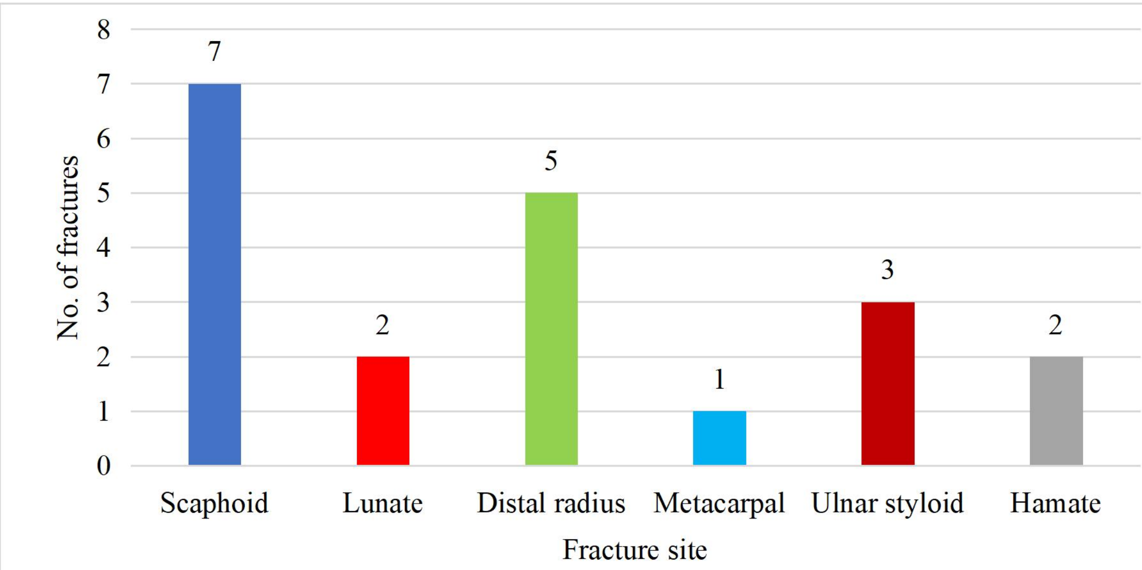

Figure 1. Features of carpal fractures detected by CBCT.

Sometimes, scaphoid fractures that were invisible on X-rays (Figure 2A) were successfully identified using CBCT (Figure 2B and 2C).

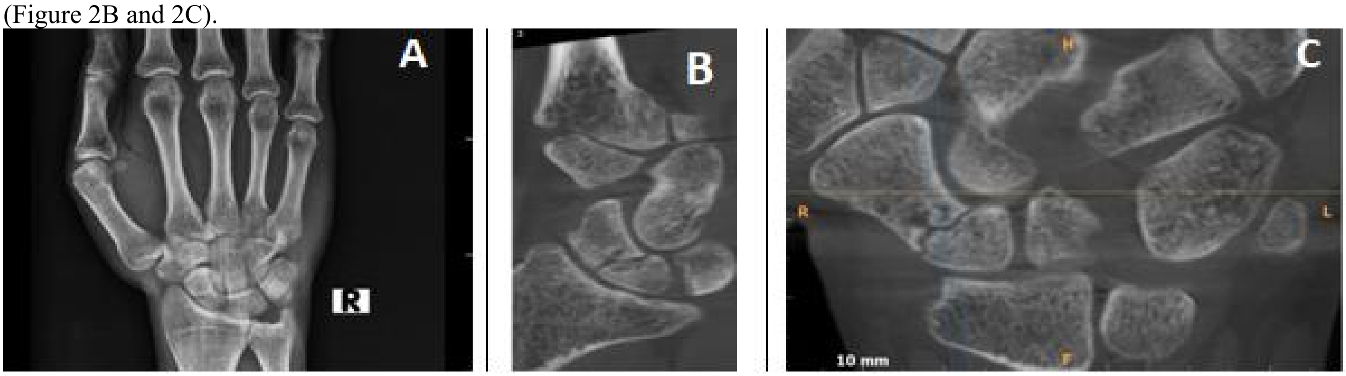

Figure 2. Radiography of the hand showing an occult fracture (A); CBCT images (B,C) demonstrating a displaced unhealed scaphoid fracture with avascular necrosis.

4.1.1. Displacement and Angulation

Displaced fractures were clearly visible on CBCT scans, showing substantial misalignments in bone structure that were not apparent on X-rays. Accurate measurement of angulation is critical in preventing complications such as non-union or malunion, which can significantly impact patient outcomes [30]. For example, Figure 3 illustrates a hook of hamate fracture that was not evident on X-rays but was clearly visible on CBCT images.

Figure 3. Hook of hamate fracture. The fracture is not visible on general radiographs (A,B) but is clearly evident on CBCT images (C-E).

High-quality radiography remains essential for the initial evaluation of fractures, but CBCT's ability to detect clear displacement (Figure 4B and 4C) in cases with minimal radiographic signs (Figure 4A) raises concerns about the adequacy of plain radiography alone in identifying displaced fractures requiring early intervention.

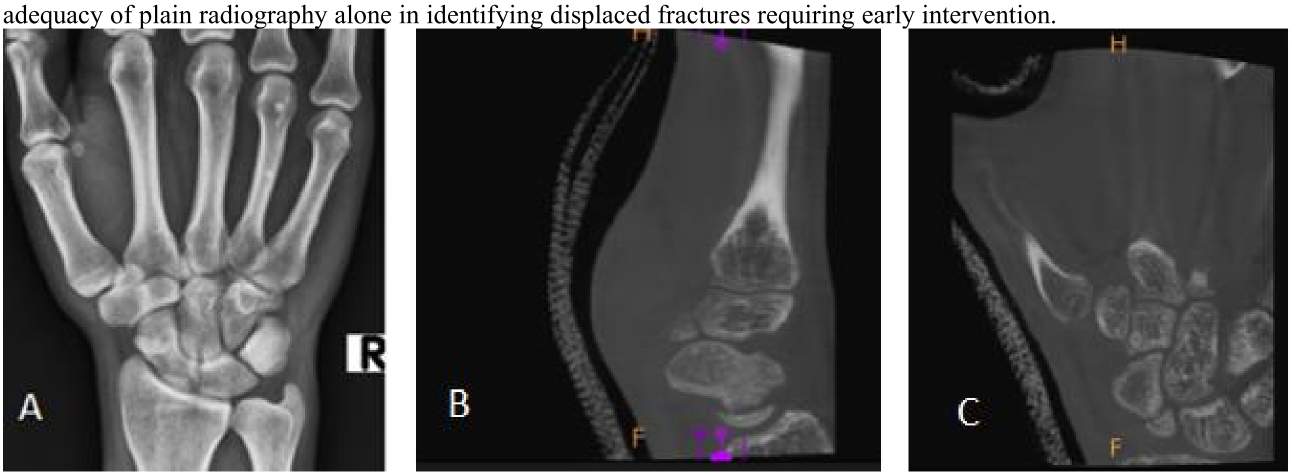

Figure 4. Scaphoid fracture with clear displacement observed on CBCT scans (B,C), while only minimal indications of the fracture are evident on the plain radiograph (A).

4.1.2. Comminution

CBCT also excelled in detecting comminuted fractures, which involve multiple bone fragments [31]. These fractures are often missed or underestimated on conventional radiographs. The precision of CBCT in identifying comminution is critical for surgical planning and predicting healing outcomes [19]. Figure 5 highlights a distal radius fracture with several hidden fragments that were revealed by CBCT, whereas radiography only detected a single linear fracture.

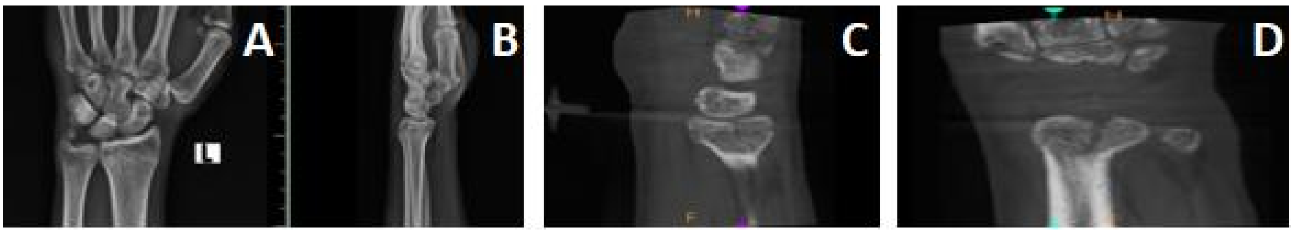

Figure 5. Distal radius comminuted fracture. General radiographs (A,B) reveal only one linear fracture, whereas CBCT images (C,D) clearly demonstrate multiple hidden fractures.

4.1.3. Fracture Instability

Fracture instability, which poses a significant risk for improper healing [32], was more accurately evaluated using CBCT. The detailed imaging provided by CBCT allowed for a thorough assessment of fracture stability, aiding in the identification of cases that may require more aggressive treatment interventions. As shown in Figure 6, CBCT was able to detect instability that was not visible on general radiographs. This enhanced detection capability provides clinicians with the information needed to make more informed treatment decisions, improving patient outcomes and reducing the likelihood of complications.

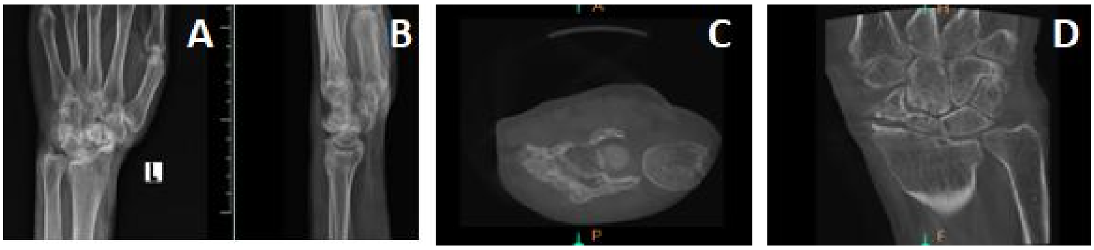

Figure 6. Fracture instability. General radiography (A,B) shows limited details, whereas CBCT images (C,D) reveal fracture instability more accurately.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Jordan University of Science and Technology (Approval No. 22/165/2023, 26 November 2023).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to privacy and ethical restrictions.

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Supplementary Materials: Supplementary Figure S1 is provided below. The diagram reflects the participant flow reported in the manuscript. The manuscript reports the enrolled sample (n = 31) and exclusion criteria, but it does not report the total number screened or excluded before enrollment

4.2. Limitations

This study has several important limitations that must be acknowledged:

- Sample size: The sample size of 31 patients limits the precision of our estimates, as reflected in the wide confidence intervals. No formal power analysis was performed.
- Single-center design: This was a single-center study conducted at one clinic in Jordan, which may limit generalizability to other settings and populations.
- Absence of gold standard: In the absence of a definitive gold standard (such as MRI or surgical confirmation), we report comparative diagnostic yield rather than formal diagnostic accuracy metrics. The additional fractures detected by CBCT may represent true occult fractures or potentially false positives; clinical follow-up data would be needed to distinguish between these possibilities.

Future studies should include larger sample sizes, multiple centers, and a definitive reference standard to validate these preliminary findings.

5. Conclusions

This preliminary study compared the diagnostic yield of CBCT and conventional radiography for suspected hand and wrist fractures. In our cohort, CBCT detected a significantly higher number of fractures than radiography, particularly for occult scaphoid, distal radius, and hamate fractures. CBCT also provided superior visualization of fracture characteristics such as displacement and comminution.

These findings suggest that CBCT may be a valuable second-line imaging tool for patients with high clinical suspicion of a fracture despite negative or equivocal initial radiographs. However, due to the limitations of this study, including the small sample size and lack of a gold standard, these results should be considered exploratory. Further investigation in larger, multi-center studies is warranted to validate these findings and to define the precise role of CBCT in the diagnostic algorithm for acute hand trauma.

Supplementary Materials: Supplementary Figure S1: STARD 2015 flow diagram for the study.

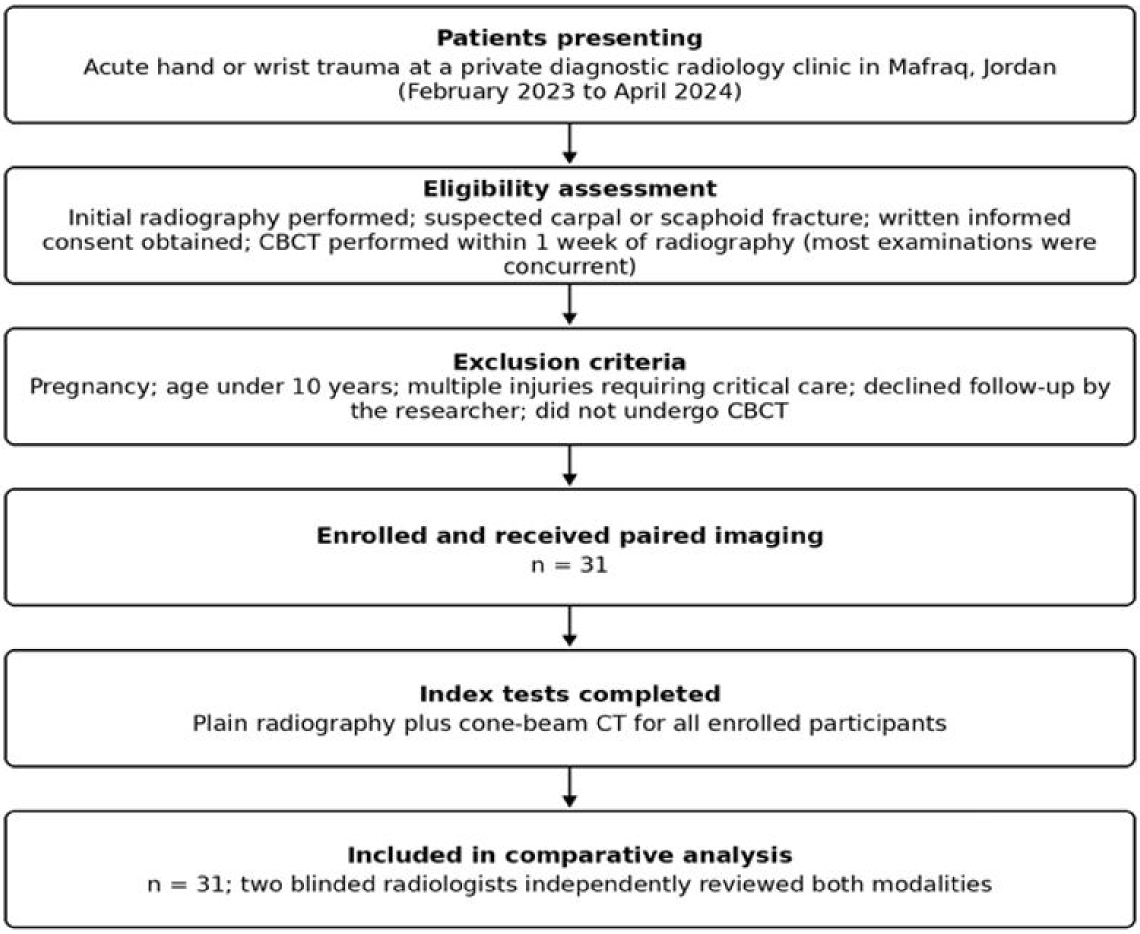

Figure S1. STARD 2015 flow diagram for the study.

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