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Clinical performance of cone-beam CT for suspected scaphoid fractures: insights from a large retrospective cohort

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Declaration:

Ethics approval and consent to participate

- Institutional Review Board approval was obtained for this study (Swedish Ethical Review Authority, Dnr 2021-03176) in accordance with the Declaration of Helsinki
- Written informed consent was waived by the Institutional Review Board.

Human Ethics and Consent to Participate declarations:

- Not applicable.
- No patients younger than 16 years were included in the study.

Consent for publication:

- Not applicable

Availability of data and materials

- The data supporting this study are not publicly available due to participant confidentiality and legal restrictions,but are available from the corresponding author on reasonable request and with appropriate ethical approvals.

Competing interests

- The authors declare that they have no competing interest

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Abstract

Background: Accurate and timely diagnosis of acute scaphoid fractures is crucial to avoid complications and unnecessary immobilization. Cone-beam computed tomography (CBCT) has recently emerged as a high-resolution, low-dose imaging modality for extremity fractures, but its clinical performance for suspected scaphoid fractures remains incompletely characterized. This study aimed to evaluate the clinical use of CBCT in detecting scaphoid fractures in patients presenting to an orthopedic emergency department.

Methods: In this retrospective study, 1,296 CBCT examinations were performed in 1,245 patients aged 16–98 years with clinically suspected acute scaphoid fractures between March 2020 and May 2022. Patients with negative CBCT findings were followed longitudinally using the regional PACS archive and radiology information system (RIS) to identify return visits, additional imaging (radiographs, CT, or MRI), or subsequent diagnoses of scaphoid fracture. Fracture type, location, and displacement were recorded.

Results: CBCT identified 175 scaphoid fractures. One fracture initially missed on CBCT was subsequently detected on MRI during follow-up and later confirmed on repeat CBCT. Fractures were more common in men than in women (20% vs. 7%, $p < 0.001$). The median age at the time of fracture was 33 years for men and 49 years for women. The most common fracture pattern was non-displaced and non-comminuted (39%), with most fractures located in the scaphoid waist (middle third; Mayo grade 4). Displaced fractures with ≥30% bone contact were more frequently observed in men than in women ($p = 0.03$).

Conclusion: CBCT identified a large number of scaphoid fractures, with only one fracture detected during follow-up after an initially negative examination. Given its rapid acquisition, low radiation dose, and detailed depiction of fracture morphology, CBCT may be a useful first-line imaging modality for adult patients with clinically suspected acute scaphoid fractures.

Keywords: Scaphoid fracture, cone-beam CT, emergency imaging, diagnostic performance, trauma

Background

The scaphoid is the most commonly fractured carpal bone, accounting for approximately 60% of all carpal fractures, 11% of hand fractures, and 2% of all fractures [1]. Acute scaphoid fractures are often readily diagnosed using conventional radiographs, computed tomography (CT), or magnetic resonance imaging (MRI). However, non-displaced fractures remain diagnostically challenging [2]. Conventional radiography fails to detect approximately 16% of scaphoid fractures, while conventional CT may miss subtle cortical disruptions. MRI, although highly sensitive, may overinterpret trabecular bone injury (bone bruise) as cortical fractures with potential for later displacement, potentially leading to unnecessary immobilization and overtreatment [2].

Treatment of scaphoid fractures depends on several factors; most importantly fracture location and degree of displacement. For clinical and therapeutic purposes, the scaphoid is commonly divided into thirds [3]. Approximately 65% of fractures occur in the waist (middle third), 25–30% in the distal third, and 5–10% in the proximal third [4]. Waist fractures with displacement up to 1.5–2.0 mm can often be treated conservatively with cast immobilization for 4–8 weeks, whereas severely displaced, angulated, and most proximal fractures typically require surgical fixation [5].

Accurate and timely diagnosis is essential to initiate appropriate treatment and reduce the risk of complications. Missed scaphoid fractures may progress to nonunion, and even with adequate treatment, approximately 10% of fractures fail to heal [6]. The scaphoid plays a central role in wrist biomechanics, and disruption of scaphoid integrity or ligamentous attachments can ultimately result in scaphoid nonunion advanced collapse (SNAC) and subsequent osteoarthritis [6].

Patients with clinically suspected acute scaphoid fractures and negative initial conventional radiographs present a well-known diagnostic dilemma [7]. Traditionally, these patients are immobilized for 10–14 days followed by repeat clinical examination and radiography, resulting in a substantial proportion of patients undergoing unnecessary immobilization despite the absence of fracture. To address this issue, early cross-sectional imaging with MRI or CT is increasingly being used. MRI has demonstrated sensitivities approaching 99%, while conventional CT has reported sensitivities of approximately 93–95% [8–10].

Cone-beam computed tomography (CBCT) has recently been introduced for extremity imaging, offering high spatial resolution with lower radiation exposure compared to

conventional CT. Early studies investigating CBCT for suspected scaphoid fractures have suggested promising performance, however, these studies have generally been limited by small sample sizes [11–13]. Consequently, the role of CBCT in the diagnostic workup of suspected acute scaphoid fractures has not yet been fully established in large clinical cohorts.

The aim of this study was to evaluate the performance of CBCT in the primary assessment of patients with clinically suspected acute scaphoid fractures in a large retrospective cohort, using longitudinal clinical and imaging follow-up as outcome reference.

Methods

Ethical Approval

Ethical approval was obtained from the Swedish Ethical Review Authority in accordance with the Declaration of Helsinki (Dnr 2021-03176), and the requirement for informed consent was waived due to the retrospective nature of the study.

Study Design and Setting

This retrospective study was conducted at a university hospital with a large orthopedic emergency department responsible for all adult musculoskeletal trauma within a primary catchment area of approximately 600,000 inhabitants. The hospital, surrounding hospitals, and private radiology clinics are all connected through a shared regional Picture Archiving and Communication System (PACS) and Radiology Information System (RIS), covering a total population of approximately 1.5 million inhabitants.

This integrated healthcare and imaging infrastructure enables longitudinal follow-up of patients across institutions, reducing the likelihood of missing patients who sought subsequent care for wrist-related symptoms at other hospitals or private facilities within the region.

Patient Selection

All consecutive patients aged 16–98 years with clinically suspected acute scaphoid fracture who underwent cone-beam computed tomography (CBCT) as the primary imaging modality between March 1, 2020, and May 15, 2022, were included.

Patients with no fracture identified on initial CBCT were followed longitudinally using the regional PACS archive and RIS for a minimum of one year to identify any return visits, additional imaging (radiographs, CT, or MRI), or subsequent diagnoses of scaphoid fracture. This follow-up strategy was used to detect fractures that were not apparent at the initial assessment.

Imaging Protocol

CBCT examinations were performed using a dedicated extremity scanner (Planmed Verity, Helsinki, Finland). The patient's wrist was positioned in the center of the gantry with a field of view of 13 × 13 cm. Acquisition parameters were 90 kV and 6 mA, with a total scan time of approximately 30 seconds. Images were reconstructed in axial, coronal, and sagittal planes with slice thicknesses ranging from 0.2 to 0.4 mm, depending on the reviewing radiologist's preference.

Image Analysis

All CBCT examinations were interpreted at the time of imaging by radiology residents or general radiologists under the supervision of a senior musculoskeletal radiologist with 15 years of experience in musculoskeletal imaging.
Scaphoid fractures were classified according to fracture type, location, and displacement using established criteria (Tables 1–3). Displaced fractures were further categorized based on the percentage of bone contact across the fracture surface. Fracture location was graded according to the Mayo classification system [10].

Follow-up and Missed Fractures

Follow-up imaging and clinical records within the PACS/RIS were reviewed to identify patients who returned with persistent or worsening wrist symptoms after an initial negative CBCT examination. Any subsequently detected scaphoid fractures were considered initially occult and analyzed descriptively with respect to patient characteristics, fracture type, and imaging findings.

Statistical Analysis

Study data were extracted from the institutional PACS/RIS system and stored in a secure institutional research database prior to analysis. Statistical analyses were performed using SPSS Statistics (IBM Corp., Armonk, NY, USA). Continuous data are presented as mean ± standard deviation or median with interquartile range (IQR), as appropriate based on data distribution. Categorical variables are presented as counts and percentages.

Group comparisons were performed using the χ^2 test or Fisher's exact test for categorical variables and Student's t-test or Mann–Whitney U test for continuous variables, depending on normality. Sex-based comparisons were conducted as exploratory descriptive analyses to characterize fracture patterns within the cohort. These analyses are exploratory to describe epidemiological patterns and fracture characteristics, not to evaluate CBCT diagnostic accuracy.

Given the exploratory nature of subgroup analyses, no formal correction for multiple comparisons was applied; p-values should be interpreted descriptively, and findings regarded as hypothesis-generating rather than confirmatory. A p-value ≤ 0.05 was considered statistically significant.

Results

During the 26½ month study period, 1,296 CBCT examinations for suspected acute scaphoid fracture were performed in 1,245 patients. Fifty-one patients underwent bilateral CBCT examinations. The demographic characteristics of the study population are summarized in Table 4. Of the 1,296 examinations, 635 were performed in men and 661 in women. Age distributions were skewed; therefore, age is reported as median and interquartile range (IQR). The median age was 33 years (IQR 24–47) for men and 49 years (IQR 38–59) for women.

A total of 175 scaphoid fractures (14%) were identified on initial CBCT examinations. Fractures were more common in men, with 127 of 635 examinations (20%) demonstrating a scaphoid fracture, compared with 48 of 661 examinations (7%) in women ($p < 0.001$).

Patients with scaphoid fractures were younger than those without fractures, particularly among men. The median age of men with scaphoid fractures was significantly lower than that of men without fractures ($p = 0.03$). Peak incidence of scaphoid fractures occurred in men aged 21–30 years and in women aged 51–60 years (Figure 1). Median age at the time of fracture was 33 years (IQR 26–44) for men and 49 years (IQR 41–58) for women.

Fracture types according to displacement are shown in Figure 2 and summarized in Table 1. In both men and women, most fractures were non-displaced and non-comminuted, accounting for approximately 39% of all fractures. According to the Mayo classification, most fractures were located in the waist or middle third of the scaphoid (Mayo grade 4) in both sexes (Table 3). There were no significant sex-based differences in the relative distribution of non-displaced, displaced, or avulsion fractures overall. However, displaced fractures with relatively extensive bone contact (≥30%) were significantly more common in men than in women ($p = 0.03$). These sex-based comparisons were exploratory, aimed at characterizing fracture patterns within the cohort. Figure 3 illustrates the distribution of scaphoid fractures according to the degree of fracture diastasis. Fracture diastasis less than 2 mm was slightly more common in women, whereas diastasis greater than 2 mm was more frequently observed in men. However, these differences did not reach statistical significance.

A small subset of patients exhibited isolated cortical avulsion fractures not associated with a scaphoid waist fracture or tubercular avulsion (Table 5). There was no statistically significant difference in the prevalence of these fractures between men and women. In both groups, cortical avulsions were predominantly located on the radial aspect of the scaphoid, and no ulnar-sided avulsions were identified.

During follow-up using the PACS/RIS system, one additional scaphoid fracture was identified in an 18-year-old male who returned to the orthopedic emergency department 22 days after the initial visit due to persistent and worsening wrist pain following an initially negative CBCT examination. MRI demonstrated a non-displaced scaphoid waist fracture (Mayo grade 4), which was subsequently identifiable on repeat CBCT performed the same day, showing early trabecular callus formation (Figure 4). No other scaphoid fractures were detected during follow-up. This case represents an initially occult fracture detected through longitudinal clinical follow-up rather than a systematic reference imaging protocol.

Discussion

In this large retrospective cohort of adult patients with clinically suspected acute scaphoid fracture, CBCT identified nearly all fractures that became apparent during follow-up. Although true sensitivity and specificity cannot be calculated due to the retrospective design and lack of standardized reference imaging, these observations suggest that CBCT may be a useful imaging tool for the initial assessment of suspected scaphoid fractures.

Consistent with previous literature, the waist or middle third of the scaphoid was the most common fracture location [14-16]. Most fractures were non-displaced, highlighting the diagnostic challenge posed by subtle scaphoid fractures, particularly on conventional radiographs [4,17]. This fracture pattern underscores the need for imaging techniques capable of resolving fine cortical disruptions, which are frequently occult on plain radiographs and may delay appropriate treatment.

Undiagnosed fractures can lead to costly surgery, hospitalization, and prolonged work absences [18]. Delayed or missed diagnosis may also increase the risk of nonunion and long-term wrist dysfunction, with substantial socioeconomic consequences. CBCT also offers practical advantages over conventional CT, including compact size for easier integration into radiology departments, superior spatial resolution for visualizing fine bone structures, and significantly lower radiation exposure (2.4 µSv for CBCT vs. 8.6 µSv for conventional CT) [18,19]. These advantages are particularly relevant in emergency settings, where rapid imaging access and radiation dose considerations are critical.

Sex-related epidemiological differences were observed, with fractures significantly more frequent in men and occurring at a younger age compared with women, peaking in men aged 21–30 years and women aged 51–60 years [19,20]. These differences likely reflect a combination of behavioral factors, such as higher exposure to high-energy activities among younger men, and biological factors including bone geometry, bone mineral density, and menopause-related changes in women [21,22]. The higher proportion of fractures with substantial bone contact in men may indicate sex-related differences in injury mechanisms and force transmission [23]. Such differences may have implications for both fracture stability and treatment selection, although further studies are required to clarify these associations.

A small number of isolated cortical avulsion fractures were identified, predominantly on the radial aspect of the scaphoid. These fractures, which were not associated with waist or tubercular fractures, may represent ligamentous or capsular avulsions and could influence

clinical management decisions [24,25]. Recognition of these injuries is important, as they may account for persistent symptoms despite the absence of a classic scaphoid waist fracture. Early and accurate detection of such injuries may help prevent unnecessary immobilization.

CBCT offers several practical advantages in the evaluation of suspected scaphoid fractures, including high spatial resolution, short acquisition time, and low radiation dose compared with conventional CT [18, 26–29]. While MRI remains valuable for soft tissue and bone marrow assessment, CBCT provides excellent depiction of cortical bone and fracture morphology, which are essential for immediate clinical decision-making. These characteristics support its use as a primary imaging modality in emergency and orthopedic settings, where rapid decision-making is essential to avoid overtreatment or delayed diagnosis.

Previous studies evaluating CBCT for scaphoid fractures have been limited by small sample sizes and heterogeneous reference standards [11–13,30–33]. The present study adds real-world evidence from a large cohort with all patients having clinical suspicion of scaphoid fracture, reflecting CBCT performance in routine clinical practice rather than controlled experimental settings. This strengthens the external validity of the findings and supports the implementation of CBCT in everyday emergency care.

This study has several limitations. The retrospective design and reliance on PACS/RIS-based follow-up introduce verification bias, as not all patients with a negative CBCT underwent a standardized reference examination such as MRI. Consequently, fractures that healed without further clinical contact may have been missed. Fracture assessment was performed by a single experienced radiologist, preventing evaluation of interobserver variability. The study population consisted primarily of adults, limiting generalizability to pediatric patients. These limitations should be considered when interpreting the results and designing future prospective studies.

In conclusion, CBCT demonstrated strong performance in the detection of scaphoid fractures within the studied clinical workflow. The low number of missed fractures suggests that CBCT is a reliable and practical imaging modality for the primary assessment of suspected acute scaphoid fractures in adult patients.

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Tables

Table 1. Fracture type and displacement in 175 scaphoid fractures in males and females.

Type	Incomplete fracture	Non-displaced fracture, non-comminuted	Non-displaced fracture, comminuted	Displaced fracture < 1 mm, non-comminuted	Displaced fracture < 1 mm, comminuted	Displaced fracture 1-2 mm, non-comminuted	Displaced fracture 1-2 mm, comminuted	Displaced fracture > 2 mm, non-comminuted	Displaced fracture > 2 mm, comminuted	Avulsion fracture/ligament injury	**Total**
Male	8 (6%)	50 (39%)	22 (17%)	10 (8%)	4 (3%)	4 (3%)	10 (8%)	2 (2%)	6 (5%)	11 (9%)	127
Female	1 (2%)	19 (39%)	11 (23%)	3 (6%)	1 (2%)	2 (4%)	5 (11%)	0	1 (2%)	5 (11%)	48
Total	9 (5%)	69 (39%)	33 (19%)	13 (8%)	5 (3%)	6 (3%)	15 (9%)	2 (1%)	7 (4%)	16 (9%)	175

Table 2. Amount of bone contact in displaced scaphoid fracture in 175 males and females.

Bone contact		**Male**	**Female**	**Total**	**P**
Non-displaced fractures		79 (62%)	31 (65%)	110 (63%)	0.08
Displaced fractures	≥30%	28 (22%)	7 (15%)	35 (20%)	**0.03**
(Percentage bone	20–29%	5 (4%)	1 (2%)	6 (3%)	0.06
contact)	10–19%	1 (1%)	1 (2%)	2 (1%)	0.07
	0–9 %	3 (2%)	3 (6%)	6 (3%)	0.06
Cortical avulsion fractures		11 (9%)	5 (10%)	16 (9%)	0.08
Total		127	48	175	

Table 3. Mayo fracture classification of 175 scaphoid fractures.

Mayo classification	**1: Distal articular surface**	**2: Tuberosity**	**3: Distal third**	**4: Waist (middle third)**	**5: Proximal pole**	**Total**
Male	0	39 (31%)	6 (5%)	73 (57%)	9 (7%)	127
Female	0	17 (36%)	4 (8%)	24 (50%)	3 (6%)	48
Total	0	56 (32%)	10 (6%)	97 (55%)	12 (7%)	175

Table 4. Demographic features of the whole patient group.

		Male	**Female**	**Total**	**p**
Patients with scaphoid fracture	Number	127 (20%)	48 (7%)	175	<0.001
	Mean age (range)	33.9 (17-81)	48.4 (16–87)	38.3 (16–87)	<0.001
Patients without scaphoid fracture	Number	508 (80%)	613 (93%)	1121	0.06
	Mean age (range)	39.5 (16–92)	47.1 (16–98)	43.7 (16–98)	0.03
Total	Number	635	661	1296	
	Mean age (range)	38.6 (16–92)	47.3 (16–98)	43 (16–98)	0.03
p-value regarding number and mean age comparisons between patients with and without scaphoid fracture		0.03	0.07		

Table 5. Frequency and localisation of solitary cortical avulsion other than the scaphoid tuberosity in scaphoid fracture in males and females.

	No avulsion	Cortical avulsion				Total
		Radial	Dorsal	Ulnar	Volar	
Male	116	6	4	0	1	127
Female	43	3	2	0	0	48
Total	159	9	6	0	1	175

Figure

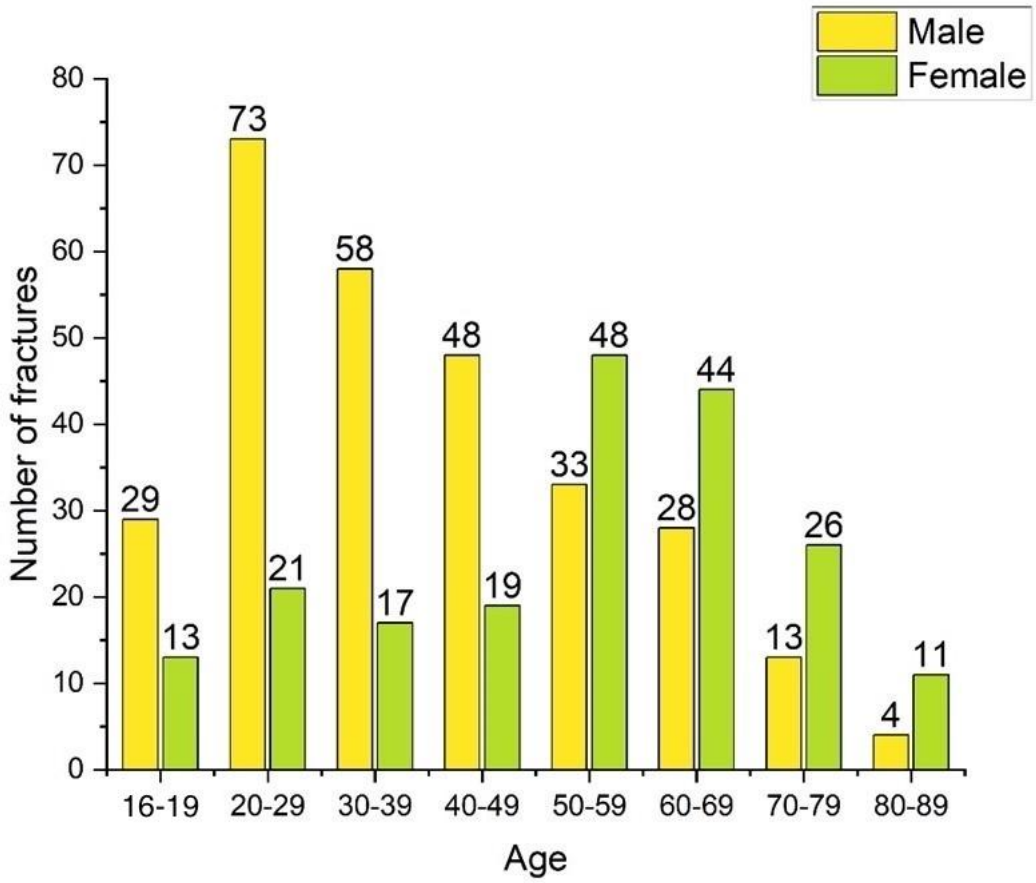


Figure 1. Scaphoid fractures in males and females per age group.

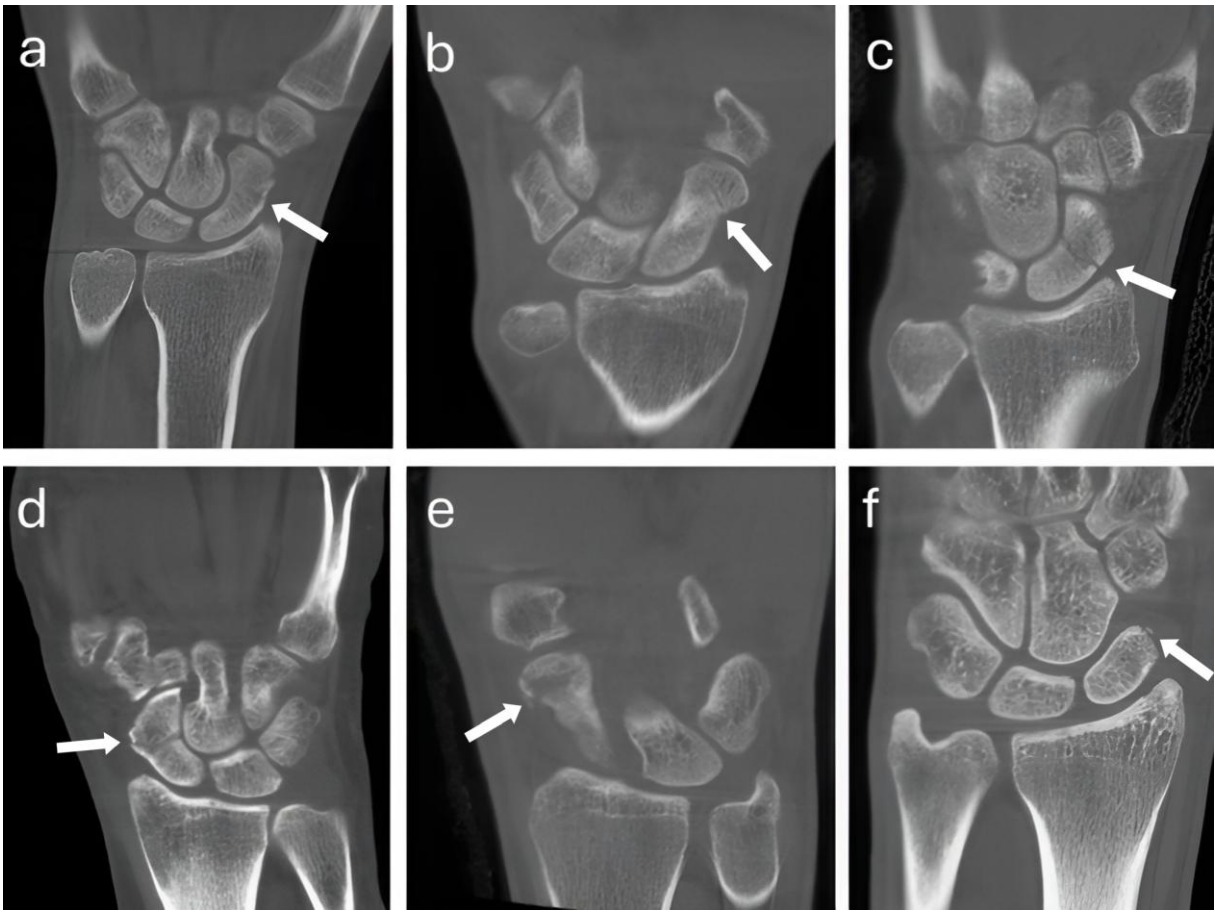


Figure 2. CBCT images of scaphoid fractures illustrating the different fracture types (arrow). **a)** A 27-year-old male with an incomplete fracture. **b)** A 48-year-old male with a non-comminuted, non-displaced fracture. **c)** A 42-year-old male with a non-comminuted < 1 mm displaced fracture. **d)** A 19-year-old male with a comminuted 1-2 mm displaced fracture. **e)** A 57-year-old female with a comminuted > 2mm displaced fracture. **f)** A 27-year-old female with an avulsion fracture/ligament injury.

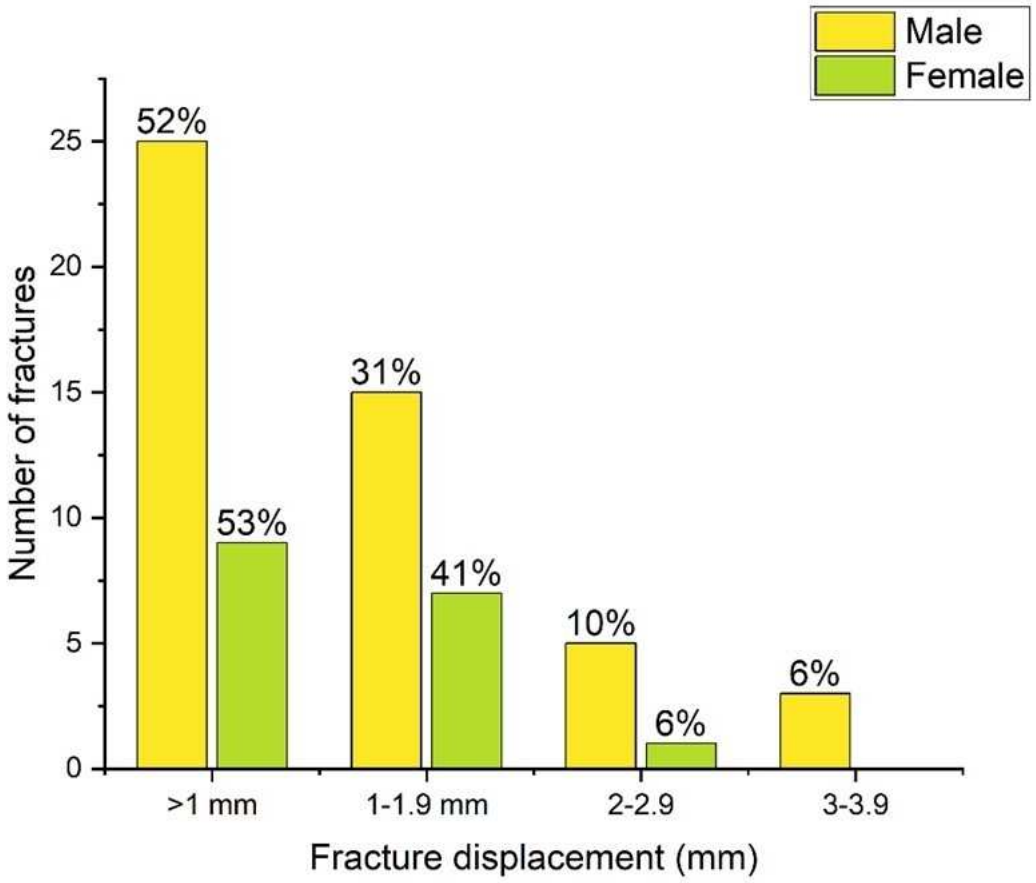


Figure 3. Extent of displacement in scaphoid fractures with associated misalignment in males and females.

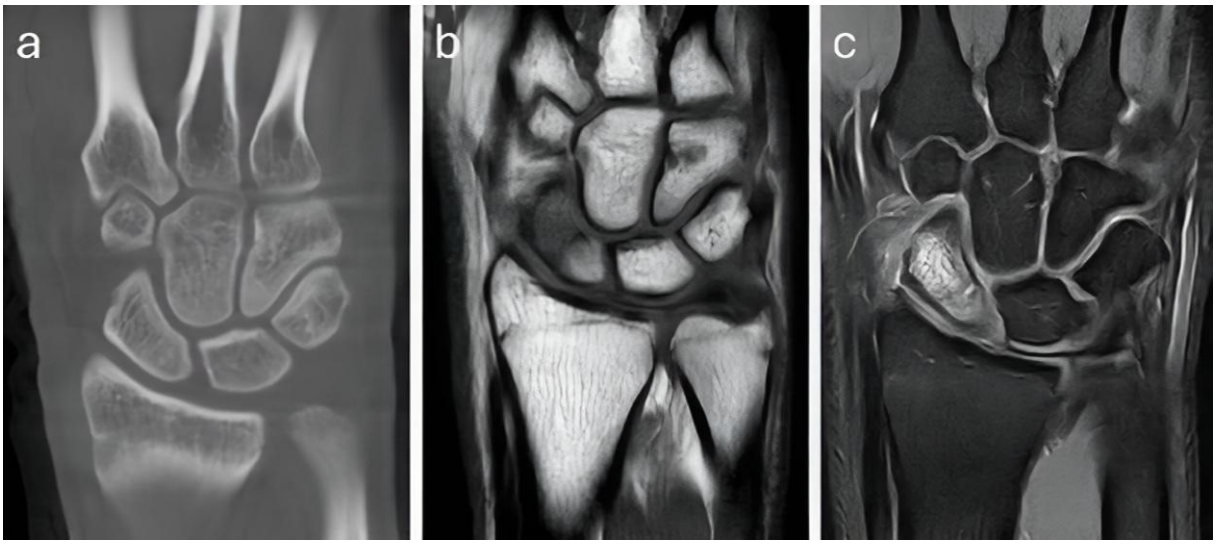


Figure 4. Wrist imaging in a 17-year-old male patient; a) The initial CBCT was interpreted as showing no fracture. b) The coronal T1-weighted MRI, performed 22 days later, reveals a hypointense cortical fracture line in the scaphoid (arrow). c) The coronal PDW SPAIR MRI sequence shows a hyperintense fracture line (arrow) along with bone marrow edema throughout most of the scaphoid bone.