Diagnostic Accuracy of Ultrasound in Detecting Elbow Fractures: A Comparison with Radiography and CT Scans

Abstract

Introduction: Elbow fractures are common in both pediatric and adult populations, and accurate diagnosis is crucial for proper treatment. While radiography is the standard method, alternative imaging techniques such as ultrasound are increasingly explored, especially when radiographic imaging is not ideal. This study evaluated the diagnostic accuracy of ultrasound in detecting elbow fractures, comparing it with radiography and computed tomography (CT) as reference standards.

Materials & Methods: Forty patients with suspected elbow fractures underwent imaging using ultrasound, radiography, and CT. Results from all three methods were compared to assess sensitivity, specificity, and agreement between ultrasound and the reference standards.

Results & Discussion: The mean patient age was 15.5 years (range: 4–49), with 72.5% male (n=29). Supracondylar fractures were most common in patients under 18, while radial head fractures predominated in those over 18. Ultrasound showed good diagnostic performance, with 88.9% sensitivity, 87% specificity, and a kappa value of 0.73 compared to radiography. Against CT, ultrasound demonstrated 94.8% sensitivity and 89.7% specificity.

Conclusion: Ultrasound is an accurate, non-invasive, and cost-effective alternative to radiography and CT for diagnosing elbow fractures, especially in emergency or resource-limited settings. Its strong diagnostic performance, particularly in children, supports its use as a reliable tool. Further studies with larger samples and follow-up are recommended.

Keywords: Elbow fractures, Ultrasonography, Computed X ray tomography, Radiography.

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Introduction

Elbow injuries are one of the common types of trauma in emergency departments. Elbow dislocations occur with an estimated incidence of 6 per 100,000 individuals, and radial head involvement is observed in approximately 30% of elbow injuries, underscoring the importance of timely and accurate diagnosis[1,2]. In such injuries, ligaments are frequently affected, and tendon damage, either partial or complete rupture, may also occur[3].

Conventional imaging modalities, such as plain radiography, have limitations—particularly in pediatric patients due to incomplete ossification of the epiphysis—which may result in missed occult fractures. In these cases, the presence of the fat pad sign can indicate joint effusion and raise suspicion of an underlying occult fracture[4,5]. However, repeated exposure to X-rays, especially in children, raises concerns regarding radiation safety[6].

In recent years, musculoskeletal ultrasonography has gained attention as an accessible, rapid, non-invasive, and cost-effective modality for fracture diagnosis. Several studies have demonstrated that the sensitivity and specificity of ultrasonography in fracture assessment are comparable to radiography, and in certain cases, it may even outperform radiography in detecting effusion and displacement[7–10]. The first sonographic description of the fat pad sign was reported by Miles and Lamont, after which numerous studies further explored the diagnostic applications of ultrasonography in elbow trauma[11].

Given that the use of ultrasonography can reduce unnecessary CT scans and radiographs, the present study aimed to evaluate ultrasonographic findings in elbow injuries and compare them with plain radiography and CT scan results in patients presenting to the emergency department of Baqiyatallah Hospital in Tehran.

Materials & Methods

This cross-sectional study compared ultrasonography, plain radiography, and computed tomography (CT) findings in cases with trauma to elbow injuries. This study included all individuals that show up in the emergency department of Baqiyatallah Hospital, Tehran with suspected elbow. A convenience sampling method was applied, and patients with traumatic elbow injuries and suspected fractures who presented to the emergency department were enrolled.

Based on the study by Eckert et al.[4] and considering the following parameters, the required sample size was calculated as 40 patients:

- Sensitivity of ultrasonography for the diagnosis of elbow fracture: 97.9%
- Significance level: 0.05 (Z = 1.96)
- Maximum allowable error in estimating sensitivity: 4.5%

This study was conducted in 2023 in the emergency department of Baqiyatallah Hospital, Tehran. Inclusion criteria were patients with traumatic elbow injuries and suspected fractures. Exclusion criteria included patients with elbow deformity, open injuries, or any suspicious to vascular or nerve involvement. After obtaining written informed consent, all patients underwent clinical examination. Following history taking and physical examination, ultrasonography of the elbow was performed first, followed by plain radiography, and finally CT scan at the discretion of the radiologist. Ultrasonography was carried out using a 12 MHz linear probe with a width of 6.5 cm. CT scan findings were compared with those of radiography and ultrasonography, and all images were interpreted by an independent radiologist.

A researcher-designed checklist that included demographic characteristics and imaging findings were used for collecting data. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of ultrasonography, radiography and CT scan were calculated in, separately for children and adults. CT scan was considered as gold standard for diagnosis of fracture. Diagnostic measures such as PPV (the percentage of true positives among all positive test results) and NPV (the percentage of true negatives among all negative test results) were calculated accordingly. Clinical management decisions were made based on clinical assessment and imaging findings.

The variables studied included age, sex, fracture type, and imaging results. Ultrasonography was performed by a specialist physician, and radiological interpretations were made independently by a radiologist.

Descriptive statistics, including mean, standard deviation, frequency, and percentage, were used to describe the data. Statistical analyses were performed using SPSS version 26 and MedCalc version 22.019. The applied statistical tests included chi-square test, independent t-test, sensitivity and specificity analysis, and receiver operating characteristic (ROC) curve analysis to assess diagnostic performance. Comparison of the area under the ROC curve was performed according to the method of Hanley and McNeil. A p-value of <0.05 was considered statistically significant.

This study was approved by the Ethics Committee of Baqiyatallah University of Medical Sciences (IR.BMSU.REC.1402.068). All imaging procedures were explained to the patients, and informed consent was obtained from them or their legal guardians. Participation in the study involved no cost to the patients. All patient data were coded and anonymized to ensure confidentiality. Imaging procedures were carried out by a radiology specialist, and uniform equipment and standardized protocols were used for all patients to minimize variability in measurements.

Results

In this study, 40 patients with elbow fractures were evaluated. The mean age of the cases was 15.2 ± 0.12 years (median age of 15.5 years). The age range of the patients was 4 to 49 years. Regarding sex distribution, 72.5% were male (29) and 27.5% were female (11).

Table 1 presents the distribution of sex according to age groups below 18 years and above 18 years. Among patients under 18 years, 69.6% were male, while among patients over 18 years, 76.5% were male (P = 0.730). Soft tissue hematoma was detected in 72.5% of ultrasounds and 60.0% of radiographs (P < 1.000). Intra-articular hematoma was observed in 77.5% of ultrasounds and 62.5% of radiographs (P = 0.705). The fracture line was seen in 45% of ultrasounds and 35% of radiographs (P < 0.001). Free fragments were reported in 45% of ultrasounds and 32.5% of radiographs (P < 0.001). Discontinuity in cortex was observed in 40% of ultrasounds and 32.5% of radiographs (P < 0.001) (Table 2).

Supracondylar fracture was the most common type, while the least common was lateral epicondyle fracture. Among patients under 18 years of age, supracondylar fracture was the most frequent type, affecting 12 patients (52.2%), whereas in patients over 18 years, radial head fracture was the most prevalent, occurring in 4 patients (23.5%).(Table 3).

Table 1: Gender distribution of patients by age group (<18 years and ≥18 years)

Variable	Age <18 years		Age ≥18 years		P-value
	No.	%	No.	%	
Sex					
Male	16	69.6	13	76.5	0.730
Female	7	30.4	4	23.5	

Table 2: Frequency distribution of signs and symptoms in elbow ultrasonography and radiography

Variable	Ultrasonography	Radiography	P-value		
	n	%	n	%	
Soft tissue hematoma					
No	11	27.5	16	40.0	>0.001**
Yes	29	72.5	24	60.0	
Intra-articular hematoma					
No	9	22.5	15	37.5	0.705**
Yes	31	77.5	25	62.5	
Fracture line (Fx line)					
No	22	55.0	26	65.0	>0.001*
Yes	18	45.0	14	35.0	
Loose fragment (Loose Frg)					
No	22	55.0	27	67.5	>0.001*
Yes	18	45.0	13	32.5	
Cortical discontinuity					
No	24	60.0	27	67.5	>0.001*
Yes	16	40.0	13	32.5	

*Chi-Square test, significance level = 0.05, **Fisher's Exact test, significance level = 0.05

Table 3. Frequency distribution of elbow fracture types in all patients, patients under 18 years, and patients over 18 years

Fracture Type	Supracondylar Humerus	Radial Head	Olecranon	Medial Epicondyle	Lateral Epicondyle	No Fracture	Total
Under 18 years	12	2	2	-	2	5	23
Over 18 years	2	4	3	3	1	4	17
Total	14	6	5	3	3	9	40

Table 4 presents the frequency of fracture detection using ultrasound, radiography, and CT scan. Based on radiography, 77.5% of patients (31 individuals) were found to have fractures. According to CT scan, 69.2% of patients had fractures, while ultrasound reported fractures in 72.5% of patients.

In the comparison of fracture detection using radiography and CT scan, both methods could detect 17 fractures but could not detect 7 fractures (Table 5). In the comparison between CT scan and ultrasound, both methods, could detect fracture in 16 cases but could not detect in 7 cases.

Table 6 presents the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of ultrasound and radiography compared to CT scan (considered the gold standard). As shown, both methods demonstrated high sensitivity and specificity. Specifically, radiography had a sensitivity of 94.4%, specificity of 87.5%, and PPV of 94.4%. Ultrasound showed a sensitivity of 88.9%, specificity of 87.5%, and PPV of 94.1%. The kappa agreement between radiography and CT scan was 81.9%, while between ultrasound and CT scan it was 73.8%.

Figure 1 shows the ROC curve and the area under the curve (AUC) for the ultrasound and CT scan tests. As observed, both methods deviate acceptably from the diagonal line and exhibit high AUC values. Comparison of the ROC AUCs indicated no statistically significant difference between the two methods (Hanley & McNeil method, P = 0.592).

Table 4: Frequency distribution of fracture diagnosis using ultrasound, radiography, and CT scan of patients' elbows

Variable	No Fracture		Fracture	
	Count	Percent	Count	Percent
Radiography	9	22.5	31	77.5
CT Scan	8	30.8	18	69.2
Ultrasound	11	27.5	29	72.5

Table 5: Comparison of fracture diagnosis in CT scan and its comparison with radiography and ultrasound of patients' elbows

Imaging Type		Radiography		Ultrasound		Total
		With Fracture	Without Fracture	With Fracture	Without Fracture	
CT Scan	With Fracture	17	1	16	2	18
	Without Fracture	1	7	1	7	8
Total		18	8	17	9	26

Table 6. Sensitivity, specificity, positive predictive value, and negative predictive value of ultrasound and radiography compared with CT scan results

Variable	Radiography		Ultrasound	
	Index Value*	95% Confidence Interval	Index Value*	95% Confidence Interval
Sensitivity	94.4	72.7 – 99.9	88.9	65.3 – 98.6
Specificity	87.5	47.3 – 99.7	87.5	47.3 – 99.7
Positive Predictive Value (PPV)	94.1	73.0 – 99.1	94.1	71.7 – 99.0
Negative Predictive Value (NPV)	87.5	50.6 – 97.9	77.8	48.0 – 93.0
Area Under ROC Curve (AUC)	0.916	0.731 – 0.986	0.882	0.695 – 0.974
Agreement (%) (Kappa)	81.9	--	73.8	--

* Values reported in percentage.

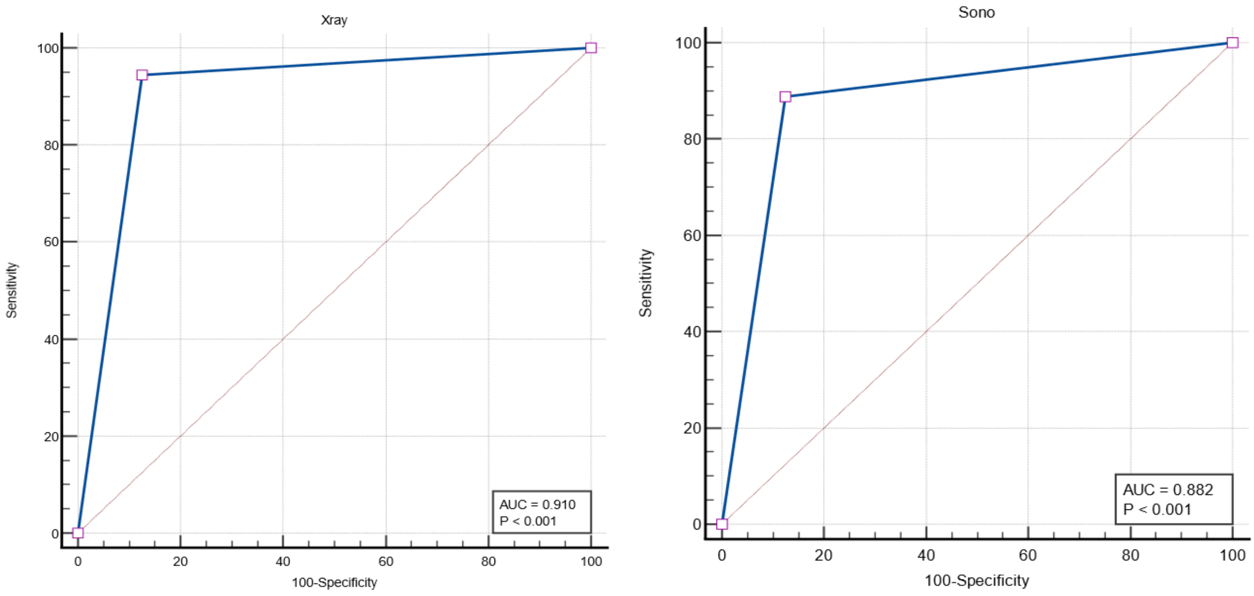

Figure 1: ROC curve and area under the curve for X-ray and ultrasound (sono) tests in the diagnosis of elbow fractures (CT scan results considered as the gold standard).

Discussion

The elbow joint is one of the most commonly affected joints in trauma and is frequently imaged in emergency departments. Suspected elbow fractures are among the most common indications for imaging in emergency settings. In most cases, standard anteroposterior and lateral radiographs are used for initial evaluation. However, due to unossified epiphyses and non-standard imaging, especially in children who may have difficulty cooperating during radiography, diagnosing elbow fractures in pediatric patients can be challenging. Additionally, growing bones are more sensitive to radiation. Therefore, alternative imaging modalities such as CT, magnetic resonance imaging (MRI), and ultrasound have been investigated to improve diagnostic accuracy[12,13].

The present study demonstrated that ultrasound provides acceptable accuracy for diagnosing elbow fractures, with results comparable to CT and radiography. Similarly, a study by Li et al. indicated that elbow ultrasound performs well in fracture detection, particularly when performed by adequately trained physicians. So, this study recommended to us ultrasound for diagnosis of elbow fracture in children as a first-line[14]. Weinberg et al. reported that ultrasound has a sensitivity of 73% and specificity of 93% in detecting long bone fractures, and it can be used as a rapid alternative when access to radiography is limited[15]. Ashoubi et al., in a meta-analysis, reported that ultrasound has a sensitivity of 97% and specificity of 90% for detecting pediatric elbow fractures[16]. Hakimi et al. found that the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of ultrasound in diagnosing metacarpal fractures compared with radiography were 84.2%, 88.5%, 83.5%, and 89.8%, respectively, with a kappa agreement of 0.78. Given its high sensitivity and specificity, ultrasound can be employed as a rapid, cost-effective, non-invasive, and repeatable tool in emergency settings[17].

Another study showed that in patients without fractures, using ultrasound saved a cost of approximately €29 per patient compared with not using it. Ultrasound demonstrates high sensitivity in detecting occult pediatric elbow fractures, and when both ultrasound and radiography results are normal, the likelihood of fracture can be confidently excluded, reducing immobilization rate, follow-up, and additional costs[18].

Eckert et al. reported that radiography detected fractures in 48 patients, whereas ultrasound detected fractures in 46. Compared with radiography, ultrasound had 97.9% sensitivity, 95% specificity, 95% NPV, and 97.9% PPV[4]. In a 2023 study by Hosseini Khameneh et al., the pooled 95% sensitivity and 87% specificity of ultrasound, with a diagnostic performance based on the area under the ROC curve of 93%, suggesting that ultrasound is a promising imaging modality for diagnosing pediatric elbow fractures[19].

As noted, radiography is commonly used for evaluating suspected fractures. However, WHO estimates indicate that approximately 75% of the world's population lacks access to any form of diagnostic imaging. Ultrasound can be utilized not only in standard healthcare settings but also in remote locations[15]. The reflective properties of bone also enable ultrasound to detect fractures as small as one millimeter[1]. Ultrasound offers several advantages over other imaging methods, including speed, portability, reliability, absence of radiation exposure, and cost-effectiveness. Nonetheless, limitations such as operator dependency and difficulty in precisely localizing fractures should be considered[20].

Conclusion

Based on the results of this study, ultrasound demonstrated acceptable accuracy in diagnosing elbow fractures, comparable to radiography and CT. Therefore, ultrasound can serve as an alternative and complementary method, particularly in clinically suspected fractures. However, in ambiguous or complex cases, standard imaging modalities such as radiography and CT remain advisable.

Limitations of this study include the sequential use of ultrasound, radiography, and CT, which was time-consuming. The presence of a radiology specialist was necessary to perform accurate and precise ultrasound. Although no costs were charged to patients in this study, the issue of cost coverage and potential increases should be considered. The use of a larger sample size posed logistical challenges; thus, future studies are recommended with larger patient populations. In addition, cohort studies and follow-up using ultrasound are suggested to further evaluate diagnostic accuracy. Ultrasound could also be investigated as a low-risk diagnostic tool in pregnant women and in aquatic environments.

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