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Diagnostic accuracy of ultrasound in upper and lower extremity long bone fractures of emergency department trauma patients

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Abstract

Background: Long bone fractures are common injuries caused by trauma. Some studies have demonstrated that ultrasound has a high sensitivity and specificity in the diagnosis of upper and lower extremity long bone fractures.

Objective: The aim of this study was to determine the accuracy of ultrasound compared with plain radiography in diagnosis of upper and lower extremity long bone fractures in traumatic patients.

Methods: This cross-sectional study assessed 100 patients admitted to the emergency department of Imam Khomeini Hospital, Ahvaz, Iran with trauma to the upper and lower extremities, from September 2014 through October 2015. In all patients, first ultrasound and then standard plain radiography for the upper and lower limb was performed. Data were analyzed by SPSS version 21 to determine the specificity and sensitivity.

Results: The mean age of patients with upper and lower limb trauma were 31.43±12.32 years and 29.63±5.89 years, respectively. Radius fracture was the most frequent compared to other fractures (27%). Sensitivity, specificity, positive predicted value, and negative predicted value of ultrasound compared with plain radiography in the diagnosis of upper extremity long bones were 95.3%, 87.7%, 87.2% and 96.2%, respectively, and the highest accuracy was observed in left arm fractures (100%). Tibia and fibula fractures were the most frequent types compared to other fractures (89.2%). Sensitivity, specificity, PPV and NPV of ultrasound compared with plain radiography in the diagnosis of upper extremity long bone fractures were 98.6%, 83%, 65.4% and 87.1%, respectively, and the highest accuracy was observed in men, lower ages and femoral fractures.

Conclusion: The results of this study showed that ultrasound compared with plain radiography has a high accuracy in the diagnosis of upper and lower extremity long bone fractures.

Keywords: Ultrasound, Plain Radiography, Upper Extremity, Lower Extremity, Long Bone Fractures

1. Introduction

Trauma, as one of the leading causes of mortality and morbidity in the world, imposes heavy health costs on society and the healthcare system (1-3). Unfortunately, current statistics indicate that this health problem is worsening (4), and is the second cause of mortality and morbidity in Iran (5). Long bone fractures are one of the most common injuries caused by trauma, accounting for 4% of all referrals. Musculoskeletal injuries (including long bone fractures) are one of the most common causes of referral to emergency wards. According to the Centers for Disease Control and Prevention, fractures are among the top 20 first-line diagnostic cases that can be discharged from an emergency ward. Fractures account for 3.5% of all visits to the acute part of the emergency ward every year (6). Long bone fractures are associated with a higher risk of bleeding and neurovascular disorder. Delayed diagnosis and treatment can lead to loss of organs (7). Radiography is routinely used to diagnose long bone fractures. This diagnostic method has disadvantages: it can be time-consuming and increase the waiting time and stay in the emergency department; in addition, it can interfere with ionizing radiation, which is worrying, especially in certain groups such as children and pregnant women. There is also a need for other diagnostic methods in some areas of the

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geographical range or in special conditions in which radiography is not available for any reason (8). Ultrasound has been used by emergency physicians in cases of trauma since 1980. Clinical evidence suggests that when ultrasound is used in the diagnosis process of multiple trauma patients, the quality of care is improved. Currently, ultrasound is widely used by emergency physicians to diagnose many diseases with high sensitivity and specificity. Advances in ultrasound technology as well as increased physician experience have led to more appropriate use of this technique (6). Ultrasound is a non-invasive, reliable and fast method, and given the portability of the ultrasound device in emergency rooms, it can speed up the decision-making and assignment of patients (9). In ultrasonography, the fracture is seen in the longitudinal view as an interrupted or irregular cortex. Also, in the short axis view, interrupted cortex is evident (10). According to studies conducted from 2000 through 2013, ultrasound has a high sensitivity and specificity in the diagnosis of bone fractures in long limbs and elbows (11-17). Bolandparvaz et al. (18) showed that ultrasound sensitivity varied between 55 and 75% depending on the fracture site, and its specificity was between 62 and 84% in detecting organ fractures. As a result, ultrasound seems to be a reliable method for diagnosis of organ and bone fractures in comparison with radiography. Hübner et al. (19), in a descriptive study in Germany, investigated the ultrasound of 163 children with 244 possible fractures and compared them with radiological findings to assess the ultrasound value in the diagnosis of bone fractures in children. The results showed that ultrasound findings were not sufficiently reliable in the diagnosis of compound fractures, fractures adjacent to joints, small bone lesions of the hands and feet, and epiphyseal fractures without displacement or fracture lines less than 1 mm. Most of the previous surveys have often studied the fractures of children and there are few studies on ultrasound diagnostic effect on adult bone fractures. Also, there are controversial results regarding the usefulness of ultrasound instead of radiography. On the other hand, ultrasound is an available, low cost and harmless method that can be performed by the patient's bedside. Therefore, the purpose of this study was to evaluate ultrasound accuracy as compared to radiography (plain X-rays), in the diagnosis of upper and lower extremity fractures in adults.

2. Material and Methods

This cross-sectional study was performed on patients referred to the Emergency Department of Imam Khomeini and Golestan General Hospitals in Ahvaz city, Khuzestan province, Iran from 2014 through 2015, and who were 15 to 55 years old. They suffered from trauma to the upper and lower extremities (from the proximal of the ankle to distal of the hip joint; from the proximal of the wrist to distal of the glenohumeral joint) caused by direct hit or fall, and had evidence of pain, tenderness or swelling of the limbs. The sample size was estimated to be 100 for upper extremity examination using d=0.09 and p=0.7, which was obtained from previous studies (17) and considering the power of 80% and the CI of 95%. Also, sample size for examining lower extremity fractures with CI of 95%, d=0.05 and p=0.902, was determined to be 139 (20). Inclusion criteria included patients aged 15 to 55 years that had developed upper and lower extremity trauma associated with pain and tenderness, and were satisfied with the provision of information needed for the research. Exclusion criteria included patients with neurovascular disorder, obvious deformity, multiple trauma, patients requiring emergency procedures, and those without consent to participate in the study. Eligible patients were enrolled in the study. All of them underwent an ultrasound examination (upper or lower extremities) by a constant trained and experienced emergency physician. Then, standard organ radiography was performed. In all the patients, ultrasound was performed by an emergency medicine resident who had completed a one-week course on ultrasound skills, and the organ fracture was diagnosed by him and approved by the emergency medicine consultants and orthopedic specialists. An ultrasound was performed in Ahvaz Imam and Golestan hospitals, using a SONO ACE ultrasound device including a linear probe with frequency of 8 to 10 Hz. Practically, the ultrasound probe was placed at the lateral surface of the bone transversely and longitudinally, and the cortex section was then examined. First, the probe was placed transversally onto the surface of the bone to examine the presence of skip. The probe was then moved longitudinally along the bone so that the cortex integrity could be investigated. In the next step, standard bone radiography was performed. Anteroposterior and lateral radiographies were taken for each patient. Then, the radiographies were reported blindly by a radiologist at the end of the study after being encoded. Results were recorded in a special radiology sheet. Finally, the forms obtained from each of the two methods were evaluated and the obtained data were collected and statistically compared. It should be noted that the radiologist was unaware of the results of the clinical examination and sonography. Orthopedic visits were carried out for all the patients. After being encoded, the obtained data were analyzed by SPSS ver. 21. The mean, median, standard deviation and percentage were used to describe the data. At first, the normality of data distribution was investigated using the Kolmogorov-Smirnov test. To determine sensitivity and specificity, positive and negative predictive values of correlations were used for Chi-square or McNemar tests (if not normalized). The significance level of the tests was 0.05.

3. Results

A total of 100 patients with upper extremity trauma were evaluated for long bone fracture using ultrasound and radiography methods. Thirty patients were excluded because of referred splinted fracture (6 people), inappropriate view (6 people), severe deformity (4 people) and open fracture (14 people). The mean age of the patients with upper extremity trauma was 31.43 ± 12.32 years (mean, 29.5 and range, 15 to 55). In total, 77 patients were male and 23 were female. Also, 139 patients with lower extremity trauma were evaluated for long bone fracture using ultrasound method. The mean age of the patients was 29.63 ± 5.89 years, and 107 were male and 32 were female. In the upper extremity trauma group, in terms of trauma mechanism, falling, multiple trauma, direct trauma and falling on equal surface accounted for respectively 6 (6%), 65 (65%), 14 (14%) and 15 (15%) cases. In terms of injury site, right arm, left arm, right forearm, left forearm, and simultaneous arm and forearm injury cases were observed in 6 (6%), 12 (12%), 44 (44%), 37 (37%), and 1 (1%) of the individuals, respectively. In the lower extremity trauma group, in terms of trauma mechanism, the most common mechanism was vehicle accident (69.8%). Also, in the case of injury site, legs and thigh injuries accounted for 89.2 and 10.8% of the total injuries (Tables 1 and 2). The sensitivity, specificity, PPV and NPV of the ultrasound for diagnosis of upper extremity long bone fractures were 95.3, 87.7, 87.2 and 96.2%, respectively. According to the radiographic findings in patients with lower extremity trauma, 33 of them (23.7%) had long bone fractures, but by ultrasonography, 51 (36.7%) were diagnosed as fractures. In this regard, there was a significant difference between the two diagnostic methods (p> 0.0001). Therefore, sensitivity, specificity, PPV, NPV and accuracy of ultrasound in detecting long bone fractures of lower extremity were 98.6, 83, 65.4100 and 87.1%, respectively. The highest sensitivity and specificity were obtained based on the type of injury in patients with thigh fractures, which was equal to 100 and 85.7% respectively (Table 3). Also, considering age, sex and type of injury variables, it was found that the highest sensitivity (100%) and specificity (98.8%) were obtained in patients in the age range of 21 to 30 years in the upper extremity trauma group. Additionally, the highest sensitivity (100%) and specificity (100%) were found in the male patients. In the lower extremity fractures, the highest sensitivity and specificity were obtained in patients in the age group of 10 to 20 years, which was equal to 100 and 88.9%, respectively. Moreover, the highest sensitivity (100%) was obtained in the female patients (Tables 4 and 5).

Table 1. Description of parameters in patients with upper and lower limbs trauma

Variable		Upper limbs	Lower limbs
Age		31.43±12.32	29.63±5.89
Gender	Male	77 (77)	107 (77)
	Female	23 (23)	32 (23)
Trauma mechanism	Falling	6 (6)	7(5)
	Multiple trauma	65 (65)	97 (69.8)
	Direct trauma	14 (14)	4 (2.9)
		15 (15)	31 (22.3)

Table 2. Site of injury in patients with upper and lower limbs trauma

Site of fracture		Frequency	Percentage
Upper limb	Right arm	6	6
	Left arm	12	12
	Right forearm	44	44
	Left forearm	37	37
Lower limb	Leg	124	89.2
	Thigh	15	10.8

Table 3. Diagnostic value of sonography in long bone fractures in patients with upper and lower limb trauma

Bone	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Right upper arm	0	100	0	100
Left upper arm	100	100	100	100
Right forearm	86.9	100	100	91.3
Left Forearm	86.4	86.7	90.5	81.3
Upper arm + Forearm	0	0	0	0
Leg	98.3	82.8	60.5	100
Thigh	100	85.7	88.9	100

Table 4. Diagnostic value of sonography in long bone fractures of upper and lower limbs according to age

Limbs	Age (year)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Upper limbs	10-20	100	95.4	83.1	95.6
	21-30	100	98.8	89.9	100
	31-40	100	100	99.8	100
Lower limbs	10-20	100	88.9	66.7	100
	21-30	98.4	82.7	59.1	100
	31-40	98.4	82.2	70.4	100

Table 5. Diagnostic value of sonography in long bone fractures of upper and lower limbs according to gender

Limbs	Gender	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Upper limb	Male	100	100	88.9	100
	Female	100	95.5	77.5	100
Lower limb	Male	98.1	83.5	69	100
	Female	100	81.5	50	100

4. Discussion

In this study, the diagnostic value of ultrasound was evaluated in comparison with simple radiography in patients with upper and lower extremity traumas. The results indicated that ultrasound had a high diagnostic accuracy in identifying the long bone fractures of the upper and lower extremities. Also, it had significant value in terms of sensitivity, specificity, PPV and NPV. In fact, ultrasonographic superiority in the diagnosis of upper and lower extremity fractures can be attributed to the dynamics of ultrasound and the operator's ability to create images in different sections of the structure extremity. The evaluation of ultrasound diagnostic value in lower extremity fracture by age variable, indicated that sensitivity and NPV of ultrasound was complete in the diagnosis of long bone fracture (100%) in all age groups, and it had the highest specificity, PPV and diagnostic accuracy in the age group of 10 to 20 years when compared with other age groups. An examination of sex-specific ultrasound showed that sensitivity and NPV of sonography were complete (100%) in the diagnosis of long bone fracture in both sexes, and its specificity, PPV and diagnostic accuracy was higher in the male gender. An examination of the diagnostic value of ultrasound based on injury site, showed that sensitivity and NPV of ultrasound were complete (100%) in the case of leg and thigh fractures, and its specificity, PPV and diagnostic accuracy in thigh fractures were higher than in the leg fractures. Other researchers also obtained different results in their studies. For example, Rabiner et al. (17), in a study on the diagnostic value of ultrasound in elbow fractures, found that 33% of cases had fractures in radiography. An ultrasonography showed elbow fractures with a sensitivity of 98% and a specificity of 70%. In the present study, the long bones of the upper extremity were studied and it was shown that 43% of the patients had fractures. The ultrasound findings showed sensitivity of 95.3% in detecting these fractures which was slightly less than the above finding, but specificity was 87.7%. The different findings may be attributed to the difference in the type of fractures and age groups studied. This difference can also be due to the low sample size in previous studies or the different quality of device used. On the other hand, ultrasonography is an operator-dependent technique, which affects its ability to detect fractures. Barata et al. (7), in a study on the diagnosis of long bone fracture in children under the age of 18 years, found that a simple radiography revealed all 43 fractures. The sensitivity, specificity, PPV and NPV of ultrasound were reported to be 95.3, 85.5, 83.7 and 96%, respectively. Overall, ultrasound detected all diaphyseal fractures and 93.1% of the fractures were at the distal part of the bone and close to the joint. The above study confirms the diagnostic value of ultrasound in the diagnosis of long bone fractures of the upper extremity and is similar to the present study in terms of the parameters of diagnostic accuracy. In a study on distal forearm fractures in patients between the ages of 2 and 14 years, Eckert et al. (15) showed that ultrasound had sensitivity, specificity, PPV and NPV of 94.9, 0.98, 96.1 and 97.4% in the diagnosis of forearm fractures, respectively. The accuracy of ultrasonography diagnosis was proved in the present study, although it had lower specificity and PPV as compared to the above study. The results also showed that the forearm fractures, especially the radial bone, were associated with higher incidence of trauma to the upper extremity, which could be due to its anatomical position, which is considered as a body restraint during the onset of trauma, and sustains the most damage. Sinha et al. (11) also found that 41% of patients had upper extremity bone fractures in ultrasound findings of traumatic children. Overall sensitivity and specificity, PPV and NPV were reported as 89, 100, 100 and 100%, respectively. The ultrasound sensitivity of the above study was less than that of the present study and higher in terms of other determinants of diagnostic accuracy. It seems that due to the openness of the growth site in children and the abundance of cartilaginous tissue in the skeletal structure, the ultrasound is used more frequently in the diagnosis of fractures, and

its diagnostic accuracy is much higher as compared to that of the adult population (with bony skeletal tissue). This diagnostic power in the clinic allows for less costly and safe detection of fractures in emergency cases without the need for exposure to ionizing radiation. Ultrasonography is therefore suitable for detecting distal fractures of the forearm with high sensitivity. A negative result in sonography reduced the need for additional radiography in children with distal lesions, but there is still the need for radiography in suspected cases (21). In their study on the accuracy of ultrasonographic diagnosis in hand fractures in children, Neri et al. (22) also showed that ultrasound with a sensitivity of 91.1% and specificity of 97.6%, detected fractures. As a result, ultrasound showed excellent sensitivity and specificity in the diagnosis of hand fractures in children. Bolandparvaz et al. (18) showed that the sensitivity and specificity of ultrasonography in the diagnosis of limbs fractures range respectively between 55 to 75 and 62 to 84%, depending on the location of the fracture. As a result, ultrasound seems to be a reliable method for diagnosis of limb bone fractures in comparison with radiography. However, the parameters: sensitivity, specificity and thus diagnostic accuracy of ultrasound in the present study, are significantly higher than that of the above study, which may be due to the expertise of the practitioner, distribution of fracture site, fracture type, age groups and study conditions. Also, this difference may be attributed to the low sample size in previous studies or the different quality of device used. Waterbrook et al. (20) in their study on the accuracy of sonography in the diagnosis of long bone fractures in the emergency department, showed that the sensitivity and specificity of sonography for the diagnosis of long bone fractures were 90.2 and 96.1%, respectively. Also, its PPV and NPV was 90.2 and 96.1%, respectively. Therefore, it can be asserted that the evaluation of long bone fractures by ultrasound in the emergency department is a good method with high accuracy, sensitivity and specificity. Considering the fact that most studies on ultrasound accuracy in diagnosing long bone fractures have been performed in the pediatric population, thus, it is not possible to fully compare the studies and their attribution to general population of adults, there are several evidences that ultrasonography, as a safe and accessible method with many abilities in confirming and completing medical diagnosis, can play an important role in diagnosing trauma in the upper and lower extremity long bones fractures. In this regard, it has the potential to replace radiography in emergency conditions and X-ray imaging restrictions. Therefore, recent efforts and research in this area have focused on the development of the use of ultrasound in orthopedics and emergency medicine. High-frequency probe ultrasonography is a valuable method in diagnosing orthopedic traumas, and has high accuracy in detecting fractures of the femur, tibia and fibula, but it exhibits some shortcomings regarding the diagnosis of articular space fractures, because it may be confused with the normal anatomy of organs. Hence, it is very important to train specialists and enhance skill levels of emergency physicians and radiologists in the sonographic detection of trauma lesions imposed on the extremities, to improve diagnostic quality and reduce the use of hazardous imaging.

5. Conclusions

In summary, the findings of this research showed that ultrasound, in comparison with simple radiography, has high sensitivity and specificity in the diagnosis of upper and lower extremity fractures, especially in pregnant women. The usefulness of these findings is that ultrasound is an accessible, easy and non-invasive method that does not need X-rays and has high sensitivity and specificity in the diagnosis of upper and lower extremity fractures. Complementary studies on ultrasonic diagnosis of fractures on a larger sample size of a children and women population and more accurate methodology is recommended so that a suitable route can be obtained for future research on this topic.

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There is no conflict of interest to be declared.

Authors' contributions:
All authors contributed to this project and article equally. All authors read and approved the final manuscript.

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