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● *Original Contribution*

A PILOT PROSPECTIVE STUDY TO VALIDATE POINT-OF-CARE ULTRASOUND IN COMPARISON TO X-RAY EXAMINATION IN DETECTING FRACTURES

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Abstract—Despite its limitations, conventional radiography is the method of choice for fracture evaluation in the emergency department. Only a few studies, moreover in limited populations, have evaluated the possible benefits of ultrasound (US), and especially of point-of-care ultrasound (POCUS), in the diagnosis of fractures. We sought to compare the accuracy of POCUS with that of conventional radiography in the diagnosis of bone fractures. This prospective study with a non-randomly allocated convenience sample was conducted at two academic medical centers. Four physicians, with focused training in musculoskeletal POCUS, evaluated consecutive patients with suspected orthopedic injury. US and X-ray examination results were treated as dichotomous variables with either fracture present or fracture absent. Descriptive statistics were calculated in addition to prevalence, sensitivity, specificity, positive predictive value and negative predictive value including 95% confidence intervals (CIs). Cohen's κ coefficient was determined as a measurement of the level of agreement. Four hundred sixty-nine patients (404 adult and 65 pediatric) ranging in age from 1−97 y were enrolled at two different hospitals. Seven hundred six examinations, both US and X-ray, were performed in 634 suspected fractures in adults (age $\geq$18 y) and 72 in children. On physical examination, swelling, localized hematoma and functional limitation were found in 64.61%, 34.97% and 53.52, respectively. The sensitivity of US examination was 93.89% (CI: 89.74%−96.49%) for all patients and 94.30% (CI: 89.77%−96.98%) and 91.67% (CI: 76.41%−97.82%) in adult and pediatric groups, respectively. Specificity was 94.13% (CI: 91.53−95.99), 94.56% (CI: 91.89−96.41) and 88.89% (CI: 73.00−96.38) for the whole group, adults and children, respectively. The positive predictive value was 88.48% (CI: 83.62%−92.08%), 88.35% (CI: 82.97%−92.24%) and 89.19% (CI: 73.64%−96.48%) for the whole group, adults and children, respectively. The negative predictive value was 96.98% (CI: 94.86%−98.27%), 97.43% (CI: 95.31%−98.64%) and 91.43% (CI: 75.81%−97.76%) in the three groups, respectively. Cohen's κ coefficient revealed high agreement of 0.87 for both the whole group and adult patients and 0.81 for pediatric patients. We found that POCUS has significant diagnostic accuracy in evaluating fracture compared with plain radiography, with excellent sensitivity, specificity and positive and negative predictive values. (E-mail: costantinocost@yahoo.it)

Key Words: **Ultrasound, Point-of-care ultrasound, X-rays, Fractures, Trauma.**

INTRODUCTION

In westernized countries, trauma is the third leading cause of death after cardiovascular disease and cancer and is the leading cause for presentation to the emergency department (ED) in patients under age 45. Further, trauma carries with it the possibility of residual disabling sequelae affecting both the individual patient and his or her family and has significant economic and social costs as described by Trunkey et al. (1988). According to recently published statistics, in the Veneto Region of Italy, traumatic injury represented 25% of all presentations to EDs:

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Sistema Epidemiologico Regionale (SER) del Veneto (2013). Most such patients are evaluated with plain radiography or X-rays. Conventional X-rays are still the first choice for detecting fractures. However, Dallaudiére et al. (2015) reported that ultrasound (US) is playing an increasing role in the management of traumatized patients. This is especially true for the most unstable patients (who are difficult to move), pediatric patients (to reduce radiation exposure), and pregnant women (in whom the danger from radiation is well established). Further, O'Brien et al. (2009) reported that elderly patients and those with cognitive dysfunction are often subject to additional and potentially unnecessary X-rays because of communication difficulties, which may limit history taking and physical examination.

Evaluation of the traumatized patient begins with a careful objective examination assessing the traumatized limb at rest for any deformities such as shortening, rotation, angling, spontaneous pain accentuated by deep palpation, bruising, tumefaction and finally functional limitation. These signs reinforce the suspicion of fracture, even if they have variable significance. However, ultimately a correct diagnosis and visualization of the fracture are critical for choosing the best therapeutic approach and avoiding long-term complications. In pediatric patients, assessment can be more complex because of the inability of the patient to participate in anamnestic collection and clinical examination. Hübner et al. (2000) reported that a high percentage of negative evaluations after traumatic events in children led to recognition of the need for precise indications to perform radiologic examinations and the importance of alternative methods that do not involve the use of ionizing radiation. Although previous studies by Neri et al. (2014) and Trunkey et al. (1988) described the benefits of US in the diagnosis of long, facial, hand and clavicle bone fractures in the pediatric population the total body of literature remains small and has not reached critical mass. Chartier et al. (2017) appear to have addressed the use of point-of-care ultrasound (POCUS) in long bone fractures with a meta-analysis. However, careful review and analysis of the included studies reveals a large portion of the patients were scanned by radiologists—and not clinicians—significantly compromising the premise of the study with a heterogeneous population including many non-POCUS scans. To date, the use of US in fracture evaluation in both pediatric and adult populations is not well established in comparison to traditional radiography. The US diagnostic criterion for fracture diagnosis is discontinuity or the interruption of the cortical bone surface. The purpose of this study was to evaluate the diagnostic accuracy of POCUS in highlighting bone fractures among patients presenting to the ED with acute injury.

METHODS

Study design

This was a prospective uncontrolled multicenter observational study. The primary objective of this study was to evaluate the accuracy of POCUS in the diagnosis of bone fracture in patients presenting to two different emergency departments as a result of trauma. The secondary objective of the study was to evaluate whether any clinical features (*i.e.,* age, mechanism type, presence of severe osteoporosis, presence of hematomas or swelling) influence the accuracy of the US diagnosis. The impact of clinical features on diagnostic US accuracy was also evaluated. The study was approved by the ethics committee of Verona, Mantova and Cremona.

Patients

Patients were eligible for enrollment if they were between 0 and 100 y of age, were being evaluated for possible fracture and would have an X-ray performed and researchers were able to obtain an informed consent for study participation. The following bones were considered for inclusion in the study: clavicle, fibula, humerus, femur, face/skull bones, patella, phalanges of the hand, phalanges of the foot, radius, rib, sternum, tibia and ulna. Patients who were unstable or critical, had open fractures, had any contraindication to US examination such as open wound at the site of injury, had joint involvement or were unwilling to participate in the study or to sign informed consent form or were pregnant were excluded.

Measures

X-Rays were obtained utilizing both portable and mounted standard radiology equipment (Mecall Eidos RF 439, GMM, General Medical Merate, Seriate [BG], Italy) and digitally transmitted *via* a picture archiving and communication system. X-Rays were interpreted by board-certified hospital-based radiologists (5y of training including X-rays, computed tomography and magnetic resonance imaging). POCUS examinations were performed utilizing one of two machines, an Esaote Mylab 25 (Esaote, Genova, Italy) or a Philips CX50 (Philips, Amsterdam, Netherlands). Ultrasound examinations were performed with high-frequency linear or convex transducers depending on body size and location. An LA522 linear array transducer with a bandwidth of 9−3 MHz was utilized with the Esaote Mylab. The Philips CX50 was utilized with a L12-3 linear transducer with a bandwidth of 12−3 MHz and with a C5-1 broadband curved array transducer with a bandwidth of 5−1 MHz.

a

b

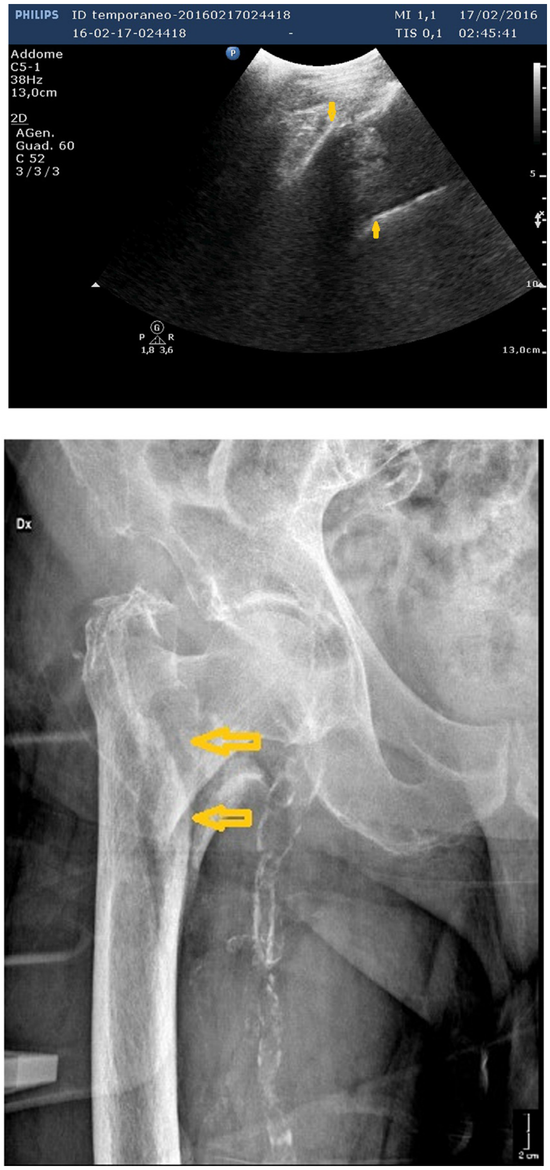

Fig. 1. (a) Ultrasound imaging of a femur fracture. *Yellow arrows* point to bones out of place at the joint connecting them. (b) X-Ray image of a femur fracture. *Yellow arrows* point to bones out of place at the joint connecting them.

All study physicians, who were US operators, had undergone a 1-y focused training period including at least 150 examinations in musculoskeletal POCUS to detect bone fracture. Ultrasound criteria for fracture diagnosis included cortical interruption (Fig. 1a) or discontinuity (Fig. 2a). For each subject we recorded the following clinical variables: age, sex, presence of osteoporosis, name of the bone examined, history of malignancy or previous fractures in the same anatomic bone region, codification of trauma (whether high energy), existence of swelling or hematoma, existence of functional limitation.

a

b

Fig. 2. (a) Ultrasound image of kneecap fracture. *Yellow arrows* point to the discontinuity of the cortical bone, expression of fracture. (b) X-Ray image of kneecap fracture. The *yellow arrow* points to the discontinuity of the cortical bone, expression of fracture.

Study protocol

Patients being seen in the ED for possible long bone fracture were approached for study enrollment, and their eligibility was checked. Written informed consent was obtained from each patient or designated guardian before enrollment into the study. To facilitate reading and understanding of the informed consent forms in different patient categories, appropriate consent forms were created. Special forms were utilized for minors and for their parents. After patient agreement, a detailed history and physical examination were performed with findings and demographic data recorded into a secure computerized database. Researchers ensured that data collection did not result in delivery of additional services to patients (except US) compared with the usual diagnostic process to avoid additional cost to the patient. Normally, in the ED, patients being seen for possible long bone fracture undergo only traditional radiography. Recruitment of patients did not require a much greater involvement of the ED staff. Four emergency physicians, with focused training, acted as the study physicians and performed POCUS evaluation before patients underwent conventional radiologic examination or while waiting for the patient's report. Ultrasound examinations utilized high-frequency linear probes or convex probes. Scans were performed utilizing both longitudinal and transverse orientations of the affected region and site of possible fracture. Ultrasound examinations were recorded in digital format. Attending physicians assigned to each patient in the ED were the treating physicians. Radiologists interpreting X-rays were those on shift for X-ray readings during the patient's stay in the emergency department.

Staff radiologists interpreted the radiographs by focusing on the bony segments indicated by the treating emergency physician. Radiologists reported blindly and did not examine the patients. On completion of the US evaluation (Fig. 1a, 2a, 3a, 4a and 5a) and X-ray reading (Fig. 1b, 2b, 3b, 4b and 5b), patients were again evaluated by the treating emergency physician to determine the appropriate therapeutic path. If a study physician identified an unrecognized fracture not seen on the radiograph by the radiologist (Fig. 6a, 6b), the two physicians would have discussed the case together with the emergency physician who was in charge of the patient to modify the diagnostic–therapeutic route. If disagreement continued, an orthopedic surgery consult would be placed, and any additional imaging such as computed tomography and magnetic resonance imaging, as might be suggested by the orthopedist, would be obtained.

a

b

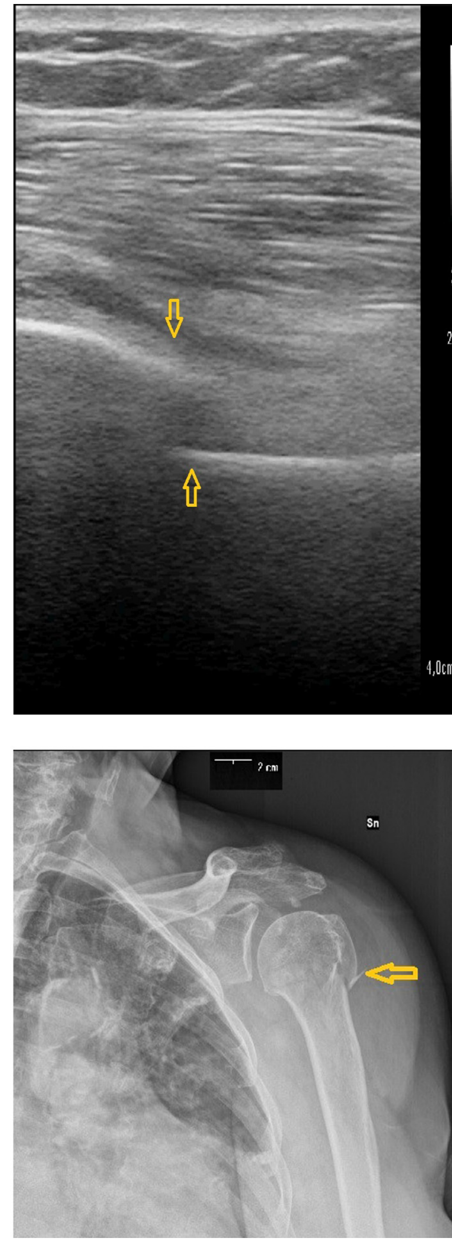

Fig. 3. (a) Ultrasound image of humerus fracture. *Yellow arrows* point to bones out of place at the joint connecting them. (b) X-Ray image of humerus fracture. *Yellow arrow* points to bones out of place at the joint connecting them.

Statistical analysis

The outcomes of the tests performed with US and X-ray were presented as a dichotomous choice: fracture present/fracture absent. The X-ray examination represented the reference standard. Diagnostic accuracy of the US examination was assessed in terms of sensitivity, specificity, positive and negative predictive values and positive and negative likelihood ratios. Categorical variables were presented as percentages and continuous variables were expressed as the median ± standard error. Regions of fractures were categorized into five groups: limb, thorax, hands/feet, face/skull and all others. Differences between adult and pediatric patients were analyzed using t-tests and χ^2-tests, where appropriate. The accuracy and agreement of US in comparison to X-ray examination was studied overall, by age, and by operator, calculating prevalence, sensitivity, specificity and positive and negative predictive values including their 95% confidence intervals (CIs). Moreover, Cohen's κ coefficient was determined as a measurement of the level of agreement.

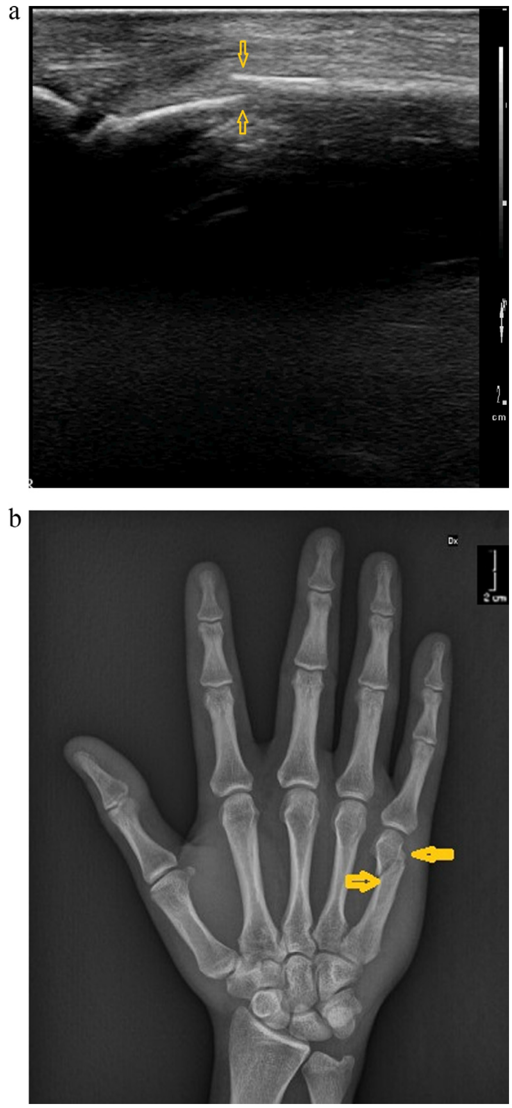

Fig. 4. (a) Ultrasound image of the fifth metacarpal with obvious stop-off. *Yellow arrows* point to the discontinuity of the cortical bone, expression of fracture. (b) X-Ray image of fifth metacarpal from (a) with obvious deformity. The *yellow arrow* points to the discontinuity of the cortical bone, expression of fracture.

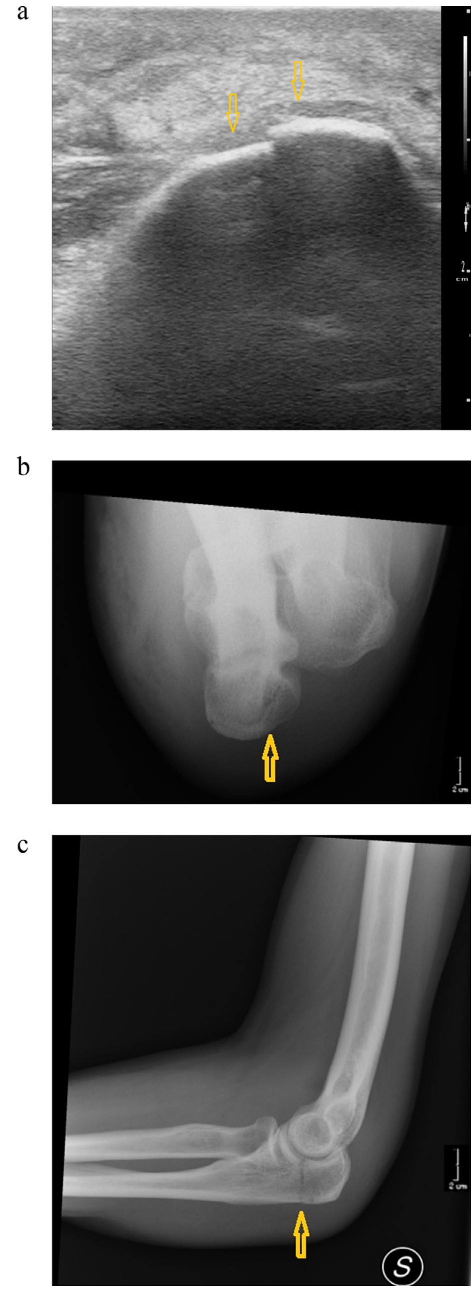

Fig. 5. (a) Ultrasound image (transverse axis) of olecranon fracture. The *yellow arrow* points to the discontinuity of the cortical bone, expression of fracture. (b) X-Ray image (transverse axis) of olecranon fracture. The *yellow arrow* points to the fracture line. (c) X-Ray image (longitudinal axis) of olecranon fracture. The *yellow arrow* points to the fracture line.

Correlations between the two procedures' discrepancies and clinical variables were explored using Pearson's correlation test or χ^2 where appropriate, and then were examined in depth by means of multiple regressions. Finally, determinants of discrepancy between US and X-ray results were verified by analysis of variance (ANOVA) models. For all tests, a p value < 0.05 was considered to indicate statistical significance.

RESULTS

Four hundred eighty-nine patients were approached to enroll in the study, and 469 ultimately participated between March 15, 2016 and March 8, 2017. In several patients, more than one bone region could be of interest. Finally, 706 examinations were performed with both US and X-ray to study 634 suspected fractures in adults (age $\geq$18 y) and 72 in children. The mean age of the study group was 49.12 $\pm$ 1.67 y; children made up 13.86% and women 52.03%. In clinical histories, high-energy trauma, osteoporosis, malignancy and previous fracture

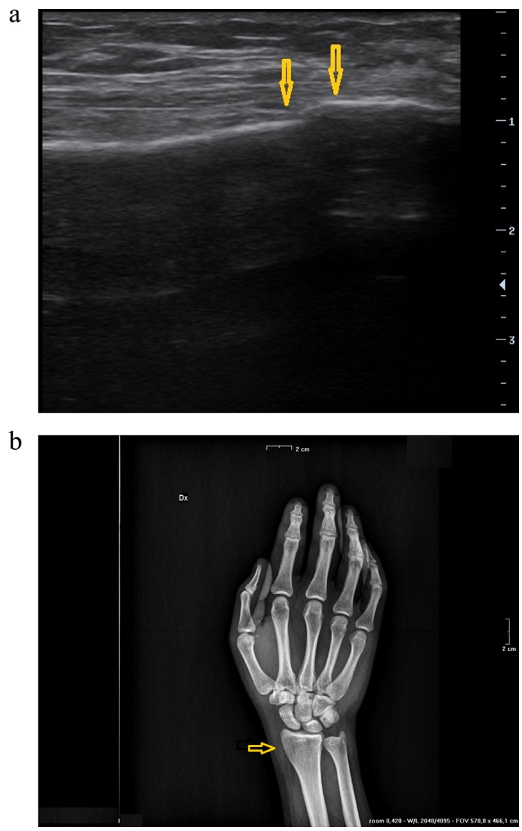

Fig. 6. (a) Ultrasound image of distal radius with very small cortical step-off (*yellow arrow*). (b) X-Ray image of distal radius with very small cortical step-off (*yellow arrow*).

were reported in 4.90%, 15.57%, 0.64% and 3.84%, respectively. At medical examination, swelling, hematoma and functional limitation were found in 64.61%, 34.97% and 53.52%, respectively. The most studied body areas were limbs (more than 50%) and hands/feet (more than 30%), with the thorax and skull less represented (Table 1). As indicated in Table 2, the adult and pediatric groups differed with respect to sex ($p = 0.008$), osteoporosis ($p = 0.0001$), micro-discontinuity or irregular bone profile ($p = 0.0001$) and age ($p < 0.0001$) of course. No differences were found in codification of trauma, swelling, hematomas, functional limitations, malignancy or previous fractures. With respect to the reference standard X-ray examinations, the prevalence of fractures was 32.44% among all examinations.

The sensitivity of US examination was 93.89%, 94.30% and 91.67% for all patients, adults and children, respectively. Similar results were found for specificity: 94.13%, 94.56% and 88.89% for whole study group, adults and children, respectively (CIs listed in Table 3). Both positive predictive value (PPV) and negative

Table 1. Characteristics of the suspected fractures in this study (n = 706 exams)

Age (y)	49.12 ± 1.67 (1−97)
Pediatric patients (age <18 y)	13.86%
Women	52.03%
High-energy trauma	4.90%
Swelling	64.61%
Hematoma	34.97%
Functional limitations	53.52%
Macro-alterations of bone profile	21.32%
Osteoporosis	15.57%
Malignancy	0.64%
Previous fractures	3.84%
Micro-discontinuity/irregular bone profile	3.68%
Limb	53.40%
Thorax	9.92%
Hands/feet	35.41%
Face/skull	1.13%
Other regions	0.14%

Values are expressed as the mean ± standard error (range) or percentage.

Table 2. Characteristics of the suspected fractures by patient age

	Adult group (634 exams)	Pediatric group (72 exams)	*p*
Age (y)	55.41 ± 1.06	10.31 ± 0.54	<0.0001
Women	54.45%	36.92%	0.0085
High-energy trauma	5.20%	3.01%	ns
Swelling	64.60%	64.62%	ns
Hematoma	34.90%	35.39%	ns
Functional limitations	53.47%	53.85%	ns
Macro-alterations of bone profile	21.78%	18.46%	ns
Osteoporosis	18.01%	0%	0.0001
Malignancy	0.74%	0%	ns
Previous fractures	3.96%	3.01%	ns
Micro-discontinuity/irregular bone profile	2.37%	15.28%	0.0001
Limb	52.68%	59.72%	ns
Thorax	10.57%	4.17%	ns
Hands/feet	35.33%	36.11%	ns
Face/skull	1.26%	0%	ns
Other regions	0.16%	0%	ns

Values are expressed as the mean ± standard error (range) or percentage

Table 3. Accuracy and agreement overall and by patient age

	Overall	Adults	Pediatrics
Prevalence %	32.44	30.44	50.00
95% CI	29.02−36.05	26.91−34.21	38.09−61.91
Sensitivity %	93.89	94.30	91.67
95% CI	89.74−96.49	89.77−96.98	76.41−97.82
Specificity %	94.13	94.56	88.89
95% CI	91.53−95.99	91.89−96.41	73.00−96.38
Positive predictive value %	88.48	88.35	89.19
95% CI	83.62−92.08	82.97−92.24	73.64−96.48
Negative predictive value %	96.98	97.43	91.43
95% CI	94.86−98.27	95.31−98.64	75.81−97.76
Cohen's κ	0.87	0.87	0.81

CI = confidence interval.

Table 4. Accuracy of and agreement among ultrasound operators

	Operator A	Operator B	Operator C	Operator D
No. of exams	122	387	156	41
No. of patients	122	150	156	41
Pediatrics (%)	2.46	3.36	23.71	46.34
Prevalence %	35.25	15.25	73.72	29.27
95% CI	26.96−44.47	11.89−19.31	65.96−80.28	16.65−45.74
Sensitivity %	97.67	96.61	90.44	100.00
95% CI	86.20−99.88	87.25−99.41	83.16−94.89	69.87−100
Specificity %	89.88	98.48	73.71	86.21
95% CI	80.50−95.21	96.27−99.44	56.79−85.25	67.43−95.49
Positive predictive value %	84.00	91.94	90.43	75.00
95% CI	70.34−92.36	81.45−96.99	83.16−94.89	47.41−91.67
Negative predictive value %	98.61	99.38	73.17	100.00
95% CI	91.46−99.93	97.55−99.89	56.79−85.25	83.34−100
Cohen's κ	0.84	0.93	0.64	0.78

CI = confidence interval.

predictive value (NPV) of US tests were around 90%. The PPV was 88.48%, 88.35% and 89.19% in all patients, adults and children, respectively. The NPV was 96.98%, 97.43% and 91.43% in the three groups, respectively (CIs listed in Table 3). Cohen's κ coefficient revealed almost perfect agreement and was >0.80 for each group. It reached a level of 0.87 for both the whole group and the adults and 0.81 for pediatric patients (Table 3).

For the four emergency physicians who were US operators, sensitivity was 97.67%, 96.61%, 90.44% and 100% for operators A, B, C and D, respectively (CIs listed in Table 4). Specificity was 89.88%, 98.48%, 73.71% and 86.21% for operators A, B, C and D, respectively (CIs in Table 4). The PPV revealed good accuracy and was 84.00%, 91.94%, 90.43% and 75.00% for the 4 operators, respectively (CIs in Table 4). The NPV reached 98.61%, 99.38%, 73.17% and 100% for operators A, B, C and D, respectively. Cohen's κ coefficient revealed almost perfect agreement for operator A and B, reaching 0.84 and 0.93, respectively. There was substantial agreement between US and X-ray examinations for operators C and D, with Cohen's κ values of 0.64 and 0.78, respectively (Table 4). On analysis, US operator ($p = 0.004$) and presence of cortical micro-discontinuity ($p < 0.0001$) were the only factors associated with disagreement between X-ray and US results. Surprisingly, no other factors examined (gender, quality of trauma, swelling, hematoma, functional limitations, alteration of profile, osteoporosis, malignancy and previous fractures) was associated with disagreement. Among these variables, macro-alterations of profile ($p = 0.009$) and micro-discontinuity ($p < 0.001$) were associated with the discrepancy in multiple regressions. Finally, we evaluated for potential determinants of the discrepancy. Operator ($F = 18.89$, $p < 0.0001$), age ($F = 1.85$, $p < 0.0001$), macro-alterations (Fig. 4a, b) of profile ($F = 5.19$, $p = 0.0231$) and micro-discontinuity (Figs. 6a, 6b; $F = 232.81$, $p < 0.0001$) were associated with the discrepancy in the ANOVA model. Figure 6a and b depict an example case of US disagreement with X-ray where US detected a fracture and caused disagreement and later reassessment of the X-ray to a fracture.

DISCUSSION

Plain film X-rays have been the standard imaging method when managing suspected fractures for well more than 100 y. X-Rays provide adequate initial depictions of many fractures. Although they are limited for detailed evaluation of fracture patterns and fragments at some joints and vertebra, X-rays are still the most common method for initial focused orthopedic injury evaluation. However, X-rays have considerable limitations in daily clinical practice. X-Ray equipment is typically expensive and often wall or ceiling mounted in radiology rooms. Portable equipment is available, but although mobile, these devices are large and heavy, limiting their access in some hospital areas and more austere environments. Further, conventional X-rays require technologists to operate the equipment, and even with electronic image transfer, delays between ordering an X-ray for a traumatic injury and being able to review the image can significantly affect clinical treatment timelines. Unlike fixed or heavy X-ray equipment, POCUS equipment is highly mobile with many portable systems and a growing number that are hand-held. In recent years, many medical systems worldwide are increasingly stretched for manpower and are seeing higher patient volumes in emergency departments, leading to growing delays. Near-immediate screening and diagnosis at the patient's bedside could improve throughput and reduce cost. However, the accuracy of POCUS in the evaluation of bone fractures must be comparable to that of standard plain X-rays, and the exposure to ionizing radiation, delay in diagnosis and greater cost over US should be justified.

Point-of-care ultrasound studies for fracture detection date back nearly two decades and reflect the significant need for a bedside diagnostic tool to replace the cumbersome process of plain X-ray use in most settings. However, critical points are the training of clinicians and their ability to detect bony fractures by means of US. Bahl et al. (2018) compared 40 emergency medicine residents' interpretations of chicken leg bone fracture assessment utilizing either US or X-ray interpretation. Residents were randomly assigned to either study arm. The authors reported that accurate fracture identification was higher in the US arm than in the X-ray arm, 0.89 (standard deviation [SD] 0.11) versus 0.75 (SD 0.11), respectively ($p < 0.001$). These provocative results, in experimental and controlled settings, indicate that emergency medicine residents may identify fractures better using US rather than the standard X-rays, as described by Bahl et al. (2018).

Frouzan et al. (2017) compared US diagnosis with plain X-ray in 100 trauma patients. Radial trauma was the most common injury among the study population and was found in 27% of the patients studied. The authors noted that US had high sensitivity, specificity, PPV and NPV compared with plain X-rays in the upper extremity; 95.3%, 87.7%, 87.2% and 96.2%, respectively. Lower extremity evaluation revealed good sensitivity, specificity, PPV and NPV of US compared with X-rays: 98.6%, 83%, 65.4% and 87.1%, respectively. Tibia and fibula fractures were the most common, accounting for 89.2% of all lower extremity fractures. This study by Frouzan et al. (2017), although small, suggests that US is comparable to X-rays in a clinical setting with trauma patients.

Not all authors have reported favorable results when comparing US with X-rays. Bolandparvaz et al. (2013) studied a small cohort of 80 polytrauma patients. Radiologists interpreted both US and X-ray findings in blinded fashion. The sensitivity and specificity of US ranged from 55%−75% and from 62%−84%, respectively, depending on the fracture location. In the hands of radiologists, who do not provide clinical care to the injured patients, the specificity and sensitivity seem too low for clinical practice, although the authors felt it was in an acceptable range. However, the PPV varied greatly among radiologists ranging from 33.3%−71%. The κ correlation for upper limbs was 0.58, but fell to 0.47 for lower limb joints. Although this study was limited by its small size, it raises a critical issue: the importance of direct patient evaluation by the clinician performing the US examination at the point of care over the consultative-type remote image interpretation approach practiced by radiology. Compared with other study results focusing on clinicians, one possible explanation for the significant difference in accuracy is that the physicians studied were not clinicians and were not actually examining the patients in the study. Bolandparvaz et al. (2013) reported that radiologists not performing the physical examination, history and US examination themselves may be at an inherent disadvantage when searching for fractures. A systematic review by Joshi et al. (2013) sought to evaluate the roles of history and physical examination versus US in fracture diagnosis. The authors' final analysis included nine studies that met inclusion criteria for physical examination and history and 8 studies that met inclusion criteria for US. The study was confounded by significant data heterogeneity according to the authors. The prevalence of fractures varied greatly among the included studies, ranging from 22%−70%. The physical examination alone had positive likelihood ratios (LRs) ranging from 1.2 to infinity and negative LRs ranging from 0−0.8 for upper extremities. The sensitivities of US ranged from 85%−100%; the specificities from 73%−100%, while the positive LRs ranged found from 3.2−56.1 and the negative LRs from 0−0.2. Joshi et al. (2013), concluded that although the diagnostic accuracy of the physical examination and history alone was inconclusive compared with that of radiographs, US performed by emergency physicians was an accurate test for ruling in and ruling out extremity fractures. Unlike prior studies, ours is one of the largest to date, looked at a variety of injury types and validated the use of US versus X-ray in facture detection. We evaluated 469 patients in total, all in the clinical ED setting at the patient's bedside. Our results suggest that emergency physicians utilizing bedside US are accurate in the diagnosis of a wide variety of fracture types (see Table 2) including face, skull, hands, feet and proximal extremities. Four emergency physicians performed 706 examinations of possible fractures in 469 patients. This is one of the largest studies to date evaluating a range of injury locations. Reflecting typical trauma populations, limb injuries accounted for most fractures. X-Ray evaluation revealed a fracture rate of 32.4%, suggesting a moderate prevalence of injury. Ultrasound examinations by the four emergency providers had a high sensitivity and specificity of 93.9% and 94.1%, respectively. Of interest, sensitivity and specificity were higher for adult than for pediatric patients. Cortical discontinuity was the most sensitive and specific finding indicative of a fracture, with high correlation to the discrepancy between US and X-ray results. Correlation analysis revealed disagreement between US and X-ray results correlated only to the operator performing the examination and cortical discontinuity. Discontinuity was statistically associated with disagreement because the fracture-positive USs generated the most disagreements with X-rays. The association between operator and discrepancy appeared to reflect lesser experience and accuracy by one operator. Factors such as functional limitation and presence of swelling had no statistical correlation.

Our study has a number of limitations. Although plane X-rays are the effective gold standard in clinical practice, they are not as accurate as computer tomography or magnetic resonance imaging for evaluation of bony injury in many cases. The impact of the inability to compare to the true disease rate is likely small. Four providers with various levels of experience (but all had an almost 1-y focused training period including at least 150 examinations in musculoskeletal POCUS to detect bone fracture) scanned all patients. This may not be representative of a wide range of medical training levels. However, studies of residents and students have been published. Several practical and theoretical improvements may be possible. Although additional experience and training will likely result in greater accuracy, there are technological improvements/changes that may improve performance as well. Lower-frequency linear transducers will penetrate bone better and could enable improved visualization of long bones, beyond the cortex. This is noted with ribs in lung US, where lower-frequency transducers unexpectedly image through ribs. However, having such specialized transducers in addition to standard high-frequency linear transducer in an ED is unlikely. Applications such as extended field of view and 4-D US can allow for more comprehensive injury site assessment in both longitudinal and transverse orientation, but such expensive technology has yet to diffuse to the POCUS world to a meaningful extent.

In summary, our study reported a good correlation between POCUS examination and X-ray findings for a variety of fracture types (Figs. 1–6) and, in particular, established good positive and negative predictive values and likelihood rations. POCUS evaluation of possible fractures can produce results comparable to those of plain X-rays.

CONCLUSIONS

In this large study evaluating a range of traumatic injuries, POCUS was highly correlated to plain X-rays in the assessment of bone fractures and had excellent sensitivity, specificity and negative and PPVs. Clinicians should consider adding POCUS to their evaluation of possible fracture.

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REFERENCES

Bahl A, Bagan M, Joseph S, Brackney A. Comparison of ultrasound and plain radiography for the detection of long-bone fractures. J Emerg Trauma Shock 2018;11:115–118.

Bolandparvaz S, Moharamzadeh P, Jamali K, Pouraghaei M, Fadaie M, Sefidbakht S, Shahsavari K. Comparing diagnostic accuracy of bedside ultrasound and radiography for bone fracture screening in multiple trauma patients at the ED. Am J Emerg Med 2013;31: 1583–1585.

Chartier LB, Bosco L, Lapointe-Shaw L, Chenkin J. Use of point-of-care ultrasound in long bone fractures: A systematic review and meta-analysis. CJEM 2017;19:131–142.

Dallaudiére B, Larbi A, Lefere M, Perozziello A, Hauger O, Pommerie F, Fraboulet B, Jacob D. Musculoskeletal injuries in a resource constrained environment: Comparing diagnostic accuracy of on-the-spot ultrasonography and conventional radiography for bone fracture screening during the Paris−Dakar rally raid. Acta Radiol Open 2015;4(5) 2058460115577566.

Frouzan A, Masoumi K, Delirroyfard A, Mazdaie B, Bagherzadegan E. Diagnostic accuracy of ultrasound in upper and lower extremity long bone fractures of emergency department trauma patients. Electron Physician 2017;9:5092–5097.

Hübner U, Schlicht W, Outzen S, Barthel M, Halsband H. Ultrasound in the diagnosis of fractures in children. J Bone Joint Surg [Br] 2000;82B:1170–1173.

Joshi N, Lira A, Mehta N, Paladino L, Sinert R. Diagnostic accuracy of history, physical examination, and bedside ultrasound for diagnosis of extremity fractures in the emergency department: A systematic review. Acad Emerg Med 2013;20:1–15.

Neri E, Barbi E, Rabach I, Zanchi C, Norbedo S, Ronfani L, Guastalla V, Ventura A, Guastalla P. Diagnostic accuracy of ultrasonography for hand bony fractures in paediatric patients. Arch Dis Child 2014;99:1087–1090.

O'Brien J, Baerlocher MO, Asch M, Myers A. Role of radiology in geriatric care: A primer for family physicians. Can Family Physician 2009;55:32–37.

Sistema Epidemiologico Regionale (SER) del Veneto. Gli accessi in pronto soccorso in Veneto. Anno 2013;.

Trunkey DD, Blaisdell FW. Epidemiology of trauma. Sci Am 1988;4: 1–7.