Prospective Use of Ultrasound Imaging to Detect Bony Hand Injuries in Adults

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Objective. We hypothesized that high-resolution linear ultrasound imaging performed by emergency sonologists would be accurate in the diagnosis of bony injuries of the hand. ***Methods.*** This was a prospective observational study of adult patients with injuries of the hand at an urban emergency department with trained emergency sonologists. After informed consent, high-frequency linear ultrasound was used to evaluate the bony structures below the area of injury or tenderness of the hand. The presence of a fracture or dislocation was recorded. A standard radiograph was taken subsequently and read by a blinded radiologist. Standard descriptive statistics with confidence intervals were calculated. ***Results.*** A total of 78 patients were enrolled in the study. The incidence of deformity was 28%; swelling, 90%; and erythema, 20%. Thirty patients had a total of 31 fractures: 21 metacarpal and 10 phalangeal. Ultrasound imaging identified 28 of 31 fractures found on standard radiographs, except for 1 patient's fractures, which were confirmed at surgery. One dislocation was found on ultrasound imaging and confirmed by radiographs. Ultrasound imaging showed the following accuracy for fracture: sensitivity, 90%; specificity, 98%; likelihood ratio (LR)(+), 42.5; and LR(–), 0.1. In comparison, individual physical examination findings of deformity, swelling, and erythema had a maximal LR(+) of 5.15 and minimum LR(–) of 0.51. One metacarpal fracture at the base of the first metacarpal, 1 spiral nondisplaced mid-third metacarpal fracture, and 1 distal tuft phalangeal fracture were missed by ultrasound imaging. There was 1 false-positive ultrasound finding. ***Conclusions.*** Ultrasound imaging performed by emergency sonologists showed excellent sensitivity and specificity in the diagnosis of hand fractures. ***Key words:*** bone; fracture; hand; injury; ultrasound.

Ultrasound has been used to evaluate bony injuries in many areas of the body.[1–8] In the hand, ultrasound has been used to evaluate ligamentous, tendon, and soft tissue injuries.[9–11] Ultrasound imaging may provide some advantage over conventional radiography in regard to access to equipment, the use of ionizing radiation, and portability. In addition, in some situations such as remote settings, battlefield scenarios, and delayed access to radiography, ultrasound may be able to provide initial imaging.[12] To initially evaluate this possibility in a controlled setting by typical emergency providers, we sought to evaluate the possible use of ultrasound for diagnosis of such injuries in the emergency department. We hypothesized that ultrasound imaging performed by emergency sonologists is sensitive and specific in detection of bony hand injuries in adults.

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Materials and Methods

This was a prospective observational study, which was conducted at an urban regional level 1 emergency department with an annual volume of 100,000 patients over a 2-year period. Trained emergency physician investigators performed focused musculoskeletal ultrasound imaging on the affected hands of eligible patients as described below. The definition of the hand was pain or tenderness beyond the distal wrist crease. Criteria for inclusion were age older than 17 years and physical examination findings of possible fractures such as swelling, erythema, tenderness, and deformity. Exclusion criteria included open wounds directly over the bony area of interest that prevented ultrasound evaluation. Informed consent was obtained from each patient, and the study was approved by the Institutional Review Board.

Ultrasound Training and Protocol

Three emergency sonologists with ultrasound training enrolled patients in the study. One physician was the institutional director of emergency ultrasound, and 2 other investigators were third-year emergency medicine residents who had completed specialty-based ultrasound training (>150 ultrasound examinations). The institutional director of emergency ultrasound trained each investigator regarding the technique of biplanar ultrasound fracture evaluation. Each investigator evaluated 5 control patients with hand injuries before enrolling patients in the study. Ultrasound equipment included a Sonix SP machine (Ultrasonix, Burnaby, British Columbia, Canada) with a linear 14–5 MHz probe and an Envisor system (Philips Medical Systems, Andover, MA) with a linear 12–3 MHz probe. The technique included evaluation of the affected areas of the hand in long and short axes on the dorsal and ventral aspects of the hand. Comparison with the nonaffected hand was allowed. A standoff pad of a thicker ultrasound gel layer was used occasionally but was not decisive in any one case. Focal zones were adjusted to include the level of the cortical surface of the bone.

Study Measurements

Investigators reported their findings of a phalangeal fracture, metacarpal fracture, dislocation, or any combination on a data sheet before radiographic or surgical evaluation. Criteria for definition of a fracture on ultrasound imaging included cortical disruption in longitudinal and transverse planes. Dislocation on ultrasound imaging was defined by loss of continuity of adjacent bony joint structures. Ultrasound images were recorded digitally on the local ultrasound machines as well as printed on thermal paper. Physicians were asked to rate the speed of the ultrasound examination using a scale of rapid (<5 minutes), average (5–10 minutes), and prolonged (>10 minutes).

Criterion Standard

Patients then had standard radiographs read by a board-certified radiologist blinded to the ultrasound findings. The official radiology reports were used as the criterion standard. If the patient underwent immediate surgery, surgical findings were also reviewed as a reference standard.

Statistical Methods

We used descriptive statistics and standard 2 × 2 tables to measure sensitivity, specificity, positive predictive value, and negative predictive value with calculated confidence intervals (SAS version 8.2; SAS Institute Inc, Cary, NC).

Results

We enrolled 78 patients over 28 months, 68% male, average age of 34 years (SD, 14 years; range, 19–86 years), with a predominance of right-handed patients (92%). Our patient population had the following physical examination findings: tenderness, 78 (100%); deformity, 22 (28%); swelling, 70 (90%); and erythema, 16 (21%). The maximal location of tenderness was identified at the phalanges in 22 (28%), metacarpal-phalangeal joint in 21 (27%), mid hand in 27 (35%), and equally phalangeal and mid hand in 8 (10%).

Ultrasound imaging showed 31 fractures in 30 patients (1 patient had a concurrent phalangeal and metacarpal fracture). There were 10 phalangeal and 21 metacarpal fractures (Table 1), as shown with representative images in Figures 1

Table 1. Distribution of Hand Fractures by Location and Digit

Location	Digit	1st	2nd	3rd	4th	5th	Total
Metacarpal	Proximal	2	0	0	2	3	7
	Middle	0	1	1	1	2	5
	Distal	0	2	1	1	5	9
Phalangeal	Proximal	1	2	1	0	1	5
	Middle	NA	1	0	0	1	2
	Distal	2	1	0	0	0	3
Total		5	7	3	4	12	31

NA indicates not applicable.

and 2. One dislocation was found on ultrasound imaging (Figure 3).

The accuracy of ultrasound imaging versus pertinent physical examination findings is shown in Table 2.

There were 3 cases with false-negative ultrasound findings: case A, 1 metacarpal fracture at the base of the first metacarpal (Figure 4); case B, 1 spiral nondisplaced mid-third metacarpal fracture (Figure 5); and case C, 1 distal tuft phalangeal fracture (Figure 6). There was 1 false-positive ultrasound finding over a phalanx. Physicians rated the speed of the examination as rapid (<5 minutes) in 73% and average (>5 minutes) in 27%.

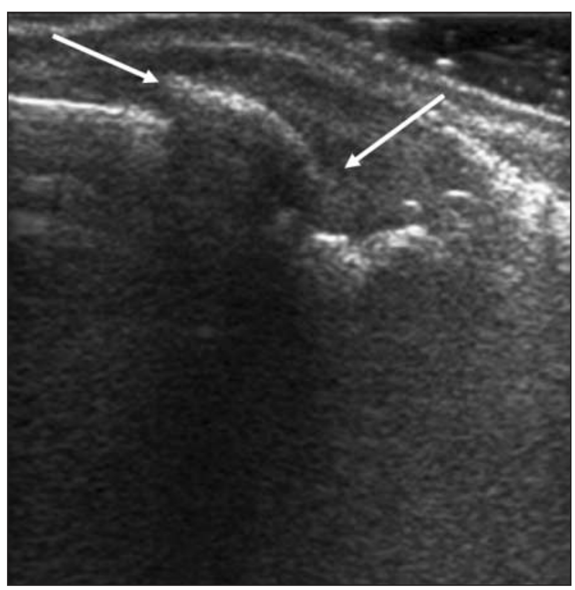
Figure 1. Longitudinal ultrasound image from a 36-year-old man with swelling and ecchymosis near the fourth metacarpal-phalangeal joint. A fracture (arrow) of the metacarpal with angulation is shown.

Discussion

Trauma to the hand has been traditionally evaluated by clinical examination, radiographic imaging, and surgical procedures. The timely evaluation of these mostly ambulatory patients is dependent on radiographic evaluation. Radiographs may not be available in remote, disaster, and clinic situations and may be delayed because of the urgency of other injuries or other patients in the emergency department.

Ultrasound has been advocated for fracture evaluation in many other traumatic situations, including femoral, carpal, rib, facial, and other fractures, because of its exquisite evaluation of the cortex.[1,2,4,5,13,14] To our knowledge, the accuracy of ultrasound for the diagnosis of hand frac-

Figure 2. Oblique ultrasound image from a 42-year-old man with penetrating trauma to the hand near the second and third fingers. A proximal phalanx fracture (arrows) is shown.



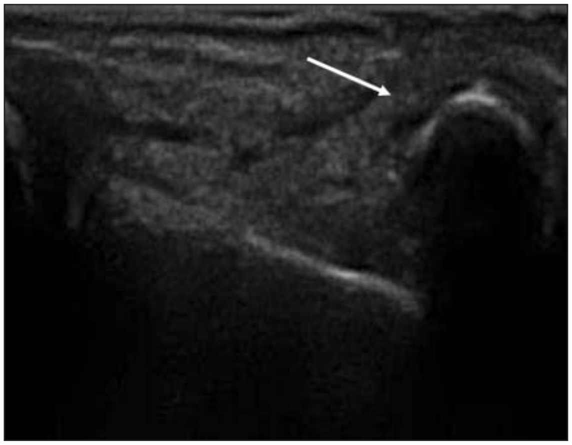


Figure 3. Ultrasound image from a 35-year-old man with swelling to the proximal fifth finger. A dislocated fifth proximal interphalangeal joint is shown. The arrow points to the proximal phalangeal head.

tures, a frequent clinical dilemma, had not been prospectively assessed in the literature.

In this study, ultrasound imaging showed excellent sensitivity and specificity in the diagnosis of hand fractures and compared favorably with clinical examination findings. Interestingly, the 3 missed fractures offered lessons and limitations in regard to the ultrasound evaluation of hand fractures. The first fracture at the carpal-metacarpal junction was difficult because of the proximity to the wrist, with a difficult lateral sonographic window. The second fracture missed, a spiral fracture of the diaphysis of the metacarpal, probably had a less obvious cortical defect than most, although with careful evaluation, it probably should have been found. The third case had a distal tuft fracture that was under the nail, a difficult area in which to a get a sonographic window because of the nail on the dorsum and a sloping volar pad. A water bath technique may have assisted in the diagnosis of this case. Our 1 ultrasound examination with false-positive findings did not reveal a radiographic fracture. Explanations of an occult fracture or a bony prominence may explain this finding; however, comparison with the other extremity should prevent overcalling fractures in this regard.

Our providers were an experienced emergency medicine attending sonologist and 2 third-year emergency medicine residents experienced with ultrasound but less so with musculoskeletal ultrasound. Although the ability to generalize the findings to other settings or providers may be raised, we suspect that physicians, midlevel providers, and sonographers with minimal ultrasound experience will adopt this application quickly.

Possible advantages to the routine use of ultrasound for hand fractures include the bedside evaluation of the afflicted patient with concomitant direct interpretation. In addition, ultrasound evaluation may prove to eliminate or defer the immediate need for a radiograph or radiography machines. Further evaluation of soft tissue, ligamentous, and vascular structures of the hand with dynamic motion may be pursued with further application and knowledge of musculoskeletal ultrasound. In addition, exclusion of fractures in the nonfractured hand may allow early mobilization of the injured hand, thus reducing disability.

Further studies of the injured hand may include a more comprehensive evaluation of the hand beyond bony fractures to examine tendon congruity, soft tissue abnormalities, ligaments, and vascular structures. As was true in one of our

Table 2. Accuracy of Ultrasound Imaging and Physical Examination Findings for Fracture

	Ultrasound			Deformity			Swelling			Erythema		
Parameter	%	Proportion	95% CI	%	Proportion	95% CI	%	Proportion	95% CI	%	Proportion	95% CI
Sensitivity	90	28/31	74–97	55	17/31	44–66	94	29/31	88–99	26	8/31	16–36
Specificity	98	46/47	95–100	89	42/47	83–96	13	6/47	5–20	85	40/47	77–93
PPV	97	28/29	93–100	77	17/22	68–87	41	29/70	30–52	53	8/15	42–54
NPV	94	46/49	89–99	75	42/56	65–85	75	6/8	65–85	63	40/63	53–74
LR(+)		42.5			5.15			1.07			1.73	
LR(–)		0.1			0.51			0.51			0.87	
Prevalence	40	31/78	29–51	40	31/78	29–51	40	31/78	29–51	40	31/78	29/51

CI indicates confidence interval; LR, likelihood ratio; NPV, negative predictive value; and PPV, positive predictive value.

Figure 4. Radiograph from a 20-year-old man with pain over the base of the thumb and index finger (case A). A fracture (arrow) of the base of the first metacarpal (missed on ultrasound imaging) is shown.

patients, ultrasound may provide the only nonsurgical ambulatory test to evaluate penetrating trauma to the hand.[15] Although a randomized study of ultrasound imaging versus radiography may be considered, both types of examination have a place and may be complementary in the evaluation of the traumatized hand.

Our study had limitations, including the design (observational), the small number of investigators, the relative experience of the investigators, the minimal numbers of dislocations, and the large majority of metacarpal fractures. Both of our transducers were larger than optimal at some sonographic windows in the hand. Some of the patients had clinical and ultrasound examinations (always in that order) by the same physician. However, we would point out that ultrasound evaluation is never blind to the patient's physical state, and elicited tenderness (or lack thereof) may guide detailed ultrasound evaluation.

Figure 5. Radiograph from a 24-year-old woman with swelling over the dorsum of the hand centered around digits 2 through 4 after a fight (case B). A nondisplaced spiral fracture (arrow) of the third metacarpal (missed on ultrasound imaging) is shown.

Figure 6. Radiograph from a 20-year-old man with ecchymosis over the third distal finger after blunt trauma (case C). A nondisplaced distal tuft fracture (arrow) of the third metacarpal (missed on ultrasound imaging) is shown.

In conclusion, ultrasound imaging performed by emergency sonologists showed excellent sensitivity and specificity in the diagnosis of hand fractures.

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