The Journal of Emergency Medicine, Vol. ■, No. ■, pp. 1–8, 2016

0736-4679/$ - see front matter

ELSEVIER

http://dx.doi.org/10.1016/j.jemermed.2016.10.013

Ultrasound in Emergency Medicine

BEDSIDE ULTRASOUND VS X-RAY FOR THE DIAGNOSIS OF FOREARM FRACTURES IN CHILDREN

Rachel Rowlands, MBCHB, MRCPCH,*† James Rippey, MBBS, FACEM,‡§ Sing Tie, MBBS, FRACP,*‡ and James Flynn, MBBS, FACEM*§||

*Princess Margaret Hospital for Children, Subiaco, Western Australia, Australia, †University Hospitals of Leicester NHS Trust, Leicester, United Kingdom, ‡Sir Charles Gairdner Hospital, Hospital Avenue, Nedlands, Western Australia, Australia, §School of Primary, Aboriginal and Rural Health Care, and ||School of Paediatrics and Child Health, University of Western Australia, Nedlands, Western Australia, Australia

Reprint Address: James Flynn, MBBS, FACEM, Princess Margaret Hospital for Children, Roberts Road, Subiaco, Western Australia 6008, Australia

☐ Abstract—Background: Painful forearm injuries after a fall occur frequently in children. X-ray study is currently the gold standard investigation. Ultrasound (US) is a potential alternative that avoids exposure to ionizing radiation and may be less painful than x-ray study; and familiarity and skill with US is increasing among emergency physicians. Objectives: The primary aim of this study was to determine if a cohort of physicians with little or no previous experience with US could, after a short training program, safely exclude forearm fractures in children. Secondary aims were to compare any pain or discomfort associated with clinical examination, US, and x-ray study and to determine the acceptability of US as a diagnostic tool to parents and patients. Methods: A prospective, nonrandomized, interventional diagnostic study was performed on children between the ages of 0 and 16 years who had a suspected fracture of the forearm. US scanning was performed by a group of physicians, most with little or no previous US experience. Results: After the brief training program, a group of pediatric emergency physicians could diagnose forearm fractures in children with a sensitivity of 91.5% and a specificity of 87.6%. Pain associated with US was no better or worse than pain associated with x-ray study. Patients and parents preferred US over x-ray study as an investigation modality for suspected forearm fractures. Conclusion: A group of pediatric emergency physicians with limited previous experience could, after a short training program, diagnose forearm fractures in children. Pain associated with US was no better or worse than pain associated with x-ray study.

☐ Keywords—pediatric forearm fractures; ultrasound; emergency physician; x-ray study

INTRODUCTION

Painful injuries to the forearm after a fall occur frequently in children, accounting for 2.2% (n = 1566) of presentations to our tertiary pediatric emergency department (ED) in 2012 (unpublished data, Princess Margaret Hospital for Children). X-ray study is currently the gold standard investigation if a fracture is suspected (1). Evidence has recently been emerging that ultrasound (US) may be more sensitive than x-ray study for the detection of fractures due to its ability to view a region in multiple planes rather than the limited views offered by conventional radiography (2–6).

Access to and familiarity with bedside US is increasing among emergency physicians (7,8). US can be performed quickly at the bedside, it is generally well tolerated, and it has the potential to expedite the patient's journey through the ED by avoiding delays waiting for transfer to the radiology department (9,10). It is noninvasive, cost-effective, and has no known adverse effects. In addition,

RECEIVED: 10 July 2016; FINAL SUBMISSION RECEIVED: 8 September 2016;
ACCEPTED: 3 October 2016

there is increasing recognition of the role of US in the remote/austere setting (e.g., outback areas of Australia), where access to conventional radiology may be unavailable or, alternatively, involve a long and expensive patient transfer (11–13). Ultrasonography does not involve exposure to radiation. Although the dose of ionizing radiation involved in performing x-ray study on the forearm is small, the concept of reducing radiation exposure wherever possible (the ALARA principle – As Low As Reasonably Possible) is important, especially in pediatrics (14).

US can visualize soft tissue structures such as muscles, tendons, and ligaments and can also capture dynamic images. The highly reflective interface between bone and soft tissue ensures that the bone cortex is clearly outlined, particularly if superficial, as is the case in the forearm. Ultrasonography findings associated with fractures include disruption of the linear cortex, often with angulation or a step, and frequently, a subperiosteal hematoma (15,16).

The major disadvantage with US is that it remains user dependent, with education, experience, and equipment integral to accurate image acquisition and interpretation (17).

A number of previous studies have looked at US as a diagnostic modality in forearm fractures in children. Many studies have used expert sonologists (18–21). Other studies have used novice sonologists but have either had a limited number of forearm fractures in their studies or used a very small pool of sonologists (9,22). A recent study by Herren et al. demonstrated excellent correlation between US and x-ray study, but the ultrasonographers were not blinded to the x-ray results (23). Only one study to date has assessed pain during US for forearm fractures, and to the best of our knowledge, no studies have assessed the consumer preference between x-ray study and US as a modality of investigation for forearm injuries in children (21).

The primary aim of this study was to determine whether a large cohort of physicians with little or no previous experience with US could, after a short training program, safely exclude forearm fractures in children.

The secondary aims were to compare any pain or discomfort associated with clinical examination, US, and x-ray study and to determine the acceptability of US as a diagnostic tool to parents and patients.

MATERIALS AND METHODS

The study was a prospective, nonrandomized, interventional diagnostic study conducted at Princess Margaret Hospital for Children, the sole tertiary Pediatric Hospital in Western Australia. Emergency attendances at the hospital are approximately 72,000 per annum.

Prospective, convenience sampling was used to recruit children presenting to the ED between November 2011 and May 2012. The trial was registered with the Australian New Zealand Clinical Trial Registry (number 347557). The study was approved by the Princess Margaret Hospital for Children Ethics Committee.

Patient Selection

Children between the ages of 0 and 16 years of age with a history of trauma to the forearm who were thought to have a suspected fracture were included. Patients with evidence of an open fracture were excluded, as were patients who had imaging performed prior to arrival.

Written parental or patient consent was obtained prior to patient enrollment.

Physician Recruitment and Training

All medical consultants and senior trainees working in the ED were invited to take part in the project. The vast majority of these doctors had no previous US experience. Participation in the study was voluntary.

Prior to recruiting patients, participating doctors were required to complete a preenrollment package that consisted of an 80-min online learning module followed by a quiz and a 2-h hands-on training session. A copy of the online training module can be seen at the following site: http://www.ultrasoundvillage.com/education resources/modules/?module=10.

Of the 33 eligible doctors, 25 completed the full training package and enrolled patients in the study. There was no requirement for a minimum number of scans to be performed prior to becoming eligible to enroll patients in the study.

Study Protocol

Potential patients were identified at triage and their parents were provided with a study information sheet. Analgesia was administered to all children on an as-required basis and recorded as part of their usual medical care. Time of analgesia, both prior to arrival and in the ED, was recorded. A record of the time that any analgesia was given prior to attendance was also recorded.

After obtaining informed consent, children were scanned on a Sonosite M-Turbo® (Sonosite Inc., Bothell, WA) with an HFL50×/15-6 MHz linear transducer using the MSK preset. Longitudinal images of the radius and ulna were obtained in four planes (dorsal, ventral, lateral, and medial), with particular attention to the distal one-third of the forearm. In instances where pain restricted movement, volar, medial, or lateral views were omitted. We defined a fracture as the presence of cortical disruption. X-ray studies were performed only when the US had been completed and the scanning physician had placed a record of their interpretation of the US images in a sealed box. Copies of images were saved on the US machine hard drive for review.

The treating doctor was blinded to the results of the US and patients were managed according to their clinical and x-ray study findings.

Definitive diagnosis of fractures was based on the consultant radiologist's report of x-ray study findings. Reading radiologists were not involved in the study and did not have access to the US images.

Pain scores were obtained 5 min after clinical examination and again after US and x-ray study using the Wong-Baker FACES® Pain Rating Scale in younger children and the numerical rating scale (0–10) for older children (24). Parental interpretation was used when the child was considered incapable of understanding the scales. After both sets of imaging were completed, children or their parents were asked whether they had a preference for either US or x-ray study as an imaging modality.

Sample Size Calculation

A priori sample size calculation determined that a sample of 400 children (assuming half would have fractures) would be sufficient to detect an observed sensitivity of 97% (based on previous studies) with a power of 80% and p-value < 0.05 (8,9,20,22).

Data Analysis

Data were entered into an Excel spreadsheet (Microsoft Corporation, Redmond, WA) and analyzed using Statistical Package for the Social Science (SPSS) version 22 (IBM, Armonk, NY). Patient characteristics were analyzed using descriptive data. If more than one analgesic agent was administered, the time of the latest administration was used to calculate the time between analgesia and US and x-ray examination. Chi-squared and Kappa agreement were used to determine sensitivity, specificity, and level of agreement between US diagnosis and plain x-ray diagnosis. Repeated-measures general linear model was used to determine the difference in pain perceived during clinical, US, and x-ray examinations.

RESULTS

Four hundred forty-nine patients were recruited during the study period. Of these, 30 patients were excluded (16 due to incomplete data and 14 due to absent documentation of consent), leaving 419 patients available for analysis (Figure 1). The average age of patients was 9.3 years (SD 3.5 years); 57% of patients (n = 238) were male, 43% of patients (n = 181) were female.

Twenty-five of 33 eligible physicians (76%) participated in the study (Figure 2). Twelve (48%) were predominantly pediatrics trained; the remainder had combined emergency and pediatric training. Number of scans performed per doctor ranged from 1 to 60 (median = 10). At the time of recruitment, 15 (60%) of the participating physicians had no prior US experience, seven (28%) had previous training (e.g., eFAST course) but had not used US since, and none of the remainder were using US regularly in their clinical practice. Seniority of physician and proportion of scans performed by seniority is shown in Figure 2. Prior US experience and proportion of scans performed by prior US experience is shown in Figure 3.

Two hundred thirty-four patients (55.8%) had a fracture diagnosed on x-ray study. Of those, US correctly diagnosed the fracture in 214 cases (sensitivity 91.5%). Of the 185 patients without a fracture, US agreed in 162 cases (specificity 87.6%). Kappa agreement was 0.792 ($p < 0.001$).

Twenty forearm bone fractures identified on x-ray study were missed on US. Four of these were radiologically obvious buckle or displaced fractures of the distal radius, and were indeed clinically relevant misses. Six of the fractures were extremely subtle buckle fractures of the distal radius and one was an undisplaced ulna styloid fracture. The remaining nine fractures missed on US were fractures of the mid-shaft of the radius and ulna, bowing fractures, or fractures of the radial neck.

Twenty-three fractures were diagnosed on US but were not apparent on x-ray study. Fourteen of these false-positive interpretations were diagnosed by people who had performed fewer than 10 scans at the time. Of the remaining 9 patients, review of the images by an expert sonologist suggests that at least four had recorded images consistent with small buckle fractures.

Post hoc analysis was performed to include only scans recorded after 10 scans had been performed by the doctor (242 scans). Of those, 137 patients (56.6%) had a fracture diagnosed on x-ray study. US confirmed the fracture in 130 of 137 patients (sensitivity of 94.9%) and had a specificity of 91.4% (96 true negatives, nine false positives).

Of the 419 eligible patients, 369 had a complete set of pain scores recorded. Pain scores during clinical examination (mean 5.5, 95% confidence interval [CI] 5.2–5.7) were significantly greater than during both US (mean 3.7, 95% CI 3.4–4.0) and x-ray study (mean 3.8, 95% CI 3.5–4.1). There was, however, no significant difference between pain associated with US and pain associated with x-ray study (mean difference −0.1, 95% CI −0.34–0.12).

Two hundred twenty-nine patients (55%) received analgesia. Drugs administered included: oral paracetamol 15 mg/kg, maximum dose 1000 mg; oral ibuprofen 10 mg/kg, maximum dose 400 mg; combination paracetamol 12 mg/kg plus codeine 0.5 mg/kg, maximum

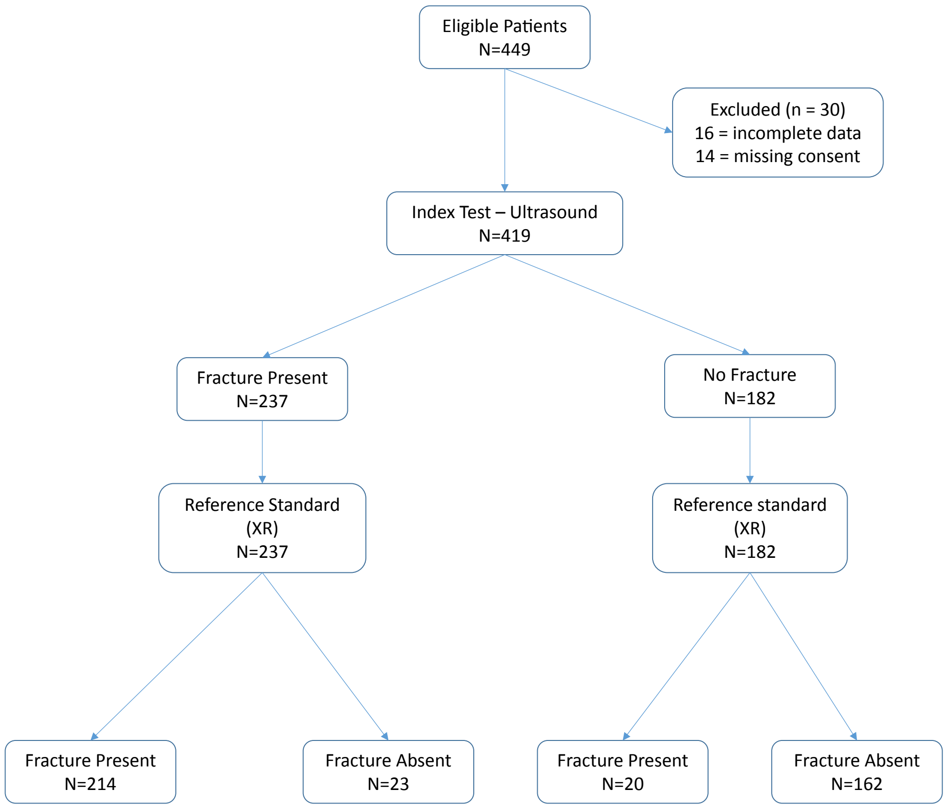

Figure 1. Standards for Reporting of Diagnostic Accuracy (STARD) diagram.

dose 1000 mg paracetamol or intranasal fentanyl 1.5 μg/kg, maximum dose 200 μg. Mean time between analgesia and US was 52 min (SD 48 min) and mean time between analgesia and x-ray study was 78 min (SD 50 min).

Three hundred sixty-two (86.3%) patients or their parents provided feedback on modality preference. Patient/parental preference demonstrated a strong preference for US (52.8%) compared with x-ray study (18.5%), whereas 28.7% declared no preference for either

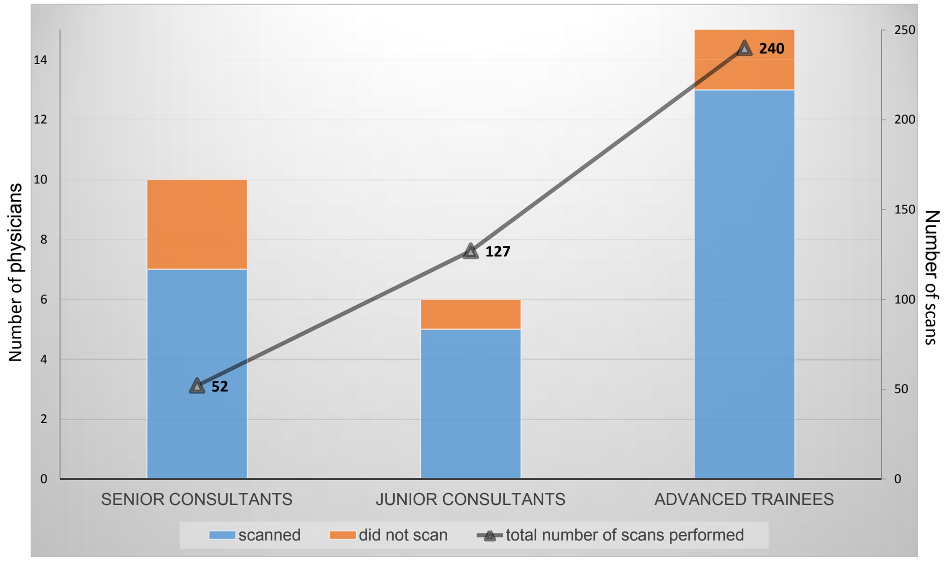

Figure 2. Number of scans performed by seniority of physician.

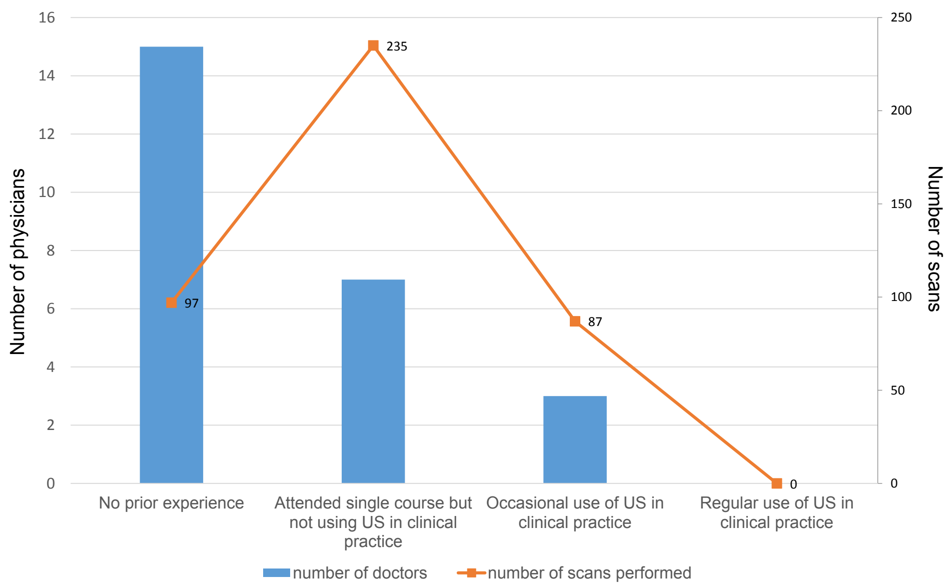

Figure 3. Number of scans performed by level of prior ultrasound (US) experience of participating physicians.

modality. Examples of comments include the following: "I have worried about my son having too many x-rays over time so I appreciate the concern of radiation exposure to children" and "X-ray hurts more because they had to turn my hand over."

DISCUSSION

This study is the first to use a large number (n = 25) of mainly US-naïve physicians to detect pediatric forearm fractures. At the time our study was conducted, the department was staffed largely by physicians with a predominantly pediatrics background, most of whom had no prior experience with US. In our study, all scans were performed by physicians who had either never used an US machine before, had attended a course (e.g., eFAST) but not used US in clinical practice, or had only occasionally used US in clinical practice prior to the study.

The study was designed to ensure physicians committed to a firm diagnosis based on their US images prior to getting an x-ray study, to prevent any potential bias. Our results demonstrated high agreement between US and plain x-ray in the detection or exclusion of distal forearm fractures.

With 419 patients enrolled, this is by far the largest published study of pediatric forearm fractures. Our results (91.5% sensitivity and 87.6% specificity), which included the initial learning curves of numerous complete novices, compare very favorably with previous studies. A group of 10 emergency physicians in Weinberg et al., all of whom had undertaken 1 h of US training, examined 70 children with forearm fractures and reported a sensitivity of 50% and specificity of 95% for ulna fractures and a sensitivity of 71% and specificity of 85% for radius fractures (9). The specific level of emergency and US experience the physicians had was not reported. Chaar-Alvarez et al. reported bedside interpretation results of 85% sensitivity and 73% specificity in 101 children with distal radial injures using four physicians trained in emergency ultrasonography, improving to 96% and specificity of 93%, with an expert US physician interpreting the images (21). Herren et al. described sensitivity of 100% and specificity of 99.5% in a study of 201 patients in which the US doctors were not blinded to the clinical or radiological findings (23). Williamson et al. reported sensitivity and specificity of 100% in a group of 26 patients scanned by two consultant radiologists (20).

Twenty forearm bone fractures identified on x-ray study were missed on US. Nine fractures missed on US were fractures of the mid-shaft of the radius and ulna, bowing fractures, or fractures of the radial neck. Review of the patient notes and x-ray images indicates that at least five of the missed mid-shaft fractures were clinically obvious. That they were missed may be explained by the fact that the focus of our training program was on distal fractures and that translation of this knowledge to other fractures was, in some cases, limited.

Twenty-three fractures were diagnosed on US but were not apparent on x-ray study. There is evidence to suggest that, in some instances, US is better than conventional plain x-ray study at diagnosing fractures, and it is possible that some of our false positives were in fact true positives (fractures missed by x-ray study) (25,26). Our study protocol was not, however, designed to test this hypothesis.

In our study we had no requirement for doctors to perform a minimum number of supervised scans prior to becoming eligible to enroll patients into the database. We deliberately chose this strategy to try to replicate a “real world” scenario, in particular looking at potential use of US by doctors in an isolated setting with minimal exposure to training. There is, however, a documented “learning curve” associated with image acquisition and interpretation (17). Review of our data reveals that our sensitivity would have improved to 94.9% and specificity to 91.4% if the first 10 scans performed by the doctor were not included.

Similar mean pain scores for US and x-ray examination suggest that pain is not a significant barrier to undertaking US in the ED.

In our study, parents gave a clear preference for US examination. This may reflect a desire for parents to limit their child’s exposure to radiation, the convenience of having the US in the ED, or, alternatively, the potential for US to expedite the patient’s journey through the department.

In the last few years, emergency physician familiarity with US has generally increased. In pediatric emergency medicine, US is commonly used for guiding intravenous access, for assessing bladder volumes, and in assessing for hip effusions. There are many other different published indications (27). As expertise and experience grows and equipment improves, it is likely that if a similar study were repeated now, using a similar representative cohort of pediatric emergency physicians, the results would be better still.

Limitations

The group of physicians who volunteered to participate may have had an interest in US and therefore may have performed better than physicians who had no interest. However, because 76% of eligible physicians participated in the study, this is unlikely to have significantly influenced the results. Additionally, the majority were physicians with a pediatric background rather than an emergency one. Consequently, the results may not be representative of a true cross-section of emergency doctors.

There is potential for bias in the selection of patients in our study given that our recruitment used prospective convenience sampling.

Our study did not include long-term follow-up of patients. Although it is postulated that missing subtle buckle fractures is of minimal clinical significance, this conclusion cannot be drawn until confirmed by further studies. An additional benefit of long-term follow-up of the study population might be that callus on a subsequent x-ray image in a false-positive US scan is, in fact, confirmation that US is more sensitive than x-ray study in the detection of some fractures.

Our results comparing pain associated with clinical examination, US, and x-ray study need to be interpreted with caution. As a pragmatic study, there was no attempt to standardize analgesic regimens and US was always performed prior to x-ray study, which may have influenced results.

Our findings that US is preferred by patients and parents over x-ray study may have been biased by the recruitment technique, which included references to “limiting exposure to radiation.”

CONCLUSIONS

After an online education package supplemented by a 2-h hands-on training session, a group of largely US-naïve pediatric emergency physicians could diagnose forearm fractures in children with a sensitivity of 91.5% and a specificity of 87.6%. Our data suggest that when doctors have performed more than 10 scans they become more proficient, but further studies are required to confirm this. Pain associated with US was no better or worse than pain associated with x-ray study. Our findings also suggest that patients and parents prefer US over x-ray study as an imaging modality for forearm injuries in children.

Acknowledgment—Thanks to Dr. Robyn Fary for help with statistical analysis.

REFERENCES

1. Metz VM, Gilula LA. Imaging techniques for distal radius fractures and related injuries. Orthop Clin North Am 1993;24:217–28.
2. Lewis D, Logan P. Sonographic diagnosis of toddler’s fracture in the emergency department. J Clin Ultrasound 2006;34:190–4.
3. Moritz JD, Berthold LD, Soenksen SF, Alzen GF. Ultrasound in diagnosis of fractures in children: unnecessary harassment or useful addition to X-ray? Ultraschall Med 2008;29:267–74.
4. Simanovsky N, Lamdan R, Hiller N, Simanovsky N. Sonographic detection of radiographically occult fractures in pediatric ankle and wrist injuries. J Pediatr Orthop 2009;29:142–5.
5. Cho KH, Lee SM, Lee YH, Suh KJ. Ultrasound diagnosis of either an occult or missed fracture of an extremity in pediatric-aged children. Korean J Radiol 2010;11:84–94.
6. Beltrame V, Stramare R, Rebellato N, Angelini F, Frigo AC, Rubaltelli L. Sonographic evaluation of bone fractures: a reliable alternative in clinical practice? Clin Imaging 2012;36:203–8.
7. Dietrich AM, Coley BD. Bedside pediatric emergency evaluation through ultrasonography. Pediatr Radiol 2008;38(suppl 4):S679–84.
8. May G, Grayson A. Towards evidence based emergency medicine: best BETs from the Manchester Royal Infirmary. Bet 4: the use of ultrasound in the diagnosis of paediatric wrist fractures. Emerg Med J 2009;26:822–5.

9. Weinberg ER, Tunik MG, Tsung JW. Accuracy of clinician-performed point-of-care ultrasound for the diagnosis of fractures in children and young adults. Injury 2010;41:862–8.
10. Chen L, Kim Y, Moore CL. Diagnosis and guided reduction of forearm fractures in children using bedside ultrasound. Pediatr Emerg Care 2007;23:528–31.
11. Knudsen L, Sandberg M. Ultrasound in pre-hospital care. Acta Anaesthesiol Scand 2011;55:377–8.
12. Nelson BP, Melnick ER, Li J. Portable ultrasound for remote environments, part II: current indications. J Emerg Med 2011;40:313–21.
13. Minardi J, Davidov D, Denne N, et al. Bedside ultrasound: advanced technology to improve rural healthcare. W V Med J 2013;109:28–33.
14. The Faculty of Clinical Radiology. Standards of practice for diagnostic and interventional radiology Version 10. Sydney: The Royal Australian and New Zealand College of Radiologists; 2014.
15. Eksioglu F, Altinok D, Uslu MM, Gudemez E. Ultrasonographic findings in pediatric fractures. Turk J Pediatr 2003;45:136–40.
16. Cho KH, Lee YH, Lee SM, Shahid MU, Suh KJ, Choi JH. Sonography of bone and bone-related diseases of the extremities. J Clin Ultrasound 2004;32:511–21.
17. Goudie AM. Credentialing a new skill: what should the standard be for emergency department ultrasound in Australasia? Emerg Med Australas 2010;22:263–4.
18. Hubner U, Schlicht W, Outzen S, Barthel M, Halsband H. Ultrasound in the diagnosis of fractures in children. J Bone Joint Surg Br 2000;82:1170–3.
19. Durston W, Swartzentruber R. Ultrasound guided reduction of pediatric forearm fractures in the ED. Am J Emerg Med 2000;18:72–7.
20. Williamson D, Watura R, Cobby M. Ultrasound imaging of forearm fractures in children: a viable alternative? J Accid Emerg Med 2000; 17:22–4.
21. Chaar-Alvarez FM, Warkentine F, Cross K, Herr S, Paul RI. Bedside ultrasound diagnosis of nonangulated distal forearm fractures in the pediatric emergency department. Pediatr Emerg Care 2011;27: 1027–32.
22. Patel DD, Blumberg SM, Crain EF. The utility of bedside ultrasonography in identifying fractures and guiding fracture reduction in children. Pediatr Emerg Care 2009;25:221–5.
23. Herren C, Sobottke R, Ringe MJ, et al. Ultrasound-guided diagnosis of fractures of the distal forearm in children. Orthop Traumatol Surg Res 2015;101:501–5.
24. Wong-Baker FACES Foundation. Wong-Baker FACES® Pain Rating Scale. Available at: wongbakerfaces.org. Accessed October 17, 2016.
25. Lalande E, Wylie K. Towards evidence-based emergency medicine: best BETs from the Manchester Royal Infirmary. BET 1: ultrasound in the diagnosis of rib fractures. Emerg Med J 2014;31:169–70.
26. You JS, Chung YE, Kim D, Park S, Chung SP. Role of sonography in the emergency room to diagnose sternal fractures. J Clin Ultrasound 2010;38:135–7.
27. Guttman J, Nelson BP. Diagnostic emergency ultrasound: assessment techniques in the pediatric patient. Pediatr Emerg Med Pract 2016;12:1–28.

ARTICLE SUMMARY

1. Why is this topic important?

Forearm fractures are common in children. Ultrasound is increasingly being used by emergency physicians and does not involve ionizing radiation.

2. What does this study attempt to show?

To see if a large group of physicians, most with minimal previous ultrasound experience, could reliably detect or exclude distal forearm fractures in children using ultrasound. Secondary aims were to assess the pain associated with ultrasound compared with x-ray study and to assess parental preference for ultrasound compared with x-ray study.

3. What are the key findings?

Our cohort of doctors correctly diagnosed 214/234 fractures (sensitivity 91.5%) with ultrasound. Specificity was 87.6% (162 true negatives, 23 false negatives). Pain scores with ultrasound were similar to those recorded for x-ray study. Patients or their parents expressed a strong preference for ultrasound compared with x-ray study.

4. How is patient care impacted?

Ultrasound is relatively accurate at diagnosing forearm fractures in children, even when performed by relatively inexperienced ultrasonographers. Further studies are warranted to see if more training and more familiarity with ultrasound leads to better results.