Use of point-of-care ultrasound in long bone fractures: a systematic review and meta-analysis

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ABSTRACT

**Objectives**: Long bone fractures (LBFs) are among the most frequent traumatic injuries seen in emergency departments. Reduction and immobilization is the most common form of treatment for displaced fractures. Point-of-care ultrasound (PoCUS) is a promising technique for diagnosing LBFs and assessing the success of reduction attempts. This article offers a comprehensive review of the use of PoCUS for the diagnosis and reduction of LBFs.

**Data source**: MEDLINE and EMBASE databases were searched through July 19, 2015.

**Study selection**: We included prospective studies that assessed test characteristics of PoCUS in 1) the diagnosis or 2) the reduction of LBFs. The methodological quality of the included studies was evaluated using the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) tool.

**Data extraction**: Thirty studies met inclusion criteria (n = 3,506; overall fracture rate 48.0%). Test characteristics of PoCUS for the diagnosis of LBFs were as follows: sensitivity 64.7%–100%, specificity 79.2%–100%, positive likelihood ratio (LR) 3.11–infinity, and negative LR zero–0.45. Sensitivity and specificity for the adequate reduction of LBFs with PoCUS were 94%–100% and 56%–100%, respectively. PoCUS diagnosis of pediatric forearm fractures in 10 studies showed a pooled sensitivity of 93.1% (95% confidence interval [CI], 87.2%–96.4%) and specificity of 92.9% (95% CI, 86.6%–96.4%), and PoCUS diagnosis of adult ankle fractures in four studies showed a pooled sensitivity of 89.5% (95% CI, 77.0%–95.6%) and specificity of 94.2% (95% CI, 86.1%–97.7%).

**Conclusion**: PoCUS demonstrates good diagnostic accuracy in all LBFs studied, especially in pooled results of diagnosis of pediatric forearm and adult ankle fractures. PoCUS is an appropriate adjunct to plain radiographs for LBFs.

**RÉSUMÉ**


**Source de données**: Des recherches ont été effectuées dans les bases de données MEDLINE et EMBASE jusqu’au 19 juillet 2015 inclusivement.

**Sélection des études**: Ont été retenues des études prospectives visant à évaluer les caractéristiques de fonctionnement de l’EPS au regard 1) du diagnostic ou 2) de la réduction des FOL. La qualité méthodologique des études sélectionnées a été évaluée l’aide de l’outil Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2).

**Extraction des données**: Trente études respectaient les critères de sélection (n = 3506; taux général de fracture : 48.0 %). Les caractéristiques de fonctionnement de l’EPS au regard du diagnostic des FOL se sont établies comme suit : sensibilité : 64,7 % - 100 %; spécificité : 79,2 % - 100 %; rapport de vraisemblance (RV) positif : 3,11 - à l’infini; RV négatif : 0 - 0,45. La sensibilité et la spécificité au regard de la réduction satisfaisante des FOL réalisée à l’aide de l’EPS étaient de 94 % - 100 % et de 56 % - 100 %, respectivement. La qualité diagnostique de l’EPS dans les cas de fracture de l’avant-bras chez les enfants, reposant sur 10 études, a atteint une sensibilité globale de 93,1 % (intervalle de confiance [IC] à 95 % : 87,2 % - 96,4 %) et une spécificité globale de 92,9 % (IC à 95 % : 86,6 % - 96,4 %), et la qualité diagnostique de l’EPS dans les cas de fracture de la cheville chez les adultes, reposant sur 4 études, a atteint une sensibilité globale de 89,5 % (IC à 95 % : 77,0 % - 95,6 %) et une spécificité globale de 94,2 % (IC à 95 % : 86,1 % - 97,7 %).

**Conclusion**: L’EPS a atteint une bonne exactitude diagnostique dans tous les cas de FOL examinés dans l’étude, tout particulièrement en ce qui concerne les résultats d’ensemble au regard du diagnostic des fractures de l’avant-bras chez les...
INTRODUCTION

Fractures account for 17% of injuries in Canadians ages 12 and older. Long bone fractures (LBFs)—that is, fractures to the humerus, radius, ulna, femur, tibia or fibula—are most often caused by traumatic events such as motor vehicle accidents, sport injuries, falls, and assaults. Immobilization, with or without reduction, is the most common treatment strategy for fractures in the emergency department (ED). Immobilization can be used as a temporizing measure until surgery is undergone or as a definitive treatment. In the latter case, adequate alignment is essential to optimize future functioning.

The diagnosis of LBFs is traditionally accomplished through plain radiographs taken at perpendicular angles to each other. Because of the resources required for around-the-clock radiographic capability, X-ray can be inaccessible in rural or remote areas, or in larger centres during off-hours. In settings where a radiography technologist is not present on-site, a point-of-care ultrasound (PoCUS) examination can be performed earlier, and at the bedside, reducing diagnostic delays and time to initiation of management. Additional advantages of PoCUS include its simplicity, portability, repeatability, and its lack of ionizing radiation.

Fluoroscopy has been advocated as an adjunct to ED-based fracture reduction. However, this technique can be impractical because of cost, size of the equipment, the training necessary for the use of this technology, the need for lead protectors on health care providers, as well as the harmful effects to patients of ionizing radiation.

The benefits of PoCUS may be even greater for the reduction of displaced fractures, where localized swelling and significant pain may lead to inadequate reduction and repeated attempts, which are known to increase the likelihood of developing compartment syndrome. Moreover, repeated attempts may also put the patient through the risky process of sedation and/or analgesia multiple times, and could possibly lead to increased rates of operative management.

PoCUS allows for real-time assessment of reduction attempts, making it possible to re-manipulate and immobilize the fracture while the patient is still sedated. PoCUS-guided fracture reduction and immobilization produces minimal discomfort when liberal amounts of transmission gel are used.

There are multiple studies and reports on the use of PoCUS in the setting of LBFs, but to our knowledge this is the first comprehensive review that includes a description of the technique and its application to LBF reduction. The objective of this study is to summarize and, where applicable, pool the diagnostic accuracy of PoCUS compared to plain radiographs in children and adults for 1) the diagnosis of suspected LBFs and 2) the adequate reduction of known LBFs.

Description of the technique

For the diagnosis of LBFs with PoCUS, the high-frequency linear probe should be used in the longitudinal plane, with a thick layer of ultrasound gel to minimize pain and improve visualization (Figure 1). The probe should be gently moved along the axis of the bone while adjusting the depth and gain to optimize the view. The deepest hyperechoic horizontal line on the PoCUS screen represents bony cortex, with its acoustic shadow preventing visualization of deeper structures. If a fracture is present, a discontinuity in this line will be seen (Figure 2, A). The degree of displacement and angulation of the distal fragment will

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Keywords: point-of-care systems, ultrasonography, fractures, bone, systematic review

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Figure 1. Simulated use of point-of-care ultrasound (PoCUS) for the diagnosis of distal radius fracture.
be visualized as a step-off and as an angulation between the cortices, respectively. Similar to plain radiography, the PoCUS examination should be obtained in two perpendicular planes for each bone of interest, as it minimizes the false-negative examinations from fractures that may be visualized at certain angles only.

For PoCUS-guided reduction of LBFs, the fracture should be visualized with PoCUS prior to a reduction attempt, to provide a comparison for the post-reduction PoCUS images (Figure 2, B). If the post-reduction images do not appear satisfactory on PoCUS, based on step-off or angulation, additional attempts at reduction may be initiated in the same procedural sedation and/or analgesia episode. When the best possible reduction is achieved, the health care provider may proceed with immobilization of the fracture and usual care strategies, including post-reduction plain radiography. All relevant PoCUS-generated images should be saved and archived for clinical and quality assurance purposes.

METHODS

Eligibility criteria

We included studies that prospectively enrolled patients with either suspected or known acute LBFs. Studies had to use PoCUS as the intervention, and compare it to plain radiography, the pragmatic standard of care. Studies had to report on the performance of PoCUS, either as a diagnostic or a management tool. Case reports and narrative review articles were excluded because they do not report diagnostic test characteristics. Other exclusion criteria included non-acute fractures, non-human models, or comparison done only with modalities other than plain radiography.

Information sources

MEDLINE and EMBASE databases were searched, from their earliest publication date to July 19, 2015. The search strategy was developed in conjunction with a health sciences librarian, and the strategy for the MEDLINE search is described in Supplementary Material Appendix 1 (available online).

Study selection

Two authors (LBC and LB) reviewed the title and abstract of the retrieved articles to determine potential eligibility for inclusion in the manuscript, and manually searched the reference list of review articles for additional relevant studies. They subsequently performed a full-text review to identify studies meeting inclusion and exclusion criteria. Disagreements were resolved by consensus.

Data collection process

A data extraction sheet (based on the Cochrane Consumers and Communication Review Group’s data extraction template) was pilot-tested for the first five studies, and refined according to the typical presentation of results. Information extracted from each study included type of study, study location, patient population, type of fracture and prevalence, number and specialty of the providers performing and interpreting PoCUS examinations, training that the providers receive, and the images analyzed or generated during the examination.
received, the actual application of PoCUS (for initial
diagnosis, reduction assessment, or both), and the per-
formance characteristics of PoCUS accuracy, including
sensitivity, specificity, and positive and negative like-
lihood ratios (LRs).

**Risk of bias in individual studies**

Methodological bias and applicability of the included
studies were assessed using the Quality Assessment of
Diagnostic Accuracy Studies (QUADAS-2) guidelines.13
As outlined in the 2011 guidelines, the authors agreed
upon signaling questions that were pertinent to the
review, encompassing five domains: patient selection,
index test, reference standard, risk of bias, and concerns
about applicability. Two of the authors (LBC and LB)
independently performed the assessments, discrepancies
were reconciled through discussion, and a consensus was
reached.

**Summary measures**

The primary outcomes were the test characteristics
of PoCUS compared to plain radiography for 1) the
diagnosis of LBFs and 2) the successful reduction of
LBFs. These included sensitivity, specificity, and positive
and negative LR. We also abstracted and reported
additional measures of success in studies pertaining to the
reduction of known LBFs, such as rates of repeat
reduction and surgical management.

**Meta-analysis**

Where multiple studies reported on diagnostic accuracy
under similar clinical and methodological conditions, a
meta-analysis was performed. Forest plots were used to
present sensitivity and specificity results from each study.
In order to provide a quantitative measure of statistical
heterogeneity, we used the model of diagnostic odds ratio
used by DerSimonian and Laird.14,15 We reported
Cochran’s Q and Higgins’ I².

Results were pooled using the bivariate random effects
model proposed by Reitsma et al. for meta-analysis of
data on diagnostic accuracy.16 Results include estimates of
the overall sensitivity, specificity, and the hierarchical
summary receiver operating characteristic (HSROC)
curve. In addition, Markov chain Monte Carlo sampling
was used to produce summary estimates of LR(+) and
LR(−) and their 95% confidence intervals (CIs).17

All analyses were performed using the mada package
version 0.5.418 for R statistical software.19

**RESULTS**

**Study selection**

The literature search yielded 1,034 articles, which
were screened by title and abstract (Figure 3). Upon
performing manual searches of the bibliographies of the
most recent review articles (less than 5 years from
publication), 16 additional studies were retrieved. Based
on the screening of these 1,050 articles by title and
abstract, 948 studies were excluded. Upon a full-text
review of the remaining 102 studies, 72 articles were
excluded; reasons for exclusion are listed in Figure 3.
Thirty studies were selected for inclusion in the
systematic review: 23 for the diagnosis of LBFs, 5 for
the management of LBFs, and 2 for the assessment of
both outcomes. There were no disagreements between
the authors.

**Study characteristics**

The 30 included studies recruited patients in unsched-
uled care environments, whether in the emergency or
radiology departments, and almost all were in
university-affiliated hospitals (Table 1).7,8,20-47 Two
studies used a second reference standard for some of the
patients, either computed tomography when the plain
radiographs were not definite or a daily clinical
evaluation for 72 hours with delayed imaging or return
to full duty for military personnel.34,42

Both the medical background and PoCUS training
of the operators varied greatly across studies. Sixteen
studies (53.3%) had emergency physicians performing
and interpreting PoCUS examinations, four studies
(13.3%) had surgeons (pediatric, hand, and/or
orthopedic), five studies (16.7%) had radiologists or
ultrasound fellows or technicians, and four studies
(13.3%) included medical students or residents. The
musculoskeletal PoCUS training received by the various
operators ranged from a 3-minute tutorial followed by
hands-on training,40 to a 1-month musculoskeletal
ultrasound course.43 On average, most providers
received between 1 and 4 hours of didactic and practical
training on basic PoCUS skills, which often focused on
musculoskeletal indications.
Table 2 shows the results of the systematic review for the studies pertaining to the diagnosis of LBFs with PoCUS. All studies reported both the sensitivity and specificity of PoCUS, and LRs were calculated from these values when the authors did not include them in their manuscripts. Twenty-five studies were included, ranging from 26 to 653 patients. Collectively, these studies included 2,982 patients and identified 1,200 fractures, with fracture prevalence ranging from 7% to 71% (aggregate prevalence of 40.2%). Twelve of the 25 (48%) studies focused on one body area only, either the forearm or the ankle, and 13 of 25 (52%) studies recruited exclusively pediatric patients.

Sensitivity for the detection of LBFs with PoCUS ranged from 64.7% to 100%, with 20 of 25 (80%) studies achieving rates of >90%. PoCUS was found to have an LR(+) ranging from 3.11 to infinity, with 19 of 25 (76%) studies having an LR(+) above 10. PoCUS was found to have an LR(−) ranging from zero to 0.45, with 19 of 25 (76%) studies having an LR(−) at or below 0.1.

Table 3 shows the results of the systematic review for the studies pertaining to the management of LBFs with PoCUS. Seven studies were included, ranging from 27 to 164 patients. Collectively, these studies recruited 524 patients with 484 known fractures. Three studies recruited exclusively pediatric patients, and four focused specifically on distal radius fractures only.

Only one study did not specifically target patients with forearm fractures, and despite these clinical similarities, there was significant methodological heterogeneity between included studies, thus precluding performance of a meta-analysis.
<table>
<thead>
<tr>
<th>Author</th>
<th>Country</th>
<th>Study setting</th>
<th># of operators</th>
<th>Operator types</th>
<th>Operators training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herren, 2015</td>
<td>Germany</td>
<td>UAH</td>
<td>Multiple</td>
<td>Traumatology residents (2nd-6th years of training)</td>
<td>30 min training session for PoCUS use in detecting distal forearm fractures; reference manual available</td>
</tr>
<tr>
<td>Kozaci, 2015</td>
<td>Turkey</td>
<td>UAH ED</td>
<td>Multiple</td>
<td>EPs</td>
<td>30 min didactic and 30 min practical session on assessment of distal radial fractures</td>
</tr>
<tr>
<td>Dalldaudière, 2015</td>
<td>France</td>
<td>UAH Radiology Dept</td>
<td>2</td>
<td>Musculoskeletal radiologists</td>
<td>NR</td>
</tr>
<tr>
<td>Atilla, 2014</td>
<td>Turkey</td>
<td>UAH ED</td>
<td>5</td>
<td>Sonographers</td>
<td>4-hour theoretical and practical training by another EP experienced in musculoskeletal PoCUS</td>
</tr>
<tr>
<td>Kodama, 2014</td>
<td>Japan</td>
<td>UAH Out-patient clinic/ED</td>
<td>2</td>
<td>Hand and orthopedic surgeons</td>
<td>Trained with at least 10 cases of closed reduction with PoCUS</td>
</tr>
<tr>
<td>Boland-parvaz, 2013</td>
<td>Iran</td>
<td>UAH ED</td>
<td>1</td>
<td>EP</td>
<td>1-month musculoskeletal ultrasound course</td>
</tr>
<tr>
<td>Waterbrook, 2013</td>
<td>United States</td>
<td>UAH ED</td>
<td>9</td>
<td>2 EPs, 3 sports medicine fellows, 3 residents, one 4th-year medical student</td>
<td>15 min in-service from principal investigator on top of prior training (none for EPs, usual residency training for residents)</td>
</tr>
<tr>
<td>Hedelin, 2013</td>
<td>Sweden</td>
<td>UAH Orthopedic ED</td>
<td>7</td>
<td>Orthopedic surgeons</td>
<td>30 min training by senior radiologist in basic PoCUS skills</td>
</tr>
<tr>
<td>Ekin, 2013</td>
<td>Turkey</td>
<td>UAH ED</td>
<td>1</td>
<td>EP</td>
<td>Informal training from musculoskeletal PoCUS workshops and congresses</td>
</tr>
<tr>
<td>Eckert, 2012a</td>
<td>Germany</td>
<td>UAH PED</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Eckert, 2012b</td>
<td>Germany</td>
<td>UAH PED</td>
<td>NR</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Narata, 2012</td>
<td>United States</td>
<td>UAH &amp; Suburban Level-1 Trauma Centre PED</td>
<td>6</td>
<td>2 EPs, 2 ultrasound fellows, two 2nd-year EM residents</td>
<td>1-hour didactic and practical session from ED PoCUS Director</td>
</tr>
<tr>
<td>Beltrame, 2012</td>
<td>Italy</td>
<td>UAH PED</td>
<td>3</td>
<td>Radiologists</td>
<td>1-day didactic program followed by a hands-on training session to detect fractures</td>
</tr>
<tr>
<td>Sinha, 2011</td>
<td>India</td>
<td>UAH Urban Level-1 Trauma Centre</td>
<td>4</td>
<td>EPs</td>
<td>Training through certified bedside emergency PoCUS course</td>
</tr>
<tr>
<td>Chaar-Alvarez, 2011</td>
<td>United States</td>
<td>UAH PED</td>
<td>4</td>
<td>PEPs</td>
<td>2-day course on musculoskeletal ultrasound that included basic ankle assessment</td>
</tr>
<tr>
<td>Canagasa-bey, 2011</td>
<td>United Kingdom</td>
<td>UAH ED</td>
<td>NR</td>
<td>EPs</td>
<td>3-min tutorial (or short computer tutorial) on PoCUS-guided fracture reduction, followed by hands-on training</td>
</tr>
<tr>
<td>Chinnock, 2011</td>
<td>United States</td>
<td>UAH ED</td>
<td>NR</td>
<td>EPs</td>
<td>1-hour of musculoskeletal PoCUS training session (30 min video, 30 min hands-on)</td>
</tr>
<tr>
<td>Weinberg, 2010</td>
<td>United States</td>
<td>UAH ED</td>
<td>10</td>
<td>PEPs</td>
<td>Online lecture and instructional video followed by one-on-one supervision by lead author (who gained prior experience through pilot study of 5 patients)</td>
</tr>
<tr>
<td>Ang, 2010</td>
<td>Singapore</td>
<td>Community hospital ED</td>
<td>Multiple</td>
<td>EPs</td>
<td></td>
</tr>
<tr>
<td>Ackermann, 2009</td>
<td>Germany</td>
<td>UAH</td>
<td>N/A</td>
<td>N/A</td>
<td>2-hour didactic and practical session, then performed 2 practice PoCUS examinations supervised by lead investigator</td>
</tr>
<tr>
<td>Patel, 2009</td>
<td>United States</td>
<td>Urban public hospital PED</td>
<td>3</td>
<td>PEPs</td>
<td></td>
</tr>
<tr>
<td>McNeil, 2009</td>
<td>United States</td>
<td>Military hospital ED</td>
<td>Multiple</td>
<td>EPs</td>
<td></td>
</tr>
<tr>
<td>Moritz, 2008</td>
<td>Germany</td>
<td>UAH</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Wong, 2008</td>
<td>Singapore</td>
<td>Referral hospital ED</td>
<td>3</td>
<td>EPs</td>
<td></td>
</tr>
<tr>
<td>Chen, 2007</td>
<td>United States</td>
<td>UAH ED</td>
<td>1</td>
<td>PEPs</td>
<td>Prior completion of accredited training on basic PoCUS use i.e., FAST examination</td>
</tr>
<tr>
<td>Marshburn, 2004</td>
<td>United States</td>
<td>3 teaching hospital ED</td>
<td>6</td>
<td>3 EPs, 2 EM residents, 1 surgery resident</td>
<td>Accredited PoCUS course, followed by 1 month of hands-on training in ED</td>
</tr>
<tr>
<td>Chem, 2002</td>
<td>Taiwan</td>
<td>UAH ED</td>
<td>2</td>
<td>Orthopedic surgeons</td>
<td>20 min video, then 40 min practice session on live normal model</td>
</tr>
<tr>
<td>Dulchavsky, 2002</td>
<td>United States</td>
<td>Urban trauma hospital ED</td>
<td>Multiple</td>
<td>Cast technicians</td>
<td>Prior experience with PoCUS</td>
</tr>
<tr>
<td>Williamson, 2000</td>
<td>United Kingdom</td>
<td>Community hospital Radiology Dept</td>
<td>2</td>
<td>Radiologists</td>
<td>2-hour didactic and practical session</td>
</tr>
<tr>
<td>Hübner, 2000</td>
<td>Germany</td>
<td>UAH</td>
<td>3</td>
<td>Pediatric surgeons</td>
<td>Performance of at least 1,500 scans and attendance at training course on scanning bony surfaces</td>
</tr>
</tbody>
</table>

UAH = university-affiliated hospital; ED = emergency department; PED = pediatric emergency department; Dept = department; EM = emergency medicine; NR = not reported; N/A = not available; EP = emergency physician; PEP = pediatric emergency physician.
Table 2. Diagnostic accuracy of point-of-care ultrasound compared to plain radiography in long bone fractures

<table>
<thead>
<tr>
<th>Authors</th>
<th>Population</th>
<th>N</th>
<th>Prevalence</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>LR+</th>
<th>LR-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herren, 2015</td>
<td>Forearm, ped</td>
<td>201</td>
<td>52%</td>
<td>Overall: 99.5%</td>
<td>Overall: 100%</td>
<td>Overall: 199</td>
<td>Overall: 0.005</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Radius: 100%</td>
<td>Radius: 100%</td>
<td>Radius:</td>
<td>Radius: 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ulna: 93%</td>
<td>Ulna: 100%</td>
<td>Ulna:</td>
<td>Ulna: 0.07</td>
</tr>
<tr>
<td>Eckert, 2012a</td>
<td>Forearm, ped</td>
<td>115</td>
<td>54%</td>
<td>94.90%</td>
<td>98%</td>
<td>47.45</td>
<td>0.05</td>
</tr>
<tr>
<td>Eckert, 2012b</td>
<td>Forearm, ped</td>
<td>76</td>
<td>55%</td>
<td>96.10%</td>
<td>97%</td>
<td>32</td>
<td>0.04</td>
</tr>
<tr>
<td>Chaar-Alvarez, 2011</td>
<td>Forearm, ped</td>
<td>101</td>
<td>45%</td>
<td>96.5%</td>
<td>93%</td>
<td>13.7</td>
<td>0.04</td>
</tr>
<tr>
<td>Ackermann, 2009</td>
<td>Forearm, ped</td>
<td>64</td>
<td>69%</td>
<td>94%</td>
<td>99%</td>
<td>94</td>
<td>0.06</td>
</tr>
<tr>
<td>Chen, 2007</td>
<td>Forearm, ped</td>
<td>68</td>
<td>71%</td>
<td>97%</td>
<td>100%</td>
<td>∞</td>
<td>0.03</td>
</tr>
<tr>
<td>Williamson, 2000</td>
<td>Forearm, ped</td>
<td>26</td>
<td>62%</td>
<td>100%</td>
<td>100%</td>
<td>∞</td>
<td>0</td>
</tr>
<tr>
<td>Kozaci, 2012b</td>
<td>Forearm, ped</td>
<td>83</td>
<td>66%</td>
<td>98%</td>
<td>96%</td>
<td>24.5</td>
<td>0.02</td>
</tr>
<tr>
<td>Atilla, 2014</td>
<td>Ankle, adult</td>
<td>199</td>
<td>23%</td>
<td>84.4%</td>
<td>97.4%</td>
<td>31.67</td>
<td>0.16</td>
</tr>
<tr>
<td>Hedelin, 2013</td>
<td>Ankle, adult</td>
<td>122</td>
<td>19%</td>
<td>100%</td>
<td>85.90%</td>
<td>7.07</td>
<td>0</td>
</tr>
<tr>
<td>Ekinci, 2013*</td>
<td>Ankle, adult</td>
<td>131</td>
<td>15%</td>
<td>100%</td>
<td>100%</td>
<td>∞</td>
<td>0</td>
</tr>
<tr>
<td>Canagasabey, 2011*</td>
<td>Ankle, adult</td>
<td>89</td>
<td>7%</td>
<td>83.3%</td>
<td>94.0%</td>
<td>13.89</td>
<td>0.18</td>
</tr>
<tr>
<td>Patel, 2009</td>
<td>UE/LE, ped</td>
<td>33</td>
<td>59%</td>
<td>97%</td>
<td>93%</td>
<td>13.86</td>
<td>0.03</td>
</tr>
<tr>
<td>Dallaudière, 2015</td>
<td>UE/LE, adult</td>
<td>83</td>
<td>70%</td>
<td>Overall: 98%</td>
<td>Overall: 98%</td>
<td>Overall: 49</td>
<td>Overall: 0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>UE: 100%</td>
<td>UE: 97%</td>
<td>UE: 5</td>
<td>UE: 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LE: 100%</td>
<td>LE: 80%</td>
<td>LE: 3.1</td>
<td>LE: 0</td>
</tr>
<tr>
<td>Bolandpar-vaz, 2013</td>
<td>UE/LE, adult</td>
<td>80</td>
<td>41%</td>
<td>Overall: 64.7%</td>
<td>Overall: 79.2%</td>
<td>Overall: 4.5</td>
<td>Overall: 0.45</td>
</tr>
<tr>
<td>McNeil, 2009</td>
<td>UE/LE, adult</td>
<td>44</td>
<td>23%</td>
<td>100%</td>
<td>94%</td>
<td>16.67</td>
<td>0</td>
</tr>
<tr>
<td>Dulchavsky, 2002</td>
<td>UE/LE, adult</td>
<td>95</td>
<td>35%</td>
<td>Forearm/arm: 92%</td>
<td>Forearm/arm: 100%</td>
<td>Forearm/arm: ∞</td>
<td>Forearm/arm: 0.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Femur: 83%</td>
<td>Femur: 100%</td>
<td>Femur: 83%</td>
<td>Femur: 0.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tibia/fibula: 83%</td>
<td>Tibia/fibula: 100%</td>
<td>Tibia/fibula: ∞</td>
<td>Tibia/fibula: 0.17</td>
</tr>
<tr>
<td>Barata, 2012</td>
<td>LB, ped</td>
<td>53</td>
<td>44%</td>
<td>95.3%</td>
<td>85.5%</td>
<td>8.29</td>
<td>0.06</td>
</tr>
<tr>
<td>Sinha, 2011</td>
<td>LB, ped</td>
<td>41</td>
<td>22%</td>
<td>89%</td>
<td>100%</td>
<td>∞</td>
<td>0.03</td>
</tr>
<tr>
<td>Hüblner, 2000</td>
<td>LB, ped</td>
<td>163</td>
<td>58%</td>
<td>98.3%</td>
<td>69.3%</td>
<td>3.2</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ulna: 91.3%</td>
<td>Ulna: 87.1%</td>
<td>Ulna: 7.1</td>
<td>Ulna: 0.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tibia: 70%</td>
<td>Tibia: 100%</td>
<td>Tibia: ∞</td>
<td>Tibia: 0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Humerus: 83%</td>
<td>Humerus: 100%</td>
<td>Humerus: ∞</td>
<td>Humerus: 0.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Femur: 100%</td>
<td>Femur: 87.5%</td>
<td>Femur: 8</td>
<td>Femur: 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>90.2%</td>
<td>96.1%</td>
<td>23.0</td>
<td>0.10</td>
</tr>
<tr>
<td>Waterbrook, 2013</td>
<td>LB, adult</td>
<td>106</td>
<td>29%</td>
<td>93%</td>
<td>83%</td>
<td>5.47</td>
<td>0.08</td>
</tr>
<tr>
<td>Marshburn, 2004</td>
<td>LB, adult</td>
<td>58</td>
<td>48%</td>
<td>99.5%</td>
<td>90.5%</td>
<td>185.8</td>
<td>0.07</td>
</tr>
<tr>
<td>Moritz, 2009</td>
<td>All bones, ped</td>
<td>653</td>
<td>37%</td>
<td>Long bones: 73%</td>
<td>Long bones: 92%</td>
<td>Long bones: 9.13</td>
<td>Long bones: 0.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Humerus: 100%</td>
<td>Humerus: 100%</td>
<td>Humerus: ∞</td>
<td>Humerus: 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Radius: 71%</td>
<td>Radius: 81%</td>
<td>Radius: 3.7</td>
<td>Radius: 0.35</td>
</tr>
<tr>
<td>Weinberg, 2010</td>
<td>All bones, &lt;25 years</td>
<td>212</td>
<td>24%</td>
<td>Overall: 98%</td>
<td>Overall: 93%</td>
<td>Overall: 9.01</td>
<td>Overall: 0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Humerus: 100%</td>
<td>Humerus: 88.9%</td>
<td>Humerus: 9.01</td>
<td>Humerus: 0</td>
</tr>
<tr>
<td>Beltrame, 2012</td>
<td>All bones, adult</td>
<td>86</td>
<td>65%</td>
<td>Overall: 100%</td>
<td>Overall: 100%</td>
<td>Overall: 100%</td>
<td>Overall: 100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Humerus: 100%</td>
<td>Humerus: 87.5%</td>
<td>Humerus: 9.01</td>
<td>Humerus: 0.125</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Radius/Ulna: 87.5%</td>
<td>Radius/Ulna: 100%</td>
<td>Radius/Ulna: ∞</td>
<td>Radius/Ulna: 0.125</td>
</tr>
</tbody>
</table>

*Data from personal correspondence with the authors.
Studies are listed by bone type studied, then ped/adult, then reverse chronological publication date.
Ped = pediatric; UE = upper extremity; LE = lower extremity; LB = long bone; All bones = long bones and non-long bones.
The sensitivity and the specificity for the adequate reduction of LBFs with PoCUS ranged from 94% to 100% and from 56% to 100%, respectively. One study found a decrease in the rate of repeat manipulation and reductions, and showed better post-reduction volar tilt measurements and lower rates of operative management in patients with PoCUS-guided reduction compared to blind reduction.8 One other study found that PoCUS-guided reduction was successful in 95% of cases, as opposed to 68% with blind technique.46

**Meta-analysis of selected studies**

Only studies of two subpopulations of patients had sufficient clinical and methodological homogeneity to warrant performance of a meta-analysis: pediatric forearm and adult ankle fractures. Many studies that evaluated multiple bones amalgamated their results and had incomplete information on the relative prevalence of each type of fracture, thus preventing inclusion in the meta-analysis. We attempted to contact study lead authors but were successful for only two of these (Drs. Ekinci and Canagasabey; personal correspondence).

Ten studies were included in the meta-analysis of the PoCUS diagnosis of forearm fractures in pediatric patients.7,20-25,39,43,44 Forest plots of the included studies’ sensitivity and specificity are shown in Figure 4. The studies’ pooled test characteristics were as follows: sensitivity 93.1% (95% CI, 87.2%–96.4%), specificity 92.9% (95% CI, 86.6%–96.4%), LR(+) 14.1 (95% CI, 6.71–25), and LR(–) 0.08 (95% CI, 0.04–0.15). Supplementary Material Appendix 2 (available online) shows the HSROC curve, demonstrating very good test operating characteristics. The calculated Cochran’s Q was 8.382 (9 df, p = 0.496), and Higgins’ I² was 0%, demonstrating statistical homogeneity between the included studies.

Four studies were included in the meta-analysis of the PoCUS diagnosis of ankle (distal tibia and fibula) fractures in adult patients.27–30 Because they are clinically different, we did not include studies of pediatric or mixed age patients, or studies of patients with mid-shaft lower leg fractures.35,39,43,44 Forest plots of the included studies’ sensitivity and specificity are shown in Figure 5. The studies’ pooled test characteristics were as follows: sensitivity 89.5% (95% CI, 77.0%–95.6%), specificity 94.2% (95% CI, 86.1%–97.7%), LR(+) 16.4 (95% CI, 6.57–33.5), and LR(–) 0.12 (95% CI, 0.05–0.24). Supplementary Material Appendix 3 (available online) shows the HSROC curve, demonstrating good test characteristics. The calculated Cochran’s Q was 3.834 (3 df, p = 0.28), and Higgins’ I² was 21.75%, demonstrating statistical homogeneity between the included studies.

**Risk of bias**

Supplementary Material Appendix 4 (available online) shows the assessment of methodological bias

<table>
<thead>
<tr>
<th>Authors</th>
<th>Population</th>
<th>Sample size</th>
<th>Prevalence</th>
<th>Sensitivity and specificity</th>
<th>Additional outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wong, 2008</td>
<td>Forearm, pediatric</td>
<td>42</td>
<td>100%</td>
<td>NR</td>
<td>Post-manipulation PoCUS corresponding with radiograph: 90%</td>
</tr>
<tr>
<td>Chen, 2007</td>
<td>Forearm, pediatric</td>
<td>68</td>
<td>71%</td>
<td>Sensitivity: 97% (95% CI, 89%-100%); Specificity: 100% (95% CI, 83%-100%)</td>
<td>Success rate of PoCUS-guided reduction: 92% (95% CI, 75%-99%)</td>
</tr>
<tr>
<td>Patel, 2009</td>
<td>Upper/lower extremity, pediatric</td>
<td>33</td>
<td>59%</td>
<td>Sensitivity: 100% (95% CI, 60%-100%); Specificity: 80% (95% CI, 50%-99%)</td>
<td>NR</td>
</tr>
<tr>
<td>Kodama, 2014</td>
<td>Forearm, adult</td>
<td>43 (PoCUS) 35 (fluoroscopy) 22 (no imaging)</td>
<td>100%</td>
<td>NR</td>
<td>Success rate: PoCUS 95%</td>
</tr>
<tr>
<td>Chinnock, 2011</td>
<td>Forearm, adult</td>
<td>46 (PoCUS) 44 (radiograph)</td>
<td>100%</td>
<td>Sensitivity: 94% (95% CI, 88%-98%); Specificity: 94% (95% CI, 60%-100%)</td>
<td>Success rate: no image 68%</td>
</tr>
<tr>
<td>Ang, 2010</td>
<td>Forearm, adult</td>
<td>62 (PoCUS) 102 (radiograph)</td>
<td>100%</td>
<td>NR</td>
<td>Rate of repeat reduction: 1.6% in PoCUS group v. 8.8% in blind technique group (p = 0.056) Operative rate: 4.9% for PoCUS group v. 16.7% for blind technique group (p = 0.02) Significant decrease in the displacement distances and significant correction of the fracture angle (&lt;p &lt; 0.05) with both PoCUS and radiography Significant association between the sonographic and radiographic measurements at time of injury and after closed reduction</td>
</tr>
<tr>
<td>Chern, 2002</td>
<td>Forearm, adult</td>
<td>27</td>
<td>100%</td>
<td>NR</td>
<td></td>
</tr>
</tbody>
</table>

PoCUS = point-of-care ultrasound; NR = not reported.
and applicability of the included studies, using the 2001 QUADAS-2 guidelines. All studies used convenience as opposed to consecutive sampling, mostly due to the small number of PoCUS-trained providers available. All PoCUS examinations pertaining to the diagnosis of LBFs occurred before radiographs were taken. Management of patients was always based on the results of the radiographs. Only 3 of 30 (10%) studies reported on the inter-rater reliability of PoCUS: 78% agreement in one study, and kappa values of 0.57 and 0.92 in two others.23,40,41 Only one study explicitly reported on a quality assurance process, with one senior sonologist reviewing all enrolled patients’ scans.43 Twenty-nine studies used plain radiographs as the only reference test for LBFs, with one using computed tomography as a secondary confirmatory tool only if necessary.42 Twenty-five studies reported on the presence of PoCUS training prior to initiating the study. Overall, all studies were of good methodological quality and were felt to be appropriate for inclusion in the analysis of this review.

**DISCUSSION**

Our review of the literature on the accuracy of PoCUS for the diagnosis of LBFs included 25 studies and 2,982 patients, of which 20 reported sensitivity rates of >90%, and 21 specificity rates of >90%. Pooled results of the meta-analyses demonstrated good performance characteristics, with a sensitivity of 93.1% and specificity of 92.9% for pediatric forearm fractures, and a sensitivity of 89.5% and specificity of 94.2% for adult ankle fractures. Seven studies of PoCUS for the reduction of LBFs met inclusion criteria, comprising 524 patients, and all demonstrated success rates of above 90%. As practitioners become more proficient with PoCUS over time, its accuracy may improve further. However, although the current evidence is promising, large randomized controlled trials (RCTs) are needed to confirm the benefits seen in smaller, non-randomized trials.

PoCUS, a relatively new tool in the emergency physician’s armamentarium, is a powerful and useful adjunct to the clinical assessment and plain radiographs. In some settings, PoCUS may be preferable to plain radiographs, because of its ease of use and portability. Nonetheless, the need for medicolegal documentation, as well as baseline images with which to compare follow-up radiographs, justify the continued use of traditional diagnostic imaging in settings where it is available. The studies that reported lower PoCUS accuracy tended to be those that recruited adult (versus pediatric) patients, and that assessed multiple bones.
(versus focusing on one specific body area only). This may indicate that the PoCUS examination is easier to accomplish and/or to interpret in pediatric patients, and that there is a learning curve associated with each specific bone being assessed.

In 2013, Joshi et al. published a review of the diagnostic accuracy of history, physical examination, and bedside ultrasound for the diagnosis of extremity fractures in the ED. In addition to eight articles that had not been published at that time, our study includes thirteen other articles not included in that review. Additional studies were possibly found as a result of a more comprehensive search strategy. Our review reaches similar conclusions, that PoCUS is a useful tool to supplement radiographs for the detection of fractures. We have provided an inclusive and updated review of the literature regarding the use of PoCUS in LBFs. Given the increasing proportion of emergency medicine practitioners who have access to and use PoCUS regularly, we hope that this article can serve as a reference to inform their practice with regards to LBFs.

As with any newer technology or procedure, training remains the most important challenge. Without proper training, practitioners run the risk of having a large number of false-positive or negative examinations, which may lead to worse patient outcomes. In the three studies where it was reported, the inter-reliability ranged from moderate to very good. However, training undergone by clinicians in these studies was minimal (3-minute tutorial, 15-minute bedside teaching, and knowledge from prior completion of a general bedside ultrasound course), and further training may therefore have increased their accuracy.

**LIMITATIONS**

Many of the included studies had small samples sizes, and none were RCTs. Overall, 40% of the recruited patients with possible LBF were diagnosed with a fracture with the reference test. This is likely higher than the true proportion of LBFs in undifferentiated patients presenting to most EDs with traumatic pain, swelling, or deformity. This may have been affected by the convenience sample selected by all authors, which introduces bias in the selected population. This recruitment strategy, by a small number of motivated PoCUS practitioners, may also have affected the results and limits the generalizability of our study findings. The lack of inter- and intra-rater reliability in most studies is also a limitation. However, the fact that in many studies the providers had no prior PoCUS experience and only limited training is reassuring for clinicians beginning to use musculoskeletal PoCUS.

**CONCLUSION**

This systematic review and meta-analysis summarizes current knowledge regarding the use of PoCUS in LBFs. The 30 prospective studies, including 2,982 individual patients, showed good test characteristics for the diagnosis and reduction of LBFs. Although results were varied, most studies reported sensitivities and specificities of 90% and above for the diagnosis of LBF with PoCUS, including in the two meta-analyses targeting pediatric forearm and adult ankle fractures. Although PoCUS should not completely replace the use of plain radiography at the current time, this review demonstrates that it is a powerful adjunct in all cases and could be used as a reasonable alternative in certain settings.

RCTs are needed to further the current knowledge on the use of PoCUS for the diagnosis and management of LBFs. Specifically, future studies should focus on determining standards for appropriate training and credentialing, on patient-centered outcomes such as satisfaction and morbidity, and on the cost-effectiveness of the use of PoCUS in the ED. In low-resource settings where access to plain radiographs may be challenging or minimal, studies should focus on the feasibility and safety of using PoCUS as an alternative to plain radiographs.

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Competing interests: None declared.

**SUPPLEMENTARY MATERIALS**

To view supplementary material for this article, please visit https://doi.org/10.1017/cem.2016.397

**REFERENCES**


