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# Diagnostic Accuracy of Waterbath Ultrasound Technique in Comparison to Conventional Radiography in Patients with Traumatic Distal Extremity Injuries Presenting to the Emergency Department of a Tertiary Care Hospital in South India

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## ABSTRACT

**Background**: Distal extremity fractures account for a significant proportion of emergency department (ED) presentations, and conventional radiography carries a well-documented miss rate for small bones of the hand and foot. The waterbath point-of-care ultrasound (POCUS) technique is a novel, painless, radiation-free approach that may improve diagnostic accuracy. This study evaluated the diagnostic accuracy of waterbath POCUS compared to conventional radiography for distal extremity fractures in a South Indian tertiary care emergency setting.

**Methods**: A prospective diagnostic accuracy study was conducted at Government Medical College, Pudukkottai, Tamil Nadu from November 2023 to October 2024. One hundred adults (≥18 years) presenting with suspected distal extremity fractures were enrolled using a random 4-hour time-block method. POCUS waterbath technique was performed using a 7–13 MHz linear probe and compared to radiologist-interpreted radiography (gold standard). Sensitivity, specificity, likelihood ratios, predictive values, accuracy, and time-to-diagnosis were calculated with 95% confidence intervals (CI).

**Results**: Mean age was 42.4 ± 15.9 years; 75% were male. Road traffic accidents were the dominant injury mechanism (75%). Fracture prevalence was 64%. Phalanges (29.7%) and metacarpals (21.9%) were the commonest fracture sites. Overall: sensitivity 95.30% (95% CI: 86.90–99.00%), specificity 88.90% (73.90–96.90%), PPV 93.80%, NPV 91.40%, accuracy 93.00%. Hand fractures: sensitivity 100%, accuracy 98.4%. Foot fractures: sensitivity 87%, accuracy 83.8%. Mean diagnosis time: 13.4 ± 2.57 min (POCUS) vs. 27.8 ± 6.08 min (X-ray).

**Conclusion**: Waterbath POCUS demonstrates high diagnostic accuracy for distal extremity fractures, with excellent performance for hand injuries and a time-to-diagnosis advantage exceeding 50% over conventional radiography. It is a reliable, radiation-free bedside adjunct suitable for high-volume emergency settings.

***Keywords****: Point-of-care ultrasound, waterbath technique, distal extremity fractures, diagnostic accuracy, emergency medicine, POCUS.*

## INTRODUCTION

Extremity injuries represent one of the most common presentations to emergency departments (EDs), affecting up to 44% of adult trauma patients. Injuries to the distal extremities — the hand, wrist, foot, and ankle — disproportionately affect the working-age population, significantly impairing productivity and quality of life [1, 2].

Plain radiography has long been the primary imaging modality for fracture diagnosis; however, it carries a well-documented miss rate. A systematic analysis by Wei et al. demonstrated that the highest rates of missed fractures on initial ED radiographs occurred in the foot (7.6%), hand (5.4%), and wrist (4.1%) [3]. Missed fractures carry the risk of serious complications including non-union, avascular necrosis, and post-traumatic arthrosis [4].

Point-of-care ultrasonography (POCUS) has emerged as a practical, radiation-free alternative for fracture diagnosis in the emergency setting. Pourmand et al. confirmed that emergency-physician-performed POCUS demonstrates high diagnostic accuracy for both upper and lower extremity fractures [5]. A systematic review and meta-analysis by Li and Tan reported sensitivities of 85–100% and specificities of 73-100% for ultrasound across various fracture sites [6]. The advantages of POCUS over radiography include the absence of ionising radiation, portability, real-time imaging, cost-effectiveness, and rapid availability at the bedside [5, 7].

A key limitation of the conventional direct-contact POCUS technique is that probe pressure over an acutely injured structure exacerbates pain and limits image quality over the complex bony topography of the hand and foot. The waterbath technique circumvents this by submerging the injured limb in water, which acts as the acoustic coupling medium, eliminating skin contact entirely. Blaivas et al. first described this approach for emergency ultrasound of painful superficial structures, demonstrating improved image quality and patient comfort [8].

A handful of studies have examined the waterbath POCUS technique for extremity fractures. Javadzadeh et al. reported favourable accuracy for distal forearm, wrist, and hand fractures [9], and Shrimal et al. at AIIMS New Delhi reported sensitivity of 97% and specificity of 94% for hand and foot fractures using this technique [10]. However, evidence from South Indian tertiary emergency care settings is absent. Moreover, comparative data on time-to-diagnosis between the two modalities remains limited.

This study was therefore designed to evaluate the diagnostic accuracy of the waterbath POCUS technique against conventional radiography for distal extremity fractures in adults presenting to an emergency department in South India, and to compare the time taken for diagnosis by each modality.

## MATERIALS AND METHODS

### Study Design and Setting

This was a prospective diagnostic accuracy study conducted in accordance with the Standards for Reporting Diagnostic Accuracy Studies (STARD) guidelines [11]. The study was carried out at the Emergency Medicine Department of Government Medical College, Pudukkottai, Tamil Nadu, a tertiary care hospital in South India from November 2023 to October 2024.

### Participants

Adult patients (≥18 years) presenting to the ED with suspected distal extremity fractures defined as acute trauma (≤48 hours) to the wrist, hand, ankle, or foot with swelling, tenderness, or restricted range of motion were eligible. Patients were excluded if they had: trauma ≥48 hours prior, previous fractures at the same site, obvious deformity, life-threatening injury, open or avulsion fractures, pre-existing degenerative or inflammatory joint disease at the site, haemodynamic instability, altered mental status, or were antenatal.

### Sample Size

Sample size was calculated using the diagnostic accuracy formula for sensitivity-based estimation [12]. Based on a reported fracture prevalence of 6.3% [13] and a minimum acceptable sensitivity of 97% for POCUS [10], with a confidence level of 95%, the calculated total sample size was 100 participants.

### Sampling Technique

A random 4-hour time-block method was employed [14]. Participants were enrolled daily between 4:00 PM and 8:00 PM until the required sample size was achieved.

### Index Test: Waterbath POCUS

POCUS was performed using a Mindray M5 colour diagnostic ultrasound system with a 7-13 MHz linear transducer in musculoskeletal mode. A 15-inch plastic container was filled with lukewarm water to three-quarters capacity, and the transducer was sheathed in a sterile 20-inch plastic sleeve to prevent water damage. The injured extremity was submerged such that the superior surface lay just below the waterline. For wounds with abrasions or lacerations, sterile water and sterile sheath covers were used. The uninjured contralateral limb was scanned first as a reference.

Scanning was performed in longitudinal and transverse planes from four surfaces (palmar/plantar, dorsal, medial, and lateral) at a 0.5-1 cm standoff. Cortical disruption, stepping, or axial deviation on the bone surface was defined as a positive (fracture present) result. The primary investigator (emergency medicine resident) completed a formal POCUS course at a regional training institute and underwent 15 days of supervised radiologist-guided training at the parent institution prior to data collection.

**Reference Test: Conventional Radiography**
Standard anteroposterior and lateral (or oblique) radiographic views were obtained. Images were interpreted by a consultant radiologist blinded to POCUS findings; this interpretation constituted the gold standard. Computed tomography (CT) was performed if radiographic findings were inconclusive.

**Outcome Measures**
Primary outcome: Diagnostic accuracy of waterbath POCUS sensitivity (Sn), specificity (Sp), positive likelihood ratio (PLR), negative likelihood ratio (NLR), positive predictive value (PPV), negative predictive value (NPV), and overall accuracy with 95% CI. Secondary outcomes: Mean time-to-diagnosis for waterbath POCUS versus conventional radiography.

**Statistical Analysis**
Data was entered in Microsoft Excel and analysed using SPSS version 23. Continuous variables are reported as mean ± standard deviation (SD); categorical variables as frequencies and proportions. A standard 2×2 contingency table was constructed, and all diagnostic accuracy statistics were computed with 95% CI.

**Ethical Approval**
Ethical clearance was obtained from the Institutional Ethics Committee, Government Medical College, Pudukkottai. Written informed consent was obtained from all participants. The study was conducted in accordance with the Declaration of Helsinki.

## RESULTS

**Demographic and Clinical Characteristics**
A total of 100 patients were enrolled. The mean age was 42.4 ± 15.9 years; the majority (44%) were in the 21-40-year age group, followed by 41-60 years (42%), 61-80 years (11%), and below 20 years (3%). Male patients accounted for 75% of participants. Road traffic accidents (RTA) constituted the most common mechanism of injury (75%), followed by assault (14%), accidental self-fall (6%), fall from height (3%), and fall of object (2%). Sixty-three participants (63%) had hand injuries and 37 (37%) had foot injuries.

**Table 1: Demographic Characteristics of Study Participants (n = 100)**

| Variable | Frequency (n) | Percentage (%) |
|---|---|---|
| Age Group (years) | | |
| < 20 | 3 | 3.0 |
| 21–40 | 44 | 44.0 |
| 41–60 | 42 | 42.0 |
| 61–80 | 11 | 11.0 |
| Mean Age: 42.4 ± 15.9 years | | |
| Gender | | |
| Male | 75 | 75.0 |
| Female | 25 | 25.0 |
| Mode of Injury | | |
| Road Traffic Accident | 75 | 75.0 |
| Assault | 14 | 14.0 |

| | | |
|---|---|---|
| Accidental Self-Fall | 6 | 6.0 |
| Fall from Height | 3 | 3.0 |
| Fall of Object | 2 | 2.0 |
| Site of Injury | | |
| Hand (including wrist) | 63 | 63.0 |
| Foot (including ankle) | 37 | 37.0 |

**Fracture Prevalence and Anatomical Distribution**

The overall prevalence of fractures was 64%. Among the 64 confirmed fractures, the most common sites were phalanges (29.7%), metacarpal (21.9%), distal radius (15.6%), malleolus (12.5%), metatarsal (10.9%), calcaneum (4.7%), scaphoid (3.1%), and distal ulna (1.6%).

**Table 2: Distribution of Confirmed Fractures by Anatomical Site (n = 64)**

| Anatomical Site | Frequency | Percentage (%) |
|---|---|---|
| Phalanges | 19 | 29.7 |
| Metacarpal | 14 | 21.9 |
| Distal Radius | 10 | 15.6 |
| Malleolus | 8 | 12.5 |
| Metatarsal | 7 | 10.9 |
| Calcaneum | 3 | 4.7 |
| Scaphoid | 2 | 3.1 |
| Distal Ulna | 1 | 1.6 |

**Index vs. Reference Test Comparison**

The 2×2 contingency table (Table 3) comparing waterbath POCUS against radiography yielded: true positives (TP) = 61, false positives (FP) = 4, false negatives (FN) = 3, and true negatives (TN) = 32.

**Table 3: Waterbath POCUS vs. Conventional Radiography (n = 100)**

| | Fracture Present (X-ray) | Fracture Absent (X-ray) | Total |
|---|---|---|---|
| POCUS Positive | 61 (TP) | 4 (FP) | 65 |
| POCUS Negative | 3 (FN) | 32 (TN) | 35 |
| Total | 64 | 36 | 100 |

**Diagnostic Accuracy Parameters**

Table 4 summarises the complete diagnostic accuracy statistics for overall, hand, and foot injuries. Overall sensitivity was 95.30% (95% CI: 86.90–99.00%) and specificity was 88.90% (95% CI: 73.90–96.90%). PLR was 8.58 (95% CI: 3.39–21.64) and NLR was 0.05 (95% CI: 0.01–0.16). PPV was 93.80% and NPV was 91.40%. Overall accuracy was 93.00% (95% CI: 86.10–97.10%). The Fagan nomogram demonstrated that a positive POCUS result raised post-test probability from a pre-test probability of 65% to 94%, while a negative result reduced it to 9%.

**Table 4: Diagnostic Accuracy of Waterbath POCUS vs. Conventional Radiography (Overall, Hand, and Foot)**

| Diagnostic Parameter | Overall (95% CI) | Hand Injuries (95% CI) | Foot Injuries (95% CI) |
|---|---|---|---|
| Sensitivity | 95.30% (86.90–99.00) | 100.00% (91.40–100) | 87.00% (66.40–97.20) |

| | | | |
|---|---|---|---|
| Specificity | 88.90% (73.90–96.90) | 95.50% (77.20–99.90) | 78.60% (49.20–95.30) |
| Positive Likelihood Ratio | 8.58 (3.39–21.64) | 22.00 (3.24–149.29) | 4.05 (1.46–11.20) |
| Negative Likelihood Ratio | 0.05 (0.01–0.16) | 0.00 | 0.16 (0.05–0.49) |
| Positive Predictive Value | 93.80% (85.00–98.30) | 97.60% (87.40–99.90) | 87.00% (66.40–97.20) |
| Negative Predictive Value | 91.40% (76.90–98.20) | 100.00% (83.90–100) | 78.60% (49.20–95.30) |
| Accuracy | 93.00% (86.10–97.10) | 98.40% (91.50–100) | 83.80% (68.00–93.80) |

CI = Confidence Interval

**Time-to-Diagnosis**

The mean time to diagnosis using waterbath POCUS was 13.40 ± 2.57 minutes compared to 27.80 ± 6.08 minutes for conventional radiography (Table 5), representing a time saving of over 50%.

**Table 5: Time-to-Diagnosis — Waterbath POCUS vs. Conventional Radiography**

| Modality | Mean (minutes) | SD (minutes) |
|---|---|---|
| Waterbath POCUS | 13.40 | 2.57 |
| Conventional Radiography | 27.80 | 6.08 |

**DISCUSSION**

This prospective diagnostic accuracy study evaluated the waterbath POCUS technique for identifying distal extremity fractures in 100 adult patients presenting to a South Indian tertiary ED. The overall sensitivity of 95.3%, specificity of 88.9%, and accuracy of 93.0% affirm that waterbath POCUS is a reliable diagnostic modality for this clinical indication. The demographic profile of our cohort — mean age 42.4 years, male predominance (75%), and road traffic accidents as the leading injury mechanism — is consistent with data from comparable settings. Javadzadeh et al. reported a similar mean age of 42.6 years [9], and Shrimal et al. described 74% male participants in their AIIMS cohort [10]. The higher prevalence of RTA in the present study compared to Western studies, where falls and sporting injuries predominate, reflects the burden of road traffic trauma in South India.

The fracture prevalence of 64% in the present study is higher than reported by Døssing et al. (27%) [15] and Aksay et al. (24.3%) [16], likely reflecting a selection bias inherent to a tertiary referral hospital that receives complex orthopaedic trauma from the surrounding region.

The overall sensitivity of 95.3% achieved in the present study is comparable to the 95.3% reported by Oguz et al. [17] and approaches the 97% reported by Shrimal et al. using the waterbath technique [10]. The sensitivity of 100% for hand fractures in this study exceeds the pooled sensitivity of 91% for hand fractures reported by Zhao et al. in a meta-analysis [18], and compares favourably with the 85.7-97.4% range reported in individual studies on metacarpal and phalangeal fractures [16, 19]. The relatively lower sensitivity of 87% for foot fractures is consistent with the intrinsic diagnostic challenge posed by the overlapping cortical anatomy of the tarsals and was within the ranges reported by Deutekom et al. [20].

The overall specificity of 88.9% is slightly lower than the 94% reported by Shrimal et al. [10] and the pooled specificity of 96% for hand fractures in the meta-analysis by Zhao et al. [18]. The lower specificity for foot injuries (78.6%) compared to hand injuries (95.5%) may be attributable to the complex bony architecture of the foot, where normal cortical irregularities can mimic fracture lines on ultrasound imaging.

The PLR of 8.58 overall (22.0 for hand fractures) confirms that a positive waterbath POCUS result substantially increases the post-test probability of fracture. These figures are consistent with the PLR of 7.93 reported by Aksay et al. [16] and the 17.5 reported by Shrimal et al. for the waterbath technique [10]. The NLR of 0.05 overall and effectively zero for hand fractures — indicates that a negative waterbath POCUS result reliably excludes fracture, which has direct clinical utility in triaging patients and avoiding unnecessary immobilisation.

The Fagan nomogram corroborated these findings: a positive POCUS result raised post-test probability from 65% to 94%, while a negative result reduced it to 9%, demonstrating strong clinical discriminatory power.

The mean diagnosis time of 13.4 minutes for waterbath POCUS versus 27.8 minutes for radiography represents a clinically meaningful advantage. The diagnosis time reported in the present study is higher than the 4 minutes reported by Dulchavsky et al. [7], likely due to the additional waterbath setup time, but is comparable to the 10 minutes reported by Alamin et al. [4]. The extended time compared to Dulchavsky et al. may also reflect the more complex multi-surface scanning protocol employed in this study.

The waterbath technique offers several additional clinical advantages: it is painless, requires no skin contact, eliminates ionising radiation (making it safe in pregnant patients and for healthcare workers during bedside procedures), is portable, and can be deployed immediately in a busy ED or at the bedside in a polytrauma scenario. These attributes make it particularly suited to resource-constrained environments and high-throughput emergency settings.

Limitations of this study include its single-centre design, enrollment restricted to a fixed 4-hour daily window, an adult-only cohort, and the relatively small sample with foot injuries, which limits the precision of foot-specific estimates. CT was not obtained for all participants, only for inconclusive radiographic cases, which may have resulted in a small number of misclassified true fractures serving as the reference standard.

## CONCLUSION

Waterbath POCUS demonstrates high diagnostic accuracy for distal extremity fractures in the emergency setting, particularly for hand and wrist injuries where sensitivity reaches 100%. It is significantly faster than conventional radiography, reducing time-to-diagnosis by over 50%, and offers the added benefit of radiation-free, painless, bedside diagnosis. It is a reliable adjunct to, or in appropriate scenarios an alternative to, conventional radiography in the initial assessment of distal extremity trauma. Future multicentre studies with larger foot injury cohorts are warranted to establish its generalisability and to validate its performance in diverse emergency care contexts.

## ABBREVIATIONS

- CI — Confidence Interval
- CT — Computed Tomography
- ED — Emergency Department
- EM — Emergency Medicine
- FN — False Negative
- FP — False Positive
- NLR — Negative Likelihood Ratio
- NPV — Negative Predictive Value
- PLR — Positive Likelihood Ratio
- POCUS — Point-of-Care Ultrasonography
- PPV — Positive Predictive Value
- RTA — Road Traffic Accident
- SD — Standard Deviation
- Sn — Sensitivity
- Sp — Specificity
- STARD — Standards for Reporting Diagnostic Accuracy Studies
- TN — True Negative
- TP — True Positive
- WBT — Waterbath Technique

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