Ultrasound-assisted external fixation: a technique for austere environments

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ABSTRACT

Introduction Ultrasound-assisted external fixation of long bones has the potential to enhance extremity damage control surgery in locations without fluoroscopy, such as forward surgical elements, the intensive care unit, and spacecraft. This pre-clinical study specifically sought to evaluate orthopaedic surgeons' ability to sonographically define fracture patterns and the associated zone of injury in order to improve surgical decision-making and safely insert Schanz pin percutaneously.

Methods We encased small composite femurs in a cylindrical echogenic gelatin matrix to simulate a human thigh. Three orthopaedic trauma surgeons with no prior ultrasound experience were taught to use sonography to diagnose fractures and assist external fixation. The surgeons were then presented with five specimens in a randomized sequence: three diaphyseal fractures (32-A2, 32-C2 and 32-C3); a distal femur fracture (33-A1.2); and an intact femur, all encased in an opaque black gelatin matrix to blind the participants to the underlying pathology. If they diagnosed a diaphyseal fracture, the surgeons were instructed to insert two Schanz pins proximal and two distal to the fracture, no closer than 40 mm from the fracture edges.

Results Fracture diagnosis and surgical decision-making were correct in all cases. All intact femurs were recognized as such. The need for a knee-spanning external fixator was recognized for all distal femur fractures. The three surgeons performed appropriate ultrasound-assisted pin placement in every case of diaphyseal fracture. The pins adjacent to the fracture site were on average 58 mm (SD ±11 mm) from the edge of the fracture. No pins were inserted in the fracture or in the knee joint.

Conclusions The current study results suggest that with minimal training, orthopaedic surgeons can use portable ultrasound to diagnose femur fractures, decide the appropriate external fixator configuration, and safely insert Schanz pins outside the zone of injury.

Key messages

- Orthopaedic surgeons in austere environments may not have access to fluoroscopy when performing external fixation during extremity damage control procedures.
- Portable ultrasound is available in most surgical facilities and has been shown to have good accuracy for the diagnosis of fractures.
- The current study used an ultrasound phantom model to examine the potential of ultrasound-assisted external fixation of the femur.
- Ultrasound-naïve orthopaedic surgeons were able to successfully perform ultrasound-assisted external fixation after a short training session.
- Ultrasound-assisted external fixation has the potential to improve patient safety in austere environments and deserves further study.

INTRODUCTION

The use of point of care ultrasound (POCUS) has grown rapidly since the widespread adoption of the focused abdominal sonography for trauma (FAST) examination in the 1990s.[1] In trauma, POCUS has become well accepted to diagnose intra-abdominal bleeding, pneumothorax, haemothorax and haemopericardium and to assess volume status. Furthermore, some ultrasound-guided procedures, such a central line insertion, have been shown to be safer and have become the standard of care.[2 3]

The inherent advantages of ultrasound also make it an attractive imaging modality in extremity trauma. The diagnostic accuracy of POCUS for detecting fractures varies according to the anatomic area, operator experience, scanning protocol and fracture prevalence in the study population.[4–10] A systematic review has shown that POCUS performed by emergency physicians yields good sensitivity (ranging from 83%–100%) and specificity (73%–100%) for fractures and has the potential to streamline care and decrease radiation exposure.[7] POCUS has also been shown to be useful for therapeutic decision-making by emergency physicians. For example, Kozaci *et al*[8] showed a sensitivity and specificity of 98% and 96%, respectively, for the diagnosis of distal radius fractures and, more importantly, that ultrasound reliably predicted the need for closed reduction. The authors characterized intra-articular extension, dorsal comminution, angulation, and associated distal ulna fracture, all established factors for surgical decision making.[8] The greatest value of POCUS for extremity trauma may be in remote locations with limited resources[7 10–13] For example, McNeil *et al* used ultrasound to evaluate 44 suspected fractures at a Battalion Aid Station during a 6 month period;[10] 12 patients with positive or inconclusive scans were evacuated to a higher echelon of care, of whom 10 were ultimately diagnosed with a fracture—the rest were safely observed for 72 h. The study highlights the potential of POCUS to limit unnecessary medical evacuations in a combat environment.

The use of ultrasound to assist external fixation of long bones has not been fully investigated. This technique could enhance extremity damage control surgery in locations without fluoroscopy, such as

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forward surgical elements, the intensive care unit and spacecraft. This preclinical study specifically sought to evaluate orthopaedic surgeons' ability to define fracture patterns and the associated zone of injury in order to improve surgical decision-making and direct safe Schanz pin insertion.

METHODS

The study protocol was approved by our institutional Research Ethics Board and endorsed by the Canadian Armed Forces Surgeon General's Health Research Board.

The technique developed by Heiner *et al* to create gelatine-encased composite bone specimens was modified.[14] The gelatine matrix was produced by dissolving 150 g/L of commercial food gelatine (Knox, Kraft Food Global, Northfield, Illinois, USA) in boiling water, which was then cooled overnight at 4°C inside a cylindrical mould containing a small composite left femur (Pacific Research Laboratories, Vashon, Washington, USA). Immediately prior to use, the mould was removed, leaving the femur circumferentially encased in an echogenic gelatine matrix from the distal articular surface to the lesser trochanter. The resulting cylindrical specimen allowed circumferential access for sonographic assessment and insertion of implants. Fractures, classified according to the AO-OTA system, were created in the composite femurs with a high-speed cutting tool.[15] In all fractures (except the AO-OTA C3, which had significant displacement), fracture displacement was limited to a 2–4 mm gap, based on experimental data showing that 2 mm is the threshold at which a fracture line can be seen as a cortical discontinuity on B-mode ultrasound.[16] Exact and reproducible fracture alignment was maintained by leaving a small bridge of cortical bone intact at the linea aspera.

Three ultrasound-naïve orthopaedic trauma surgeons underwent a 15 min training session covering the basics of ultrasound imaging of bone, including fracture identification. Imaging was performed with a Sonosite Nanomax ultrasound machine (Sonosite, Bothell, Washington, USA) using a 10-5 MHz linear array probe. Two training specimens (one mid-shaft transverse fracture, AO 32-A2; the other a mid-shaft wedge fracture, AO 32-B3), were encased in clear matrix to allow the trainee to correlate the ultrasound image with direct visualisation of the fracture (Figure 1). Emphasis was given to imaging the entire length of the femur from the medial, lateral and anterior perspectives to fully define the fracture pattern and zone of injury. The surgeons were taught to mark the proximal and distal extent of the zone of injury on the surface of the specimen in order to safely insert Schanz pins outside the zone of injury. The experiment was conducted immediately after the training session.

The surgeons were presented with five specimens in a randomised sequence. These included three diaphyseal fractures (AO 32-A2, 32-C2 and 32-C3), a distal femur fracture (AO 33-A1.2) and an intact femur, all encased in an opaque black gelatine matrix to blind the participants to the underlying pathology (Figure 2). The surgeons were instructed to proceed with sonographically assisted external fixation when they diagnosed a diaphyseal fracture. This consisted of inserting two 4.0 mm self-drilling Schanz pins (Synthes, West Chester, Pennsylvania, USA) proximal and two distal to the fracture site from lateral to medial. The appropriate management of the distal femur fracture was to indicate that knee-spanning external fixation would be performed. It was established a priori (and mentioned to the surgeons) that Schanz pins should be inserted no closer than 40 mm from the fracture to avoid the zone of injury. The time of each procedure was recorded. Schanz pin position proximal and distal to the fracture site was measured with a digital calliper. The pin insertion sites were also assessed for aberrant placement, such as intra-articular penetration, by two orthopaedic traumatologists.

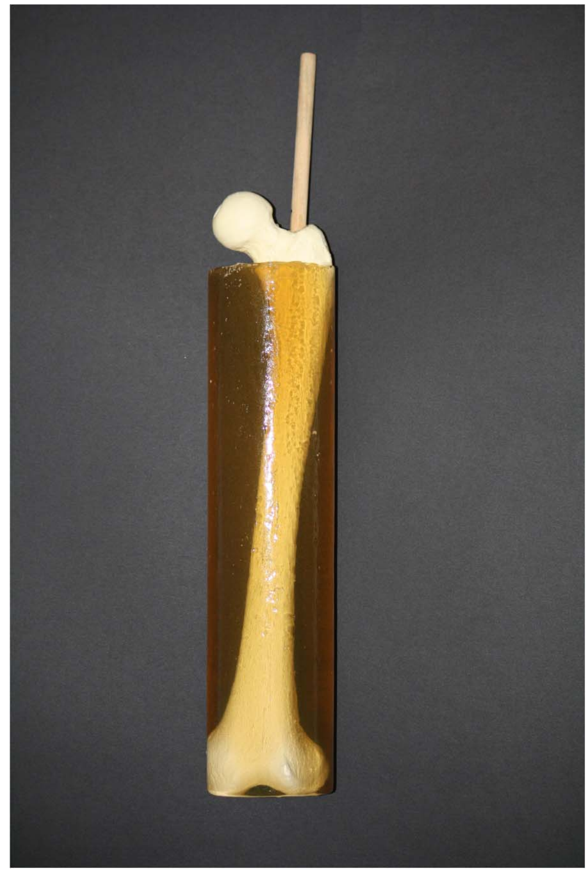

Figure 1 Composite femur encased in clear gelatine matrix. Wood dowels were inserted and epoxied into the piriformis fossa to facilitate handling of the specimens.

RESULTS

Diagnostic accuracy for the presence of fracture was 100%. Surgical decision-making was correct in all cases. All intact femurs were recognised as such in a mean time of 2 min 2 s (SD ±43 s). The need for a knee-spanning external fixator was recognised for all distal femur fractures in a mean time of 2 min 47 s (SD±152 s). The three surgeons performed appropriate ultrasound-assisted Schanz pin placement in every case of diaphyseal fracture in a mean time of 6 min 41 s (SD±117 s). The most challenging fracture pattern to delineate was the 32-C3, which required a mean time of 8 min 14 s (SD±123 s) for safe Schanz pin insertion. The pins adjacent to the fracture site were on average 58 mm (SD±11 mm) from the edge of the fracture. No pins were inserted in the fracture or in the knee joint.

DISCUSSION

Temporary external fixation of long bone fractures is an essential component of extremity damage control surgery. It is commonly used in extremity war injuries due to extensive soft tissue destruction, associated vascular injury and long transport times to definitive care. Additionally, standard military practice for closed fractures not otherwise requiring a damage control approach has been to apply a temporary external fixator to delay definitive fixation until transfer to a Role 4 facility.[17 18] Most field hospitals will have the benefit of fluoroscopy, which

Figure 2 Composite femur encased in black gelatine matrix, completely obscuring underlying fractures.

allows accurate and safe insertion of percutaneous Schanz pins. In some austere locations, such as forward surgical elements, surgeons do not have the benefit of fluoroscopy or even preoperative plain X-rays. This may also be the case during future space exploration, where ultrasound is expected to be the primary imaging tool.[19 20] In such circumstances, external fixation should be limited to select cases. The most widely accepted indication is an extremity requiring revascularisation, where skeletal stability is necessary to protect the vascular shunt or repair. The three most common arteries injured in combat are the femoral, brachial and popliteal.[21] In each of these cases, the vascular approach is distant from the usual Schanz pin insertion sites. For example, a combined mid-shaft femur fracture and superficial femoral artery injury requires a subsartorial vascular approach and leg fasciotomy, neither of which provides direct access to the lateral pin insertion sites proximal and distal to the fracture. Despite the often-extensive soft tissue destruction and wide surgical approaches necessary in extremity war injuries, it is often desirable to insert Schanz pins percutaneously in unaffected areas.

External fixation performed without radiographic assistance poses two major challenges, both of which can be addressed with portable ultrasound. The first is neurovascular injury from overpenetration of pins, which was shown to occur in 1.5% of cases in a cadaveric study, most often in the popliteal fossa.[22] Although surgeon experience may lessen this risk, sonography can adequately show pin protrusion beyond the far cortex.[23] The second challenge is to understand the fracture pattern in order to decide the proper external fixator configuration and insert Schanz pins outside the zone of injury, which was the focus of the current study. If plain X-rays are available preoperatively, this problem is diminished. Without radiological support, attempts to determine the fracture pattern by clinical examination are generally unreliable and Schanz pin insertion is erratic. For biomechanical and infectious reasons, pin placement close to or in the fracture site is suboptimal. Clasper *et al* reported a high rate of instability requiring revision in external fixators applied in the field. Early pin loosening occurred in 33% of constructs and was a major cause of frame instability. The authors did not specifically report on the proportion of loose pins which were secondary to misplacement nor did they document the proportion of fixators applied without fluoroscopy.[24] Possley *et al*[25] reviewed 55

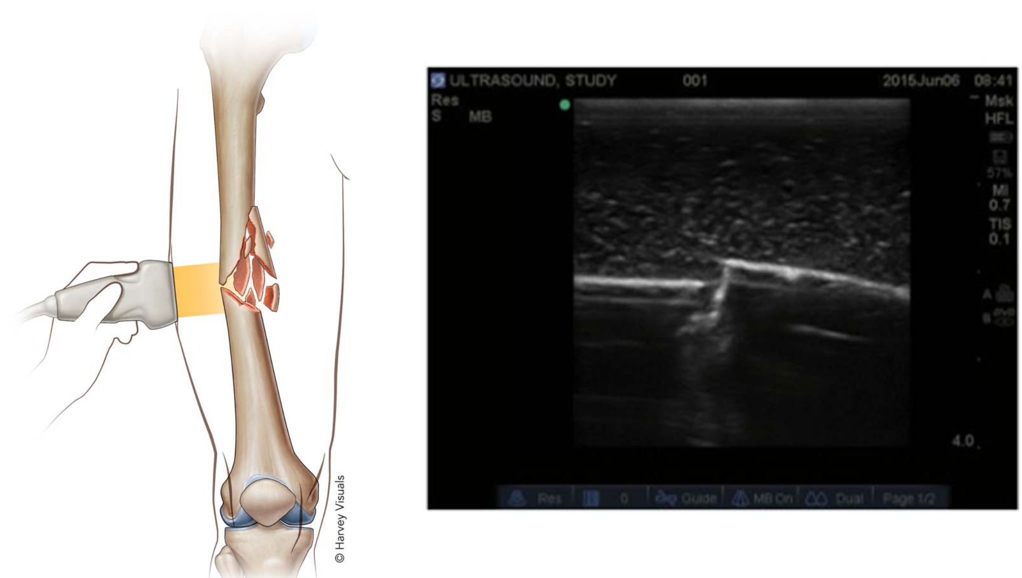

Figure 3 The small field of view of a linear array probe combined with the acoustic shadow of the cortex make it essential to scan the entire bone from multiple perspectives to fully appreciate the fracture pattern.

external fixators applied to high-grade open tibia fractures in a deployed setting and found that 1.8% of pins had deep overpenetration (>26 mm) and 9.6% had shallow overpenetration (9–25 mm).Additionally, 5.3% of pins were within 25 mm of the fracture site and 1.8% were intra-articular. Since these results combine frames applied with and without fluoroscopy, it is likely that these numbers underestimate the complication rates for frames applied without any imaging.

This study illustrates that with minimal training, orthopaedic surgeons can use sonography to determine fracture morphology, decide the appropriate external fixator configuration and insert percutaneous pins at a safe distance from the fracture site in a simulated thigh model. Optimal pin position will vary according to the fracture pattern, anatomic location and surgeon preference. We chose 4 cm as the closest acceptable distance from the edge of the fracture, although we recognise some situations may warrant inserting pins closer. This distance is the length of the linear array probe's footprint, which provides a convenient intraoperative reference. Due to the small field of view afforded by a linear array probe, it is essential to scan the entire length of the femur from multiple perspectives to fully define the fracture pattern and to confirm intact bone at the chosen pin insertion site (Figure 3). We advocate marking the skin at the level of the proximal and distal extent of the fracture to ensure correct spatial orientation.

The current study has some inherent limitations. All fractures were minimally displaced, except the comminuted shaft fracture which included a large rotated cortical fragment. Wide displacement of the fracture fragments could be more difficult to image, although we believe operator experience would easily overcome this issue. This model also does not allow manipulation or reduction of the fracture, which would disrupt the gelatine matrix. The femoral neck was not encased in gelatine to allow experimenters a solid grip on the specimen during pin insertion. In practice, careful imaging of the femoral neck should be performed to exclude an associated fracture, reported to be present in up to 9% of femoral shaft fractures.[26] The accuracy of ultrasound to diagnose femoral neck fractures is unknown, although previous studies have suggested that this area might be problematic.[4 5] Additionally, in open fractures, air in the soft tissues could compromise image quality and prevent acquisition of useful ultrasound images.

CONCLUSION

The current study suggests that surgeons deploying to austere locations could acquire the skills necessary to perform ultrasound-assisted external fixation with minimal additional training. The proposed technique involves scanning the entire femur from multiple perspectives to determine the fracture pattern followed by percutaneous Schanz pin insertion. We believe that sonographically assisted external fixation is an elegant and precise procedure that has the potential to increase patient safety in remote locations. Further studies in anatomic specimens will allow us to better define the indications and limitations of the technique.

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REFERENCES

1 Boulanger BR, Kearney PA, Brenneman FD, *et al*. Utilization of FAST (Focused Assessment with Sonography for Trauma) in 1999: results of a survey of North American trauma centers. *Am Surg* 2000;66:1049–55.
2 Brass P, Hellmich M, Kolodziej L, *et al*. Ultrasound guidance versus anatomical landmarks for internal jugular vein catheterization. *Cochrane Database Syst Rev* 2015;1:CD006962.
3 Brass P, Hellmich M, Kolodziej L, *et al*. Ultrasound guidance versus anatomical landmarks for subclavian or femoral vein catheterization. *Cochrane Database Syst Rev* 2015;1:CD011447.
4 Marshburn TH, Legome E, Sargsyan A, *et al*. Goal-directed ultrasound in the detection of long-bone fractures. *J Trauma* 2004;57:329–32.
5 Dulchavsky SA, Henry SE, Moed BR, *et al*. Advanced ultrasonic diagnosis of extremity trauma: the FASTER examination. *J Trauma* 2002;53:28–32.
6 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.
7 Joshi N, Lira A, Mehta N, *et al*. Diagnostic accuracy of history, physical examination, and bedside ultrasound for diagnosis of extremity fractures in the emergency department: a systematic review. *Acad Emerg Med* 2013;20:1–15.
8 Kozaci N, Ay MO, Akcimen M, *et al*. Evaluation of the effectiveness of bedside point-of-care ultrasound in the diagnosis and management of distal radius fractures. *Am J Emerg Med* 2015;33:67–71.
9 Atilla OD, Yesilaras M, Kilic TY, *et al*. The accuracy of bedside ultrasonography as a diagnostic tool for fractures in the ankle and foot. *Acad Emerg Med* 2014;21:1058–61.
10 McNeil CR, McManus J, Mehta S. The accuracy of portable ultrasonography to diagnose fractures in an austere environment. *Prehosp Emerg Care* 2009;13:50–2.
11 Vasios WN, Hubler DA, Lopez RA, *et al*. Fracture detection in a combat theater: four cases comparing ultrasound to conventional radiography. *J Spec Oper Med* 2010;10:11–15.
12 Brooks AJ, Price V, Simms M, *et al*. Handheld ultrasound diagnosis of extremity fractures. *J R Army Med Corps* 2004;150:78–80.
13 Heiner JD, Baker BL, McArthur TJ. The ultrasound detection of simulated long bone fractures by U.S. Army Special Forces Medics. *J Spec Oper Med* 2010;10:7–10.
14 Heiner JD, McArthur TJ. A simulation model for the ultrasound diagnosis of long-bone fractures. *Simul Healthc* 2009;4:228–31.
15 Marsh JL, Slongo TF, Agel J, *et al*. Fracture and dislocation classification compendium—2007: Orthopaedic Trauma Association classification, database and outcomes committee. *J Orthop Trauma* 2007;21(10 Suppl):S1–133.
16 Grechenig W, Clement HG, Fellinger M, *et al*. Scope and limitations of ultrasonography in the documentation of fractures—an experimental study. *Arch Orthop Trauma Surg* 1998;117:368–71.
17 Galvin JW, Dannenbaum JH IV, Tubb CC, *et al*. Infection rate of intramedullary nailing in closed fractures of the femoral diaphysis following temporizing external fixation in an austere environment. *J Orthop Trauma* 2015;29:e316–20.
18 Beech Z, Parker P. Internal fixation on deployment: never, ever, clever? *J R Army Med Corps* 2012;158:4–5.
19 Wagner MS, Garcia K, Martin DS. Point-of-care ultrasound in aerospace medicine: known and potential applications. *Aviat Space Environ Med* 2014;85:730–9.
20 Fincke EM, Padalka G, Lee D, *et al*. Evaluation of shoulder integrity in space: first report of musculoskeletal US on the International Space Station. *Radiology* 2005;234:319–22.
21 Markov NP, DuBose JJ, Scott D, *et al*. Anatomic distribution and mortality of arterial injury in the wars in Afghanistan and Iraq with comparison to a civilian benchmark. *J Vasc Surg* 2012;56:728–36.
22 Topp R, Hayda R, Benedetti G, *et al*. The incidence of neurovascular injury during external fixator placement without radiographic assistance for lower extremity diaphyseal fractures: a cadaveric study. *J Trauma* 2003;55:955–8.
23 Dahl BP, Pemberton AJ, Beck RT, *et al*. Is portable ultrasonography accurate in the evaluation of Schanz pin placement during extremity fracture fixation in austere environments? *Am J Disaster Med* 2013;8:91–6.
24 Clasper JC, Phillips SL. Early failure of external fixation in the management of war injuries. *J R Army Med Corps* 2005;151:81–6.
25 Possley DR, Burns TC, Stinner DJ, *et al*. Temporary external fixation is safe in a combat environment. *J Trauma* 2010;69(Suppl 1):S135–9.
26 Tornetta P III, Kain MS, Creevy WR. Diagnosis of femoral neck fractures in patients with a femoral shaft fracture. Improvement with a standard protocol. *J Bone Joint Surg Am* 2007;89:39–43.

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