Diagnostic Accuracy of Emergency Bedside Ultrasonography to Detect Cutaneous Wooden Foreign Bodies

Does Size Matter?

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ABSTRACT

Background: Soft-tissue occult foreign bodies are a concerning cause of morbidity in the emergency department. The identification of wooden foreign bodies is a unique challenge because they are often not detectable by plain radiography. The purpose of this study was to determine the diagnostic accuracy of emergency physician–performed ultrasonography to detect wooden foreign bodies of varying sizes. We hypothesized that sonographic sensitivity would improve with increasing foreign body size. **Methods:** We conducted a blinded, prospective evaluation using a previously validated, chicken, soft-tissue model to simulate human tissue. We inserted wooden toothpicks of varying lengths (1mm, 2.5mm, 5mm, 7.5mm, 10mm) to a depth of 1cm in five tissue models. Five additional models were left without a foreign body to serve as controls. Fifty emergency physicians with prior ultrasonography training performed sonographic examinations of all 10 models and reported on the presence or absence of wooden foreign bodies. **Results:** Subjects performed 10 ultrasonography examinations each for a total of 500 examinations. For the detection of wooden foreign bodies, overall test characteristics for sonography included sensitivity 48.4% (95% confidence interval [CI], 42.1%–54.8%) and specificity 67.6% (95% CI, 61.3%–73.2%). Sensitivity did not change as object size increased (p = s.709). **Conclusion:** Emergency physician bedside ultrasonography demonstrated poor diagnostic accuracy for the detection of wooden foreign bodies. Accuracy did not improve with increasing object size up to 10mm. Providers should consider alternative diagnostic modalities if there is persistent clinical concern for a retained, radiolucent, soft-tissue foreign body.

KEYWORDS: *ultrasound; foreign body; wooden object*

Introduction

Detection of cutaneous penetrating foreign bodies can prove a difficult task in the emergency department.[1] Failure to identify and remove these foreign bodies can lead to complications such as infection and result in significant morbidity and mortality.[2,3] Historical and physical examination features often have inadequate sensitivity to rule out the existence of a foreign body.[4] Similarly, although plain radiographs are a commonly used modality to rule out foreign bodies, they have limited utility in the identification of radiolucent substances such as wood.[5]

Previous studies have examined the use of ultrasound to identify a variety of materials including wood, metal, plastic, and glass.[6–11] Many of these studies report successful use of ultrasound to identify foreign bodies despite limited ultrasound training.[12–14] Moreover, studies have found that ultrasound outperforms plain radiography[9,15,16] and computed tomography[17] in identifying radiolucent foreign bodies. Beyond these assertions of its superior diagnostic accuracy, ultrasound is an attractive option for the assessment of retained foreign bodies in wounds, given negligible radiation exposure and portability for bedside use.[18–20]

Reported sensitivity values for the use of ultrasound to detect foreign bodies vary widely in the existing literature. Published sensitivity estimates for the detection of wooden foreign bodies range from 50%[10] to 100%.[21] The reasons for this variability are unclear. Potential explanations include differences in operator skill, ultrasound machine variability, inconsistent anatomic locations, differing ultrasound settings (e.g., gain, depth, frequency, focal zones), and dissimilar foreign body characteristics such as size and echogenicity.

The goal of this investigation was to build on the existing literature examining the use of ultrasound to detect wooden foreign bodies by examining the association between ultrasound sensitivity and foreign body size. We hypothesized that sensitivity would increase as wooden foreign body size increases.

Methods

Study Design and Setting

We conducted a diagnostic accuracy study of the use of ultrasound to detect wooden foreign bodies of varying sizes in soft tissue. We conducted the study at San Antonio Military Medical Center, an academic tertiary care center that largely treats military personnel and beneficiaries in the Greater San Antonio Metropolitan area. The Brooke Army Medical Center Institutional Review Board approved the study.

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Selection of Participants

We recruited a convenience sample of emergency medicine physician volunteers to participate in the study. The inclusion criteria were that participants be residents, attending physicians, and physician assistants (PAs) with self-reported prior ultrasound training. The extent of prior training could vary from a 2-day introductory course to completion of a formal ultrasound fellowship. Of note, all the emergency medicine residents and PAs recruited to participate had been previously required to complete a dedicated 4-week ultrasound rotation during which trainees must perform 175 proctored ultrasound examinations to include 25 soft-tissue and musculoskeletal studies. The exclusion criterion was lack of any prior experience using ultrasound for foreign body detection.

Study Protocol

We used a previously described tissue simulator of food-grade chicken thigh to model human tissue.[10,13,14,21] Common wooden toothpicks were the wooden foreign bodies and were cut to standard similar sizes. Each participant performed ultrasound examinations on 10 separate models and were blinded to the presence or absence of foreign bodies. Five models were free of any foreign body. The remaining five models each contained one wooden toothpick of a different known length (1mm, 2.5mm, 5mm, 7.5mm, and 10mm). Investigators inserted the toothpicks by pulling back the tissue model skin and inserting directly into the subcutaneous tissue at a 30° angle. Investigators then performed ultrasound to confirm a depth of insertion between 5mm and 10mm. After insertion, investigators replaced the anatomic situation of the model skin so there were no marks visible to the study subjects to suggest the underlying placement of a foreign body.

The order in which participants examined each of the 10 tissue models was randomized using a random number generator to produce tissue model sequences. Each participant examined each tissue model once. Participants performed all ultrasound examinations using standard coupling gel and a 7.5mHz linear probe with a Sonosite M-Turbo machine (https://www.sonosite.com). Investigators did not permit any direct contact between subjects' hands and the individual tissue models. Investigators instructed each participant to examine each tissue model for the presence of a foreign body for no more than 30 seconds per model. The time started when the subject placed the ultrasound probe on the tissue model and ended by the subject reporting their determination of the presence or absence of a foreign body. Subjects were not privy at any point in the study as to the presence or absence of a foreign body in each individual tissue model. Similarly, subjects were not privy to the proportion of models with or without foreign bodies.

Investigators verbally asked each subject about their level of education (i.e., resident, PA, attending physician, ultrasound fellow, or attending physician with formal ultrasound fellowship training). Investigators also asked each subject whether he or she identified a foreign body in each tissue model. Investigators recorded all data on a hardcopy data collection form.

Outcomes

The primary outcome measure was subject determination as to the presence or absence of a foreign body for each tissue model.

Analysis

We based our sample size estimate on $\alpha = .05$ and $\beta = .20$ with two-sided testing. We expected overall sensitivity to be approximately 50%.[8] With 50 subjects, each making a determination as to the presence of a foreign body of a given size, our study had power to detect a 20% difference in sensitivity across the range of foreign body sizes.

Investigators aggregated all hardcopy data into an Excel database (version 14; Microsoft,www.microsoft.com). We used SPSS version 22 (IBM, www.ibm.com) for statistical analysis. We calculated test characteristics for the use of ultrasound for foreign body detection including sensitivity, specificity, and positive and negative likelihood ratios. We generated 95% confidence intervals (CIs) for these estimates, using bootstrap techniques. We further stratified these calculations by subject education level and foreign body size. The primary outcome analysis used a χ^2 test to compare subject sensitivity in foreign body detection between foreign bodies of alternative sizes.

Results

Characteristics of Study Subjects

Investigators enrolled 50 subjects for study participation via convenience sampling, all of whom were eligible and agreed to participate. Of these participants, there were 37 residents (74%), eight attending physicians (16%) without ultrasound fellowship training, three PAs (6%), one ultrasound fellow (2%), and one attending physician (2%) with ultrasound fellowship training. All subjects completed the study approximately within the 30-second time limit.

Main Results

The pooled sensitivity for all 250 examinations of tissue models with foreign bodies was 48.4% (95% CI, 42.1%–54.8%). The overall specificity for all 250 examinations of tissue models without foreign bodies was 67.6% (95% CI, 61.3%–73.3%). These values corresponded to a positive likelihood ratio of 1.5 (95% CI, 1.2–1.9) and negative likelihood ratio of 0.8 (95% CI, 0.7–0.9).

There was no statistically significant difference in sensitivity based on foreign body size ($p = .709$; Table 1). Moreover, sensitivity and specificity were broadly comparable across all education levels (Table 2). Similarly, sensitivity stratified by education level remained largely stable across all foreign body sizes studied (Figure 1).

Table 1 *Sensitivity of Ultrasound in Detecting Wooden Foreign Body Stratified by Object Size (N = 50)*

Object Size, mm	Scans Identifying Object, No.	Sensitivity, %	95% CI
1	22	44.0	31.2–57.7
2.5	21	42.0	29.4–55.8
5	25	50.0	36.6–63.4
7.5	26	52.0	38.5–65.2
10	27	54.0	40.4–70.6

CI, confidence interval.

Discussion

Overview of Findings

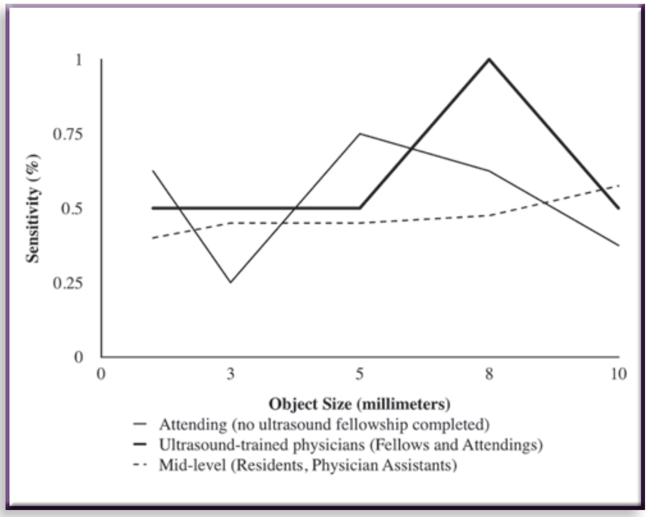
This study found generally poor diagnostic accuracy for ultrasound to detect wooden foreign bodies in a chicken-tissue model. We did not identify any association between ultrasound sensitivity and foreign body size ranging from 1mm to

Table 2 *Accuracy of Ultrasound in Detecting Wooden Foreign Bodies, Stratified by Level of Training*

Training	Sensitivity (95% CI), %	Specificity (95% CI), %	LR+ (95% CI)	LR– (95% CI)
Resident	47.0 (39.7–54.5)	68.6 (61.4–75.1)	1.5 (1.2–2.0)	0.8 (0.7–0.9)
Attending physician (no fellowship)	52.5 (36.3–68.2)	62.5 (45.8–76.8)	1.4 (0.9–2.3)	0.8 (0.5–1.1)
Physician assistant	46.7 (22.2–72.6)	66.7 (38.7–87.0)	1.4 (0.6–3.4)	0.8 (0.5–1.4)
Ultrasound fellow	60.0 (17.0–92.7)	60.0 (17.0–92.7)	1.5 (0.4–5.5)	0.7 (0.2–2.5)
Attending physician (ultrasound fellowship)	60.0 (17.0–92.7)	80.0 (29.9–99.0)	3.0 (.5–19.9)	0.5 (0.2–1.6)

CI, confidence interval; LR, likelihood ratio.

Figure 1 *Ultrasound sensitivity to detect wooden foreign bodies as a function of foreign body size. Attending physicians,* n = 8; *ultrasound-trained physicians,* n = 2; *midlevel,* n = 40.



10 mm. Furthermore, we did not identify any association between diagnostic accuracy and education level.

The pooled sensitivity was 48.4% for the use of ultrasound to detect wooden foreign bodies. This aligns with the lower range of values previously reported in the literature for detection of various foreign bodies in tissue models (50%[10] to 52.6%[6]). These values contrast with studies reporting significantly higher sensitivities for ultrasound in detecting foreign bodies ranging up to 93% to 100%.[12,13,19] There are several potential explanations why other studies reported significantly higher sensitivities. First, some of these studies entailed didactic sessions immediately before data collection, which may have improved subject diagnostic accuracy.[13] Second, some used differing tissue models, such as human cadaveric tissue, and it is possible that this medium is more amenable to sonographic penetration or creates more echogenic contrast between modeled tissue and foreign body than our fresh-tissue model.[12,19] Third, none of these prior studies reported an imposed time limit on participants and may have enabled more time for aspects of procedure completion, increasing diagnostic test characteristics. Finally, some of these studies aggregated examinations of tissue models with alternative substances (e.g., metal, glass), the inclusion of which may have confounded accuracy estimates.[13,17]

Our findings contrast with at least one study that suggested improved sensitivity of ultrasound for detecting wooden foreign bodies with increasing size.[20] That study, by Jacobson et al.,[20] reported a sensitivity of 86.7% for foreign bodies measuring 2.5mm and 93.3% for foreign bodies measuring 5.0mm. However, the subjects differed from our emergency medicine provider population as musculoskeletal radiologists with extensive ultrasound knowledge and expertise. Second, the Jacobson et al. study[20] used cadaver specimens, which may have created an environment more amenable to ultrasound examinations than our fresh-tissue models. Third, their study did not impose a time limit for ultrasound examinations on subjects. Finally, because our study does suggest a trend toward improved sensitivity with increasing object size, it is possible that our study lacked adequate power to demonstrate an association between foreign body size and identification via ultrasound.

Limitations

The principal limitation of this study related to lack of generalizability to real-world clinical settings. There are several reasons for this. First is the use of the tissue model. Although the chicken-tissue model is fresh and not preserved, as is a cadaveric model, the transmission of ultrasound through this tissue may be different than that in living human models. Moreover, subjects were not allowed to use physical examination maneuvers (e.g., point of maximal tenderness) to direct their ultrasound examinations and increase suspicion for an underlying foreign body.

The setting including a time limit imposed on our subjects similarly may limit generalizability. Our intent was to simulate the circumstances of a busy emergency department and consistently limit the resource of available time to complete the procedure. However, had we offered subjects more time to complete their examinations, it is possible they would have achieved higher diagnostic accuracy. On the other hand, to the point of simulating an emergency department environment, our subjects performed their examinations in a relatively quiet, dark, and secluded room, which may have increased their diagnostic accuracy and may not approximate the typical clinical care setting in the emergency department.

Another limitation is the sample size. Though our dataset comprised 500 ultrasound studies, only 50 studies were performed for each foreign body size. This yielded a study powered to detect sensitivity differences of 20% or more. It may be that diagnostic accuracy, indeed, improves with increasing foreign body size but in smaller increments, which could not be detected because of a small sample size.

Future Research

Our results highlight several potential areas for investigations. An ideal investigation may be a clinical study of emergency department patients with suspected radiolucent foreign bodies in penetrating wounds. Such a study would ideally compare the diagnostic accuracy of ultrasound as performed in the emergency department versus a gold standard such as magnetic resonance imaging or surgical exploration. Such a study would likely be logistically challenging to accumulate sufficient numbers of patients for a well-powered analysis. In the interim, further insight may be gained from replication of our study using alternative tissue models (e.g., cadavers) and materials (e.g., metal) to determine if there is an association between size and diagnostic accuracy of ultrasound for detecting foreign bodies. Future studies could also strive to achieve sample sizes capable of detecting smaller differences in sensitivity values.

Conclusion

We found poor diagnostic accuracy for the use of ultrasound to detect wooden foreign bodies in a standard tissue model. We also found no significant association between foreign body size and diagnostic accuracy. Clinicians with self-reported prior ultrasound experience performed poorly across all training levels and often disagreed on the presence or absence of foreign body. Based on these results, we would caution emergency medicine providers against relying upon this imaging modality to rule out the presence of potentially clinically significant small wooden foreign bodies.

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Disclaimer
The view(s) expressed herein are those of the author(s) and do not reflect the official policy or position of Brooke Army Medical Center, the US Army Medical Department, the US Army Office of the Surgeon General, the Department of the Army, the Department of Defense, or the US Government.

Disclosure
The authors have nothing to disclose.

Author Contributions
J.H. conceived the study and worked with E.C. and E.F. on study design. E.F. collected the data. S.S., M.A., E.C., and E.F. performed data analysis and interpretation. E.F. drafted the manuscript, which was then critically revised by all authors. Final approval of the version of the manuscript to be published was given by all authors.

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