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Original Contribution

Do we really need plain and soft-tissue radiographies to detect radiolucent foreign bodies in the ED?

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Abstract

Objective: The objective of this study was to compare 3 imaging techniques—plain radiography, soft-tissue radiography, and ultrasonography—in detecting nonradiopaque foreign bodies in soft tissue.

Methods: In this randomized, blinded, and descriptive in vitro study, 40 chicken thighs with 2 types of nonradiopaque foreign bodies (wood and rubber) and 40 chicken thighs as part of a control group were evaluated to detect soft-tissue foreign bodies with plain radiography, soft-tissue radiography, and high-frequency ultrasonography.

Results: The overall sensitivity, specificity, as well as positive predictive and negative predictive values of plain radiography for both nonradiopaque foreign bodies were 5%, 90%, 33%, and 48%, respectively; those of soft-tissue radiography for both nonradiopaque foreign bodies were 5%, 90%, 33%, and 48%, respectively; and those of ultrasonography for both nonradiopaque foreign bodies were 90%, 80%, 81%, and 89%, respectively.

Conclusions: In this experimental model, the results show that high-frequency ultrasonography is superior to plain and soft-tissue radiographies and that the latter 2 techniques are similarly poor at detecting nonradiopaque foreign bodies.

1. Objective

Various types of foreign bodies become embedded in soft tissue and can be difficult to detect in clinical practice [1,2]. If the interior of a wound is incompletely visualized, then further diagnostic tests are often justified in the ED to exclude foreign body presence. Plain radiography is the customary initial screening modality for a suspected foreign body [3]. It is well known that radiopaque bodies such as metal, glass, and gravel are easily detected on plain radiographs, but detection of nonradiopaque (radiolucent) fragments such as rubber, thorn, and wood is problematic [4].

Ultrasonography has an increasing role in diagnosing radiolucent foreign bodies in the ED. However, the diagnostic relevance of ultrasonography is related to its

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technical properties, as the length of the wavelengths (frequency) produced by transducers determines the depth of examination area into the tissue.

Primary applications of emergency ultrasound include trauma ultrasound, emergency ultrasound in pregnancy, emergency echocardiography, biliary and renal ultrasound, and foreign body localization during procedural ultrasound [5,6].

Because the primary clinical applications of ultrasonography are frequently on intra-abdominal organs or cardiac abnormalities in the ED, low-frequency transducers (3.5-5 MHz) are most likely to be available in the ED. Unfortunately, these are clearly suboptimal for foreign bodies [7,8].

There are several studies with poor sensitivity and specificity rates of ultrasonography, so other imaging modalities such as soft-tissue radiography, computed tomography, and magnetic resonance imaging (despite their limitations such as availability and cost-effectiveness) have been suggested to detect foreign bodies in soft tissue [9-13].

To date, however, the accuracy of higher-frequency ultrasonography has not been compared with plain and soft-tissue radiographies.

The purpose of this study was to investigate the comparative accuracy of high-frequency transducer ultrasonography as well as plain and soft-tissue radiographies in determining the nonradiopaque soft-tissue foreign body in an established chicken thigh model, with the hypothesis that high-frequency ultrasonography could eliminate the option of plain and soft-tissue radiographies in the ED.

2. Methods

In this randomized, blinded, and descriptive study, 40 chicken thighs were evaluated for nonradiopaque foreign bodies with standard (plain) 2-view radiography, soft-tissue radiography, and 12.5-MHz ultrasonography.

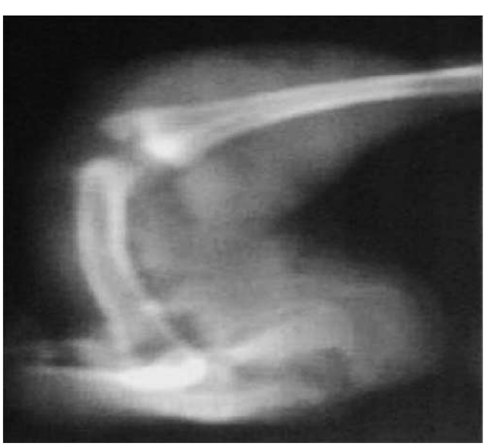

Fig. 1 Plain radiography image of wood.

Fig. 2 Plain radiography image of rubber.

2.1. Study setting

1. Foreign body acquisition and preparation: 20 pieces of each type of material—wood (toothpick) and rubber (shoe sole)—to represent 2 types of nonradiopaque foreign bodies were prepared. Wooden pieces were prepared in 5 mm of length and 1 mm in diameter from toothpicks, and rubber pieces were cropped in 5 × 5 × 2 mm in size from a used sport shoe's sole.
2. Soft-tissue model and chicken thigh acquisition: chicken thighs are preferred because of their proximity to the hand and foot anatomy in puncture-wound traumas.
   Eighty chicken thighs were taken daily from a chicken fresh cutting market and kept cool in a refrigerator at 4°C. All the chicken thighs were of similar weight (mean = 250 ± 45 g) and size.
3. Chicken thigh model preparation: 40 foreign bodies were implanted in 40 fresh chicken thighs; 40 other chicken thighs were used as part of a control group. A similar technique was applied to all chicken thighs to simulate an open puncture wound: with the use of a no.15 scalpel, 10-mm skin incisions were applied with 30° of stabbing and a hemostat was inserted in a 1-cm depth into meat and manipulated inside the meat. One foreign body had been embedded in each chicken thigh and manipulated with hemostats to ensure uniform tissue damage. Other 40 chicken thighs were used as part of a control group, with similar incisions and manipulations with hemostats applied without inserting any foreign body.
4. Diagnostic imaging: images were obtained using plain radiography, soft-tissue radiography, or ultrasonography. Plain radiographs were of 2 views (anteroposterior [AP] and lateral) with standard dosage (48 kV and 2.5 mA for AP view; 52 kV and 2.7 mA for lateral view). Soft-tissue radiographs were of 2 views (AP and lateral) but with a low kilovolt dosage (45 kV and 2.8 mA for AP view; 50 kV and 3.2 mA for lateral view). Ultrasonography images were of 2 views (transverse and longitudinal) with a high-frequency linear trans-

Fig. 3 Soft-tissue radiography image of wood.

ducer (12.5 MHz; ATL 5000 HDI, Bathell, Wash) without a standoff pad.

5. Diagnostic image interpretation: 2 attending radiologists with at least 5 years of professional experience were enlisted. They were blinded to each other's interpretations and model preparation.

2.2. Data analysis

The Statistical Package for Social Sciences (version 11.0, SPSS, Chicago, Ill) for Windows was used for statistical evaluation within 95% confidence intervals. The sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, negative predictive value, and positive predictive value of each technique were calculated.

3. Results

3.1. Plain radiography

The radiologists failed to detect any of the wood foreign bodies in 20 chicken thighs (0%) (Fig. 1). In the

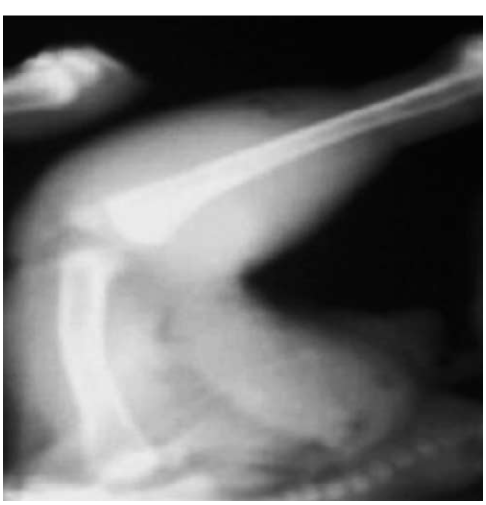

Fig. 4 Soft-tissue radiography image of rubber.

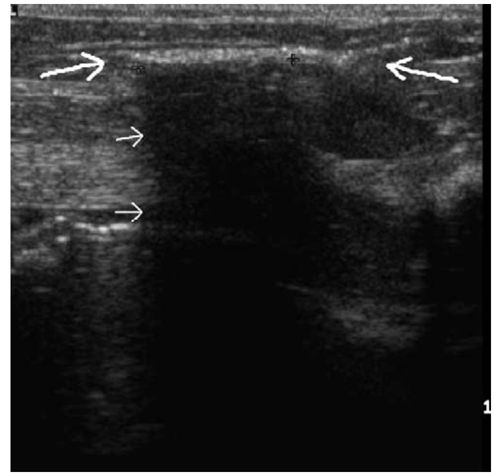

Fig. 5 Ultrasonography image of wood.

control group, 2 false-positive wood foreign bodies were detected by the radiologists (the sensitivity, specificity, as well as positive predictive and negative predictive values were 0%, 90%, 0%, and 47%, respectively). The positive likelihood ratio and negative likelihood ratio were 0 and 1.1, respectively.

With the plain radiography technique, only 2 of 20 rubber foreign bodies (10%) were detected (Fig. 2). In the control group, 2 false-positive rubber foreign bodies were also detected by the radiologists (the sensitivity, specificity, as well as positive predictive and negative predictive values were 10%, 90%, 50%, and 50%, respectively). The positive likelihood ratio and negative likelihood ratio were 1 and 1, respectively.

3.2. Soft-tissue radiography

The results of soft-tissue radiography were not different from those of plain radiography. The radiologists failed to detect any of the wood foreign bodies in 20 chicken thighs (0%) (Fig. 3). In the control group, 2 false-positive wood

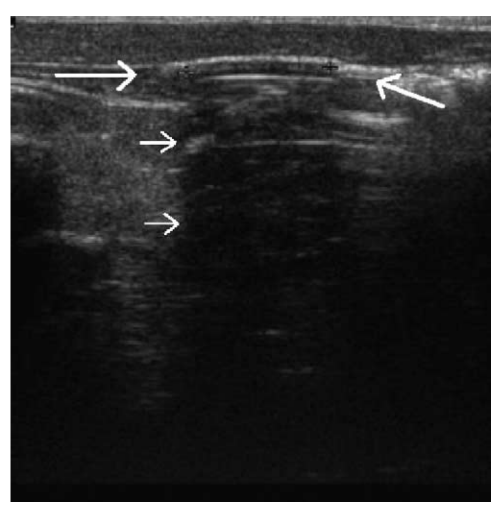

Fig. 6 Ultrasonography image of rubber. Long arrows, image of toothpack; short arrow, shadow of the image.

Table 1 Overall sensitivity, specificity, positive predictive and negative predictive values, as well as positive and negative likelihood ratios of the 3 modalities used for both wood and rubber foreign bodies

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	LR positive	LR negative
Standard radiography	5	90	33	48	0.5	1.05
Soft-tissue radiography	5	90	33	48	0.5	1.05
Ultrasonography	90	80	81	89	4.5	0.5

PPV indicates positive predictive value; NPV, negative predictive value; LR, likelihood ratio.

foreign bodies were detected by the radiologists (the sensitivity, specificity, as well as positive predictive and negative predictive values were 0%, 90%, 0%, and 47%, respectively). The positive likelihood ratio and negative likelihood ratio were 0 and 1.1, respectively.

Only 2 of 20 rubber foreign bodies (10%) in 20 chicken thighs were detected with the soft-tissue technique (Fig. 4). In the control group, 2 false-positive rubber foreign bodies were also detected by the radiologists (the sensitivity, specificity, as well as positive predictive and negative predictive values were 10%, 90%, 50%, and 50%, respectively). The positive likelihood ratio and negative likelihood ratio were 1 and 1, respectively.

3.3. Ultrasonography

Seventeen of 20 wood foreign bodies (85%) were detected positive with ultrasonography in 20 chicken thighs, whereas 4 false-negative wood foreign bodies were detected in the control group (the sensitivity, specificity, as well as positive predictive and negative predictive values were 85%, 80%, 81%, and 83%, respectively) (Fig. 5). The positive likelihood ratio and negative likelihood ratio were 4.25 and 0.19, respectively.

Nineteen of 20 rubber foreign bodies (95%) were detected by ultrasonography in 20 chicken thighs (Fig. 6). The number of false-positive rubber foreign bodies was also 4 in the control group (the sensitivity, specificity, as well as positive predictive and negative predictive values were 95%, 80%, 82%, and 94%, respectively). The positive likelihood ratio and negative likelihood ratio were 4.75 and 0.06, respectively.

For nonradiopaque foreign bodies, the overall sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, positive likelihood ratio, negative likelihood ratio, as well as positive predictive and negative predictive values of the 3 modalities used are shown in Table 1.

4. Discussion

In this in vitro study, we compared plain radiography, soft-tissue radiography, and high-frequency ultrasonography in detecting foreign bodies in soft tissue. Our results revealed that using a higher-frequency ultrasonography to detect nonradiopaque foreign bodies could eliminate the inessential use of plain and soft-tissue radiographies.

The evaluation of a soft-tissue foreign body typically begins with routine radiography if the physical examination fails to uncover the suspected foreign body.

In the literature, it is well documented that plain radiographs are successful in detecting radiopaque foreign bodies in soft tissue [3]. However, the detection of nonradiopaque foreign bodies in the soft tissue limits the utility of relying on plain radiographs in all cases [14-17].

The poor accuracy of plain radiography has led some authors to conclude that soft-tissue radiographs could better reveal details through the soft tissue and could be successful in detecting foreign bodies [10,11,18]. Soft-tissue radiography is a radiographic modality in which the technique factors are adjusted to enhance and display the anatomical details of soft tissue. In the soft-tissue technique, decreasing the x-ray tube voltage lightens the film and enhances the contrast between some materials and the surrounding tissue. Altering exposure factors as kilovolts, current, and time may discriminate between the densities of soft tissues and foreign bodies [19].

However, none of these suggestions has been corroborated with clinical studies in the medical literature. In a case report, Koornhof et al [20] concluded that especially the presence and the location of a swallowed fish bone could easily be detected with lateral soft-tissue radiography. However, it was a virtual case report that externally taped fishbone to one's throat and used soft-tissue radiography. In one clinical observational study in which most patients with a complaint of foreign body sensation had undergone soft-tissue radiography of the neck, it was concluded that routine use of radiography in the assessment of foreign body in the throat was inappropriate [21].

In our animal study, plain and soft-tissue radiographies failed to detect nonradiopaque foreign bodies in soft tissue. Although a low kilovolt dosage was used for soft-tissue radiography according to plain radiography (45 vs 48 kV for AP views; 50 vs 52 kV for lateral views), the sensitivity and specificity of both modalities were the same. Soft-tissue radiography was as accurate as plain radiography in our study, and altering the x-ray dosage did not help physicians detect the nonradiopaque foreign body. (We applied an approximately 6% reduction in kilovolts for a low dosage according to the standard dosage to accommodate the smaller thickness of chicken thighs compared with actual human tissue, but this should be investigated with further studies).

Several studies have tested the effectiveness of ultrasonography in detecting nonradiopaque foreign bodies in soft tissue. Investigations with high-frequency transducers had better results than those with low-frequency transducers [22-26], suggesting that transducer frequency and operator competence are limiting factors in clinical practice. The power of ultrasonography is important as the depth of penetration of the ultrasound wave into the body is directly related to wavelength (shorter wavelengths [higher frequency] penetrate a shorter distance than longer wavelengths [lower frequency]). The higher the frequency used, the better the resolution (the ability to distinguish 2 adjacent objects). When the frequency is increased, more of the ultrasound beam is absorbed by the medium and the beam penetration declines. (The penetration depth into tissue and axial resolution are approximately 10 cm and 1 mm for 3.5 MHz, approximately 7 cm and 0.6 mm for 5 MHz, approximately 5 cm and 0.4 mm for 7.5 MHz, and approximately 2 to 20 cm and 0.2 mm for 12 MHz, respectively [27].

Overall sensitivities and specificities with a 7.5-MHz transducer ultrasonography in detecting nonradiopaque foreign bodies are imperfect, but many still felt that ultrasound was possibly useful in screening for superficial foreign bodies [4,7]. Since the introduction of higher-frequency transducers, more accurate images have been obtained [17,22-24,27]. We conducted our research with a 12.5-MHz frequency transducer and found higher-frequency ultrasonography superior not only to plain and soft tissue radiographies but also to low-frequency ultrasonography. Although we have used one type of transducer in this study, when we compared our results with those of other clinical studies, we concluded that higher-frequency ultrasonography is superior to low-frequency transducers [17,22-24]. (It should be noticed that the efficiency of a 12.5-MHz ultrasonography is limited to superficial foreign bodies embedded less than 2 cm in depth of soft tissue, but there is no research specifically revealing the average depth of foreign body in soft tissue).

Other modalities have been suggested to detect soft-tissue foreign bodies. If a nonradiopaque object cannot be visualized on plain radiographs, alternative imaging techniques such as computed tomography and magnetic resonance imaging have been suggested; however, technical problems, cost-effectiveness, the time required to complete the test, and availability in clinical settings limit widespread use of these methods in the ED [28-31]. (Xeroradiography is no longer suggested as an alternative method [9].) New methods such as diffraction-enhanced imaging and multiple-image radiography show promise in visualizing a variety of soft tissues [32,33].

Wood and rubber were used as nonradiopaque foreign bodies in this study. Wood is the most common nonradiopaque foreign body in soft tissue, and plain radiographs have been reported to reveal a wooden foreign body in only 15% of patients [1]. Rubber is also another common foreign body type in penetrating foot injuries. (When a nail penetrates shoes, socks, and feet, it may drive rubber into the wound cavity.) Sport shoes with rubber soles especially predispose to infection with *Pseudomonas aeruginosa* after penetrating wounds [2,34].

There are several limitations to this study. First of all, we could not correlate the interobserver reliability because only 2 radiologists individually interpreted the results of ultrasonography and x-ray views. Personal experiences and skills of the radiologists may play a role in the interpretation of the results; however, a previous study demonstrated a strong concordance between 2 radiologists in detecting foreign bodies with ultrasonography [35]. Second, this was an established chicken thigh model. Although the composition of layers of soft tissue in a chicken thigh is similar to that of human soft tissue, the thickness of the layers may be different and may cause altered absorption and reflection values of ultrasound waves and x-rays. Third, the depth of the ultrasound waves with a 12.5-MHz frequency transducer is limited to 2 to 20 mm, so deeply embedded foreign objects could have been missed.

We conclude that sonography is superior to plain and soft-tissue radiographies and that the latter 2 techniques are both poor at detecting nonradiopaque foreign bodies. If the type of foreign body is felt to be nonradiopaque and less than 2 cm deep, high-frequency ultrasonography might be the logical choice. In the clinical setting, an effort to detect the foreign body with plain and soft-tissue radiographies before ultrasonography will result in increased radiation exposure as well as increased cost and probably in a waste of time without significant clinical benefit. We also suggest that plain and soft-tissue radiography series should no longer be used as diagnostic imaging modalities to detect nonradiopaque foreign bodies if high-frequency ultrasonography is available in the ED.

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