Surgeon-Performed Ultrasound for Pneumothorax in the Trauma Suite

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Background: Surgeon-performed ultrasound has become ubiquitous in the trauma suite. Initial reports suggest that sonography may be used for the detection of pneumothorax. The purpose of this study was to evaluate the efficacy of sonography to rule out the presence of a pneumothorax in the trauma population.

Methods: A prospective analysis of 328 consecutive trauma patients at an American College of Surgeons-verified Level I trauma center was undertaken. Thoracic ultrasound was performed before chest radiography. The presence or absence of a "sliding-lung" sign or "comet-tail" artifact was recorded.

Results: Of 328 evaluations, there were 312 true-negatives, 12 true-positives, 1 false-negative, 1 false-positive, and 2 exclusions. Specificity, negative predictive value, and accuracy were 99.7%, 99.7%, and 99.4%, respectively.

Conclusion: Ultrasound is a reliable modality for the diagnosis of pneumothorax in the injured patient. This modality may serve as an adjunct or precursor to routine chest radiography in the evaluation of injured patients.

Key Words: Ultrasound, Trauma, Pneumothorax, Lung-sliding, Comet-tail.

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Pneumothorax has a range of presentations—from a subtle decrease in breath sounds to cardiopulmonary arrest caused by tension pneumothorax. Pneumothorax is a common finding in the trauma setting. It may occur in locations where access to traditional means of diagnostic confirmation (i.e., chest radiography) is not readily available, such as remote military operations, space travel, and during natural disasters and mass-casualty situations. In such situations, surgical decision making relies on the physical examination conducted in less than optimal surroundings. This scenario may result in either performance of unnecessary procedures or a delay in definitive treatment.

Ultrasound offers many advantages in these situations. Its portability is a quality that distinguishes it from routine radiography. As technology has advanced, ultrasound image quality has improved. Ultrasound units continue to decrease in size, weight, and cost. These technological improvements have enhanced the utility of ultrasound for remote applications. In comparison to radiographic equipment, initial costs for equipment and maintenance are nominal. Ultrasound performed by surgeons or emergency physicians greatly decreases the time required to obtain clinically relevant information, even when radiographic equipment is readily available. Proficiency in basic ultrasound skills is taught in a matter of hours as opposed to months. The American College of Surgeons (ACS) sponsors several different courses for various levels of ultrasound training.

Thoracic ultrasound continues to gain acceptance in a variety of settings, both for critical decision making and novel uses. This study evaluates the reliability of ultrasound to rule out pneumothorax when performed in the trauma suite by appropriately trained surgical residents and trauma staff.

PATIENTS AND METHODS

The study protocol was approved by the Institutional Review Board at Via Christi Regional Medical Center, an ACS-verified Level I trauma center in Wichita, Kansas. All patients who arrived at our facility between December 2002 and June 2003 as a designated trauma were considered for enrollment in the study. Exclusionary criteria were the absence of properly trained residents or faculty, the inability to obtain a chest radiograph, patient refusal to undergo evaluation, and hemodynamic instability that precluded ultrasound evaluation.

Either a chief surgical resident or staff trauma surgeon, all of who had completed an ACS-sponsored ultrasound course, performed each ultrasound examination. The technique and salient findings of thoracic ultrasonography were reviewed with residents and trauma staff. The examination was performed before reviewing any radiographic studies. The absence or presence of the "lung-sliding" sign, seen as a to-and-fro motion at the interface between the visceral and parietal pleura (Fig. 1), and the "comet-tail" artifact, which is manifest by hyperechoic "streaks" extending downward from the visceral/parietal pleural interface (Fig. 2), were noted.

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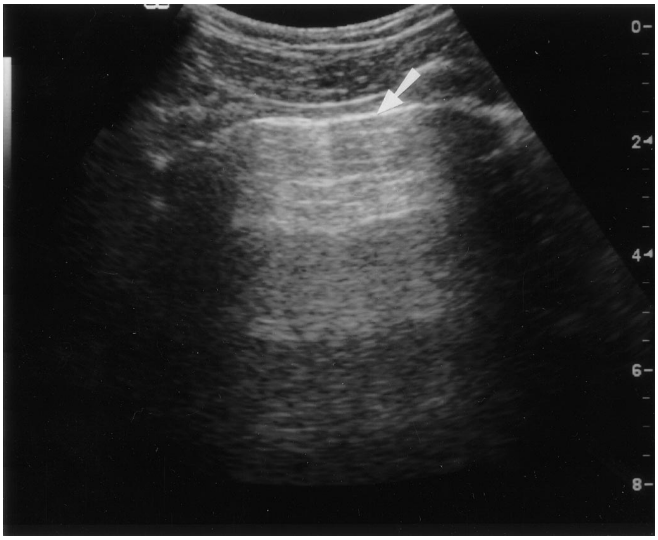

Fig. 1. *Example of the pleural/parietal interface where the lung-sliding sign would be demonstrated in a dynamic image (*arrow *at pleural/parietal interface).*

The ultrasound examination was performed with an Acuson 128XP/10C (Mountain View, CA) machine using a 2.5- to 4-MHz phased array transducer. Each patient underwent thoracic ultrasound as an addition to the focused abdominal sonography for trauma examination. The probe was placed sagittally over the second intercostal space in the midclavicular line, and a minimum of five respiratory cycles were observed. The presence or absence of the lung-sliding sign and/or the comet-tail artifact was recorded. If the lung-sliding sign and the comet-tail artifact were absent, the diagnosis of a pneumothorax was recorded. In addition to these findings, age, mechanism of injury, and whether a thoracostomy tube was placed was recorded. Findings recorded at the time of the ultrasound were compared with the official radiology report at a later date. Data were tabulated, and sensitivity, specificity,

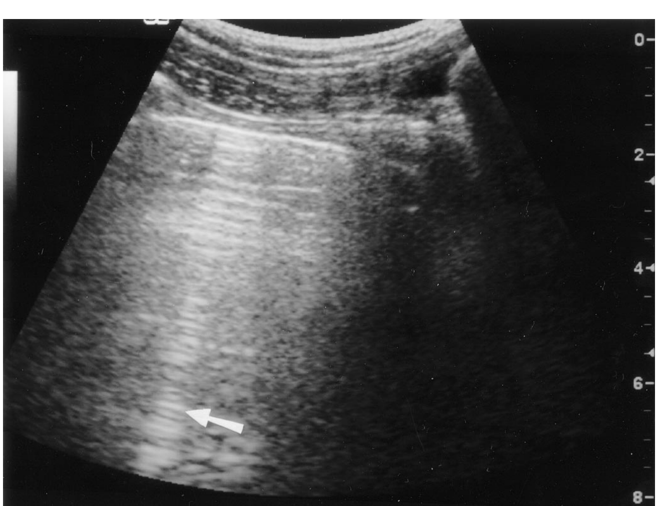

Fig. 2. *Example of a comet-tail artifact (*arrow*).*

Table 1 **Sensitivity, Specificity, Positive Predictive Value, Negative Predictive Value, and Accuracy of Lung-Sliding Sign as compared with Chest Radiography in the Diagnosis of Pneumothorax (n = 326)**

	%
Sensitivity	92.3
Specificity	99.6
Positive-predictive value	92.3
Negative-predictive value	99.7
Accuracy	99.3

negative predictive value (NPV), positive predictive value (PPV), and accuracy for detection of pneumothorax were calculated for both the lung-sliding sign and the comet-tail artifact as compared with radiologic findings. Identification of hemothorax and evaluation of pulmonary contusions by ultrasound were not evaluated as independent variables during the course of this study.

RESULTS

There were 328 subjects enrolled in the study over a 7-month period. Only patients who arrived when a properly trained surgical resident or staff surgeon was present were included for analysis. Two patients were excluded from the study. One patient underwent placement of a chest tube after thoracic ultrasound but before a chest radiograph was obtained for confirmation. A second patient had already undergone chest tube placement before transfer to our facility with numerous chest wall injuries. Of the remaining 326 patients, the average age was 37.3 $\pm$ 20.2 years (range, 6 months–94 years). Sixteen percent of trauma patients were considered to have serious injuries on the basis of prehospital triage criteria and 84% were patients with moderate or minor injuries. Blunt injury was the mechanism of injury for 93.6% of the patients, and 4.3% of all patients underwent chest tube placement. Thoracic ultrasound evaluation added approximately 30 to 60 seconds to the standard focused abdominal sonography for trauma evaluation. Body habitus did not interfere with the ultrasound evaluation of the thorax in any patient.

There were 313 subjects (96.0%) with identification of a lung-sliding sign, and in 312 of the 313 patients with positive identification of pleural sliding, chest radiographs confirmed the absence of a pneumothorax, resulting in a 99.7% NPV (Table 1). The solitary false-negative study was a very small apical pneumothorax, which was managed without tube thoracostomy. There were 12 true-positive examinations and one false-positive examination. The single false-positive finding was in a patient who presented with subcutaneous emphysema. Sensitivity, specificity, and accuracy were 92.3%, 99.6%, and 99.3%, respectively (Table 1). Nineteen of the patients enrolled were documented to have a comet-tail artifact. When comparing the comet-tail artifact with chest radi-

Table 2 Sensitivity, Specificity, Positive Predictive Value, Negative Predictive Value, and Accuracy of Thoracic Ultrasound as Compared with Chest Radiography in the Diagnosis of Pneumothorax in Patients Who Suffered Blunt vs. Penetrating Trauma

	Blunt (n = 305 [93.6%])	Penetrating (n = 21 [6.4%])
Sensitivity (%)	88.9	100
Specificity (%)	99.7	100
Positive-predictive value (%)	88.9	100
Negative-predictive value (%)	99.7	100
Accuracy (%)	99.3	100

ography findings in these patients, sensitivity and NPV were both 100%.

Of the group of patients that received chest tubes (n = 14), 28.6% were in patients that sustained penetrating injuries. The sensitivity, specificity, PPV, NPV, and accuracy of thoracic ultrasound to rule out a pneumothorax for patients who sustained blunt and penetrating injury are shown in Table 2.

DISCUSSION

Conventional wisdom holds that a pneumothorax can be diagnosed with a careful and thorough physical examination. In ideal circumstances (e.g., a quiet room, a cooperative patient, an accurate history), this is often the case. However, the care of trauma patients is rarely performed under these ideal conditions. There are occasionally scenarios when the diagnosis of pneumothorax is apparent from physical examination, but in most cases, the diagnosis of pneumothorax is made by chest radiography in the trauma suite. Less commonly, computed tomographic scan will detect an otherwise undiagnosed pneumothorax.

In 1986, the first report using ultrasound to diagnose a pneumothorax was published in the veterinary literature,[1] and 1 year later, the first report of ultrasound diagnosis of pneumothorax in humans followed.[2] Since that time, numerous favorable reports have been published bolstering support for this use of ultrasound, particularly in the trauma setting.[3] Ultrasound's portability, immediacy, lack of ionizing radiation, cost effectiveness, and rapid learning curve make it an attractive modality for integration into the routine evaluation of trauma patients. These characteristics of ultrasound offer promise for the use of ultrasound in a multitude of locations, that is, where conventional radiography may not be readily available. Indeed, the National Aeronautics and Space Administration has expressed interest in this technology for use during space travel.[4]

The primary use of ultrasound in the diagnosis of pneumothorax has been to confirm its absence by visualization of lung-sliding. This is the sonographic finding of the visceroparietal pleural interface as they slide across one another during the course of respiration (Fig. 1). If air comes between these two surfaces, the lung-sliding sign is lost and the diagnosis of pneumothorax must be suspected. The presence of lung-sliding has been documented to be highly sensitive and specific in ruling out a pneumothorax in both nontrauma[5–8] and trauma[3,9–11] settings. Our series of trauma patients demonstrated similar sensitivity, specificity, and accuracy.

It is generally accepted that the efficacy of ultrasound is enhanced if the same individual both performs and interprets the study. One previous study has demonstrated a sensitivity of 73% and a specificity of 68% for diagnosing a pneumothorax with ultrasound when the individual interpreting the study is different from the person performing the ultrasound examination.[12] However, a case report recently published contends that the use of color Doppler will allow a pneumothorax to be diagnosed from static images.[10] The relevance of this approach requires further evaluation in formal clinical trials.

It is common for a trauma patient to sustain a pulmonary contusion. It has been proposed in a study performed in a medical intensive care unit that the presence of a comet-tail artifact (Fig. 2) also rules out pneumothorax.[13] In this study, an NPV of 100% and a specificity of 96.5% were reported. This hypothesis is based on the premise that an area of lung with interstitial edema will produce hyperechoic streaks extending down into the lung parenchyma. More simply, a comet-tail artifact is present anytime there is an air/fluid interface. Therefore, if a comet-tail artifact is present, the visceral and parietal pleura are in opposition, precluding the possibility of a pneumothorax, making it a secondary indicator to confirm the absence of pneumothorax. Although only 19 comet-tail artifacts were documented in our population, our data support this finding despite the fact that our patient populations were somewhat different, as were the circumstances surrounding the evaluation of the two patient populations. Foreign bodies or other findings common in trauma patients could produce a similar sonographic finding, so this sign must be interpreted in the context of the patient's injuries.

Thoracic ultrasound, although not yet a substitute for chest radiography, is a valuable adjunct for the early diagnosis of a pneumothorax. Currently, much additional information is obtained from a chest radiograph that cannot be adequately obtained with ultrasound. Our experience indicates that ultrasound offers excellent specificity and sensitivity with a modicum of training. The number of applications where ultrasound could prove valuable is almost limitless as we increase the number and duration of our forays into space, as our military continues to operate in remote locations around the world, and as we are called to respond to mass-casualty situations. Thoracic ultrasound will be useful anywhere circumstances preclude the immediate use of radiography. This is increasingly true as technological advancement allows for higher quality images to be derived from increasingly smaller, lighter, less expensive machines. Continued investigation and education are important to ensure that the efficacy of thoracic ultrasound is optimized in the trauma setting.

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DISCUSSION

Dr. Scott A. Dulchavsky (Detroit, Michigan): Dr. Knudtson and colleagues have completed one of the largest prospective investigations of surgeon-performed ultrasound in the detection of pneumothorax and have demonstrated excellent sensitivity and specificity. I congratulate the authors on responding to the challenge of verifying the efficacy of ultrasound in expanded indications, and I am encouraged that our clinical experience was corroborated.

The additional contribution of this study was the finding that thoracic ultrasound sensitivity is not degraded using a curvilinear probe, which simplifies the continuity of the focused abdominal sonography for trauma examination into the chest. Higher frequency linear transducers allow greater image fidelity. How did you maximize image quality for the thoracic ultrasound examinations?

Visualization of lung-sliding requires motion at the pleural interface, which is greater at the third or fourth interspace. Why was the second intercostal window chosen?

It would be important to determine whether the false-negative and false-positive examinations reported in this study were the result of technique versus a failure of interpretation by the operator. Were dynamic images archived for later re-review?

All of the surgeon-ultrasonographers in your investigation completed an ACS-sponsored course; however, thoracic ultrasound is not a core component in these sessions. Please comment on the training methods used to familiarize your participants with thoracic ultrasonography.

We recently completed a remote-guided, thoracic ultrasound examination on the International Space Station using an astronaut who completed 5 minutes of training. I believe that familiarity with the appearance of positive and negative examinations is essential.

Dr. Jason L. Knudtson (closing): Again, Dr. Dulchavsky, your contribution in this area has been our measure of success. Regarding the image quality, we adjusted the depth of our transducer to approximately 5 cm and tailored it to the patient's body habitus. We did become rather adept at adjusting the gain to obtain optimal images in that regard.

As for why we chose the second intercostal space, we found that we had excellent motion detected at that space, and our hope was that we would have a higher probability of identifying an apical pneumothorax in that position.

Regarding our false-positives, the first one where the patient had the chest tube placed in between the ultrasound and the chest radiograph, one could argue that that would not have potentially even been a false-positive. However, we included it for the sake of completeness.

The other two were a result of subcutaneous emphysema, which is a known problem in terms of imaging with ultrasound. The false-negative is probably a true false-negative.

Presence of subcutaneous emphysema is one of the drawbacks of this technique. However, I think as our experience improves, those issues will be meted out.

As I did look back at when these occurred in the course of our study, the false-negative was in the first 10 ultrasound periods, as was the initial false-positive. We did not archive our images for future reference.

Regarding the training, because of Dr. Smith's interest and proficiency in ultrasound, the residents at our program are intimately familiar with this technique, and we had been performing thoracic ultrasound for many months before initiating this study. Thus, the majority of us had a very good sense of what we were looking for.

However, Dr. Dort, Dr. Smith, and I at one point or another discussed it on a personal level, and we did play video for the group and instructed them on the technique. It really isn't a very big leap for people who are familiar with an ultrasound machine. Again, thank you for the opportunity to present today.