Confirmation of Endotracheal Tube Placement after Intubation Using the Ultrasound Sliding Lung Sign

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Abstract

Objectives: To evaluate the performance of the ultrasound (US) *sliding lung sign* as a predictor of endotracheal tube (ETT) placement. Many other tools and examination findings have been used to confirm ETT placement; erroneous placement of the ETT has even been confirmed by US.

Methods: This was a laboratory study using fresh, recently dead cadavers. Cadavers were obtained at a medical school anatomy laboratory on the basis of availability during a four-month period. Subjects who died from significant trauma or after thoracic surgery were excluded. A numerical randomization tool was used to direct where the tube would be placed on intubation. Laryngoscopy was performed, and the ETT was placed in the esophagus, in the trachea, or in the right main stem (RMS) bronchus. Placement was confirmed by direct laryngoscopic visualization of ETT passage through vocal cords or with fiber optic visualization, as needed. US images of the sliding lung sign, sliding of visceral and parietal pleura past each other, were taken on both sides of the chest at the mid axillary line during ventilation with an ambu bag. Two board-certified emergency physicians with hospital credentialing in emergency US used a 4-2 MHz micro-convex transducer on a Sonosite 180 Plus for imaging. The sonologists were blinded to the location of the endotracheal tube and imaged and recorded their results individually. A positive sliding lung sign was taken to signify lung expansion with ventilation in a hemithorax. Endotracheal versus esophageal ETT placement, as well as tracheal versus RMS, was determined on the basis of sliding lung findings on both sides of the chest. Interpreter agreement, sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and likelihood ratios (LHR) were calculated for tracheal (including RMS) versus esophageal, as well as main trachea versus RMS intubation.

Results: Nine cadavers yielded 68 intubations. For esophageal versus tracheal (including RMS) intubation, sonologist 1 (S1) had a sensitivity of 95.4% (95% CI = 84.2% to 99.4%), a specificity of 100% (95% CI = 86.3% to 100%), an NPV of 92.6% (95% CI = 75.7% to 99.1%), and a PPV of 100% (95% CI = 91.4% to 100%) with an LHR of 0.05 (95% CI = 0.01 to 0.2) for a negative test. Sonologist 2 (S2) had a sensitivity of 100% (95% CI = 91.8% to 100%), a specificity of 100% (95% CI = 86.3% to 100%), an NPV of 100% (95% CI = 86.3% to 100%), and a PPV of 100% (95% CI = 91.8% to 100%); agreement was 97% (κ = 0.94; 95% CI = 0.7 to 1.2). In RMS versus tracheal, S1 had a sensitivity of 69.2% (95% CI = 48.2% to 85.7%), a specificity of 93.3% (95% CI = 68.1% to 99.8%), a PPV of 94.7% (95% CI = 73.9% to 99.9%), and an NPV of 63.6% (95% CI = 40.7% to 82.8%) with an LHR for a positive test of 10.4 (95% CI = 2.2 to 59.1) and of 0.4 (95% CI = 0.2 to 0.6) for negative test. S2 had a sensitivity of 78.6% (95% CI = 59.1% to 91.7%), a specificity of 100% (95% CI = 78.2% to 100%), a PPV of 100% (95% CI = 84.6% to 100%), NPV of 71.4% (95% CI = 47.8% to 88.7%), with an LHR for a negative test of 0.2 (95% CI = 0.1 to 0.4); agreement was 85.9% (κ = 0.6; 95% CI = 0.4 to 0.9).

Conclusions: These results show that US imaging of the sliding lung sign in a cadaver model is an accurate method for confirmation of ETT placement. Further, the technique may have some utility in differentiating RMS bronchus from main tracheal intubations.

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Keywords: emergency ultrasound, intubation confirmation, ultrasound, cadaver model, emergency medicine, sliding lung sign

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In the emergency setting, visualization of endotracheal tube placement may be limited. Hence, with the significant morbidity and mortality associated with incorrect placement in critically ill patients, reliable endotracheal tube insertion confirmation procedures are essential. Auscultation of the chest, left upper quadrant, end tidal CO_2 monitors, esophageal detector devices, as well as other methods, are currently used as confirmation procedures. However, each of these has disadvantages in the emergency setting and can lead to false-positive results.[1–6] Further, several require purchase of equipment not otherwise used in the emergency department (ED), as in the case of end tidal CO_2 detectors.

Bedside ultrasound (US) has proven utility in the care of critically ill patients and is likely to be available in many large EDs for use in trauma and cardiac arrest patients.[7–9] The sonographic representation of normal, functioning lung has been described elsewhere and is used as a basis for detection of lung disease and injury, such as pneumothorax.[10,11] The sonographic feature representing the normal lung (without a pneumothorax) is the back and forth sliding of visceral and parietal pleura past each other.[12] This is commonly referred to as the *sliding lung sign*. The sliding lung sign is seen when the lung expands and is noted in both positive-pressure and negative-pressure ventilation. The purpose of this study was to assess the performance of the sliding lung sign in differentiating between esophageal and tracheal intubation. The secondary purpose was to assess the ability of the sliding lung sign to differentiate between main tracheal and right main stem intubation once esophageal intubation has been ruled out.

METHODS

Study Design

This was a laboratory study using a cadaver model for the detection of endotracheal, right main stem, and esophageal intubations, using the sliding lung sign and a portable ultrasound machine. This study was exempt from informed consent because of the use of cadaveric material. The study was reviewed and approved by the department of anatomy and the gross anatomy laboratory director.

Study Protocol

Nine fresh cadavers, within 48 hours of death, were used for all intubations. Cadavers that had died from significant thoracic trauma or that had significant thoracic pathology, such as lung cancer and radiation therapy, were excluded.

Each cadaver was intubated by an emergency physician using a laryngoscope. No time limit was placed on intubation. A random number generator was used to decide endotracheal tube placement into the esophagus, main trachea, or right main stem bronchus. Tube placement was confirmed by the physician by using direct visualization of tube passage through vocal cords or into the esophagus after the tube was secured. If needed, such as in cases in which cords and endotracheal tube path were not completely and clearly visualized, confirmation with a fiber optic scope was performed. Right main stem intubation was ensured by deep placement of the endotracheal tube with rotation of the bend of the tube to the right bronchus. This was confirmed with clinical examination by auscultating both sides of the chest. The fiber optic bronchoscope was used for confirmation if right main stem intubation was in doubt after clinical examination. Each cadaver's head and neck were draped with a sheet to blind the examiners to endotracheal tube depth and placement (Figure 1). The cadavers were ventilated with the same tidal volume for esophageal, tracheal, and right main stem intubations to ensure blinding of the sonologists and also to simulate a clinical situation in which tracheal intubation is assumed.

Two board-certified emergency physicians with hospital credentialing in emergency US performed chest sonography after each intubation. Each sonologist had previously performed more than 50 lung US examinations for detection of pneumothorax in trauma patients. The sonologists were blinded to the placement of the endotracheal tube, as well as to each other's results. A Sonosite 180 Plus (Bothell, WA) with a 4-2 MHz broadband microconvex transducer was used to obtain real-time images of the sliding lung sign. This transducer was used because it is likely to be available on almost all US systems that are used in the emergency setting. Linear transducers, such those used in some previous studies, are not as common in the ED. Further, because the rest of the typical trauma or hypotensive patient evaluation is performed with a microconvex, convex, or phased array transducer, no switching of probes is required in the middle of the examination when use of a linear transducer is avoided.

Images were taken on both sides of the chest within the third to fifth rib interspaces, along the anterior and mid axillary line, during positive-pressure ventilation with an ambu bag. Each examiner performed the US examination and recorded results individually. A positive sliding lung sign signified lung expansion with ventilation. On the basis of the presence or absence of the sliding lung sign on both sides of the chest, a determination of endotracheal tube position was made. Sliding lung sign

Figure 1. An image of the draped cadaveric specimen with an ultrasound probe scanning in the right anterior to middle axillary line. The cadaver's head and neck are draped to mask tube placement.

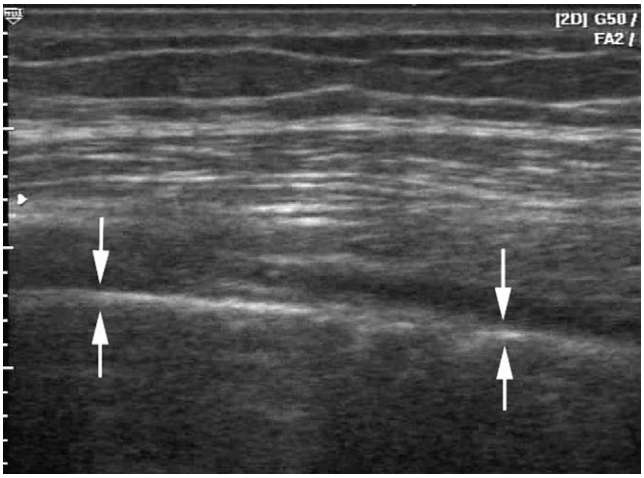

Figure 2. **The bright interfaces of the parietal and visceral pleura are seen (arrows).**

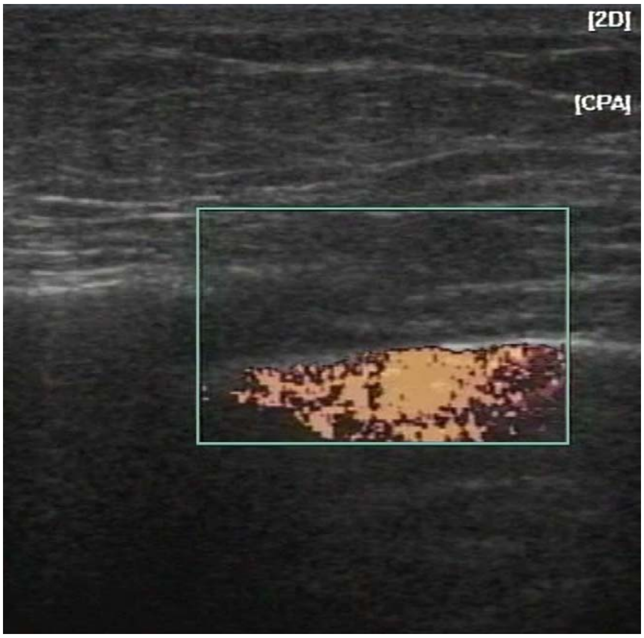

Figure 3. **The power Doppler box displays color representing movement of the two layers.**

presence on both sides of the chest was assumed to signify tracheal intubation. Sliding lung sign presence on the right but absence on the left was assumed to indicate right main stem intubation. Finally, absence of sliding lung sign on either side was assumed to indicate esophageal intubation. The sonologists were allowed to use the power Doppler settings as well as to manipulate the other settings of the US as desired (Figure 2). Power Doppler was used to pick up pleural movement (Figure 3).[4] Each sonologist entered the room, made observations, and then left the room without having contact with the other sonologist. There was no time limit placed on the sonologists.

Measures

The sonologists marked the presence or absence of the sliding lung sign on each side of the chest for each intubation. The sonologists also marked whether they felt that the tube was endotracheal, esophageal, or placed in the right main stem. Data were stored in a Microsoft Access database (Microsoft Corp., Redmond, WA). For the primary outcome measure of this study, sensitivity and specificity referred to the ability of the sonologists to distinguish esophageal intubation from tracheal (main trachea and right main stem). For the secondary measures, sensitivity and specificity referred to the ability of sonologists to distinguish right main stem intubation from main tracheal intubation, once esophageal intubation had been ruled out.

Data Analysis

Statistical analysis included observer agreement, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). Data were analyzed by using statistical calculators from a commercially available software package, StatsDirect (Cheshire, United Kingdom).

RESULTS

Nine cadavers yielded a total of 68 intubations. The fiber optic scope was used five times to confirm endotracheal tube placement: three times in endotracheal intubations and twice in right main stem intubation. Eight randomized intubations were performed on each cadaver, with the exception of one cadaver wherein only four intubations were performed because of time constraints in the anatomy lab. There were 27 right main stem intubations, 16 main tracheal intubations (not in the right main stem), and 25 esophageal intubations. One sonologist misidentified two esophageal intubations as tracheal intubations (one thought to be a right main stem and the other a main tracheal, not right main stem). The second sonologist correctly identified all esophageal intubations (Table 1). S1 misidentified eight right main stem intubations as main tracheal intubations. S2 misidentified six right main stem intubations as main tracheal intubations. S1 used power Doppler to enhance sliding lung detection in 15 cases, and S2 used it in 17 cases.

In differentiating esophageal versus tracheal (including right main stem bronchus) intubation, S1 showed a sensitivity of 95.4% (95% CI = 84.2% to 99.4%), a specificity of 100% (95% CI = 86.3% to 100%), an NPV of 92.6% (95% CI = 75.7% to 99.1%), and PPV of 100% (95% CI = 91.4% to 100%), with a likelihood ratio of 0.05 (95% CI = 0.01 to 0.2) for a negative test. S2 showed a

Table 1
Results of Sliding Lung Evaluation by Sonologist 1 and Sonologist 2

Location	Actual Placement	Sonologist 1	Sonologist 2
Trachea (not RMS)	16	22	21
Esophagus	25	27	25
RMS	27	19	22
Trachea (including RMS)	43	41	43

RMS = right main stem.

sensitivity of 100% (95% CI = 91.8% to 100%), a specificity of 100% (95% CI = 86.3% to 100%), an NPV of 100% (95% CI = 86.3% to 100%), and a PPV of 100% (95% CI = 91.8% to 100%). Observer agreement was 97% (κ = 0.94; 95% CI = 0.7 to 1.2) for the two sonologists.

In differentiating right main stem intubation versus main tracheal (the detection of a right main stem intubation when esophageal intubation has been ruled out), S1 showed a sensitivity of 69.2% (95% CI = 48.2% to 85.7%), a specificity of 93.3% (95% CI = 68.1% to 99.8%), a PPV of 94.7% (95% CI = 73.9% to 99.9%), and NPV of 63.6% (95% CI = 40.7% to 82.8%), with a likelihood ratio for a positive test of 10.4 (95% CI = 2.2 to 59.1) and one of 0.4 (95% CI = 0.2 to 0.6) for a negative test. S2 showed a sensitivity of 78.6% (95% CI = 59.1% to 91.7%), a specificity of 100% (95% CI = 78.2% to 100%), a PPV of 100% (95% CI = 84.6% to 100%), and an NPV of 71.4% (95% CI = 47.8% to 88.7%), with a likelihood ratio for a negative test of 0.2 (95% CI = 0.1 to 0.4). Observer agreement was 85.9% (κ = 0.6; 95% CI = 0.4 to 0.9) for the two sonologists.

DISCUSSION

In the emergency setting, it may occasionally be difficult or even impossible to directly visualize endotracheal tube placement through the vocal cords. Even if this is accomplished, the tube is occasionally capable of slipping out of place before being secured. Many tools and clinical examination findings are available to help confirm endotracheal tube placement. Each method inherently has its own limitations and may result in false-positive findings in certain circumstances. Thus, most emergency physicians employ a number of parallel tests to confirm correct placement of the endotracheal tube.

Chest auscultation has been found to be unreliable, especially with the inexperienced examiner.[1–3] Mistaking air movement in the esophagus for breath sounds can lead to false-positive results.[2] Further, in a noisy ED, in out-of-hospital settings, and in air medical transport, accurate auscultation may be impossible. Transtracheal illumination also has been previously tested and observed to have high error rates, ranging from 13% to 16% regardless of the examiners' clinical experience.[3] Esophageal detector devices have been widely examined. Numerous studies have shown this method to have overall sensitivity for detecting tracheal intubation of 65% to 87%.[4–6] This poor sensitivity can result, in part, from pulmonary edema or tracheobronchial obstructions, such as mucus plugging the endotracheal tube. In comparison trials, capnography has proven to be superior to esophageal detector devices and transtracheal illumination.[2,3] However, end-tidal CO_2 detection also has been shown to have some limitations. In cardiac arrest patients, end-tidal CO_2 detection has been shown to have sensitivity from 69% to 88%.[2,13,14] Colorimetric devices are primarily used in the emergency setting, whereas spectrographic, quantitative capnography is not routinely available. However, compared with the spectrographic capnography, colorimetric devices have shown decreased sensitivities in emergency settings. Further, a false-negative result may occur when there is an obstruction by blood, debris, or secretions.[14] Whether with capnography or a colorimetric device, detection of CO_2 relies on a patient's physiologic mechanisms for CO_2 excretion and can therefore fail because of dysfunction in the circulatory, ventilatory, or metabolic systems, as is often present in the critically ill or cardiac arrest patients. Fogging of the endotracheal tube with ventilation also has proven to be unreliable.[15]

Earlier studies evaluating US as a mode of secondary confirmation of intubation focused on distinguishing a non-intubated versus an intubated trachea by scanning the anterior neck between the cricoid and suprasternal notch.[16] Raphael et al. imaged the interface between the tracheal wall and endotracheal tube balloon, filled with saline, or an endotracheal tube with a foam cuff.[16] Distinction between tracheal and bronchial intubation was made, but esophageal intubation was not examined. Drescher et al. repeated this technique on cadavers and live patients.[17] In this study, detection of endotracheal intubation was unsuccessful in two of eight patients and two of five cadavers, despite the examiners not being blinded to endotracheal tube placement. A more recent examination that used US images of diaphragmatic motion for secondary confirmation of endotracheal tube placement showed some promise as a reliable method but only was studied with pediatric patients.[18]

Ultrasound of the lung pleura can provide direct anatomic evidence of lung expansion and therefore of ventilation. Sonologists use an US finding that has been relied upon to signify normal anatomy and function of the lung pleura.[4–6] In functional, ventilated lungs, the parietal and visceral surfaces can be visualized by US as distinct bright interfaces or echogenic lines (Figure 2). With ventilation, these two surfaces slide upon each other, and this should indicate tracheal intubation.[6] In theory, one should be able to differentiate between right main stem and proper tracheal intubation by looking for the sliding lung sign bilaterally. In a right main stem intubation, the right lung should expand and produce a sliding lung sign, but the left should not.

Our results showed that evaluating for the sliding lung sign bilaterally was highly sensitive and specific for differentiating tracheal versus esophageal intubation. High negative predictive values for both sonologists indicate that this may be a highly reliable test for endotracheal tube placement. The study yielded a high kappa value, indicating good reliability of identifying endotracheal tube placement between examiners. Although right main stem intubation may not be as immediately life threatening as is accidental esophageal intubation, its discovery is important. Patients with limited pulmonary reserve caused by pulmonary edema, pulmonary embolism, pneumonia, reactive airway disease, or other process affecting oxygenation may not be ventilated adequately with just one lung. Further, collapse of the left lung may be seen with right main stem intubation and ventilation, potentially resulting in complications such as pneumonia.

Although we were able to differentiate esophageal versus tracheal intubation (main tracheal and right main stem) with considerable accuracy, we were not able to distinguish between right main stem intubation from main tracheal intubation as reliably. This likely resulted from transmitted movement of the left lung from expansion of the right lung. Although of concern during the development of the study, insufflation of large quantities of air into the stomach did not cause enough pleural layer movement to produce a sliding lung sign. The two cases of misidentified sliding lung sign were reviewed by both sonologists. Both agreed that although a very small shimmering of the pleural interface was present, it was not true movement.

There are several advantages to using the ultrasonographic sliding lung sign for confirmation of endotracheal tube placement. In contrast to end-tidal CO_2 detection, because the sliding lung sign relies on anatomic relationships, the patient does not need intact metabolic function or normal blood flow for the method to work. Ultrasound is already used on critically ill patients for other indications such as pericardial tamponade, unexplained hypotension, trauma, and cardiac function evaluation. The examiner only needs vision to perform this procedure. Therefore, this confirmation procedure can be performed in austere environments such as in air medical transport, low-light or dark situations, or in remote locations in which radiological capability may be limited.

Potential pitfalls of using the sliding lung sign to confirm intubation include the presence of a pneumothorax. The presence of air between the pleural layers interferes with visualization of lung sliding, thereby helping diagnose the pneumothorax. However, by scanning laterally on the chest, as we did in our study, only larger pneumothoracies would cause a problem with visualization of the sliding lung sign, because smaller ones would be found anteriorly only.[19] Further, if a large pneumothorax were present to obscure all evidence of the sliding lung sign, examination of the other hemithorax should reveal a sliding lung sign if the patient were intubated correctly. Of course, the presence of large bilateral pneumothoracies could negate the utility of the sliding lung sign completely; this presentation is fairly rare and may be present in patients who are in such extremis that bilateral chest tubes may be warranted regardless. Lung contusions, acute respiratory distress syndrome (ARDS), and lung blebs can cause the disappearance of the sliding lung sign in rare cases.[20] However, ARDS should take time to develop. Lung blebs should not pose a significant problem when evaluating both hemithoracies and lung contusions; unless they are very severe they should not obliterate the sliding lung sign bilaterally.

LIMITATIONS

The limitations of our study arise from the use of cadavers for subjects. Although ventilation of the lungs yielded a sonographic sliding lung sign, postmortem changes could affect US images. We do not believe, however, that the capacity to image the sliding lung sign on live patients would provide any greater difficulty or differences in imaging. We excluded any cadaver with known thoracic trauma or surgery. Therefore, in the undifferentiated critically ill patient, thoracic pathology may yield a different result. Mucous plugging, foreign body, pulmonary contusions, or subcutaneous air could all affect results in real patients. The anatomic response of the pleura as visualized by US could be different from that of a patient in the ED. False-negative results could be seen in patients with a pneumothorax and possibly in those with large bullae. Both scenarios can interfere with the normal pleural interface and subsequently disrupt the production of the sliding lung sign on US images, despite ventilation of the affected lung. Finally, only two sonologists were compared in this study. Further studies on live patients and examinations of the sliding lung sign in the face of these potential confounding factors are warranted.

CONCLUSIONS

Our results show that US imaging of the sliding lung sign in a cadaver model is an accurate method for confirmation of endotracheal tube placement. Further, the technique may have some utility in differentiating right main stem bronchus from main tracheal intubations.

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