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A Prospective Evaluation of Transverse Tracheal Sonography During Emergent Intubation by Emergency Medicine Resident Physicians

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Objectives—Establishing a definitive airway is often the first step in emergency department treatment of critically ill patients. Currently, there is no agreed upon consensus as to the most efficacious method of airway confirmation. Our objective was to determine the diagnostic accuracy of real-time sonography performed by resident physicians to confirm placement of the endotracheal tube during emergent intubation.

Methods—We performed a prospective cohort study of adult patients in the emergency department undergoing emergent endotracheal intubation. Thirty emergency medicine residents, who were blinded to end-tidal carbon dioxide detection results, performed real-time transverse tracheal sonography during intubation to evaluate correct endotracheal tube placement.

Results—Seventy-two patients were enrolled in the study. Sixty-eight instances (94.4%) were interpreted as correct placement in the trachea; 4 (5.6%) were interpreted as esophageal, of which 1 was a false-negative finding, therefore conferring sensitivity of 98.5% (95% confidence interval, 92.1%–99.9%) and specificity of 75.0% (95% confidence interval, 19.4%–99.4%) for correct placement. There was no significant difference in accuracy among resident sonographers with different levels of residency training.

Conclusions—A simple transverse tracheal sonographic examination performed by emergency medicine resident physicians can be used as an adjunct to help confirm correct endotracheal tube placement during intubation. In our cohort, the level of training did not appear to affect the ability of residents to correctly identify the endotracheal tube position.

Key Words—airway confirmation; emergency medicine; intubation; sonography

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Abbreviations

CI, confidence interval; CO_2, carbon dioxide; ED, emergency department; EM, emergency medicine; $ETCO_2$, end-tidal carbon dioxide

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Securing a definitive airway via endotracheal intubation is often necessary in the treatment of critically ill patients in an emergency department (ED) setting. In the United States, approximately 3 million endotracheal intubations take place outside the operating room annually.[1] According to the National Hospital Ambulatory Care Survey provided by the Centers for Disease Control and Prevention in 2011, approximately 259,000 intubations were reported in EDs in the United States. Despite this volume, however, there continue to be challenges in confirming correct placement of endotracheal tubes, with studies reporting rates of esophageal intubation between 1% and 24%.[2–5] Although esophageal intubation is less common in the hands of well-trained emergency medicine (EM) physicians, the inability to detect an improperly placed endotracheal tube can lead to disastrous outcomes such as death and hypoxic brain injury if not discovered and corrected quickly.[6–10] Current methods of confirmation include auscultation of breath sounds, colorimetric end-tidal carbon dioxide ($ETCO_2$) detection, digital $ETCO_2$ detection, and carbon dioxide (CO_2) waveform capnography. In the operating room, the current standard is the combination of direct visualization during intubation, coupled with CO_2 waveform capnography.[9–11]

Given the importance of accuracy during endotracheal intubation coupled with the growing presence of ultrasound in the hands of EM physicians, there has been a greater role for sonography in confirming endotracheal intubation. A recent study by Chou et al[12] demonstrated sensitivity of 98.9% and specificity of 94.1% for physicians thoroughly trained in airway sonography.[13] However, to the best of our knowledge, no previous studies have compared EM resident physicians at different stages of training using real-time bedside sonography to confirm correct placement of endotracheal intubation. Our primary objective was to determine whether EM resident physicians were able to confirm correct placement of endotracheal tubes using bedside sonography in real time compared with colorimetric $ETCO_2$ detection. A secondary objective was to determine whether the level of training played a role in the diagnostic accuracy of sonography.

Materials and Methods

Study Design and Setting

We performed a prospective cohort study designed to assess the diagnostic accuracy of real-time ED bedside sonography in confirming the position of endotracheal intubation. Patients were enrolled at a single center between December 2013 and December 2015. All data was collected at our county hospital ED with a level 1 trauma center supporting an EM postgraduate year 1–3 residency program and an annual census of more than 120,000. We included a total of 30 EM resident physicians in our data collection. None of these physicians had any previous sonography training in medical school or any formal sonography training on anterior neck anatomy. Each resident physician participated in a 30-minute training session, which included a lecture on how to perform tracheal sonography. This session was followed by a hands-on sonography training session with standardized live human models. Resident physicians performed a single scan of the anterior neck and identified the anterior airway and esophagus. Once the resident physicians were able to identify the correct anatomy, they were able to enroll patients in the study. No additional training sessions were performed. The ultrasound director objectively assessed and ensured competency of each resident physician.

This study was conducted in compliance with the rules and regulations of the Health Insurance Portability and Accountability Act as well as in adherence to the Declaration of Helsinki and all other relevant federal and state laws. The study was approved by the Institutional Review Board with waiver of informed consent.

Patient Selection

We considered all patients requiring emergent intubation for study enrollment between December 2013 and December 2015. Patients were enrolled by the research team using convenience sampling any time EM resident physicians were present in the ED. No patients were enrolled during protected weekly resident teaching conference time, as no resident physicians were in the ED. Patients were considered eligible for study enrollment if they were older than 18 years and required emergent intubation in the ED. We excluded patients who were younger than 18 years, were pregnant, had cervical spine immobilization, were suspected of neck injuries, or had anterior neck lesions, masses, or lacerations. We also excluded patients who had a need for cricothyroid pressure or bimanual laryngeal manipulation that could not be performed concomitantly with sonography. Patients undergoing active cardiopulmonary resuscitation were also excluded to maximize all resuscitative efforts toward patient care.

Methods and Measurements

All intubations were done under direct supervision of an attending physician to ensure patient safety at all times. Enrolled patients were deemed to need emergent intubation in the ED before consideration for the study. Before the intubation attempt, all patients had a colorimetric $ETCO_2$ detector and ultrasound system ready at the bedside. We instructed physicians to perform the intubation using the medication, technique, and equipment they thought was most appropriate for the patient.

During the intubation attempt, a resident performing sonography was positioned at the side of the patient with the sonographic screen facing away from the resident performing the intubation. An M7 ultrasound system (Mindray North America, Mahwah, NJ) was used to capture images and video clips. In the moments before the intubation attempt, a 6-MHz linear transducer was placed on the patient's anterior neck above the suprasternal notch with the transducer marker to the patient's right to identify the patient's anatomy, including the trachea and esophagus (Figure 1). During the intubation attempt, while the endotracheal tube was being passed, a 6-second video clip was recorded, followed by a still postintubation image (Figure 2).

Immediately after the intubation attempt and before $ETCO_2$ results, the residents performing sonography recorded their perceived interpretation of tube placement based on their sonographic findings. An intubation was considered endotracheal if there was the presence of hyperechoic comet tail artifacts with posterior shadowing in the trachea (Figure 2). An intubation was considered esophageal if there was the presence of a second airway adjacent to the midline of the trachea with a hyperechoic artifact, also known as the "double-tract sign." Once the patient was stabilized, the intubating resident recorded basic demographic data, including markers of intubation difficulty (ie, Cormack-Lehane score). Both the resident intubator and the resident performing sonography were blinded to each other's results and had separate data collection forms. We recorded the postintubation $ETCO_2$ confirmation using colorimetric detection and considered this method the reference standard. Last, we performed clinical assessments of proper tube depth, including chest radiography. Any patient found to have an esophageal intubation based on objective postintubation findings could be eligible for reenrollment in the study. Data were combined in Microsoft Excel (Microsoft Corporation, Redmond, WA).

Outcome Measures

The primary outcome measure of the study was the accuracy of real-time bedside tracheal sonography performed by minimally trained resident physicians to detect passage of the endotracheal tube into the trachea or esophagus. A true-positive finding was considered an endotracheal intubation that was correctly identified, and a true-negative finding was considered an esophageal intubation that was correctly identified. A secondary measure was a to compare EM resident physicians with different levels of training to determine whether sonographers with greater experience had improved accuracy in determining tube placement.

Figure 1. Sonogram showing a transverse view of the trachea (anterior) and the esophagus (posterior). The carotid artery is also shown on the lateral aspect of the image.

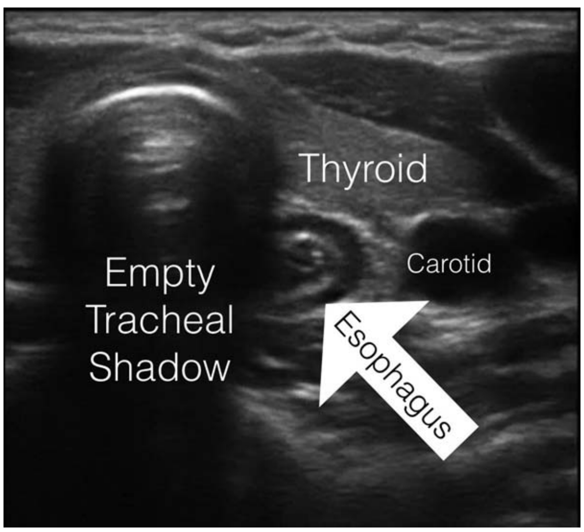
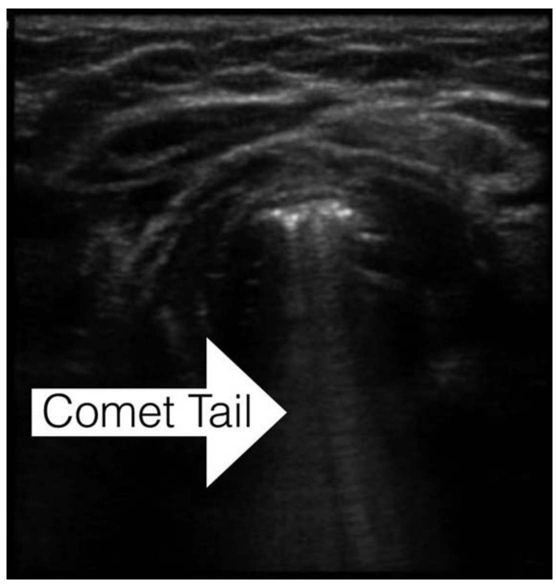


Figure 2. Sonogram showing a transverse view of the anterior trachea with the comet tail artifact emanating from the trachea, indicating that the endotracheal tube is in the correct position.



Data Analysis

All data were collected and managed on REDCap secured servers (Vanderbilt University, Nashville, TN). We analyzed the data using Stata version 12.1 software (StataCorp, College Station, TX). We calculated test characteristics for sonographic interpretation using CO_2 capnography as the reference standard for tracheal intubation. The sensitivity, specificity, positive predicted value, negative predictive value, and overall accuracy for point-of-care sonography compared with the reference standard were calculated.

Results

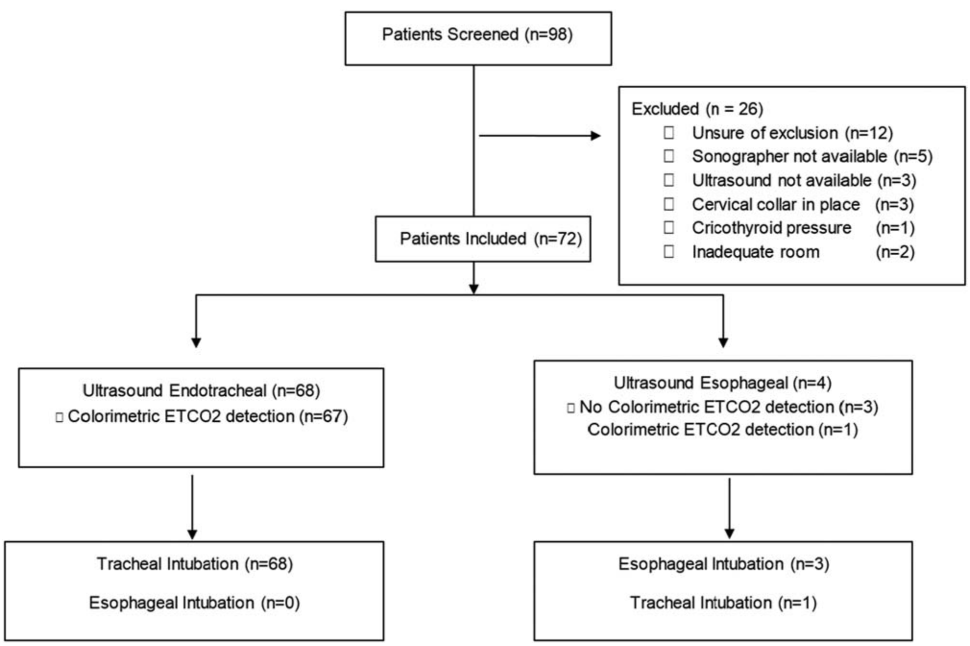
A total of 72 patients were enrolled in the study (Figure 3). The average age was 57.7 years (range, 20–91 years); the average body mass index was 28.5 kg/m^2 (range, 13.6–55.1 kg/m^2); and 57 (56.9%) were male. Additional demographic data are outlined in Table 1.

Sonography correctly showed endotracheal tube placement in 68 patients (94.4%). There were 4 instances (5.6%) in which the sonographic findings were interpreted as esophageal; however, 1 of these was in the trachea. The test characteristics of sonography conferred sensitivity of 98.5% (95% confidence interval [CI], 92.1%–99.9%), specificity of 75.0% (95% CI, 19.4%–99.4%), positive predictive value of 98.5% (95% CI, 92.1%–99.9%), negative predictive value of 75.0% (95% CI, 19.4%–99.4%), and accuracy of 97.2% (95% CI, 91.7%–99.9%). The breakdown for each subgroup is listed in Figure 4.

Discussion

Multiple studies to date have already validated bedside sonography as a reasonable choice for airway confirmation by experienced users.[13–15] Airway confirmation is required in patients to confirm correct tube placement to prevent hypoxic brain injury.[14–21] Although there are multiple views and techniques that one can use to confirm intubation, Rosenstein et al[22] showed that the transverse tracheal approach is the most accurate and easiest for novice users to learn in cadaver models. In this study, we sought to determine whether real-time tracheal sonography, in the hands of minimally trained EM resident physicians, was able to correctly show endotracheal tube placement. Based on our data, we believe that this outcome was achievable, as transverse tracheal sonography had high sensitivity but relatively low specificity and negative predictive value. We believe that this low negative predictive value was likely due to the limited number

Figure 3. Flow diagram depicting the total numbers of patients enrolled and excluded and the categories of patients.



of esophageal intubations that occurred during our study period.

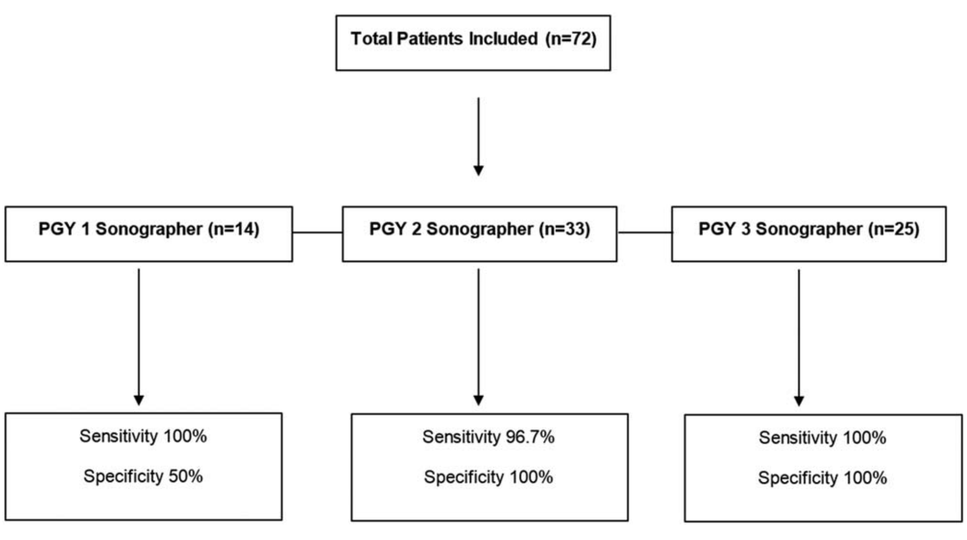
In our data set, the single observed false-positive finding (endotracheal by sonography but esophageal by $ETCO_2$) was likely entered in error. In this particular instance, the interpretation of endotracheal intubation was recorded on the basis of a sonographic examination that was performed by the resident and confirmed by the ultrasound director when he reviewed the images. Indeed, the data collection sheet suggested no direct visualization of the vocal cords during the intubation. Furthermore, it was documented on the data collection form that the $ETCO_2$ device had failed to show accurate colorimetric verification. However, on further review of the procedure dictation note, it was revealed that this particular intubation required two attempts, as the first was thought to be esophageal in nature. We therefore concluded that the sonographic examination likely was performed during the second intubation attempt, but data were used from the $ETCO_2$ result of the initial intubation. Therefore, this factor likely falsely skewed our specificity for a lower-than-actual result. However, to the maintain accuracy and fidelity of our initial collection points, we included this result even though it was most likely obtained incorrectly.

One notable finding from our data was that the level of residency training did not significantly play a role in the ability of the EM resident sonographer to correctly identify endotracheal tube placement. In our data, only 1 false-negative finding (esophageal by sonography but endotracheal by $ETCO_2$) existed, and incidentally, this examination was performed by a postgraduate year 2 resident. On retrospective review, the false-negative sonographic finding, determined to be esophageal by the resident sonographer, was correctly identified as endotracheal by the ultrasound director. This result may

Table 1. Complete Patient Demographics

Characteristic	Value
Average age, y	57.7
Male, %	56.9
Average body mass index, kg/m^2	28.5
White, %	56
Cormack-Lehane score, %	
Grade 1	39
Grade 2	44
Grade 3	15
Grade 4	1
Intubation indication, %	
Altered mental status	43
Respiratory distress	54
Cardiac disorder	3
Medical history, %	
Pulmonary disease	19
Cardiac disease	21
Diabetes mellitus	14
Hypertension	14
Renal disease	8
Nervous system disease	7
Unknown	8
Other	8

Figure 4. Flow diagram depicting the total number of patients enrolled in the study divided by the resident physician in each postgraduate year (PGY).



indicate that some mastery of sonography may influence the ability of the sonographer to determine correct endotracheal tube placement, although level of residency training may not be the most predictive factor. Future studies may be done to determine the amount of sonography training required to correctly identify the endotracheal tube position after emergent intubation. Based on our data, it appears that EM resident physicians can successfully use bedside sonography as an adjunct to auscultation, $ETCO_2$ detection, and waveform capnography to confirm the location of the endotracheal tube during intubation. Although our results are promising, further larger clinical studies must be performed to thoroughly evaluate the usefulness of real-time transverse tracheal sonography to confirm tube placement during emergent intubation.

There were several limitations to our study. First, the total number of esophageal intubations was quite low relative to the number of endotracheal intubations. Second, although all efforts were made to blind the sonographer and the intubator, it was nearly impossible to keep objective and subjective data completely private, given the information exchange during intubation. Despite the fact that we had postgraduate year 1, 2, and 3 residents in separate data pools, most of the ability to perform sonography is user dependent, and it is possible that some postgraduate year 1 residents may have had more experience with sonography than a postgraduate year 3 resident. Additionally, at academic EDs, multiple personnel may be present during intubations and can assist with confirmation using sonography. This situation may not be the case at many smaller single-coverage EDs. Furthermore, the most challenging airways are often encountered during cardiopulmonary resuscitation or in patients wearing cervical collars, and those patients were excluded from the study to maximize all efforts toward the resuscitation. Future studies will need to assess this population, as these patients may not show $ETCO_2$ colorimetric changes, and bedside sonography in this population could be of great value in confirming correct placement of the endotracheal tube. No attempts were made to determine the depth of the endotracheal tube using sonography. Last, because of resident time restraints and exclusion criteria, patient enrollment was by convenience.

In conclusion, our data suggest that minimally trained EM resident physicians can use real-time transverse tracheal sonography during emergent intubation as an adjunct to determine correct placement of an endotracheal tube. Additionally, the level of training did not appear to have a significant impact on the ability of the sonographer to determine endotracheal versus esophageal intubation.

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