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ARTICLE

A Prospective Comparison of Diaphragmatic Ultrasound and Chest Radiography to Determine Endotracheal Tube Position in a Pediatric Emergency Department

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What's Known on This Subject

Diaphragmatic ultrasound is one of several potential applications of sonography to the process of confirming endotracheal intubation. One previous study, lacking formal comparison to a gold standard, found diaphragmatic ultrasound accurate for both mainstem and esophageal misplacement.

What This Study Adds

Diaphragmatic ultrasound results disagree significantly with chest radiography results for confirming ETT position within the airway in emergently intubated children. Ultrasound results were faster and highly reproducible.

ABSTRACT

BACKGROUND. Investigators report endotracheal tube misplacement in up to 40% of emergent intubations. The standard elements of confirmation have significant limitations. Diaphragmatic ultrasound is a potentially viable addition to the confirmatory process. Our primary hypothesis is that ultrasound is equivalent to chest radiography in determining endotracheal tube position within the airway in emergent pediatric intubations.

METHODS. We enrolled a prospective, convenience sample from all intubated patients in our emergency department. The primary outcome was the agreement between diaphragmatic ultrasound and chest radiography for endotracheal tube position. On ultrasound, tracheal placement equaled bilateral diaphragmatic motion, bronchial placement equaled unilateral diaphragmatic motion, and esophageal placement equaled no or paradoxical diaphragmatic motion during delivery of positive pressure. Study sonographers were blind to radiographic results. Our secondary outcome was the timeliness of ultrasound versus chest radiography results. Our institutional review board approved this study with a waiver of informed consent.

RESULTS. One hundred twenty-seven patients were enrolled. In 24 (19%) patients, the endotracheal tube was in the mainstem bronchus on chest radiography. There were no esophageal intubations in the sample. Ultrasound and chest radiography agreed on endotracheal tube placement in 106 patients (94 tracheal and 12 mainstem), for an overall agreement of 0.83. The sensitivity of ultrasound for tracheal placement was 0.91. The specificity of ultrasound for mainstem intubation was 0.50. Thirty-four patients had a second ultrasound by a separate, blinded sonographer; 33 of 34 of the results of the second sonographer were in agreement with the initial sonogram, for an interrater agreement of 97%. Clinically useful chest radiography results took a median of 8 minutes longer to achieve than ultrasound results.

CONCLUSIONS. Diaphragmatic ultrasound was not equivalent to chest radiography for endotracheal tube placement within the airway. However, ultrasound results were timelier, detected more misplacements than standard confirmation alone, and were highly reproducible between sonographers. *Pediatrics* 2009;123:e1039–e1044

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Key Words
intubation, ultrasound, pediatric, radiograph, emergency

Abbreviations
ETT—endotracheal tube
CXR—chest radiograph
ED—emergency department
$ETCO_2$—end-tidal carbon dioxide
CI—confidence interval

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PUBLISHED ESTIMATES OF endotracheal tube (ETT) misplacement in emergently intubated children range from 17% to 40%.[1–3] The 2 types of ETT misplacement are airway, exemplified by mainstem intubation, and nonairway. In an unpublished, 12-month review of emergency department (ED) intubations at our institution, 43% were in the right mainstem bronchus on the confirmatory chest radiograph (CXR). Nonairway misplacement is potentially more serious and typified by esophageal intubation. In the only study from a pediatric ED, investigators reported that 9 of 48 (18%) intubations were esophageal.[2] Any ETT misplacement puts patients at risk of hypoxia and hypercarbia, compounding existing illness before corrective action.

The guidelines for pediatric advanced life support require highly reliable confirmatory methods after intubation.[4] We consider primary confirmation as those elements performed before the ETT is secured, including visualization of the ETT passing the glottis, notation of mist in the ETT, observation of chest rise, auscultation of breath sounds, and end-tidal carbon dioxide ($ETCO_2$) measurement. The usefulness of direct visualization is limited by a lack of evidence. Few studies address the accuracy of ETT mist, chest rise, and auscultation. What has been reported suggests these elements are inadequate indicators of ETT placement.[2,5–8]

$ETCO_2$ detection is the gold standard within the primary or immediate confirmatory process. The presence of $ETCO_2$ confirms an ETT is in the airway, with excellent sensitivity and specificity in the nonarrest patient.[9] A major limitation of $ETCO_2$ detection is the inability to distinguish between tracheal and mainstem intubation.

CXR is the gold standard for secondary confirmation, which determines the position of an ETT within the airway after primary confirmation has detected all nonairway placements. A major limitation of CXR is the time required for results to be received by the resuscitating team.[10]

Diaphragmatic ultrasound is a novel adjunct to the confirmatory process. Potential advantages include detection of both mainstem and esophageal intubations and less time to image availability than CXR. The sole study on confirmatory, diaphragmatic ultrasound was limited by the lack of a formal gold standard comparison.[1] The objective of our study was to determine if diaphragmatic ultrasound rapidly and accurately confirms ETT placement. Our principal hypothesis was that diaphragmatic ultrasound is equivalent to CXR in determining the position of an ETT within the airway after the intubation of critically ill or injured children.

METHODS

Study Design and Sample

Patients were enrolled in a prospective, convenience fashion. The eligible sample consisted of intubated ED patients after both securing of the ETT and the performance of a confirmatory CXR. Patients were ineligible for enrollment if the results of any confirmatory CXR were known or if a CXR was not performed. There was no exclusion for age. We excluded otherwise eligible patients if the care team deemed enrollment would have disrupted patient care, if no study sonographer was available, or if the only sonographer was the physician in charge of the resuscitation.

Outcomes

The primary outcome was agreement for ETT position between diaphragmatic ultrasound and CXR. The diaphragm on ultrasound is an echogenic line best visualized apposed to the spleen/stomach on the left and the liver on the right.[1] Study sonographers were instructed to define ETT position as (1) tracheal if ventilation produced bilateral diaphragmatic movement in the caudal direction, (2) bronchial if ventilation produced ipsilateral hemidiaphragmatic movement in the caudal direction, and (3) esophageal if ventilation produced no or cephalad diaphragmatic movement. The final CXR interpretation by an attending radiologist was the gold standard for comparison. The radiographic definitions of ETT placement were (1) tracheal, (2) bronchial, and (3) nonairway/esophageal. We dichotomized ultrasound and CXR results into tracheal or nontracheal placement, the latter to include esophageal and mainstem intubations.

Our secondary outcome was the time required for the communication of ultrasound and CXR results. Ultrasound time started when the device was turned on and ended when the sonographer gave his or her impression to the physician in charge. CXR time was from the performance of the CXR by the radiology technician until an interpretation was communicated in any fashion to the physician in charge.

When available, a separate study sonographer performed a second sonogram, which was used only to calculate a percent agreement and κ statistic.

Sonographer Recruitment and Training

Ten ED physicians and 9 respiratory therapists volunteered to be study sonographers. Drs Kerrey and Geis, both study sonographers and self-taught with diaphragmatic ultrasound, conducted the training program. Sonographers were instructed to perform diaphragmatic ultrasound in the following steps: (1) turn on the ultrasound device (time: 0); (2) hold the probe (a low frequency, 2-MHz transducer) in the right hand with the thumb placed in the probe's notched side; (3) position the probe midline and transversely at the subxiphoid space, with a 45° angle to the skin; (4) vary the angle until either 1 or both halves of the posterior diaphragm are seen; (5) observe for motion of each half of the diaphragm during positive pressure ventilation; (6) if only the right hemidiaphragm is visible, note its movement then shift the probe toward the left nipple/shoulder at a 45° angle; and (7) again, vary the angle until the left hemidiaphragm is visualized and note its movement with positive pressure.

Sonographers performed training sonograms on pediatric volunteers, 1 each from 5 age ranges (0–12 months, 13–36 months, 3–7 years, 8–12 years, and >12 years). Study authors confirmed accurate recognition of diaphragmatic motion for each training sonogram.

Enrollment Protocol

The study protocol was approved by the institutional review board of the Cincinnati Children's Hospital Medical Center with a waiver of informed consent. After intubation, the resuscitating team confirmed ETT placement as per standard of care. A study sonographer performed diaphragmatic ultrasound after the confirmatory CXR to limit disruption of the confirmatory process by an unproven modality. CXR images were processed in standard fashion. On completion, the sonographer immediately communicated the results to the physician in charge. The care team was expected not to reposition any ETT based solely on the results of the ultrasound.

Blinding
Sonographers were blind to the CXR results but not to the primary confirmation and $ETCO_2$ results. Sonographers performing a second (κ) ultrasound were blind to the primary ultrasound interpretation and CXR results. Radiologists were blind to the entire confirmatory process and sonography.

Data Collection
A clinical research coordinator and/or sonographer recorded on a standard form all data available at enrollment. Study authors met twice a month to record the attending-verified CXR interpretation. In addition, study authors regularly reviewed ED records to collect data on all missed eligible and excluded patients.

Sample-Size Calculation
To calculate a sample size for the primary outcome, we made the following assumptions: (1) an α value equal to .05; (2) a β value equal to .1; and (3) disagreement between ultrasound and CXR results would be 5% or less for tracheal versus nontracheal ETT placement. On the basis of these assumptions, we estimated 127 patients would be needed to detect a statistically significant disagreement of 5% or more between ultrasound and CXR results. We estimated a separate sample size of 33 patients for the second (κ) sonogram.

Statistical Analysis
For each of the following variables we used either a *t* test (continuous variables) or Fisher's exact test (categorical variables) to determine statistically significant differences between enrolled and missed-eligible patients: percentage of misplaced ETTs, age, BMI, gender, ethnicity, type of resuscitation, presence of thoracic disease on CXR, and presence of cardiopulmonary arrest.

Our primary outcome was a binary indicator of agreement between CXR and ultrasound. We used a *t* test to determine if the disagreement between ultrasound and CXR was statistically significant. We calculated sensitivity, specificity, and positive and negative predictive values for ultrasound against CXR as the gold standard. We calculated the area under the receiver operating characteristic curve for ultrasound predicting CXR without the use of covariates. We calculated the median time difference between ultrasound and CXR, along with interquartile and overall ranges. Finally, we examined, both individually and as potential candidates in a multivariable model, the effect of the following variables on the primary outcome: patient age, race, gender, BMI, type of resuscitation, type of sonographer, and the presence of thoracic disease and stomach distention on the confirmatory CXR. The presence of the final 2 variables was taken from the attending-verified CXR impression.

RESULTS

Enrolled Versus Missed Eligible Patients
Over 16 months there were 244 intubated patients in our ED (Fig 1). Of the 197 eligible patients, we enrolled 127 (65%). Seventy patients were eligible but not enrolled (missed eligibles). The percentage of mainstem intubations was similar between the 2 groups (Table 1). The proportion of patients with a traumatic injury and in cardiopulmonary arrest at intubation was significantly lower in the enrolled group. There were no other significant differences between groups.

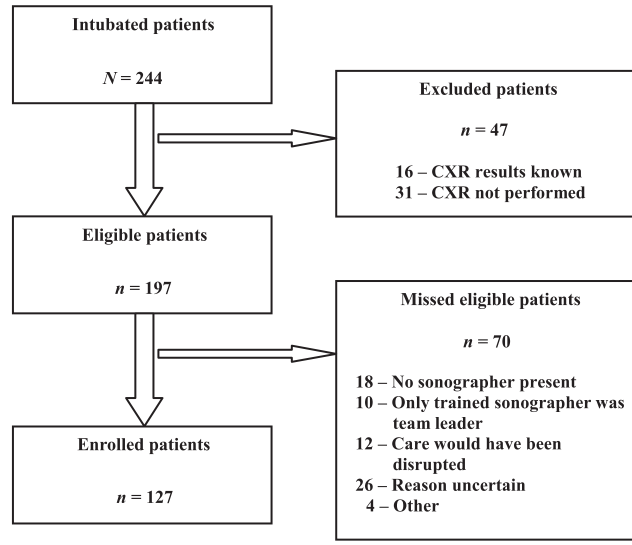

FIGURE 1
Flowchart of patient enrollment.

Primary Outcome
$ETCO_2$ was detected in all study patients after intubation. No study patient had an esophageal intubation detected by any means after enrollment. Because there

TABLE 1 Comparison of Enrolled Versus Missed Eligible Patients

	Enrolled (*N* = 127)	Missed Eligible (*N* = 70)	*P*
Misplaced ETT, *n* (%)	24 (19)	15 (22)	.709
Age, mean (SD), y	5.75 (6.42)	6.98 (6.52)	.204
BMI, mean (SD)	18.1 (5.2)	17.8 (4.1)	.712
Male gender, *n* (%)	83 (65)	39 (56)	.220
Ethnicity, *n* (%)			.771
White	71 (56)	36 (51)	
Black	39 (31)	25 (36)	
Hispanic	5 (4)	1 (1)	
Multiethnic	5 (4)	4 (6)	
Other	6 (4)	4 (6)	
Asian	1 (1)	0 (0)	
Type of Resuscitation			
Medical illness	109 (86)	46 (66)	.002
Traumatic injury	18 (14)	24 (34)	.002
Thoracic disease on CXR, *n* (%)	67 (53)	44 (63)	.605
Bronchiolitis	15	7	
Basilar opacity	40	18	
Distended stomach	6	12	
Pulmonary edema	1	7	
Pneumothorax	0	2	
Pleural effusion	2	2	
Scoliosis	3	1	
Cardiopulmonary arrest at intubation, *n* (%)	2 (2)	10 (14)	$<.001$

TABLE 2 Primary Outcome

	CXR Tracheal, *n*	CXR Nontracheal, *n*	Total, *n*
Ultrasound tracheal	94	12	106
Ultrasound nontracheal	9	12	21
Total	103	24	127

were no esophageal intubations in our sample, the outcome of "nontracheal" for ETT placement was equivalent to mainstem intubation.

Ultrasound and CXR agreed on ETT placement in 106 patients (94 tracheal and 12 mainstem), for an overall agreement of 83% (95% confidence interval [CI]: 0.76–0.90) (Table 2). This percentage agreement is significantly lower ($P < .001$) than the level of equivalency assumed for the sample-size calculation (95% agreement). The area under the receiver operating characteristic curve for ultrasound predicting CXR was 0.71 without accounting for any covariates.

Ultrasound falsely reported mainstem misplacement in 9 of 103 tracheal intubations, giving a sensitivity of ultrasound for tracheal placement of 0.91 (95% CI: 0.84–0.96). For 24 (19%) patients, mainstem intubation went undetected by primary confirmation. Ultrasound correctly identified 12 of these 24 mainstem intubations, giving a specificity of ultrasound for mainstem intubation of 0.50 (95% CI: 0.30–0.70). When the ultrasound determined the ETT was tracheal, 94 of 106 patients had a tracheal placement by CXR, giving a positive predictive value of 0.89 (95% CI: 0.81–0.94). When the ultrasound determined the ETT was mainstem, 12 of 21 patients had mainstem placement by CXR, giving a negative predictive value of 0.57 (95% CI: 0.34–0.77).

Interrater Reliability for Ultrasound

In 34 of 127 patients, a second sonographer performed an independent ultrasound. The 2 sonographers agreed on ETT placement for 33 of 34 patients (97% agreement). There were 29 agreements on tracheal placement, 4 on mainstem, and 1 disagreement where the first sonographer determined the ETT was tracheal and the second mainstem. The κ statistic was 0.87.

Secondary Outcome

We had time data from both ultrasound and CXR for 72 (57%) of 127 patients. CXR results took a median of 8 minutes longer than ultrasound to be communicated to the physician in charge. The interquartile range for time difference was 6 to 14 minutes, and the overall range was 0 to 46 minutes.

Logistic Regression

Disagreement was 15.8 times more likely for patients with stomach distention versus patients without stomach distention on CXR ($P = .004$; Table 3). Agreement between ultrasound and CXR was 3.5 times as likely in nonwhites versus whites ($P = .035$). Each year of age ($P = .066$) was associated with an increase of 10.4% in agreement. Lastly, there was a trend for study sonographers who were respiratory therapists to achieve higher agreement than physicians ($P = .071$).

TABLE 3 Association of Individual Factors With Agreement Between Chest Radiograph and Ultrasound

Factor	Odds Ratio	95% CI
Age (per year)	1.07	0.98–1.18
Gender (male vs female)	1.46	0.56–3.79
Ethnicity (nonwhite vs white)	2.23	0.80–6.19
BMI (per 10 points)	1.67	0.53–5.25
Pathology on CXR	0.78	0.31–2.00
Stomach distention	0.08	0.01–0.50
Type of resuscitation (trauma vs medical)	1.69	0.36–7.97
Sonographer (RT vs MD)	2.05	0.80–5.28

RT indicates respiratory therapist; MD, physician.

DISCUSSION

In this study, diaphragmatic ultrasound performed by novice sonographers on emergently intubated children was not equivalent to CXR in determining ETT placement within the airway. The superior accuracy of CXR to detect mainstem intubation was at the cost of timeliness. We found high interoperator agreement, suggesting ultrasound might be applied with at least equal accuracy by other novice sonographers in similar settings. Finally, we found that ultrasound agreed more often with CXR for older, nonwhite patients without stomach distention on CXR.

Although we anticipated both types of ETT misplacement, our study design made the inclusion of patients with esophageal misplacement highly unlikely. Because no study patients had a nonairway ETT after enrollment, we cannot comment on the accuracy of diaphragmatic ultrasound for esophageal intubation.

For sonographic assessment of ETT placement, investigators have used 3 windows: tracheal (direct), intercostal (indirect), and subxiphoid or diaphragmatic (indirect).[1,10–18] Direct ultrasound at the cricothyroid membrane or suprasternal notch assesses airway placement of the ETT and in theory is the confirmatory equivalent of $ETCO_2$ detection. Drescher et al[12] first described the use of tracheal ultrasound in 5 human cadavers. Other investigators have demonstrated its accuracy for confirming ETT placement in the airway.[13–15,18] In a recent 2-phase study performed in pediatric ED patients, tracheal ultrasound at the cricothyroid membrane had a sensitivity and specificity of 100% compared with clinical examination and CXR.[10]

Tracheal ultrasound and its supporting literature have several limitations, which our study addresses. First, tracheal ultrasound has no ability to differentiate tracheal from mainstem intubation.[10] Second, in several studies, there was no clear, blinded comparison to a gold standard.[12,15] Third, most of these studies involved patients intubated in relatively controlled settings, making results less applicable to emergently intubated patients.[12–15,18]

The intercostal sonographic window, an offshoot from a technique to diagnose pneumothorax, uses the "lung-sliding" sign to assess ETT position.[19] In 1 study, 2 sonographers using intercostal ultrasound on human cadavers each achieved a sensitivity and specificity close to 100% for tracheal versus esophageal placement. However, sensitivity for mainstem versus tracheal placement was only 70% per sonographer.[17] Chun et al[11] reported that lung sliding accurately determined ETT placement in 15 adult patients. Blaivas and Tsung[20] recently described the use of lung sliding to detect mainstem intubation in 3 adult emergency patients. Images from the intercostal window were significantly more difficult to obtain and interpret for the authors of our study (B.T.K. and G.L.G., unpublished observations, 2007). We chose to investigate the diaphragmatic window rather than the lung-sliding sign on the basis of author experience, the lower reported sensitivity of intercostal ultrasound for mainstem intubation, and the high number of right mainstem intubations in our population.

Investigators have demonstrated accurate visualization of diaphragmatic motion by sonography,[21,22] but only 2 have reported on its use to confirm ETT placement.[1,20] In a series of 59 pediatric intensive care patients, Hsieh et al[1] used diaphragmatic ultrasound to accurately detect ETT position, including 2 esophageal and 8 mainstem intubations. The primary limitation to the Hsieh et al study that we attempted to address was the lack of a formal, gold standard comparison for ultrasound.

Although we achieved a reasonably high percentage agreement, the 9 "false-negatives" in our sample are concerning. These were cases where tracheal intubations were falsely determined to be mainstem by ultrasound. If ultrasound were used as the main determinant of ETT repositioning, these patients would be at risk for extubation.

Multivariable analysis was performed to define a subpopulation of intubated patients where agreement was highest and the risk of false-negatives lowest. Our results indicate ultrasound may be more accurate, and therefore safer, in older children with nondistended stomachs. Of the 9 false-negatives, 3 had a distended stomach on confirmatory CXR. It is likely that for at least these patients, the distended stomach prevented visualization of the left hemidiaphragm in the subxiphoid window. If the sonographer cannot visualize the left hemidiaphragm, then alternate windows, such as intercostal, could be used.

False-positives were mainstem intubations assessed incorrectly as tracheal by ultrasound. Increasing age was likely associated with more agreement in our multivariable analysis because of the increased risk of a false-positive ultrasound in younger patients. The median age of patients with a false-positive was <6 months versus 3 years for the other 115 patients. One potential explanation of this is the low frequency of the study transducer, because visualization of relatively superficial structures is difficult with low-frequency transducers.

We are surprised by the greater agreement in nonwhite children. In light of the ethnic disparities found in other areas of health care, this represents an interesting result. Future investigations into confirmatory ultrasound should assess for a similar association.

We found only 1 other study reporting the timeliness of CXR images. Galicinao et al[10] demonstrated that ultrasound was quicker to perform; CXR took a mean of 14 minutes from ordering to the point the result was obtained and ultrasound a mean of 17 seconds from initiation to the reporting of images. In demonstrating that the use of sonography also reduces the time to useful results, we added evidence for the considerable time advantage of sonography over CXR.

There were several limitations to our study. First, we had a brief training program for a novel technique. Although we did not assess agreement by individual sonographer, we expect that novice sonographers achieve proficiency after significantly >5 training sonograms. We feel strongly that more experienced sonographers would produce better agreement with CXR.

Second, we did not ask sonographers to specifically document visualization of the left hemidiaphragm, only to record an impression of ETT position. If the sonographer failed to visualize the left hemidiaphragm, it may have been documented as not moving and potentially affected the accuracy of the ultrasound results.

Third, the convenience sample design excluded patients for whom ultrasound might have been more or less accurate. We failed to enroll the majority of children in cardiopulmonary arrest, in whom a CXR is often not obtained, and enrolled no patients with an esophageal intubation, because these were likely detected before CXR (Table 1). These 2 not mutually exclusive groups are important populations for additional study. To capture these patients and determine the ability of diaphragmatic ultrasound to reduce the number of undetected, misplaced ETTs, we intend to study the incorporation of ultrasound into primary or immediate confirmation.

CONCLUSIONS

We found that diaphragmatic ultrasound is not equivalent to CXR in determining the position of an ETT within the airway. On the basis of our results, diaphragmatic ultrasound should not be the sole determinant of ETT repositioning with mainstem misplacement. However, ultrasound results were timelier than CXR results, detected more misplacements than standard confirmation alone, and were highly reproducible between sonographers despite limited training. We feel diaphragmatic ultrasound is a viable yet unproven adjunct to the confirmatory process and that additional investigation is justified.

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