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RESAERCH ARTICLE

A Novel Approach to Confirm Endotracheal Tube Depth Using Ultrasound Color Doppler: A Cadaveric Model

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Abstract

Objectives: Proper endotracheal tube (ETT) depth must be confirmed immediately after intubation. We developed a novel point-of-care ultrasound examination called the cuff puff (CP) and hypothesized it would accurately confirm appropriate ETT depth in a cadaveric model. CP comprises visualization of cuff inflation using color Doppler sonography.

Methods: On a single fresh frozen cadaver, a well-positioned tube was defined as the tip lying between 6.5 cm below the vocal cords and 3 cm above the carina. The ETT was placed at random depths predetermined by an online random number generator while a blinded sonologist visualized the ETT within the trachea in a transverse plane at the level of the suprasternal notch. A positive CP was defined as presence of a focused color Doppler signal during ETT cuff inflation. We compared CP results to bronchoscopy as a gold standard. Two blinded reviewers interpreted CP results on video review and inter-rater agreement was calculated.

Results: The sensitivity was 0.44 (0.20-0.70), specificity 0.91 (0.72-0.99), PPV 0.78 (0.40-0.97) and NPV 0.70 (0.51-0.85) for a positive CP representing a well-positioned ETT. The inter-rater agreement between the two blinded reviewers yielded a κ of 0.90 (0.72-1.00) and between each blinded reviewer and the bedside sonologist a κ of 0.90 (0.72-1.00) and 1.00 (1.00-1.00), respectively.

Conclusions: In a single cadaver, a positive CP is a reliable and specific sign that the ETT is inserted to an appropriate depth. Further study is needed in live patients.

Keywords

Intubation, Endotracheal tube, Ultrasound, Doppler, Cadaver

Background

Endotracheal intubation is a commonly performed procedure in the operating room, intensive care unit and emergency department. Following intubation, endotracheal tube (ETT) depth must be confirmed in order to ensure proper and safe placement. Low intubations, or endobronchial placement, occur in 1.5-28% percent of intubations [1,2] and are associated with ipsilateral barotrauma and contralateral lung collapse [3]. Shallow intubations are present in up to 10% of intubations and are associated with unintentional extubation and vocal cord injury [4]. With proper ETT placement, the ETT cuff is anatomically positioned at the sternal notch [5].

Plain chest radiography and bronchoscopy are the current gold standards for identifying ETT depth [6]. Bronchoscopy is limited in that it requires an interruption of ventilation and is not available in all settings. Chest radiographs are more commonly utilized to confirm proper ETT placement; however, they take

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time to acquire, necessitate repositioning the patient, and are a non-trivial source of ionizing radiation.

Physical exam has its limitations as well. In one study, bilateral breath sounds were paradoxically auscultated in 60% of right main stem intubations [7]. Visualization of bilateral lung sliding on ultrasound has been studied; however, sensitivity ranges from 69-78% for detecting endobronchial intubation [8]. Neither physical exam nor sonographic lung sliding is reliable methods to identify high ETTs.

Using ultrasound to visualize the ETT cuff in the suprasternal notch has been proposed as a method to confirm appropriate ETT depth [9]. One study found that visualization of a saline-filled ETT cuff in the suprasternal notch had a sensitivity of 99% and specificity of 96% for a well-positioned tube in anesthetized operating room patients [10]. However, the safety of this technique is questionable for prolonged intubations in the acute care setting; filling the cuff with saline constitutes an off-label use, and its long-term effects on cuff integrity are unknown.

We developed a novel method, the cuff puff (CP), for visualizing the ETT cuff in the suprasternal notch. We hypothesized that the presence of a focused color signal in the suprasternal notch during cuff inflation with air correlates with an endotracheal tube inserted to the appropriate depth; and conversely, that the absence of a color signal in the suprasternal notch correlates with a high or low ETT. Additionally, we tested the CP with different volumes of air to determine the minimal "dose" required to produce a positive signal. Finally, we explored the inter-rater reliability of the CP between blinded ultrasound clip reviewers and between the blinded reviewers and the bedside sonologist, respectively.

Methods

A single fresh frozen cadaver was intubated with a 6.0 mm GE RediTubeETT (GE Healthcare, IL). Using an Olympus BF-P40 fiberoptic bronchoscope (Olympus Corporation, PA), an anesthesiologist measured the endotracheal tube depth when its tip was at the carina and vocal cords to establish a starting position for the tube. A well-positioned ETT was defined as one whose tip was 3 cm superior to the carina and 6.5 cm inferior to the vocal cords. These limits were chosen prior to data collection to represent a safe buffer from high/low intubations accounting for tube migration that occurs with neck flexion, extension and rotation [11]. All ultrasound clips were obtained using a Zonare z. one Ultra connected to a 3 cm 10 Hz linear probe (Mindray, NJ).

For 39 consecutive trials carried out on a single day, the ETT was placed to depths at random 1 cm increments (using a predetermined randomization scheme from random.org) from the level of the vocal cords (too high) to 3 cm below the carina (too low). To test for proper ETT placement using the CP technique, a trained sonologist blinded to ETT depth placed the ultrasound probe over the suprasternal notch in the transverse plane and used color Doppler mode to visualize a cross-section of the trachea. The ETT cuff was then inflated with 3 cc of air, while simultaneously looking for a focused color signal within the trachea. If a signal was seen, the CP was considered positive, and if no signal was seen, it was considered negative (Videos 1 and 2). Test characteristics were determined by comparing ultrasound results to the depth as determined by the gold standard bronchoscopy.

To determine the minimal dose of air needed for positive signal, various volumes of air were tested (6 mL, 5 mL, 4 mL, 3 mL, 2 mL, 1 mL, 0.5 mL, pilot balloon squeeze) while the ETT was well positioned with the tip 5 cm above the carina [12]. With each respective volume of air, the sonologist noted whether the CP was visible or not.

At a later date, the inter-rater reliability of the CP was measured by comparing the interpretations of two independent reviewers who were shown 33 (6 of the original 39 measurements were inadvertently lost) digital video recordings in a random order.

For the statistical analysis, we used SAS 9.4. The test itself was analyzed against the "gold standard" using correlation statistics and Fisher's exact test. The sensitivity, specificity, PPV and NPV were also generated for the test against the gold standard as well as their respective 95% confidence intervals. Inter-rater reliability was calculated using 2 × 2 tables and correlation statistics with the reviewer "LN" as reference. Fisher's exact test was used to observe the consistency of the reviewers. Cohen's Kappa coefficient was used to test for agreement between blinded reviewers, and 95% confidence intervals were generated.

In consultation with the Columbia University IRB, ethics approval was not required as cadaver research was deemed outside the purview of human subject research.

Results

The cadaver's carina and vocal cords were at depths of 28 cm and 11.5 cm, respectively, using the lip as a reference point. Thus, the ETT was considered well-positioned when its tip was between 25 cm and 18 cm from the lip. Of the 39 random ETT depths tested, 16 were well-positioned and 23 were mal positioned based on the gold standard bronchoscopy (Table 1). The sensitivity of the CP for detecting a well-positioned tube was 0.44 (95% CI 0.20-0.70) and specificity was 0.91 (95% CI 0.72-0.99). The positive predictive value was 0.78 (95% CI 0.40-0.97), and negative predictive value was 0.70 (0.51-0.85). The positive likelihood ratio was 4.89, and negative likelihood ratio was 0.62.

Table 1: Results of the cuff puff *vs.* the gold standard bronchoscopy.

		Gold standard bronchoscopy		
		Well-positioned	High/Low	Total
Cuff Puff	Positive	7	2	9
	Negative	9	21	30
	Total	16	23	39

With the ETT tip placed at 5 cm above the carina, the CP was visible (true positive) regardless of the volume of air used (0.5 ml to 6 ml), and it was also seen for both inflation and deflation of the cuff. However, simply pressing on the pilot balloon did not provide an observable Doppler signal (false negative).

The inter-rater reliability between the two blinded reviewers was excellent with a κ = 0.9 (95% CI: 0.72-1.00). The inter-rater reliability between each blinded reviewer and the bedside sonologist yielded a κ of 0.90 (0.72-1.00) and 1.00 (1.00-1.00), respectively.

Discussion

In this cadaver study, a positive CP had a high specificity for detecting a well-positioned ETT. In other words, the presence of a CP signal is highly specific for a well-positioned tube. The specificity was low, however, meaning that some well-positioned tubes will have a negative CP. The CP was easy to perform and was visible even with varying techniques (inflation *vs.* deflation) and at nearly any volume of air down to 0.5 ml.

Our specificity of 0.91 was similar to a study by Tessaro that utilized ultrasound to visualize a saline-inflated cuff, yielding a specificity of 0.96 (95% CI 0.87-1.00). However, our sensitivity of 0.44 was much lower than that obtained by Tessaro of 0.99 (95% CI 0.90-1.00) [10]. One possible explanation for this discrepancy is that Tessaro employed a dynamic technique, gradually withdrawing the ETT until it was visible in the suprasternal notch, whereas we took sonographic snapshots of the suprasternal notch of randomly positioned tubes without manipulating their positions. It is also plausible that the discrepancy in sensitivities relates to a quality inherent to the air-filled technique as compared with the saline-filled technique.

The inter-rater agreement for what constituted a positive CP was excellent, with near-complete agreement between the two blinded reviewers. There was disagreement in only a single clip, in which motion artifact was interpreted as a positive CP by one of the reviewers. Our reviewers had extensive bedside ultrasound experience. Thus, future studies might examine agreement among those with less ultrasound experience.

This study has several limitations. First, it was performed in a single cadaver and thus the results may not be generalizable to other body habit. Second, the cadaver was not actively ventilated or moving, thus raising the question of whether motion artifact in live patients would increase the number of false positives. Third, the velocity inflation of the cuff was not standardized. Lastly, our confidence intervals were wide, with lower limit of confidence level being 72% for predicting a well-positioned tube in a positive CP.

Conclusions

In a cadaver model, a positive CP is a good indication that the ETT was inserted to an appropriate depth. Additionally, there is excellent agreement among reviewers about what constitutes a positive CP. Further studies are needed to determine the clinical feasibility and utility of this method.

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