Sensitivity and Specificity of a Novel Approach to Confirm the Depth of the Endotracheal Tube

A Pilot Study

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Abstract: This study aimed to explore the sensitivity and specificity an approach to confirm the depth of the endotracheal tube. It was a prospective, diagnostic study (Registration number: chiCTR-TRC-14005170) conducted in the Department of Anaesthesiology of West China Hospital. A total of 100 patients underwent general anesthesia were included. The distance between the upper margin of the cuff and the manubriosternal joint (CM) and the distance between the upper margin of the cuff and the carina (CC) were measured. The accuracy of the confirmed approach against fiberoptic bronchoscopy (FOB) was evaluated. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated. The correlation and agreement between CM and CC were explored. The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were determined to be 94.74% (95% CI: 87.07–98.55%), 79.17% (95% CI: 57.85–92.87%), 93.51% (95% CI: 85.49–97.86%), 82.61% (95% CI: 61.22%–95.05%), respectively. The k value was 0.75 (95% CI: 0.60–0.90). There was a significant correlation between CM and CC (P < 0.001) with a correlation coefficient of 0.91(95% CI: 0.87–0.94). Bland and Altman plots also demonstrated a good agreement between the CM and CC. This novel method may be used to confirm the depth of the endotracheal tubes.

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Abbreviations: CC = The distance between the upper margin of the cuff and the carina, CM = The distance between the upper margin of the cuff and the manubriosternal joint, CS = The distance between the upper margin of the cuff and the suprasternal notch, TC = The distance between the tip of the endotracheal tube and the carina, CT = The distance between the upper margin of the cuff and the tip of the endotracheal tube, FOB = fiberoptic bronchoscopy, PPV = positive predictive value, NPV = negative predictive value, SM = The distance between the suprasternal notch and manubriosternal joint, TC = The distance between the tip of the ET and the carina.

INTRODUCTION

Confirmation of the depth of the endotracheal tube (ETT) is the important focus of airway management. Improper depth of the ETT may lead to unplanned extubation or one-lung intubation. Both of them are associated with mortality and morbidity. Auscultation is often the only practical method used to identify the depth of the ETT in the operation room, but it cannot measure the distance between the tip of the ETT and the carina. Whereas the use of a fiberoptic bronchoscope (FOB) is regarded as the gold standard for measuring ETT depth, FOB is time-consuming. Raphael and Conard have reported that the depth of the ETT proper for the saline-filled cuff was to identify with placement of transducer (i.e. a 3.5-MHz linear phased-array transducer and a 5.0-MHz phased-array sector transducer) in the suprasternal notch. Uya et al confirmed by the chest x-ray that this position would place the distal end of the tube at about 2 cm from the carina. Pollard also reported that the location of the ETT could be verified if the cuff was at notch. However, the length of the cuff is about 3 cm. The authors did not reveal how long the cuff above the sternal notch should be kept for patient with different heights and whether a part of the cuff or the entire cuff should be kept? What is more, for different patients with different heights, the depths of the cuff should not always be the same.

The depth of the ETT is defined as the distance between the depth of the tip and the carina (TC). The distance between the upper margin of the cuff and the tip of the endotracheal tube (CT) could be measured before insertion. We calculated CC (the distance between the upper margin of the cuff and carina) by summing both TC and CT after insertion. Thus the depth of the ETT could be defined as CC. The manubriosternal joint was a well-known surface landmark for the carina although there may be individual variations. Thus CC could be switched to the distance between the upper margin of the cuff and the manubriosternal joint (CM). We hypothesized that both CM and CC could be clinically interchangeable. If the proper depth of the ETT is to keep TC in the range of 2 to 5 cm, then it would be equal to keep CM in the range from CT + 2 cm to CT + 5 cm after insertion. As a result, we could identify the depth of the ETT by CM instead of by TC. Because both TC and CC were immeasurable unless with the help of FOB, whereas CM could be easily measured by ultrasound and ruler on the surface of the body. Thus, we believed that keeping CM in the distance between the upper margin of the cuff and the suprasternal notch after insertion, CM = The distance between the upper margin of the cuff and the tip of the endotracheal tube, FOB = fiberoptic bronchoscopy, NPV = negative predictive value, PPV = positive predictive value, SM = The distance between the suprasternal notch and manubriosternal joint, TC = The distance between the tip of the ETT and the carina.
the range from CT + 2 cm to CT + 5 cm may be a convenient and individualized method to confirm the depth of the ETT. The study aimed to evaluate the sensitivity and specificity of the approach against fiberoptic bronchoscopy (FOB).

**METHODS**

**Study Design and Setting**

This was a prospective, diagnostic, pilot study conducted in the Department of Anesthesiology of West China Hospital between September 2014 and December 2014. The study protocol was approved by the Ethic Committee of West China Hospital and registered in Chinese Clinical Trial Registry with Registration number of chiCTR-TRC-14005170. Written informed consent was obtained from each of all the participated patients.

**Inclusion and Exclusion Criteria**

A total of 100 patients were recruited for this study. Their ages were between 18 and 65 and their body mass index was \( \leq 30 \text{kg/m}^2 \). They were scheduled to undergo operations under general anesthesia and had ASA physical status I or II. For those patients who suffered difficult airway, abnormal airway or chest anatomy, severe neck trauma, and bullae of lung, they were excluded.

**STUDY PROTOCOL**

The Distances and Their Relationship

**The Distance Between the Upper Margin of the Cuff and the Suprasternal Notch (CS)**

The ETT, a well-lead reinforced endotracheal tube (Medical Devices Co., Ltd. Guangzhou Peacekeeping Force, Guangzhou, Guangdong, China) was inserted 24 cm for males whereas 22 cm for females according to the endotracheal tube marking at the upper incisor after induction. A high-frequency of linear transducer (13–6 MHz, Sonosite, Bothell, WA) was placed longitudinally over anterior neck with the mark next to the suprasternal notch. We obtained the image of the cuff and the wire reinforcement of the tube after the cuff was filled with 10 ml of saline. The distance was measured by ultrasonic instrument (Figure 1, Figure 2a).

**The Distance Between the Suprasternal Notch and Manubriosternal Joint (SM)**

The distance between the suprasternal notch and manubriosternal joint was directly measured by the ruler.

**The Distance Between the Upper Margin of the Cuff and the Manubriosternal Joint (CM)**

The distance between the upper margin of the cuff and the manubriosternal joint (CM) was calculated by summing both CS and SM.

**The Distance Between the Upper Margin of the Cuff and the Tip of the Endotracheal Tube (CT)**

We used well-lead reinforced endotracheal tube for all the patients and chose certain ETT whose CT was 6.2 cm.

**The Distance Between the Tip of the ETT and the Carina (TC)**

After the ETT was inserted, the distance between the tip of the ETT and the carina was measured by FOB. First, the FOB was advanced to the depth of the carina. A tape was attached to it close to the connector. Then the FOB was withdrawn until the tip of the ETT was visualized. Another tape was marked on the FOB. The distance between two tapes was equal to the TC (Figure 2b).

**The Distance Between the Upper Margin of the Cuff and the Carina (CC)**

The distance between the upper margin of the cuff and carina was calculated by summing CT and TC (Figure 2b).

**The Relationship Between the Distances**

The proper depth of the endotracheal tube was its tip 2 to 5 cm from carina.\(^2,7\) We chose certain ETTs with CT of 6.2 cm. If the TC was 2 cm, the CC would be 8.2 cm (Figure 2c); if the TC was 5 cm, the CC would be 11.2 cm (Figure 2d). Thus, the CC would be in the range of 8.2 to 11.2 cm as well as the CM.

**The FOB Criteria**

The proper depth of the endotracheal tube was its tip 2 to 5 cm from the carina. FOB, regarded as the gold standard of the depth of the ETT, was used to measure the distance between the tip of the ETT and the carina (TC).

**The Novel Approach**

We hypothesized that there was a correlation and an agreement between CM and CC. If the tip of the ETT was 2
to 5 cm away from the carina, CC (also CM) should be in the range of CT + 2 cm to CT + 5 cm. In this study, CT was 6.2 cm. When CM was in the range of 8.2 to 11.2 cm, the depth was regarded as proper.

Methods and Measurements

After standard monitorings including electrocardiogram, noninvasive arterial blood pressure measurement, and pulse oximetry had been established, oxygen was administered via a face mask for 5 min. Induction of anesthesia was achieved with 1 to 2 mg midazolam, 2 mg/kg propofol, and 0.3 μg/kg sufentanil. Muscle relaxation was obtained with 1.5 mg/kg cisatracurium besilate. Anesthesia was maintained with sevoflurane (2–3%). After induction, ETT was inserted by a senior resident who majored in anesthesia. The depth was 24 cm for male whereas 22 cm for female according to the endotracheal tube marking at the upper incisor. Auscultation and waveform capnography (>4 mm Hg at least 5 breaths) were used to rule out esophageal intubation. Pressure ventilation mode was used in the case of one lung ventilation. We used both the new approach and FOB to confirm the depth of the ETT, respectively, and compared the result of the new approach with that of the FOB. Operator A, who had experienced in performing airway ultrasound test for >300 times, measured both CS and SM, calculated CM, and recorded the number of proper and improper depth. Operator B measured TC by FOB, recorded the number of proper and improper depth, and adjusted the depth of the ETT to 2 cm away from the carina. Both operators were blinded to the results of each other.

Outcome Measures

The primary measured outcome was the sensitivity and specificity of the novel approach compared with that of the gold standard of FOB for confirming the proper depth of the endotracheal tube. The secondary measured outcome was the correlation and the agreement between CM and CC.

Data Analysis

SPSS statistical software, version 18.0 (SPSS Inc., Chicago, IL) was used for data management. The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of the approach were computed. The corresponding 95% confidence intervals (CIs) were calculated based on the Wilson interval method. The agreement between the approach and FOB was evaluated by the kappa (κ) statistic. Correlation analysis was tested with linear correlation. The degree of agreement between CM and CC was assessed by the Bland and Altman method. Continuous data were expressed as mean ± standard deviation (SD) where applicable. Any P value < 0.05 was considered statistically significant.

Sample Size Determination

We calculated that we would need 99 patients to have a power of 80% based on the preliminary study with an alpha of 0.05.

RESULTS

Characteristics of the Studied Subjects

A total of 100 patients were recruited in the study (Figure 3). All of them were included in the final analysis. Their characteristics were presented in Table 1.

The Accuracy of the Approach Compared with that of the Gold Standard of FOB

The results of approach were shown in Table 2. The overall accuracy was 91% (95% CI: 85–97%), and the value of κ was 0.75 (95% CI: 0.60–0.90), indicating a high degree of agreement.
between the ultrasound and FOB. The sensitivity, specificity, PPV, and NPV of the ultrasound, using FOB as the gold standard, were presented in Table 3.

The Correlation and Agreement Between CM and CC

The correlation between CM and CC was significant ($P < 0.001$) with a correlation coefficient of 0.91 (95% CI: 0.87–0.94). Bland and Altman plots also demonstrated a good agreement between CM and CC as well. The differences between CM and CC were 0.37 cm (95% CI: 0.31–0.44); standard deviation (SD) was 0.32; limits of agreement was ($-0.26, 1.00$); percentage of error was 7.4% (Figure 4).

DISCUSSION

The Murphy eye may reduce the reliability of auscultation in distinguishing endobronchial intubation. In our study, one tip of the ETT was just beyond the carina whereas bilateral auscultation and chest movement were normal. It was not revealed until FOB was applied. The distance between the upper incisor and the tip of the ETT is usually regarded as the depth of the ETT, because it is quite difficult to exactly measure the length of the airway. Most of the time, confirming the depth of the ETT according to the mark at the upper incisor was used. However, because the airway is curved, repositioning ETT based on measurement at the incisors was inaccurate and the magnitude of the intervention did not correlate with the degree of error. Lee et al concluded that the straight length from the upper incisor to the manubriosternal joint could be used to predict the real airway length. However, it is risk to fully extend the head and neck under a condition of relaxed muscles.

### TABLE 1. The Characteristics of the Participated Patients

|                | Male (n = 48) | Female (n = 52) |
|----------------|--------------|-----------------|
| Age (year)     | 43.71 ± 17.68 | 44.06 ± 12.01 |
| Height (cm)    | 167.06 ± 5.39 | 158.88 ± 3.75 |
| Weight (kg)    | 64.62 ± 7.34  | 58.83 ± 7.57  |
| BMI (kg/m²)    | 23.15 ± 2.31  | 23.92 ± 2.76  |
| SM (cm)        | 7.85 ± 0.33   | 7.39 ± 0.21   |

BMI = body mass index, SM = the distance between the suprasternal notch and manubriosternal joint.

### TABLE 2. 2 × 2 Table of Comparison of the Novel Approach versus that of FOB

|                | Novel Approach | Fiberoptic Bronchoscopy |
|----------------|----------------|-------------------------|
|                | Positive       | Negative                |
| Proper         | 72             | 5                       |
| Improper       | 4              | 19                      |

Fiberoptic bronchoscopy: identifying the depth of the endotracheal tube by fiberoptic bronchoscopy. Positive: the tip of the endotracheal tube was 2 to 5 cm from the carina; otherwise it is true negative. For the novel approach: the proper depth was CM in the range of 8.2 to 11.2 cm; otherwise it is improper.
In the operation room, FOB is often unavailable. In some noisy circumstance, or patients suffered pneumothorax and hemothorax, auscultation may be difficult to confirm the depth of the ETT. With the help of ultrasound, the new approach achieved a high sensitivity for confirming the depth of the ETT and the value of \( \kappa \) (0.75), indicating a good degree of agreement between the approach and FOB. The novel method had an accuracy of 91%, which may be better than the old method of auscultation and observation. We owe the low specificity to the small sample size. In summary, this study indicates that the new approach may be used to individually confirm the depth of the endotracheal tube. A further study on the application of this method should be done.

The correlation and agreement between CM and CC were relatively good. As a result, one could use CM to confirm the depth of the ETTs by adjusting CM in the range from CT + 2 cm to CT + 5 cm after insertion, in order to keep the depth of the ETTs 2 to 5 cm away from the carina. For example, in this study, CT was 6.2 cm. As long as CM was kept in the range from 6.2 + 2 cm to 6.2 + 5 cm, the depth of the ETTs should be 2 to 5 cm away from the carina. After insertion, if CM is > 11.2 cm, we should advance the ETT until CM < 11.2 cm; if CM is < 8.2 cm, we should withdraw the ETT until CM > 8.2 cm. Considering that there could be difference between CM and CC, we suggested that the depth of the ETT be kept near or at the middle of the proper range, that is ~9.7 cm in this example. After having known the correlation and agreement between CM and CC, the parameter of 6.2 cm will not influence the depth of the ETTs anymore. Thus, we can measure the CT of any ETT to calculate the range of CM and use it to confirm or guide the depth of the ETTs.

Vocal cord is placed approximately at the level of cricothyroid membrane. Positioning the linear probe transversely over the cricothyroid membrane during the intubation process could obtain the bullet sign. As we can know the location of the cuff by ultrasound, we are sure that the cuff is passed through the vocal cord and the upper margin of the cuff has a safe distance away in the study. There is no danger of adjustments resulting in the cuff being at the cords and exerting pressure on the cords.

The trachea is full of air, which keeps ultrasound wave from reaching the ETT in it. Saline in the cuff can eliminate the airy tissue-specific acoustic impedance mismatch and introduce an anechoic sphere that is easy to be visualized by ultrasound. This is an optimal approach to reposition the ETT under the direction of visualization. Inflating saline into the cuff has been described in laser laryngeal surgery to prevent fires. The saline was replaced by air as soon as the measurement was finished in the study. None of the cuffs ruptured. Reinforced endotracheal tubes were used to help imaging the tube. Before we inflated the cuff with saline (Figure 1, the left picture), there was not the image of the wire reinforcement. When the saline was inflated, we could see the image of the wire reinforcement (Figure 1, the right picture). It helped us to identify the margin of the cuff. The rate of appearance of the wire reinforcement was found to be 100% in the test. With the test going on, we are sure that cuff can be identified without the help of the wire reinforcement. But we did not change the type of the tube.

There were several limitations in this study. First, the use of this method must be limited in patients with abnormal airway,

### TABLE 3. Test Characteristics of the Approach for Proper Depth of the Endotracheal Tube

|                  | 95% CI          |
|------------------|-----------------|
| Sensitivity (%)  | 94.74% 87.07%, 98.55% |
| Specificity (%)  | 79.17% 57.85%, 92.87% |
| PPV (%)          | 93.51% 85.49%, 97.86% |
| NPV (%)          | 82.61% 61.22%, 95.05% |
| Accuracy (%)     | 91% 85%, 97%    |

CI = confidence interval, NPV = negative predictive value, PPV = positive predictive value.

![Figure A](image1.png)  
![Figure B](image2.png)

**FIGURE 4.** The correlation between CM and CC (\( R^2 = 0.831, r = 0.91, P < 0.001 \)). CM: the distance between the upper margin of the cuff and the manubriosternal joint; CC: the distance between the upper margin of the cuff and the carina; b: the agreement between CM and CC. [bias: 0.37 cm (95% CI: 0.31–0.44) standard deviation (SD): 0.32, limits of agreement: −0.26, 1.00; and percentage of error: 7.4%] ○: female, ●: male.
subcutaneous emphysema and neck wound. Second, although several studies have demonstrated that the saline-filled cuff can be used in children, the agreement between CM and CC had not been proved among these studies. Third, a large sample sized, prospective and randomized controlled study should be done in order to evaluate the value of this individualized approach.

CONCLUSIONS
We developed a novel method, which may be used to confirm the depth of the endotracheal tubes.

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