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# Real-time tracheal ultrasonography for confirmation of endotracheal tube placement during cardiopulmonary resuscitation☆,☆☆

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ABSTRACT

*Objective:* This study aimed to evaluate the accuracy of tracheal ultrasonography for assessing endotracheal tube position during cardiopulmonary resuscitation (CPR).
*Methods:* We performed a prospective observational study of patients undergoing emergency intubation during CPR. Real-time tracheal ultrasonography was performed during the intubation with the transducer placed transversely just above the suprasternal notch, to assess for endotracheal tube positioning and exclude esophageal intubation. The position of trachea was identified by a hyperechoic air–mucosa (A–M) interface with posterior reverberation artifact (comet-tail artifact). The endotracheal tube position was defined as endotracheal if single A–M interface with comet-tail artifact was observed. Endotracheal tube position was defined as intraesophageal if a second A–M interface appeared, suggesting a false second airway (double tract sign). The gold standard of correct endotracheal intubation was the combination of clinical auscultation and quantitative waveform capnography. The main outcome was the accuracy of tracheal ultrasonography in assessing endotracheal tube position during CPR.
*Results:* Among the 89 patients enrolled, 7 (7.8%) had esophageal intubations. The sensitivity, specificity, positive predictive value, and negative predictive value of tracheal ultrasonography were 100% (95% confidence interval [CI]: 94.4–100%), 85.7% (95% CI: 42.0–99.2%), 98.8% (95% CI: 92.5–99.0%) and 100% (95% CI: 54.7–100%), respectively. Positive and negative likelihood ratios were 7.0 (95% CI: 1.1–43.0) and 0.0, respectively.
*Conclusions:* Real-time tracheal ultrasonography is an accurate method for identifying endotracheal tube position during CPR without the need for interruption of chest compression. Tracheal ultrasonography in resuscitation management may serve as a powerful adjunct in trained hands.


## 1. Introduction

A secure airway and effective ventilation are key components of advanced life support.[1] Unrecognized misplacement of endotracheal tube can lead to morbidity and mortality, with a reported incidence of approximately 2.9–16.7% in previous cardiac arrest studies.[2–4] Many traditional methods, including direct visualization of the vocal cords, observation of chest expansion, and chest auscultation can be employed to confirm endotracheal tube position, but each of these methods has limitations and may interrupt chest compressions during cardiopulmonary resuscitation (CPR).[5,6] Chest auscultation is the most common method used to confirm endotracheal tube placement, but it usually requires interruption of chest compressions during examination. Quantitative waveform capnography is recommended as the gold standard for confirming correct endotracheal tube placement in the 2010 American Heart Association (AHA) Guidelines for CPR and Emergency Cardiovascular Care (ECC).[1] However, it has some well-known limitations in cardiac arrest patients, and can be affected by low cardiac output, low pulmonary flow, airway obstruction, or epinephrine use.[6,7]

Ultrasonography is a non-invasive, real-time diagnostic tool commonly used during resuscitation. Real-time airway sonographic approaches could enhance physician confidence and decision-making in relation to tracheal tube placement, and may have a role in combination with continuous capnography in

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emergency patients.[8] For sonographic assessment of endotracheal tube position, previous investigators have used several different methods, including tracheal ultrasonography (direct), and detecting sliding of the pleura or diaphragm movement (indirect).[9–13] Unlike tracheal ultrasonography, indirect sonographic methods can exclude both esophageal and endobronchial intubation. Although these methods have high accuracy for assessing tube position, they require additional ventilation of the patients and may increase chest compression interruptions during CPR.

Tracheal ultrasonography can be performed in real-time when the tube is passed through the trachea or esophagus. Our previous prospective study revealed that tracheal ultrasonography could feasibly and rapidly confirm tracheal intubation during emergency intubation.[12] In cardiac arrest patients, interruption in chest compressions could be minimized when tracheal intubation is confirmed by ultrasonography. However, no study has thus far specifically investigated the accuracy of tracheal ultrasonography in airway management during CPR. We evaluated the use of tracheal ultrasonography in cardiac arrest patients. This study aimed to determine the accuracy of tracheal ultrasonography in assessing endotracheal tube position during CPR.

## 2. Methods

### 2.1. Study design and setting

This prospective observational study was conducted from September 2010 to June 2012 at the emergency department (ED) of National Taiwan University Hospital. The institution is a tertiary teaching hospital and the annual ED census is over 100,000 patients. The study protocol was approved by the Institutional Review Board of the National Taiwan University Hospital with a waiver of informed consent, and was registered with ClinicalTrials.gov before study initiation (NCT01148732).

### 2.2. Study entry criteria

Eligible study subjects were cardiac arrest patients receiving emergency intubation during CPR. Exclusion criteria included severe neck trauma, neck tumors, a history of neck operation or tracheotomy, or age less than 18 years. This study protocol and inclusion criteria differed from our prior studies. None of the subjects had been in any patient cohort from our previous studies.[12,13]

### 2.3. Study protocol

The intubation process, training of sonographers, and sonographic examination for confirming intubations have been described in details in prior work by the study group.[12,13] The emergency intubations were performed and cross-checked by junior or senior emergency medicine residents, supervised by attending physicians on duty. In this study, the gold standard of correct tracheal intubation was the combination of bilateral breath sounds on auscultation and exhaled carbon dioxide ($CO_2$) (>4 mm Hg after at least 5 breaths) with a typical $CO_2$ waveform on capnography. Esophageal intubation was diagnosed when breath sounds were absent and waveform capnography was abnormal.

An SSA-550A ultrasonography scanner (Toshiba, Tokyo, Japan) with a 3.75 MHz convex transducer was used for sonography. Tracheal ultrasonography was performed by 3 senior emergency medicine residents, who had completed 2 months of an ultrasonography training course during their clinical rotation, including tracheal ultrasonography training by oral instruction, video review, and hands-on practice. High inter-rater reliability was noted during the training course. All sonographers were supervised by 2 emergency medicine attending physicians, who had over 10 years of experience in emergency sonographic examinations.

Real-time tracheal ultrasonography was performed during and immediately after the endotracheal tube was inserted. The scanning time was restricted to the minimum possible; in general, it could be accomplished within 10 s. The transducer was placed transversely on the anterior neck just above the suprasternal notch. The position of the trachea could be demonstrated by the appearance of "comet-tail artifact", a hyperechoic air–mucosa (A–M) interface with posterior reverberation artifact. The identified endotracheal tube position was defined as endotracheal if only one A–M interface with comet-tail artifact was observed, or intraesophageal if a second A–M interface appeared, mimicking a second airway (double tract sign).[12] If the position of the esophagus was suspected to be immediately posterior to the trachea, sonographers could adjust their scanning planes by slightly tilting the probe left and right to identify the esophagus' position. To avoid influences of verbal communication during CPR, sonographers wore earplugs during the exam. The sonographers were not involved in the patients' care, and not aware of the results of auscultation and waveform capnography.

### 2.4. Data collection and analysis

The ED nurses recorded the enrolled subjects' age, height, weight, body mass index (BMI), Cormack and Lehane (CL) grade, any underlying medical conditions, and results of auscultation and quantitative waveform capnography. The results of ultrasonography interpretation and sonographic images were collected on separate data collection sheets.

Test characteristics including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and positive and negative likelihood ratios were calculated using standard formulas for a binominal proportion, and the corresponding 95% confidence intervals (CIs), by the Wilson interval method.[14,15] We conducted a logistic regression analysis to identify the factors associated with diagnostic inaccuracy of tracheal ultrasonography. All statistical analyses were performed using the SPSS statistical software, version 18.0 (SPSS Inc. Chicago, IL, U.S.A.), and the SAS system ver. 8.2 (SAS Institute Inc., Cary, NC, USA). Any $P$-value <0.05 was considered statistically significant.

## 3. Results

The researchers identified 99 potential study subjects during their duty hours. Of these, 89 patients (age range, 24–98 years) were included in the final analyses (Fig. 1). The history and clinical characteristics of enrolled patients were obtained from family members or the previous hospital records. Their demographics and clinical characteristics are listed in Table 1. No significant differences were found between the tracheal and esophageal intubation groups except the rate of return of spontaneous circulation and intubation difficulty.

The results of tracheal ultrasonography assessment are shown in Table 2. During the study period, 7 (7.8%) esophageal intubations occurred during CPR. The test characteristics of tracheal ultrasonography are listed in Table 3. The positive and negative likelihood ratios were 7.0 (95% CI: 1.1–43.0) and 0.0, respectively. There was no significant difference in the diagnostic accuracy of tracheal ultrasonography based on age, gender, out-of-hospital or in-hospital cardiac arrest, intubation difficulty, or time of day.