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Comparison between ultrasonography and capnography for ascertaining placement of endotracheal tube in patients undergoing general anesthesia – A prospective observational study

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ABSTRACT

Background: Confirmation of the position of the endotracheal tube (ETT) is an essential step for verification of intubation. Failure to diagnose esophageal intubation may lead to fatal consequences. Capnography is the gold standard for confirmation of ETT position, but it is practically impossible to be performed in all situations. Ultrasonography (USG) or "visual stethoscope" can be used as an effective alternative for all intubators in all situations. **Aims and Objectives:** The study was conducted to evaluate the ultrasonography (USG) technique with respect to its efficacy to detect the proper endotracheal position of ETT compared to end-tidal capnography among patients undergoing general anesthesia; to compare the time taken by the USG technique with that of capnography for detection of proper placement of ETT; to assess the feasibility of USG to detect accidental esophageal intubation. **Materials and Methods:** This prospective comparative cross-sectional observational study was conducted on 68 patients. Both capnography and upper airway USG were performed immediately after intubation to confirm the ETT placement. Sensitivity, specificity, and positive and negative predictive values of upper airway USG were determined against capnography as the reference method. The time required to determine ETT placement by the two methods was found out and compared. Agreement between the methods was assessed with kappa statistics. **Results:** USG detected all three cases of esophageal intubation but could not detect two patients with correct tracheal intubation. Upper airway USG had a sensitivity of 96.92% (95% confidence interval [CI]: 93.54–100%), specificity of 100%, positive predictive value of 100%, and negative predictive value of 60% (95% CI: 50.4–69.6%). The Kappa value was found to be 0.735, indicating a good agreement between upper airway USG and capnography for confirmation of ETT placement. Time taken for confirmation of ETT by capnography was 21.68 ± 2.63 s versus 11.44 ± 1.38 s for upper airway USG ($P < 0.001$). USG demonstrated bilateral lung sliding in 60 (88.2%) patients, unilateral lung sliding in 3 (4.4%) patients, and lung sliding was absent in 5 (7.4%) patients. **Conclusion:** Real-time upper airway USG is an alternative method of confirmation of ETT that is not only sensitive and accurate but is faster than the current gold standard method, capnography.

Key words: Intubation; Capnography; Ultrasonography; Endotracheal tube

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INTRODUCTION

Endotracheal intubation is an integral maneuver for the protection and maintenance of the airway during general anesthesia in an operation theater setting or during the delivery of critical care. Failure to detect inadvertent esophageal intubation at the correct point of time can have lethal consequences.[1] Studies report the incidence of esophageal intubation at 6% in emergency conditions and 1.75% in elective settings.[2,3] Therefore, identification

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of the correct positioning of the endotracheal tube (ETT) is essential, to avoid serious complications even death. Various methods have been described to identify the correct position of ETT such as direct visualization of the ETT passing through the glottis.[4] Visualizing bilateral symmetrical chest expansion and five-point auscultation of bilateral lung field and epigastrium are considered the most reliable clinical method of confirmation of ETT placement. Besides, the use of negative pressure devices, fiberoptic bronchoscopy, sonometric confirmation of tracheal intubation device, and chest X-ray are also a useful tool for the detection of the correct position of ETT.

Capnography along with its continuous waveform is considered the gold standard[5,6] with 100% sensitivity and 100% specificity in verifying the correct ETT position. However, it may not be reliable under certain circumstances such as endobronchial intubation, low cardiac output state[5] as in cardiac arrest, severe hypotension,[7] pulmonary embolism, severe bronchospasm, pleural effusion, pneumothorax, pulmonary malignancy,[7,8] prior bag-mask ventilation leading to gastric insufflation, and antacid consumption. All these situations may give rise to false positive or false negative results with capnography.[7] Hence, this study was planned to compare the confirmation of ETT positioning after general anesthesia by upper airway ultrasonography with reference to capnography.

Aims and objectives

This study was undertaken to evaluate the efficacy of ultrasonography (USG) technique to detect the proper endotracheal position of ETT compared to end-tidal capnography among patients undergoing general anesthesia; to compare the time taken by the USG technique with that of capnography for detection of proper placement of ETT and to assess the feasibility of USG to detect accidental esophageal intubation.

MATERIALS AND METHODS

After necessary clearance from the Institutional Ethics Committee, this prospective comparative cross-sectional observational study was conducted on adult patients of either sex, belonging to age group 18–80 years, body mass index (BMI) ≤35 with American Society of Anesthesiologists physical status (ASA-PS) I–II, who required intubation for general anesthesia during elective surgeries between November 15, 2023, and February 15, 2024, over a period of 3 months, were included in this study. The study was registered under Clinical Trials Registry-India. Informed consents were taken from all the participants before enrollment. Patients with American Society of Anesthesiologists grades III-V, a history of difficult tracheal intubation, abnormal airway anatomy, high risk of aspiration, severe cardiac, pulmonary, hepatic, renal, or coagulative diseases are excluded from the study.

A total of 75 patients underwent elective surgeries under general anesthesia during the study period (n=75). Five patients were not included in data collection due to technical issues (n=5) and two patients were excluded due to improper imaging and anatomical distortion (n=2). Finally, the study was conducted on 68 patients (n=68) and data were collected and analyzed (Figure 1).

All patients received a tablet of alprazolam (0.25 mg) at night before surgery, a tablet of ranitidine (150 mg) on the previous night, and another in the morning on the day of surgery.

Four senior anaesthesiologists were involved in the study at any time. The patient was induced with propofol (2 mg/kg) or etomidate (0.3 mg/kg) intravenously and was paralyzed by suxamethonium (1.5 mg/kg) intravenously. Time counting started when the incubator announced the visualization of the vocal cords. E Cube 8 Ultrasound machine was used. Screens of USG (ultrasonography) monitor and capnography were faced toward opposite sides so that one observer could see only one screen at a time. The ultrasound probe (linear, L3–12T; 15 Hz) was placed transversely over the suprasternal notch initially and then moved cephalad to identify the vocal cord. The ultrasound images of endotracheal intubation showed a single, comet tail appearance an "empty esophagus sign" whereas esophageal intubation depicted by "double comet tail" appearance, where the probe was moved to the left to look at the esophagus. A single sonographer identified all intubation. After tube fixation, the sliding sign was checked bilaterally along mid clavicular line in the third intercostal space to rule out endobronchial intubation. When the incubator announced the visualization of the vocal cords, the investigator connected the capnography sampling line to ETT and observed the capnography waves. Philips capnography machine (CAPNOSTAT, M2501A) was used. Endotracheal intubation was confirmed when the square waveform was maintained for five breaths, that means until the appearance of five consecutive wave patterns.

The time taken by each diagnostic method (i.e., the time taken from visualization of the vocal cord until the appearance of comet tail artifact in case of USG confirmation and until the appearance of five consecutive square wave patterns in case of capnographic confirmation) was recorded in seconds using a stopwatch.

For the diaphragmatic view, a 3.5 MHz curved probe was used. The probe was placed in the right upper quadrant

of the abdomen exactly below the edge of the ribs with a 45° angle toward the chest near the mid-clavicular line. The probe was placed toward the right side of the patient. This view provided a suitable vision of the liver and echogenic diaphragm. During positive pressure ventilation with a bag, diaphragm motion toward the abdomen was registered as an intratracheal intubation. In contrast, the observation of diaphragm motion toward the chest or non-significant motion suggested esophageal intubation. In all patients, auscultation was performed simultaneously.

Capnography was taken as the gold standard for the detection of ETT position. Sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of USG for detecting ETT position were determined. against the capnography.

Categorical variables are expressed as the number of patients and percentage of patients and compared across the groups using Pearson's Chi-square test for Independence of attributes/Fisher's exact test as appropriate. Continuous variables are expressed as mean, median, and standard deviation and compared using the Wilcoxon Sign Rank test. Associations captured using Cohen's Kappa. The statistical software SPSS version 25 has been used for the analysis. An alpha level of 5% has been taken, that is, if any P<0.05 it has been considered significant.

RESULTS

The physical characteristics of the 68 patients finally included in the study are depicted in Table 1. The mean age of participants was 51.88±14.25 years, of which 37 (54.4%) patients were male and 31 (45.6%) were female. The airway characteristics of the participants were assessed using the ASA-PS grading system. Forty (58.8%) belonged to ASA-PS grade I and the remaining 28 (41.2%), ASA-PS grade II. The mean BMI was 26.02±2.42 kg/m^2.

Real-time USG of the upper airway showed a "single comet tail" artifact in 63 (92.3%) patients with tracheal intubation and a "double comet tail artifact" in all three patients with esophageal intubation (as confirmed by capnography showing ≤1 waveform). However, USG failed to detect 2 cases of tracheal intubation (falsely showed "double comet tail sign") which was confirmed by capnography (showing ≥5 waveforms). These negative USG findings were seen in an elderly group of patients (>60 years of age, P<0.004) with ASA-PS category II (P<0.005) of which the two false negative cases (USG showing esophageal intubation and capnography showing tracheal intubation) were among 71–80 years age group.

Table 1: Patient characteristics (n=68)

Parameters (unit)	Values
Age (years)	51.88±14.25
Sex (male/female)	37 (54.4%)/31 (45.6%)
Body mass index (kg/m^2)	26.72±3.86
American Society of Anesthesiology status (I/II/III)	40 (58.8%)/28 (41.2%)/0

Table 2: 2×2 contingency table comparing USG confirmation and capnography confirmation of endotracheal tube placement

Position of ETT	Capnography		Total (n=68)
USG	Endotracheal intubation	Esophageal intubation	
Inside the trachea	63	0	63
Not inside the trachea	2	3	5
Total	65	3	68

ETT: Endotracheal tube

Table 2, a fourfold contingency table, depicts the statistical results. The sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of real-time USG of the upper airway to detect ETT position were 96.92% (95% CI: 93.54–100%), 100%, 100%, 60% (95% CI: 50.4–69.6%), and 97.06% (95% CI: 93.75–100%), respectively.

Kappa value was found to be 0.735 indicating a good agreement between upper airway USG and capnography for confirmation of ETT placement with statistically significant association (P<0.05).

The mean time taken to detect the position of ETT by capnography was 21.68±2.63 s, whereas that by real-time upper airway ultrasonogram was 11.44±1.32 s, and the difference was statistically significant (Wilcoxon signed ranks test, P<0.001). The spearman's rank correlation coefficient between the 2 variables was 0.266 with p value as 0.028 which signifies a weak positive but significant correlation (Figure 2).

Of the 68 patients who participated in the study, USG successfully demonstrated bilateral lung sliding in 60 (88.2%) patients, thereby ruling out endobronchial intubation, and diagnosed the same in three patients by eliciting unilateral lung sliding. Lung sliding was absent in 5 (7.4%) patients.

Table 3 shows the correlation of the time taken by capnography and USG to detect ETT position in the study population based on BMI. It was found that USG was faster in confirming ETT position than capnography irrespective of the patient's BMI, which was statistically significant (P<0.001).

Table 3: Correlation between different BMI group with capnography and USG

BMI	Capnography – time taken to detect position of ETT (seconds)-appearance of 5 waveforms	USG – time taken to detect position of ETT (seconds)	P-value	Significance
Normal				
Mean	20.95	10.89	<0.001	Significant
Median	20.00	11.00		
SD	3.26	1.20		
Overweight				
Mean	22.02	11.67	<0.001	Significant
Median	22.00	11.50		
SD	2.31	1.33		
Obese				
Mean	21.00	11.33	0.109	Not significant
Median	22.00	12.00		
SD	2.65	1.15		
Total				
Mean	21.68	11.44	<0.001	Significant
Median	22.00	11.00		
SD	2.63	1.32		

BMI: Body mass index, ETT: Endotracheal tube, SD: Standard deviation

No adverse events occurred when USG or capnography was performed.

DISCUSSION

Verification of ETT placement is of paramount importance because unrecognized esophageal intubation can rapidly prove to be fatal.[9,10]

In the present study, the sensitivity and specificity of real-time upper airway ultrasound were 96.92% and 100%, respectively, for confirmation of the correct position of ETT. This is similar to the results obtained by previous studies.[5,11,12]

The positive and negative predictive values in our study were 100% and 60%, respectively.

Upper airway USG detected all three esophageal intubations which did not show any waveform of capnography, that is, USG was found to have 100% specificity in the detection of esophageal intubation. Hosseini et al.,[13] Abbasi et al.,[14] Park et al.,[15] and Milling et al.,[16] also had similar findings in their study. However, USG failed to detect two out of 65 tracheal intubations (false negative) which were detected as positive by capnography. This could be attributed to increased soft-tissue thickness in the neck region leading to suboptimal USG image, which might have made identification of comet tail shape difficult, so ETT position was not detected. Thomas et al.,[17] also found similar results in their study.

The endobronchial intubation was excluded from study participants by demonstration of bilateral lung sliding. Lung sliding was absent in five patients indicating esophageal intubation. Chun et al.,[18] Sim et al.,[19] and Weaver et al.,[8] used the lung sliding method to confirm ETT position.

In the present study, the USG required much less time than capnography (21.68±2.63 s, and 11.44±1.32 s, respectively) for confirmation of ETT position which was statistically significant. These times are slightly higher than those of Chou et al.,[5] where the median time taken was 9.0 s but was much shorter (median time 40 s) than the findings of the study conducted by Pfeiffer et al.[20] These discrepancies could be attributed to the differences in the methodologies used to calculate the time needed to confirm the ETT position. This study revealed that upper airway USG was faster than capnography to detect the position of ETT among all subgroups of patients categorized based on BMI and the difference was statistically significant. These findings were similar to a study by Pfeiffer et al., who also concluded that USG was faster in obese than capnography.[21]

The present study thus suggested that upper airway USG may be used for primary confirmation of ETT placement.

After endotracheal intubation, one can perform primary or secondary confirmation of ETT position. Primary confirmation methods are done before securing the ETT. Upper airway ultrasound, a portable, simple, safe, and novel non-invasive technique for direct visualization of upper airway structures and ETT location in real-time, can differentiate between the tracheal or the esophageal position of ETT. The present study suggested that upper airway USG may be used for primary confirmation of ETT placement. Capnography is also a direct method that determines the position of the ETT by finding the amount

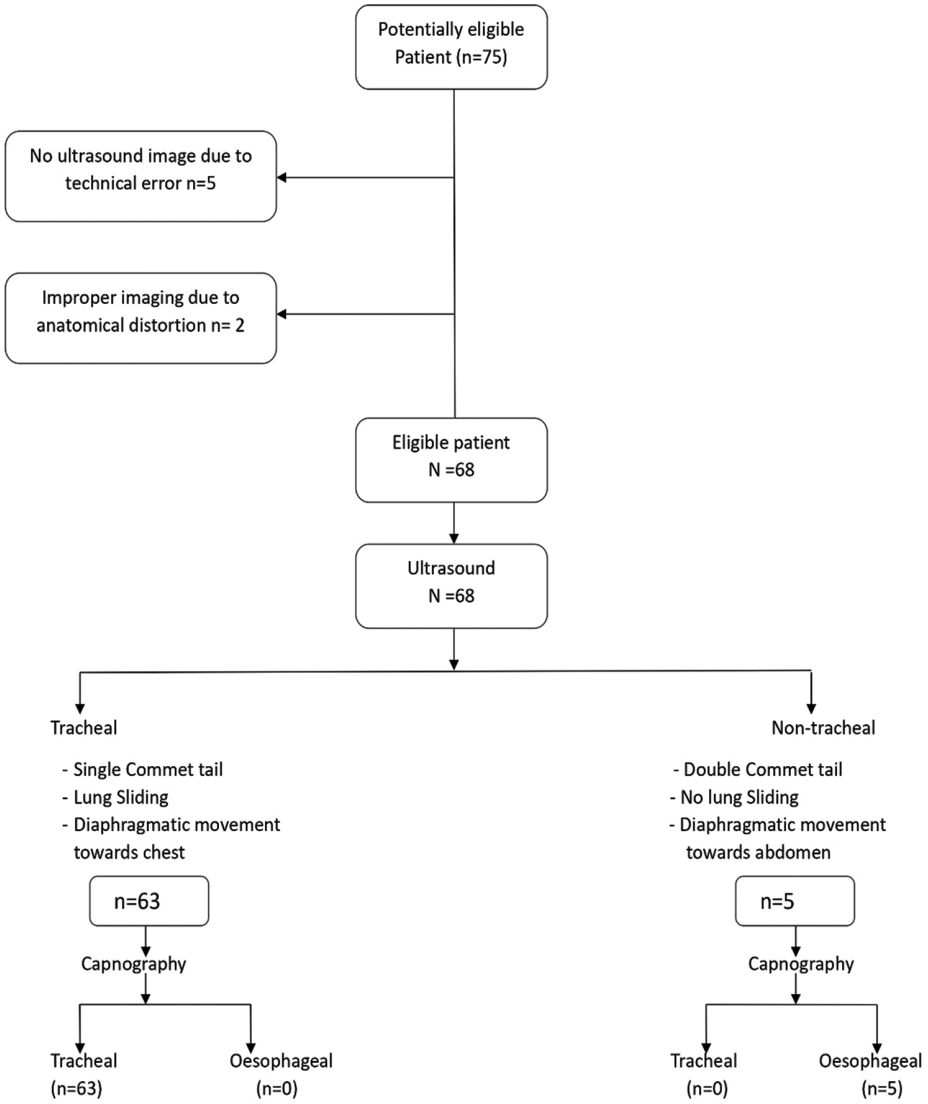

Figure 1: Flow diagram participants

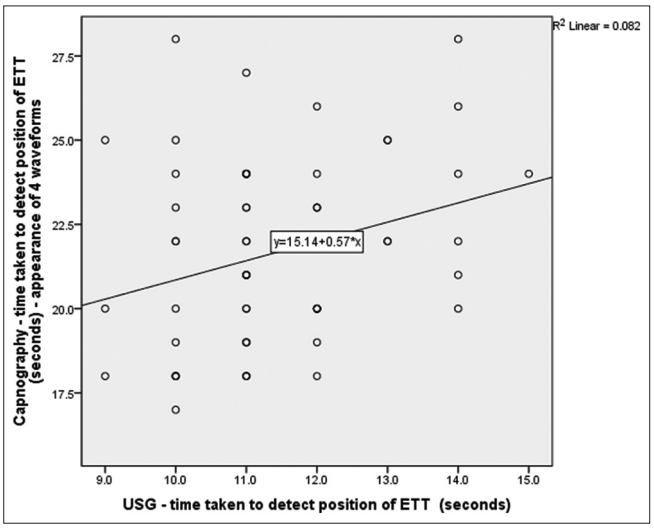

Figure 2: Scatter diagram showing the relation between time taken by capnography and upper airway ultrasonography to detect endotracheal tube position

of carbon dioxide in the exhaled air. Our study showed that both methods have good accuracy, good correlation, good agreement, and quick confirmation times. In the present study, the Kappa value was found to be 0.735 indicating a good agreement between upper airway USG and capnography for confirmation of ETT placement with statistically significant association.

Further, the reliability of capnography is doubtful in some situations with low pulmonary flow such as cardiac arrest or severe shock. Under these circumstances, low pulmonary flow does not distort upper airway USG images. Therefore, upper airway USG may be used in such conditions to confirm the ETT placement.

Limitations of the study

The present study had few limitations. It was a single centre study conducted in a controlled environment. Critically ill

patients, trauma patients, obese patients and those with lung pathology were excluded from the study.

CONCLUSION

This study shows that real-time upper airway USG is an alternative method of confirmation of ETT that is not only sensitive and accurate but is faster than the current gold standard method, capnography. Both methods have good agreement in the detection of ETT position.

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