Original Article

Comparison of ultrasonography, clinical method and capnography for detecting correct endotracheal tube placement- A prospective, observational study

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ABSTRACT

Background and Aims: In emergency airway management, unstable haemodynamics of the patients calls for the early need to detect correct endotracheal tube (ETT) placement. Ultrasonography has an advantage of being readily available along with being non-invasive and providing real time images. We aimed to study the usefulness of tracheal ultrasonography and use it as a tool to assess correct tracheal intubation in patients in the intensive care unit. **Methods:** This was a hospital-based observational study. The study included 92 patients who needed and were taken up for endotracheal intubation. Tube placement was confirmed simultaneously by three different observers with their respective method, i.e., ultrasonography, clinical method and capnography. **Results:** Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) of ultrasonography against capnography were 100% each with *P* value of 1. However, for clinical method against capnography, the sensitivity was 96.5%, specificity 28.6%, PPV 94.3% and NPV 40% with *P* value of 0.727. Mean time taken to detect correct placement of the ETT by ultrasonography, capnography and clinical method was 4.93 s, 15.39s and 17.80s, respectively. Out of 92 intubations, 85 were tracheal and 7 were oesophageal. All intubations were detected accurately with ultrasonography and capnography, ultrasonography being faster. Clinical method correctly detected 82 out of 85 tracheal intubations and 2 out of 7 oesophageal intubations, and was therefore less accurate than the other two methods. **Conclusion**: The study shows that ultrasonography is as reliable a method for confirmation of endotracheal intubation as capnography and is more reliable than clinical method. Besides, ultrasonography is faster than the other two methods.

Key words: Capnography, endotracheal intubation, ultrasonography

INTRODUCTION

Endotracheal intubation is one of the most commonly implemented procedures in the intensive care unit (ICU). Delay in confirmation of correct placement of the endotracheal tube (ETT) can lead to life-threatening complications (cardiac arrest, severe hypoxaemia, cardiovascular collapse, death, etc.) because of the hazardous haemodynamic and respiratory status of these critically ill patients.[1,2] Therefore, the confirmation of ETT placement is very important.

Various techniques have been used over the years for the verification of ETT position. These include chest auscultation, bag resistance, visualisation of condensation within the ETT, gastric auscultation, exhaled volume and chest radiography.[3] But these techniques are likely to yield false positive or negative results. Qualitative and quantitative end-tidal carbon

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dioxide ($ETCO_2$) detection[4] is a reliable method, but there are situations where this may not be reliable such as during cardiac arrest, severe bronchospasm or hypothermia.

Recently, ultrasonography (USG) and transthoracic impedance have been added into the list.[5] Confirmation with ultrasound is a potential alternative when detection of CO_2 by capnography is compromised, where capnography is not available or as an adjunct to capnography.[6]

USG is a relatively new technique for ETT confirmation. It is non-invasive, portable and serves as a real-time diagnostic tool with rapid and accurate results. Also, the ultrasonographic images are not affected by low pulmonary blood flow.[3]

Most of the studies conducted earlier included American Society of Anesthesiologists (ASA) grade I and II patients. There are limited studies on higher ASA grade III and IV patients. Therefore, the present study was conducted in ASA grade III and IV patients to compare three different methods, i.e., USG, capnography and clinical method for their efficacy in confirming correct ETT placement in the ICU. The secondary objective of the study was to determine the difference in time taken to detect tube placement by the three different methods. As an ancillary observation, the feasibility of USG to detect accidental oesophageal intubation (if it occurred) by checking lung sliding sign was also studied.

METHODS

This prospective, observational study was performed in patients requiring endotracheal intubation in the ICU. Approval for the study was obtained from the institutional ethics committee and research review board (167:(5)/MC/EC/2020 dated 22nd May 2020). The protocol of the study was registered prospectively with the Clinical Trials Registry of India (CTRI/2020/08/027326). Written informed consent was obtained from the relatives of all the participants. The study was conducted over a period of six months from September 2020 to February 2021 in the ICU of a tertiary care hospital.

Ninety-two patients of either gender, aged between 20 and 60 years and requiring emergency or planned intubation in the ICU were included in the study [Figure 1]. Patients with thyromental

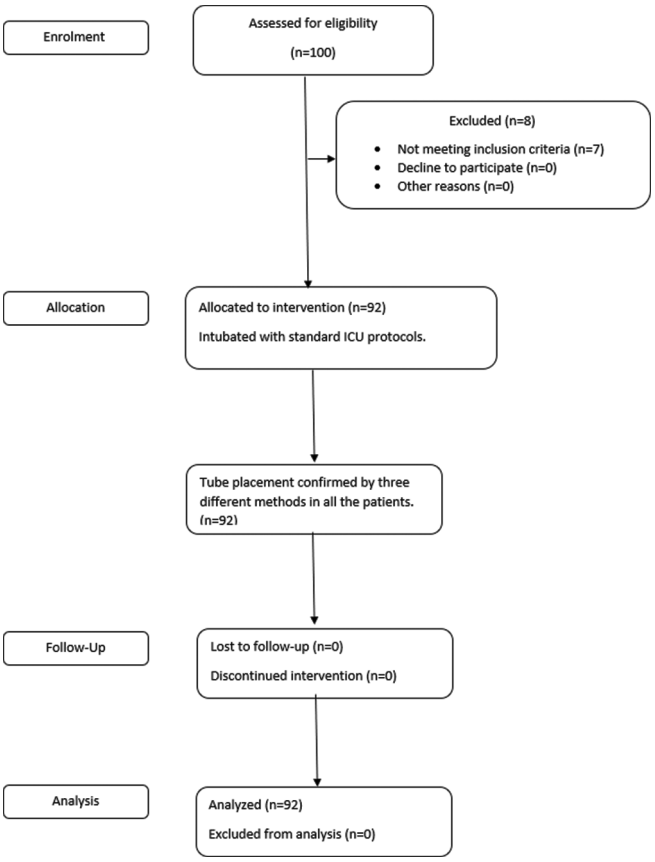

Figure 1: Study flow diagram

distance <6 cm, history of previous difficult intubation, anatomical neck distortion, having neck swellings, cervical spine disease, facial trauma, history of pneumonectomy, pleurodesis, pneumothorax, body mass index (BMI) more than or equal to 35 kg/m^2 and difficult intubation were excluded.

The patients were assessed, intravenous access was obtained, and the laryngoscope, ETT and other instruments required for intubation were checked. Baseline vitals (pre intubation) were recorded. The patients were preoxygenated with 100% oxygen. Intubation was performed as per protocol followed in the ICU. Direct laryngoscopy was done, and the ETT was inserted by a senior resident in Anaesthesiology who was posted in the ICU.

Time zero was from the time the ETT was being inserted after successful laryngoscopy, and the person who did the intubation confirmed the completion of intubation.

As soon as the ETT was placed, the procedure for confirming the placement of the ETT by three different

methods, i.e., USG, clinical method and capnography, was carried out by three different anaesthesiologists at the same time. The person who performed tracheal sonography was an anaesthesiologist who was experienced in performing airway ultrasound. A single sonographer (researcher) identified all intubations. The other two were third year trainee residents in the department of Anaesthesiology. Each of them started their stopwatch as soon as the intubator declared 'intubation done' and stopped the stopwatch as the confirmation was done by the respective methods. The time was noted.

The first anaesthesiologist confirmed tube placement by USG using a SonoSite M-Turbo linear probe (13-6 MHz). The USG probe was placed transversely on the neck above the suprasternal notch after laryngoscopy. As soon as intubation was completed, two hyperechoic lines were seen confirming ETT placement, in the transverse view. The probe was then moved laterally to look at the oesophagus. If the oesophagus was intubated, the empty trachea and distended oesophagus were seen as the 'Double tract sign' [Figure 2].

The second anaesthesiologist checked the ETT placement by the clinical method looking for bilateral chest rise and 5-point auscultation on the infra-clavicular and infra-axillary areas on both the sides.

The third anaesthesiologist confirmed the placement of ETT via capnography (after starting of ventilation) by looking for the appearance of a typical square waveform along with detection of $ETCO_2$ of more than 4 mmHg, after five breaths. A multi-parameter monitor with a sidestream $ETCO_2$ analyser was used for capnography.

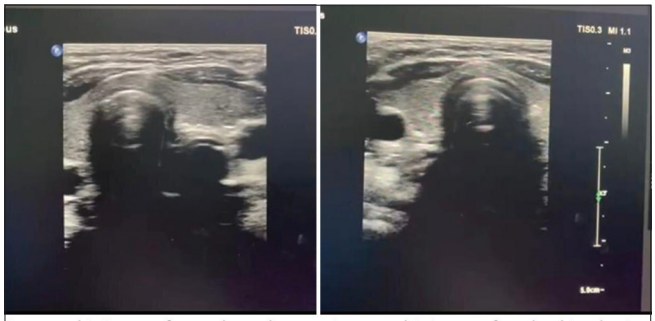

Figure 2: Ultrasonographic view of oesophageal and tracheal intubation

End point of the time of time taken was when each anaesthesiologist confirmed the placement of the ETT by their respective methods. The ETT was then fixed.

Also, after the confirmation of tracheal intubation, an USG curvilinear 13.6 MHz probe was placed in the midclavicular line in the sagittal plane with the arrow mark below the clavicle so that the upper part of the probe was over the second intercostal space. The ribs followed by the pleural line were then identified.[7] This was done to see the lung sliding signs on both sides to rule out endobronchial intubation. Haemodynamics were also recorded till seven minutes post intubation. The 7th minute post intubation was the end point of the study.

In case of an oesophageal intubation, the ETT was taken out and patients were reintubated correctly in the second attempt, but this second attempt was then not included in the study.

A sample size of 92 cases was calculated at 95% confidence and 3% absolute error to verify the expected 98% accuracy of USG against $ETCO_2$ for determining the right ETT position. This sample size was adequate to verify the expected sensitivity of 97.8% and specificity of 100%.[8]

Data analysis was done using Statistical Package for the Social Sciences (SPSS) software version 21.0 (Chicago, Illinois). Quantitative data were expressed as mean, range and standard deviation, whereas qualitative data were expressed as frequencies and percentages. Results of USG and clinical method were compared with capnography using McNemar's test. Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) with 95% confidence interval (CI) were calculated for both methods (USG and clinical method) using capnography as gold standard to confirm tracheal intubation. Continuous variables (time for procedure) were compared using one-way analysis of variance (ANOVA) test followed by Tukey's post-hoc analysis test. A P value ≤ 0.05 was considered as statistically significant.

RESULTS

The mean age of the participants was 37.05 ± 14.78 years. Out of 92 patients, 52 (56.5%) were males and 40 (43.5%) were females. 73 (79.3%) belonged to ASA grade III, and the rest belonged to ASA grade IV. The mean weight of the study participants

was 65.05 ± 12.72 kg. Accident and poisoning were the most common causes of intubation in the ICU.

Out of 92 patients, 85 were tracheal intubations and 7 were oesophageal intubations in the first attempt. Both USG and capnography could detect correct tracheal or oesophageal intubation accurately in all patients [Table 1]; whereas clinical method correctly detected 82 tracheal and 2 oesophageal intubations and falsely detected 3 tracheal intubations as oesophageal (FN) and 5 oesophageal intubations as tracheal (FP) [Table 2].

Thus, the sensitivity, specificity, PPV and NPV of USG in the detection of tube placement were 100% with respect to capnography (P-value = 1.00) [Table 1], whereas for the clinical method, it was 96.5%, 28.6%, 94.3% and 40%, respectively (P = 0.727) [Table 2].

Tukey's test for post-hoc analysis revealed that the mean time taken to detect ETT placement by USG (4.9 ± 1.09 s) and capnography (15.39 ± 1.63 s) was significantly lower than that taken by the clinical method (17.8 ± 1.7 s) (P < 0.05) [Table 3].

Out of 92 patients, the left-side lung sliding sign was present in 87 patients (94.6%) and absent in five patients (5.4%), whereas the right-side lung sliding sign was present in all 92 patients [Table 4].

DISCUSSION

The rapid determination of correct endotracheal intubation is vital to prevent detrimental consequences of prolonged oesophageal intubation. Proper endotracheal intubation is usually confirmed by visualising the vocal cords, adequate bilateral chest expansion, presence of bilateral breath sounds, fogging of ETT, capnography and auscultation over the epigastrium.[9,10] The vocal cords may not always be visualised, particularly in difficult airway and emergency settings. Quantitative waveform capnography is considered as the gold standard, but it has many limitations and is also not widely available in ICU settings. Various studies mention using USG in confirming ETT placement as it is real-time, noninvasive, harmless and produces fast results.[11] Ultrasound is mostly available in ICUs for purposes such as focused intensive care echocardiography, focused assessment of sonography in trauma and for vascular access. Thus, it can be a useful tool for ETT confirmation.[12]

Table 1: Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) of ultrasonography to detect tube placement when compared against capnography

Variable	Capnography (Gold standard)	Clinical Method
Tracheal intubation		
Correctly detected (TP)	85 (100%)	85 (100%)
Incorrectly detected (FN)	0 (0%)	0 (0%)
Oesophageal intubation		
Correctly detected (TN)	7 (100%)	7 (100%)
Incorrectly detected (FP)	0 (0%)	0 (0%)
P (McNemar's test)	1.00	
Sensitivity	100%	
Specificity	100%	
PPV	100%	
NPV	100%	

TP: True positive; FN: False negative; TN: True negative; FP: False positive

Table 2: Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) of clinical method to detect tube placement when compared against capnography

Variable	Capnography (Gold standard)	Clinical Method
Tracheal intubation		
Correctly detected (TP)	85 (100%)	82 (96.5%)
Incorrectly detected (FN)	0 (0%)	3 (3.5%)
Oesophageal intubation		
Correctly detected (TN)	7 (100%)	2 (28.6%)
Incorrectly detected (FP)	0 (0%)	5 (71.4%)
P (McNemar's test)	0.727	
Sensitivity	96.5%	
Specificity	28.6%	
PPV	94.3%	
NPV	40%	

TP: True positive; FN: False negative; TN: True negative; FP: False positive

Table 3: Mean time taken by different methods

	Mean (seconds)	Standard Deviation	*P* (by one-way ANOVA)
Clinical method	17.8096	1.74821	<0.001*
Capnography	15.3958	1.62902	
USG	4.9340	1.09180	

ANOVA: Analysis of variance; USG: Ultrasonography. *Statistically significant (with *f*=1872.38, df1=2.0, df2=273.0).

The present study revealed that the sensitivity and specificity of USG in the detection of ETT placement were as good as capnography (100% with respect to capnography) (P-value = 1.00) but was only 96.5% and 28.6% respectively for the clinical method with respect to gold standard capnography (P-value = 0.727).

USG, clinical method and capnography have been compared for confirming ETT placement in a previous study by Chowdhury *et al*.[13] Similar to our study, the sensitivity and specificity of ultrasound were found

Table 4: Appearance of left- and right-side lung sliding sign

	Number	Percent
Left-side lung sliding sign		
Absent	5	5.4
Present	87	94.6
Total	92	100.0
Right-side lung sliding sign		
Absent	0	0
Present	92	100
Total	92	100.0

to be 99.17% and 100%, respectively, and with a PPV and NPV of 100% and 83.33%, respectively. In another study, sensitivity of the technique was found to be 97.89% and specificity 100% ($P = 0.47$) compared to that of the other two modalities, i.e., capnography and clinical method using McNemar's test.[8] Usefulness of ultrasound as a novel tool to confirm endotracheal intubation with an overall sensitivity of 98% (95% CI 97 to 99) and specificity of 98% (95% CI 95 to 99) has also been proven in a systematic review and meta-analysis.[14]

This means that USG can prove to be a promising alternative in critical care scenarios where clinical methods and capnography cannot be used or in some low pulmonary flow conditions like cardiac arrest, severe shock, inadequate pulmonary perfusion and gas exchange wherein the reliability of quantitative capnography is doubtful.[15] Also, USG is easily accessible to the anaesthesiologist nowadays because of its increasing use in the operation theatre and the ICU.

In the present study, the mean operating time taken by USG (4.9 ± 1.09 s) was significantly less compared to the clinical method and capnography even with first waveform and this is comparable to the results of the previous studies.[3,16]

In another study, the time taken for confirmation by USG method was 8.27 s compared to clinical method (T2 = 20.72) and waveform capnography (T3 = 18.06).[8] This was slightly more than the time taken in our study.

In contrast to our study, in a study by Abhishek *et al*.,[17] the time taken for confirmation of correct ETT placement by USG was more (12.0 ± 1.318 s) than capnography (8.989 ± 1.043 s).

The time required to confirm ETT placement is an important consideration for any method used, more so in already compromised patients in the ICU. Transtracheal ultrasound can be used for verification, while the intubation is being performed or upon completion. Even before ventilating the patient, tracheal ultrasound detects oesophageal intubation which prevents unnecessary forced ventilation to the stomach and its associated complications. In our study also, in some cases, ETT could be confirmed simultaneously with intubation.

The sliding lung sign (the to-and-fro movement observed at the pleural line, spreading below) has also shown to be an accurate indicator of endotracheal intubation.[18] On ultrasound of the thoracic cavity, lung sliding sign can identify movement of the lung and also helps in identifying endobronchial intubation.[14] Therefore, this was used in our study to identify endobronchial intubation. Physiologically, this sign is most discrete in the upper parts of the lungs.[19]

In our study, the left-side lung sliding sign was present in 87 patients (94.6%) and absent in five patients (5.4%). However, the right-side lung sliding sign was present in all 92 patients (100%). The negative left lung sliding sign in five patients was due to endobronchial intubation. In these cases, the tube was withdrawn till the bilateral lung sliding sign was confirmed. Nevertheless, the usefulness of lung sliding sign in confirming correct ETT placement is also established in many previous studies.[20-22]

The advantage of transtracheal over transthoracic ultrasound is that the former does not need ventilation for confirmation; however, the transtracheal method cannot differentiate between tracheal and endobronchial intubation.

The present study has certain limitations. It was a single-centre study, the results of clinical method could have been influenced by observation of other signs such as chest expansion, and the study excluded patients of major trauma with extensive haematoma of the neck, which are a challenge for endotracheal intubation and rapid confirmation. The main strength of the study was that a single operator performed all the ultrasound examinations.

CONCLUSION

In conclusion, we found ultrasound to be as reliable a method for confirming endotracheal intubation as

capnography and more reliable than clinical method. USG consumed less time than both chest auscultation and capnography. Also, it was able to detect the misplaced oesophageal intubations promptly and redirect the ETT towards the trachea.

Declaration of patient consent

The authors certify that they have obtained all required patient consent. In the form, the patients have given their consent for their clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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