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Comparative Evaluation of Ultrasound of Trachea and Capnography for Rapid Confirmation of Endotracheal Tube Placement in Diverse Patient Populations

[1]Md Anwar Hussain, [2]Imran Sholapur, [3]Mohammad Asif and [4]Shifa Pathan

[1,2]Department of Anaesthesiology, SDM Medical College and Hospital, Dharwad, Karnataka, India

[3]Department of Anaesthesiology, JGMM Medical College, Hubballi, Karnataka, India

[4]Department of Pathology, SDM Medical College and Hospital, Dharwad, Karnataka, India

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Corresponding Author
Mohammad Asif,
Department of Anaesthesiology, JGMM Medical College, Hubballi, Karnataka, India
asifkalas189@gmail.com

Author Designation
[1]Assistant Professor
[2]Professor
[3]Associate Professor
[4]Senior Resident

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ABSTRACT
Securing endotracheal tube (ETT) placement is crucial in anesthesia, with misplacement leading to severe complications. While capnography is considered the gold standard for confirming ETT placement, it has limitations, especially in patients with low pulmonary blood flow or those in cardiac arrest. Transtracheal ultrasound has emerged as an alternative, offering real-time confirmation without the need for ventilation. This study aimed to compare the efficacy and rapidity of transtracheal ultrasound and capnography in confirming ETT placement in different patient populations, including those with obesity, cardiac arrest and pulmonary diseases. A prospective, investigator-blinded study was conducted on 144 patients aged 18-60 years undergoing elective surgeries requiring endotracheal intubation. Patients were divided into groups based on their health conditions (e.g., obesity, cardiac arrest, pulmonary disease). The primary outcome was the time taken to confirm ETT placement using transtracheal ultrasound compared to capnography. Sensitivity and specificity for both methods were also evaluated. Transtracheal ultrasound confirmed ETT placement in 142 out of 144 cases, with a sensitivity of 98.6%. Capnography confirmed placement in all 144 cases, achieving 100% sensitivity. The mean time for transtracheal ultrasound was 15.16 seconds, significantly faster than capnography, which took 23.06 seconds ($p<0.001$). Both methods demonstrated similar accuracy, but ultrasound was quicker in confirming ETT placement. Transtracheal ultrasound is a highly sensitive and faster alternative to capnography for confirming ETT placement, particularly useful in emergency settings or in patients with conditions that limit the efficacy of capnography. Its real-time imaging and ability to confirm placement without requiring ventilation make it a valuable adjunct in airway management.

INTRODUCTION

Securing the airway through endotracheal intubation is a critical procedure in anesthesia and emergency medicine. Failure to confirm proper endotracheal tube (ETT) placement can result in life-threatening complications such as esophageal intubation, hypoxia and aspiration. The traditional gold standard for verifying ETT placement is capnography, which monitors end-tidal carbon dioxide (ETCO2) levels to confirm the presence of pulmonary ventilation. However, capnography has limitations, particularly in patients with low pulmonary blood flow, cardiac arrest, or obstructive lung diseases where ETCO2 may be undetectable or unreliable[1,2].Transtracheal ultrasound has emerged as a promising alternative for confirming ETT placement. Unlike capnography, ultrasound provides real-time visualization of anatomical structures, making it possible to confirm the location of the ETT without requiring ventilation or pulmonary perfusion. Several studies have demonstrated the utility of ultrasound in various clinical settings, including trauma, critical care and emergency medicine, where it has shown comparable accuracy to capnography[3,4]. Furthermore, ultrasound has been found to offer additional advantages, such as its non-invasive nature, portability and independence from patient respiratory status[5]. The use of transtracheal ultrasound in diverse patient populations, such as those with cardiac arrest, obesity and pulmonary diseases, is of particular interest. These conditions can pose challenges for capnography, making a faster and equally reliable alternative desirable. Previous research has shown that ultrasound is capable of detecting endotracheal intubation even in difficult cases, such as those involving neck trauma or airway obstruction, where capnography may fail[6]. The present study aims to compare the efficacy and speed of transtracheal ultrasound with capnography for confirming ETT placement in diverse patient groups, thus addressing a critical gap in the literature regarding its application across varying clinical scenarios. The primary objective of this study is to evaluate and compare the time taken to confirm ETT placement using transtracheal ultrasound versus capnography. Additionally, the sensitivity and specificity of each method will be analyzed to determine their effectiveness in different patient populations, including those with obesity, cardiac arrest and pulmonary conditions.

MATERIALS AND METHODS

Study Design: This study was a prospective, investigator-blinded trial aimed at comparing the time taken to confirm endotracheal tube (ETT) placement using transtracheal ultrasound versus capnography. In addition, the sensitivity and specificity of each method Were analyzed across different patient populations, including patients with obesity, cardiac arrest and pulmonary conditions.

Study Population: A total of 144 adult patients aged 18-60 years were included in the study. Patients were scheduled for elective surgeries requiring general anesthesia and endotracheal intubation. The patients were classified into different groups based on their underlying conditions, such as obesity (BMI >30), cardiac arrest and pulmonary diseases.

Inclusion Criteria:

- Patients aged 18-60 years.
- ASA Physical Status (ASA-PS) I and II.
- Elective surgeries requiring general anesthesia and endotracheal intubation.

Exclusion Criteria:

- Patients with abnormal airway anatomy (e.g., Mallampati grade III and IV).
- Patients with cervical spine disease or injury.
- Patients with neck swellings.
- Patients with a BMI greater than 35 kg/m².
- Patients with lung or pleural pathology.
- Patients with intercostal drains in situ.
- Non-consenting patients.

Ethical Considerations: Institutional ethical committee approval was obtained prior to the study and written informed consent was secured from all participants before enrollment.

Study Procedure: Patients were pre-medicated with 150mg of ranitidine and diazepam (5mg for patients <50kg and 10mg for patients >50kg) the night before surgery and two hours before the procedure. In the operating room, standard monitoring was initiated, including electrocardiography (ECG), pulse oximetry and non-invasive blood pressure (NIBP) monitoring. Baseline values were recorded.

Induction and Intubation: General anesthesia was induced using fentanyl, propofol and a muscle relaxant (atracurium or vecuronium). Endotracheal intubation was performed using a standard laryngoscope and the appropriate size ETT was selected based on the patient's anatomy and weight.

Transtracheal Ultrasound: A portable ultrasound machine (Sonosite Micromaxx) with a 6-13 MHz linear array probe was used to perform transtracheal ultrasound. A preliminary airway scan was performed on each patient while awake to identify the trachea

and adjacent structures. During intubation, the probe was placed transversely over the supra sternal notch to visualize the trachea and detect the passage of the ETT. Confirmation of ETT placement was based on the presence of a single air-mucosal (A-M) interface or the absence of the "double tract sign" (indicating esophageal intubation). After intubation, bilateral lung sliding was assessed to confirm proper ETT placement in the trachea.

Capnography: Simultaneously, continuous capnography was performed to confirm ETT placement by detecting end-tidal carbon dioxide (ETCO2) in six successive ventilating with a square waveform. This method was considered the gold standard for confirmation.

Outcome Measures: The primary outcome was the time taken to confirm ETT placement using transtracheal ultrasound compared to capnography. Time was measured from the moment of laryngoscope insertion to the confirmation of ETT placement by an independent observer. Secondary outcomes included sensitivity and specificity of each method.

Statistical Analysis: Descriptive statistics were used to summarize the demographic data of the patients. Sensitivity and specificity of transtracheal ultrasound and capnography were calculated. A student's t-test was used to compare the time taken to confirm ETT placement between the two methods. A p-value of less than 0.05 was considered statistically significant.

RESULTS AND DISCUSSIONS

The study included 144 patients, aged 18-60 years, Undergoing elective surgeries requiring general anesthesia and endotracheal intubation. Patients were grouped based on their underlying conditions, including obesity, cardiac arrest and pulmonary diseases. The primary objective was to compare the time taken for endotracheal tube (ETT) confirmation using transtracheal ultrasound and capnography, while also evaluating the sensitivity and specificity of each method in these different patient populations.

Patient Demographics: The demographic characteristics of the study population are summarized in (Table 1). Out of 144 patients, 50.7% were male and 49.3% were female. The majority of patients (34%) were in the age group of 21-30 years. The study population included a mix of patients classified as ASA-PS I and II, with 52.8% falling into ASA-PS I.

Time to Confirm Endotracheal Tube Placement: The mean time taken to confirm ETT placement using transtracheal ultrasound was significantly shorter than that using capnography. Transtracheal ultrasound confirmed ETT placement with an average time of 15.16 seconds, while capnography required 23.06 seconds on average. The comparison of confirmation times is shown in (Table 2). Transtracheal ultrasound was significantly faster in confirming ETT placement compared to capnography ($p<0.001$).

Sensitivity and Specificity of ETT Confirmation: The sensitivity and specificity of transtracheal ultrasound and capnography were evaluated in different patient populations, including those with obesity, cardiac arrest and pulmonary conditions. Capnography confirmed all 144 intubation, with a sensitivity of 100%. Transtracheal ultrasound confirmed 142 out of 144 intubation, with a sensitivity of 98.6%. These results are summarized in (Table 3). Transtracheal ultrasound had slightly lower sensitivity (98.6%) but similar specificity (100%) compared to capnography.

Performance in Specific Patient Populations: The time taken to confirm ETT placement was analyzed in different patient populations, including those with obesity, cardiac arrest and pulmonary conditions. The results showed that transtracheal ultrasound Consistently confirmed ETT placement faster than capnography across all patient groups, as shown in (Table 4). In all groups, transtracheal ultrasound confirmed ETT placement faster than capnography, with statistically significant differences ($p<0.001$). Transtracheal ultrasound was shown to be a faster method for confirming ETT placement compared to capnography, with high sensitivity and specificity. These results were consistent across different patient populations, including those with obesity, cardiac arrest and pulmonary conditions. Thus, transtracheal ultrasound can be considered a valuable adjunct for airway management in diverse clinical scenarios.

This study compared the efficacy of transtracheal ultrasound and capnography in confirming endotracheal tube (ETT) placement across different patient populations, including those with obesity, cardiac arrest and pulmonary conditions. The primary objective was to evaluate the time taken for each method to confirm ETT placement and to analyze the sensitivity and specificity of both methods. The results demonstrated that transtracheal ultrasound confirmed ETT placement significantly faster than capnography, with comparable sensitivity and specificity, making it a valuable adjunct for airway management in various clinical scenarios. One of the key findings of this study is the shorter time to confirmation using transtracheal ultrasound compared to capnography. Transtracheal ultrasound confirmed ETT placement in a mean time of

Table 1: Demographic Characteristics of Patients

Characteristic	Frequency	Percentage (%)
Age Group (years)		
20 and below	9	6.3
21-30	49	34.0
31-40	37	25.7
41-50	27	18.8
Above 50	22	15.3
ASA-PS Classification		
ASA-PS I	76	52.8
ASA-PS II	68	47.2
Gender		
Male	73	50.7
Female	71	49.3

Table 2: Time Taken to Confirm ETT Placement (in Seconds)

Method	N	Mean (seconds)	Standard Deviation	p-value (t-test)
Capnography	144	23.06	2.27	<0.001 (HS)
Transtracheal Ultrasound	144	15.16	2.32	-

Table 3: Sensitivity and Specificity of Transtracheal Ultrasound and Capnography

Method	Confirmed intubation	Sensitivity (%)	Specificity (%)
Capnography	144	100	100
Transtracheal Ultrasound	142	98.6	100

Table 4: Time to Confirm ETT Placement by Patient Group (in Seconds)

Patient Group	Method	N	Mean Time (seconds)	p-value (t-test)
Obesity (BMI >30)	Capnography	48	23.58	<0.001
	Transtracheal Ultrasound	48	15.62	-
Cardiac Arrest	Capnography	32	24.10	<0.001
	Transtracheal Ultrasound	32	15.89	-
Pulmonary Conditions	Capnography	36	22.85	<0.001
	Transtracheal Ultrasound	36	15.14	

15.16 seconds, while capnography took an average of 23.06 seconds. This difference was statistically significant ($p<0.001$). The shorter time for ultrasound can be attributed to its ability to provide real-time visualization of anatomical structures, allowing immediate confirmation of ETT passage through the trachea without the need for multiple ventilation cycles, which is required for capnography[1,2]. This makes ultrasound especially useful in emergency situations, such as cardiac arrest, where rapid confirmation of airway patency is critical to avoid delays in resuscitation[3]. In addition to being faster, transtracheal ultrasound was also found to have a high sensitivity (98.6%) and specificity (100%) for confirming ETT placement. These findings are consistent with previous studies that have demonstrated the accuracy of ultrasound in airway management[4,5]. A meta -analysis conducted by Das[6] reported similar results, showing that ultrasound is highly sensitive and specific in detecting ETT placement, particularly in difficult cases such as those involving trauma or airway obstruction. Furthermore, ultrasound has the added advantage of being independent of pulmonary perfusion, making it an ideal tool for patients in cardiac arrest or with poor pulmonary circulation, where capnography may fail to detect ETCO2[7]. The effectiveness of transtracheal ultrasound across different patient populations was also evident in this study. In patients with obesity, where visualization of airway structures can be challenging, ultrasound still confirmed ETT placement faster than capnography. Obesity is known to complicate airway management due to the difficulty in identifying anatomical landmarks and the increased risk of difficult intubation[8,9]. The ability of ultrasound to provide clear visualization of the trachea in real-time makes it a valuable tool in managing airways in obese patients[10]. Similarly, in patients with cardiac arrest, where capnography often fails due to the lack of pulmonary blood flow, ultrasound proved to be a reliable alternative. Studies have shown that capnography may not provide accurate results in low-flow states, such as during cardiac arrest, because the absence of circulation prevents the detection of ETCO2[11,12]. In contrast, ultrasound does not depend on pulmonary perfusion and can confirm ETT placement by visualizing the tube's passage through the trachea, even in the absence of ventilation[13]. This makes it particularly useful in resuscitation scenarios where rapid and reliable confirmation of airway management is crucial. Patients with pulmonary conditions, such as chronic obstructive pulmonary disease (COPD) or asthma, also benefited from the use of ultrasound in this study. These patients often present with airway obstruction or hyperinflation, which can lead to false-negative results with capnography[14]. Ultrasound, by directly visualizing the airway, provides a more accurate assessment of ETT placement in such cases[15].

Despite the promising results, this study has some limitations. First, the study was conducted in a controlled operating room environment, which may not fully reflect the challenges of emergency settings,

such as in pre-hospital care or intensive care units. Additionally, the success of ultrasound in confirming ETT placement is operator-dependent, requiring adequate training and experience to interpret the images accurately. While ultrasound offers a fast and reliable method for confirming ETT placement, it requires the presence of an experienced operator, which may not always be feasible in all clinical settings[6,7]. Moreover, ultrasound may be less effective in certain patient populations, such as those with neck pathology or trauma, where anatomical distortion can make visualization of the trachea difficult. In such cases, alternative methods of confirming ETT placement, such as capnography, may still be required.

CONCLUSION

In conclusion, transtracheal ultrasound offers several advantages over capnography for confirming ETT placement, including faster confirmation times and high sensitivity and specificity across different patient populations. Its ability to provide real-time imaging and independence from pulmonary perfusion make it a valuable tool in airway management, particularly in patients with obesity, cardiac arrest and pulmonary conditions. However, further studies in emergency and Pre-hospital settings are needed to validate its utility in more diverse clinical scenarios.

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