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Original Research Article

Comparative evaluation of linear and curvilinear ultrasound transducers for confirmation of endotracheal tube placement in emergency intubation

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ABSTRACT

Background: Accurate and rapid confirmation of endotracheal tube (ETT) placement is critical in emergency airway management, as unrecognized oesophageal intubation can lead to catastrophic outcomes. Although waveform capnography is considered the gold standard, it has limitations in low pulmonary flow states. Point-of-care ultrasonography has emerged as a useful adjunct, but the optimal choice of ultrasound transducer for ETT confirmation remains unclear. This study aimed to compare the speed and reliability of linear and curvilinear ultrasound transducers for confirming ETT placement in emergency intubation.

Methods: A hospital-based non-randomized controlled trial was conducted over 18 months (January 2020 to June 2021) in the Emergency Department of a tertiary care centre in South India. Adult patients (≥18 years) undergoing emergency endotracheal intubation were included, while those in cardiac arrest with ongoing CPR or requiring surgical airways were excluded. Participants were allocated to linear or curvilinear transducer groups using the serial-numbered opaque sealed envelope technique. The primary outcomes were time to exclusion of oesophageal intubation and time to confirmation of left lung sliding, while secondary outcomes included total procedure time up to five-point auscultation and operator confidence.

Results: Eighty-seven patients were analyzed (46 linear, 41 curvilinear). Baseline characteristics were comparable between groups. The linear transducer demonstrated significantly shorter times for exclusion of oesophageal intubation, confirmation of left lung sliding, and total procedure time ($p<0.0001$ for all). Operator confidence was significantly higher with the linear transducer. Procedural times showed no association with age or indication for intubation, though shorter times were observed in male patients.

Conclusions: Linear ultrasound transducers provide faster and more reliable confirmation of ETT placement with higher operator confidence compared to curvilinear transducers, supporting their preferential use in emergency airway management.

Keywords: Airway ultrasound, Curvilinear transducer, Emergency medicine, Endotracheal intubation, Linear transducer, Point-of-care ultrasound

INTRODUCTION

Endotracheal intubation is a medical procedure in which a tube is inserted into the trachea, usually through the mouth, to maintain airway patency, deliver oxygen, medications or anaesthesia, support breathing, prevent aspiration, and facilitate airway clearance. Endotracheal intubation enables medical professionals to get a better view of the upper airway. It is performed on people who cannot breathe on their own or are unconscious.[1,2]

Confirmation of the proper placement of an endotracheal tube (ETT) is a crucial step in airway management since unrecognized oesophageal intubation leads to catastrophic consequences. The incidence of oesophageal intubation was reported at 6% in emergency conditions and 1.75% in the elective setting.[3] Oesophageal intubation is one of the main causes of accidents leading to death or neurologic damage. An investigation of anaesthesia mortality revealed that 69% of the deaths were related to airway management, with oesophageal intubation as one of the contributing factors.[4]

Although direct visualization of the ETT passing through the glottis is commonly used, it is not always feasible, and therefore multiple confirmation methods such as chest rise, auscultation, capnometry/capnography, bronchoscopy, and chest radiography are employed, each with varying accuracy.[5] Ultrasound, once the domain of the radiologist, has now found its place in pre-hospital applications (e.g., emergency responders), emergency wards, intensive care units, and operation theatres. Portable ultrasound is easy to carry, non-invasive, relatively economical, easily reproducible, and widely available, and it has a good safety record. Various studies have shown that ultrasound is a novel tool to confirm proper ETT placement.[6-8]

Upper airway ultrasonography is a simple, non-invasive, and portable point-of-care tool that remains reliable in low pulmonary flow states such as shock or cardiac arrest, where capnography may be unreliable, and can be used for both primary and secondary confirmation of endotracheal tube placement, with primary verification performed before securing the tube.[9] Selection of the ultrasound transducer is crucial, as linear (5-14 MHz), curvilinear (~4 MHz), and micro-convex (~8 MHz) probes each offer distinct advantages for airway and lung imaging, with micro-convex transducers being particularly useful for posterior thoracic access in supine patients.[10] Endotracheal tube placement can be confirmed using real-time anterior neck ultrasound, indirect pleural or diaphragmatic ventilation assessment, or a combination of both, enabling immediate detection and correction of oesophageal intubation, partial differentiation of endobronchial placement, and reliable confirmation even in very low cardiac output states where capnography may be unreliable, with added superiority over auscultation in noisy environments such as helicopter retrievals.[11,12] Bilateral lung ultrasound further aids in identifying endobronchial intubation by asymmetric lung sliding and lung pulse, guiding tube repositioning until bilateral lung sliding is achieved, and given ongoing debate regarding optimal transducer choice, this study was undertaken to compare the speed and reliability of linear and curvilinear ultrasound transducers for ETT confirmation.[13]

Recent literature has increasingly demonstrated that ultrasonography is a highly accurate modality for confirming endotracheal tube placement, with consistently high sensitivity and specificity across studies. Comparable diagnostic accuracy between linear and curvilinear probes has been reported, with faster confirmation times and higher operator confidence using linear probes, along with excellent pooled sensitivity and specificity on meta-analysis and strong agreement with capnography for detecting oesophageal intubation.[1,14,15] Real-time tracheal ultrasound has also shown strong concordance with bronchoscopy in ICU patients, faster confirmation than auscultation and capnography, improved tube positioning using ultrasound-based depth assessment, rapid confirmation with the T.R.U.E. method, and reliable differentiation of tracheal versus oesophageal placement using lung sliding in both cadaveric and elective surgery settings.[16-21]

Multiple studies have reinforced the utility of airway ultrasonography across varied clinical settings, demonstrating improved diagnostic performance when tracheal and lung views are combined and faster confirmation compared with pleural, diaphragmatic, and traditional clinical methods.[22,23] Ultrasound has also shown versatility in paediatric airway sizing, consistent accuracy across tube sizes, rapid learnability among novices, and the usefulness of specific signs and protocols such as the double-line sign, three-window POCUS approach, and transtracheal techniques, all with high sensitivity and specificity.[24-31] Several investigations have shown ultrasound to be faster than capnography and auscultation, with high accuracy even during CPR and emergency intubations, and rapid skill acquisition with minimal training.[32-39] Importantly, ultrasound remains reliable in low-flow states where capnography has limitations, supporting its effectiveness across different providers, techniques, and clinical scenarios, including RSI and elective surgery.[40]

This study aimed to compare the speed and reliability of linear and curvilinear ultrasound transducers in confirming endotracheal tube placement. Specifically, among adults (>18 years) intubated for airway or breathing management in a tertiary care hospital in Thrissur, the study compares the mean time required to identify correct tube placement using left lung sliding and evaluates the mean operator confidence associated with each transducer type.

METHODS

A hospital-based non-randomized controlled trial was conducted in the Department of Emergency Medicine at Jubilee Mission Medical College and Research Institute, Thrissur, South India, over an 18-month period from January 2020 to June 2021. Adult patients (≥18 years) requiring endotracheal intubation for airway or breathing management were included, while those in cardiac arrest with ongoing CPR, overt tracheal injury, open thoracic wounds, or requiring a surgical airway were excluded.

Sample size

A total of 80 patients were calculated using the below equation based on the accuracy of two transducers

observed in a study conducted by Mishra PR et al.[27] Of which a minimum 40 cases for each group were needed for the study. It was estimated with the following equation

$$N = s_1^2 + s_2^2 \frac{\left[z1-\frac{\alpha}{2}+z1-\beta\right]2}{(x-x)2}$$

with 95% confidence interval and 80% power.

Study procedure

Study participants were assigned to sonography-aided intubation using either linear or curvilinear transducers, with transducer allocation determined by the serial-numbered opaque sealed envelope (SNOSE) technique. All airway management decisions and use of additional imaging modalities were made solely by the treating medical team, and endotracheal intubation in both groups followed standard departmental protocols after obtaining consent from legally authorized representatives. Time measurements were recorded by an independent observer using an electronic stopwatch, with the start point defined as the laryngoscope blade crossing the incisors and the endpoint as sonographic confirmation of lung sliding. During the procedure, the sonographer first scanned the tracheal rings to exclude oesophageal intubation, identified by a hyperechoic ETT lumen with posterior acoustic shadowing, and subsequently confirmed tracheal placement by left lung sliding after repositioning the probe. Intubations were performed by postgraduate residents trained in basic airway management, sonography was conducted by residents trained in ATLS and ultrasound-guided intubation, and all timing parameters were recorded by trained nursing staff.

Statistical analysis

Data were analysed using IBM SPSS Statistics version 21 for Windows, with continuous variables expressed as mean (SD) or median (IQR) and categorical variables presented as frequencies and percentages. Associations were assessed using chi-square test for categorical variables, independent samples t-test and one-way ANOVA with Bonferroni post-hoc analysis for continuous variables, Mann-Whitney U test for confidence scores, and a p value <0.05 was considered statistically significant.

Ethical consideration

The ethical approval was sought from the Institutional Ethics Committee (IEC). Informed consent was obtained from the caretakers of the study participants before data collection. Confidentiality was maintained by limiting the identifying variables to the minimum.

RESULTS

A total of 87 patients undergoing endotracheal intubation for airway or breathing management were included in the study of which linear ultrasound transducer was used in 46 patients for confirmation of endotracheal intubation and in the remaining 41 patients, curvilinear transducer was used for confirmation of endotracheal intubation. The minimum age of the patient where linear transducer was used was 18 years and a maximum of 86 years. The minimum age of the patients where curvilinear transducer was used was 18 years and a maximum of 76 years.

Table 1: Distribution of patients by age, gender, and indication for intubation according to ultrasound transducer type (n=87).

Variable	Linear (n=46), N (%)	Curvilinear (n=41), N (%)	P value
Age (years)			
Mean (SD)	48.2 (20.5)	47.5 (17.4)	0.88
Gender			
Male	26 (56.5)	23 (56.1)	0.96
Female	20 (43.5)	18 (43.9)	
Indication for intubation			
Haemodynamic instability	8 (17.4)	10 (24.4)	0.26
Poor GCS	22 (47.8)	23 (56.1)	
Ventilatory support	16 (34.8)	8 (19.5)	

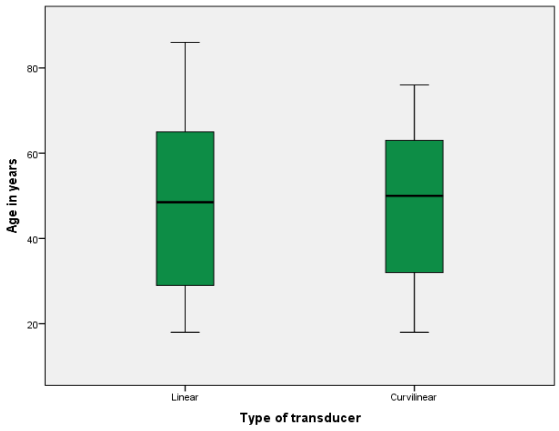

Figure 1: Distribution of patients by age (n=87).

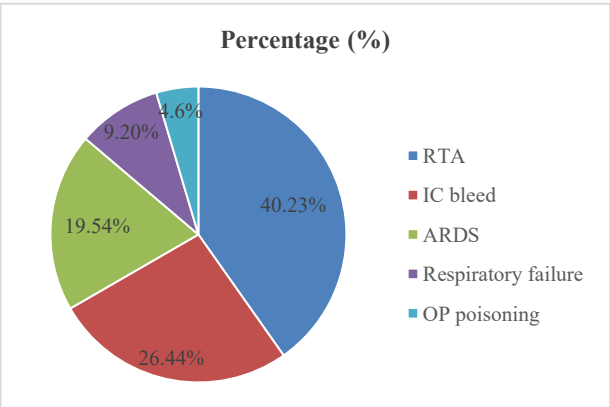

Figure 2: Provisional diagnosis of the patients (n=87).

Table 1 and Figures 1-2 summarize the baseline characteristics of the study population. Age, gender distribution, and indications for intubation were comparable between the linear and curvilinear transducer groups, confirming baseline equivalence. Road traffic accidents were the most common provisional diagnosis, followed by intracranial bleeding (Figure 2). The mean time from intubation to exclusion of oesophageal intubation, the time to confirmation of left lung sliding, and the total procedure time up to five-point auscultation were all significantly shorter with the linear transducer compared to the curvilinear transducer (Table 2; p<0.01 for all).

Table 2: Comparison of intubation-related time intervals between linear and curvilinear ultrasound transducers (n=87).

Time parameter (seconds)	Linear (n=46), Mean (SD)	Curvilinear (n=41), Mean (SD)	P value
Time from intubation to exclusion of oesophageal intubation by USG	72.76 (11.48)	90.44 (10.78)	<0.01
Time from intubation to confirmation of left lung sliding	80.02 (10.96)	97.10 (10.93)	<0.01
Total procedure time till five-point auscultation	99.59 (7.47)	103.71 (9.41)	0.02

Table 3: Comparison of intubation-related time intervals between male and female patients (n=87).

Time parameter (seconds)	Male, Mean (SD)	Female, Mean (SD)	P value
Time from intubation to exclusion of oesophageal intubation by USG	72.76 (11.48)	90.44 (10.78)	<0.01
Time from intubation to confirmation of left lung sliding	80.02 (10.96)	97.10 (10.93)	<0.01
Total procedure time till five-point auscultation	99.59 (7.47)	103.71 (9.41)	0.02

Table 4: Correlation between patient age and intubation-related time intervals assessed by ultrasound (n=87).

Time parameter vs age	Correlation coefficient (r)	P value*
Time from intubation to exclusion of oesophageal intubation by USG	-0.07	0.52
Time from intubation to confirmation of left lung sliding	-0.03	0.73
Total procedure time till five-point auscultation	-0.07	0.48

*Pearson correlation

Table 5: Comparison of intubation-related time intervals according to indication for intubation (n=87).

Indication of intubation	Time from intubation to exclusion of oesophageal intubation by USG (Mean±SD)	Time from intubation to confirmation of left lung sliding (Mean±SD)	Total procedure time till five-point auscultation (Mean±SD)	P value*
Haemodynamic instability	79.28 (15.88)	86.89 (15.23)	8.70 (2.05)	0.39
Poor GCS	83.11 (14.65)	89.64 (14.54)	9.00 (1.34)	0.54
Ventilatory support	78.67 (11.86)	86.00 (11.45)	7.82 (1.59)	0.34

*ANOVA test

Table 6: Comparison of the confidence level of the use between two transducers (n=87).

Types of transducers	Median (IQR)	Mean rank	P value*
Linear	90 (77.50-92.50)	61.61	<0.01
Curvilinear	41 (40.00-55.00)	24.24	

*Mann-Whitney U test

Gender-based analysis showed that male patients had significantly shorter times for exclusion of oesophageal intubation, confirmation of left lung sliding, and total procedure time compared to female patients (Table 3).

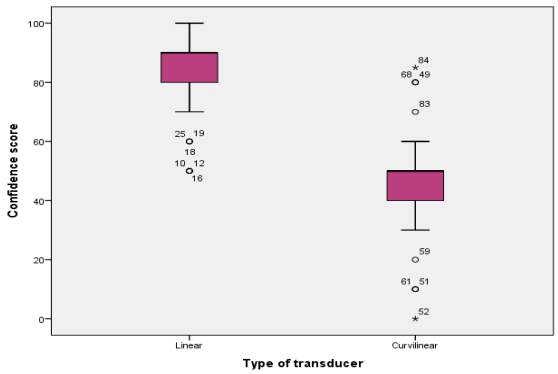

Figure 3: Comparison of the confidence level of the use between two transducers (n=87).

Correlation analysis demonstrated no significant association between patient age and any of the measured time intervals (Table 4), and no significant relationship was observed between indications for intubation and procedural times (Tables 5). Operator confidence was significantly higher with the linear transducer compared to the curvilinear transducer, as demonstrated by mean rank confidence levels (Table 6 and Figure 3; $p<0.01$).

DISCUSSION

In recent years, ultrasound has gained increasing popularity for confirming endotracheal tube placement due to the ease and rapidity with which images can be obtained, especially when other confirmation tools have limitations or are not readily available in the emergency department. Despite this, quantitative waveform capnography remains the gold standard for confirming correct endotracheal tube placement as recommended by the 2010 American Heart Association Guidelines for CPR and Emergency Cardiovascular Care. Airway ultrasonography is particularly useful for ETT confirmation when end-tidal CO_2 monitoring is unreliable, radiology is unavailable, the patient arrives already intubated, or post-intubation response is inadequate, and because it does not interrupt CPR, it serves as an effective screening tool for verifying tube placement. In a systematic review and meta-analysis by Chou et al, a pooled sensitivity of 93% and specificity of 97% was determined for detection of oesophageal intubations in adult patients and cadaveric models.[7] Gottlieb et al reported a pooled sensitivity of 98% and specificity of 98% in a snapshot summary of a systematic review of live adult patients.[30]

Our study demonstrated that use of the linear transducer resulted in significantly shorter times for exclusion of oesophageal intubation, confirmation of left lung sliding, and completion of the total procedure up to five-point auscultation compared with the curvilinear transducer. A comparable result was reported in a study conducted by Gottlieb et al where the mean time to identification was significantly lower with the linear transducer as compared with the curvilinear transducer.[14] Other studies conducted by Abhishek et al, Werner et al, where linear transducers were used showed that the sensitivity was significantly higher compared to other methods.[1,14] Also, in studies by Chou et al, Sun et al, where a curvilinear transducer was used showed significantly higher sensitivity compared to other methods.[19,33]

Ultrasonography employs high-frequency sound waves (2.5-10 MHz) generated by piezoelectric probes, where lower frequencies allow deeper penetration with reduced resolution, and in airway imaging a 7.5-MHz linear probe is preferred for superficial structures while a 5-MHz curvilinear probe is used for deeper structures, with images formed through reflection, refraction, scattering, absorption, and transmission of sound through tissues. Reflection of sound is marked at interfaces between tissues of different acoustic impedance and the image is built from the reflected sound signals.

Our study showed that the mean rank confidence level of the use of linear transducer was statistically higher than the use of curvilinear transducer. Similar finding was reported in a study conducted by Gottlieb et al where the mean operator confidence was significantly higher with the linear transducer compared to the curvilinear transducer also, all operators preferred the linear transducer over the curvilinear transducer.[14] Although our study found no correlation between patient age and ultrasound confirmation times, in contrast to known age-related anatomical challenges that may prolong intubation, the clinical significance of these findings should always be interpreted in correlation with overall airway assessment. Our study also reported that the meantime intubation to confirming left lung sliding and the mean of total procedure time till five-point auscultation were significantly lesser in male gender as compared to the female gender.

One of the main strengths of the study is the inclusion of the representative sample of the population and hence the external validity. However, randomisation was not done which could have resulted in selection bias. Owing to the nature of the procedure blinding was not possible and hence the chance of regression of the study finding towards the favourable result. BMI and ASA; the potential confounders were not included in the study which could have affected the study results. Furthermore, there was no objective measurement of confidence among the sonographers. The chances of interobserver bias could not be ruled out.

CONCLUSION

The mean age of patients intubated using linear and curvilinear transducers was comparable, and road traffic accidents constituted the most common indication for intubation. The linear transducer significantly reduced the time to exclude oesophageal intubation, confirm left lung sliding, and complete the overall procedure including five-point auscultation when compared with the curvilinear transducer. Operator confidence was also significantly higher with the linear transducer. Procedural times showed no significant association with patient age or indication for intubation, though confirmation of left lung sliding and total procedure time were shorter in male patients. These findings suggest that linear transducers offer faster and more reliable confirmation of ETT placement, warranting further validation through multicentric randomized controlled trials.

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