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Comparison of real-time ultrasonography with waveform capnography in verifying endotracheal tube location- An observational study

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ABSTRACT

Background: Immediate post-intubation confirmation of endotracheal tube requires direct observational or secondary gadgets-dependent measures having variable sensitivity and specificity. In this study, dynamic real-time ultrasonography is used for the evaluation of endotracheal tube. The correlation between the gold standard test(Capnography) and the unconventional test(Ultrasonography) is also evaluated.
Materials and Methods: One hundred ASA PS 1, and ASA PS 2 patients were evaluated for endotracheal intubation using real-time ultrasonography. The desired endotracheal intubation was further confirmed by using time capnography. Victorious tracheal intubation was identified using some radiological signs, only one air-mucosa interface with a comet-tail artefact and enhanced posterior acoustic shadowing indicative of endotracheal intubation. Two air-mucosa interfaces with comet-tail artefacts with posterior shadowing were indicative of oesophageal intubation.
Results: The mean (± SD) ages of the studied patients were 41.25±7.76 Yrs. A total of 87% of patients had endotracheal intubation and 13% had oesophageal intubation based on ultrasonography scan findings. Capnography finding was 91% endotracheal intubations, 9% were true oesophageal. The true positive and true negative rate, positive predictive value and negative predictive values of real-time ultrasonography were 95%, (95% confidence interval (CI) 88% to 98%) 100% (95% CI 62% to 100%), 100% (95% CI 94% to 100%), 69% (95% CI 38% to 89%) respectively. Kappa (k) value was 0.8.
Conclusion: Ultrasonography is a portable sensitive screening equipment for ETT position confirmation. There is a strong association between USG findings with time capnography results.

1. Introduction

Anaesthesiologists have to adopt a piece of safe and time-tested equipment for effective emergency airway management. Anaesthesiologists should be aware of the expanding applications of the technology and status of ultrasound. Control of a patient's air passage and timely intervention is the fundamental adeptness required by anaesthesiologists. Familiarity with the basic physics of USG, regional ultrasound-anatomy and suitable transducer selection is salient to obtain the utmost advantage of the new diagnostic modality. A 7.5-megahertz (10^6hertz) linear and 5-megahertz curved array transducer is required for the scanning of superficial laryngeal composition and deeper structure respectively.[1] Airspace filled with air is an inferior medium for ultrasound (US) transmission. The easy accessibility and superficial location of the airway give a good sonographic resolution. Ultrasonographic images

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of the laryngeal structure obtained using a high-frequency transducer have greater resolution compared to conventional machinery-dependent imaging.[2] Ultrasonographic imaging technique has become evident as a new, portable, non-invasive, easy learning curve tool for airway-related issues. Now USG Scanning of the airway is emerging as a new horizon in airway management.[3–6]

Potential uses of USG other than the identification of endotracheal tube (ETT)[7] include percutaneous tracheostomy[8,9] and cricothyroidotomy,[10] measurement of subglottic diameter,[11] anticipation of difficult intubation[12] and prediction of post-extubation stridor,[13] size determination of paediatric ETT[14] and double-lumen tube (DLT) size.[15] Prolonging the diagnosis of oesophageal intubation after certain time can lead to morbidity.[16] Conventional imaging of the airway includes simple skiagram, non-contrast or contrast-enhanced computed tomography-assisted scanning, and Contrast or non-contrast Magnetic resonance imaging scanning. Some of the available techniques have risks of radiation hazards and non-feasibility to provide real-time images. Ultrasound (US) is a more suitable handheld gadget for anaesthesiologists. Time capnographic detection of end-tidal CO_2 when added with direct eye witnessing of the endotracheal tube passing through the larynx, is the gold standard method for ETT position detection. The existing methods of confirming tracheal intubation, including breath sound auscultation, end-tidal CO_2 monitoring and oesophageal detector can lead to false positive results.[17–19] Ultrasonography aided scanning of the airway has high sensitivity and specificity for this purpose.[19,20] A sharp hyperechoic curve on one side of the dorsal aspect of the trachea should be considered as ETT is misplaced at the oesophagus.[20] If the ETT passes into the bronchus the movement of the pleura and the diaphragm is seen on the same side. ETT location can be augmented by filling the cuff of the ETT with sound-reflecting media.[21] In a study by Adi et al[22] concluded that ultrasonography is a feasible test for ETT location. Pfeiffer et al[23] showed that US confirmation of ETT placement is a less time-consuming test than the standard method.

In this study, we were trying to observe and analyse the utility of the US in the real-time ETT position compared to Capnography. The correlation between the gold standard test(capnography) and the unconventional test(USG) is evaluated. Literature favoured capnographic sensitivity to be only 93% in detecting ETT.[24] In Patients with cardiac arrest and another low-volume state, exact spotting of the value of $ETCO_2$ either by capnography or colourimetric measurement is nondefinitive and is approximately 72%sensitive.[25] Ultrasonographic detection of oesophageal intubation can be made before initiation of ventilation for auscultation of breath sound thus preventing the probable chance of stomach distention and aspiration of its acidic content.

2. Materials and Methods

After receiving the ethical committee approval (Institutional Ethics Committee, North Bengal Medical College, Sushrutanagar, Darjeeling, WB, Memo No: PCM/2013-14/IEC/57 Date 16/12/14) and informed patient consent, 100 patients of either sex, aged between 18-65 years were included between July 2015 to June 2016 with ASA PS I and ASA PS II, anticipated non-difficult airway after considering exclusion criteria (i. Patient refusal, ii. Anatomical distortion of neck, iii. Oesophageal functional and structural disease iv. Patients with aspiration risk, v. Anticipated difficult intubation and more than two attempts at intubation). Sample size at the required precision level for sensitivity and specificity can be calculated by Buderer's formula[26] based on specificity$n = \frac{Z^2_{1-\frac{\alpha}{2}} \times s_P\left(1-s_p\right)}{L\, square\left(1-prevalance\right)}$.

It is estimated from the expected specificity of 0.94, prevalence of oesophagal intubation as 0.15[22] Where n = required sample size. S_N = anticipated sensitivity, S_P = anticipated specificity, α = size of the critical region (1-α is the confidence level). $Z_{1-\alpha/2}$ = standard normal deviation corresponding to the specified size of the critical region (α), $Z_{1-\alpha/2}$=1.96 at 95% confidence limit. L = absolute precision(0.05) desired on either side (half-width of the confidence interval) of sensitivity or specificity. The sample size can also be calculated by using a simple nomogram[27] for anticipated sensitivity specificity using the formula described by Buderer. Sample size (n) = 101.

A multipara monitor (Philips Intellivue MX430) was attached to the patient for monitoring pulse rate, blood pressure, continuous ECG, SpO_2, and $ETCO_2$. Keeping all drugs, circuit, and checked anaesthesia machine ready, slow intravenous injections of midazolam 0.05mg/kg and fentanyl 1 μ/kg body weight of the patient were given. After pre-oxygenation for three minutes, induction with etomidate 0.4mg/kg was done. One senior anaesthesiologist performed the endotracheal intubation after giving rocuronium 0.5mg/kg. After more than two attempts at intubation, the patient was excluded from the study to avoid unwanted consequences related to airway management. In the meantime, a portable ultrasound machine (LOGIQ e, GE Healthcare, India.) and capnography were pretested and were ready for use. Just before the induction the non-invasive haemodynamic parameters and oxygen saturation were recorded. One senior anaesthesiologist has performed the endotracheal intubation and another anaesthesiologist has performed the USG of upper airways simultaneously. The dynamic ultrasonography time was started from the starting of endotracheal intubation up to the real-time evaluation of the position of the tube. Real-time sonography search for the following 1. Triangular sign;[25] If the linear transducer is placed over the cricothyroid membrane, a triangular pre-epiglottic area is visible 2. Snowstorm sign;[25] a “brief flutter” is visible when the ETT passes the trachea. 3. Bullet sign;[25] through the trans-cricothyroid window during endotracheal intubation its triangular appearance will be round. 4. Enhanced tracheal posterior shadow sign;[25] ETT was considered endotracheal if one air-mucosa interface with a comet-tail artefact and an enhanced posterior shadowing. Double-tract sign;[25] ETT placement was oesophageal if two air-mucosa interfaces with comet-tail artefact and a posterior shadowing. We accepted the “snowstorm” appearance as a sign of endotracheal intubation.

The absence of a “snowstorm” and visible movement posterior to the two laryngeal lines is a sign of an oesophageal ETT presentation. When the determination of tube position is completed, the time of confirmation is recorded. Next, the capnograph is attached to the circuit and the characteristics wave from finding whether it is in the trachea or oesophagus was recorded. When the test result was oesophagus, according to the capnography finding, then proper airway management was done before the usual safe desaturation time. Haemodynamic parameters and oxygen saturation were again recorded in 3 minutes. All the required data collected the results of real-time USG compared with the finding of capnography. Demographic data were calculated by using MS Excel and GraphPad QuickCalcs. Sensitivity, specificity and positive predictive value of real-time upper airways USG were computed in the results and analysis section. The strength of agreement between the two tests was also performed with kappa statistics. A new diagnostic procedure or equipment (with the advantage of being less invasive or easier to implement) could be compared to an established diagnostic technique, typically if the result is dichotomous (disease vs no disease, positive vs negative). The alternative methods of comparison are greatly impacted by the presence and/or applied applicability of gold standard methods. When a reference standard is available, we can estimate the true-positive rate(TPR), true-negative rate(TNR), and ROC (receiver operation characteristics). When a reference standard is not available, we can evaluate the agreement and the kappa.[2]

CMM1 indicate column 1 marginal, CMM2 indicate column 2 marginal, RMM1 indicate row 1 marginal, RMM2 indicate row 2 marginal, and n represents the number of observations (not the number of raters).

Statistical calculations were conducted in the following order 1. Sensitivity= 87/ (87+4) *100 = 95 2. Specificity = 9/ (9+0) *100 = 100 3. Positive predictive value= 87/ (87+0) *100 = 100. 4. Negative predictive value = 9/ (9+4) *100 = 69. The next step of the calculation is the calculation of agreement statics of this study (kappa coefficient). (Table 5)

Figure 1: Orientation of trachea and oesophagus

Table 1: Table for agreement statistic

		Rater 1		**Row Marginal (RMM)**	
		Normal	Abnormal		
Rater 2	Normal	P	Q	P+Q	RMM 1
	Abnormal	R	S	R+S	RMM 2
Colum marginal(CMM)		P+R	Q+S		
		CMM 1	CMM 2		

Table 2: Kappa value and the level of agreement[28]

Kappa value range	**Strength of Agreement**	**% of Repeatable Data**
0–.20	None	0–4%
.21–.39	Minimal	4–15%
.40–.59	Weak	15–35%
.60–.79	Moderate	35–63%
.80–.90	Strong	64–81%

3. Results

The mean age distribution was 41.25±7.76 years and the mean weight was 57.28±16.43kg. Out of a hundred study subjects, capnography was able to display typical and adequate waveform favourable for endotracheal intubation in 91 patients and oesophageal intubation in 9 patients. Real-time ultrasonography of the upper airway detects 87 endotracheal intubation and 13 oesophageal intubations, out of 13, 9 were true oesophageal and 4 were tracheal intubation.

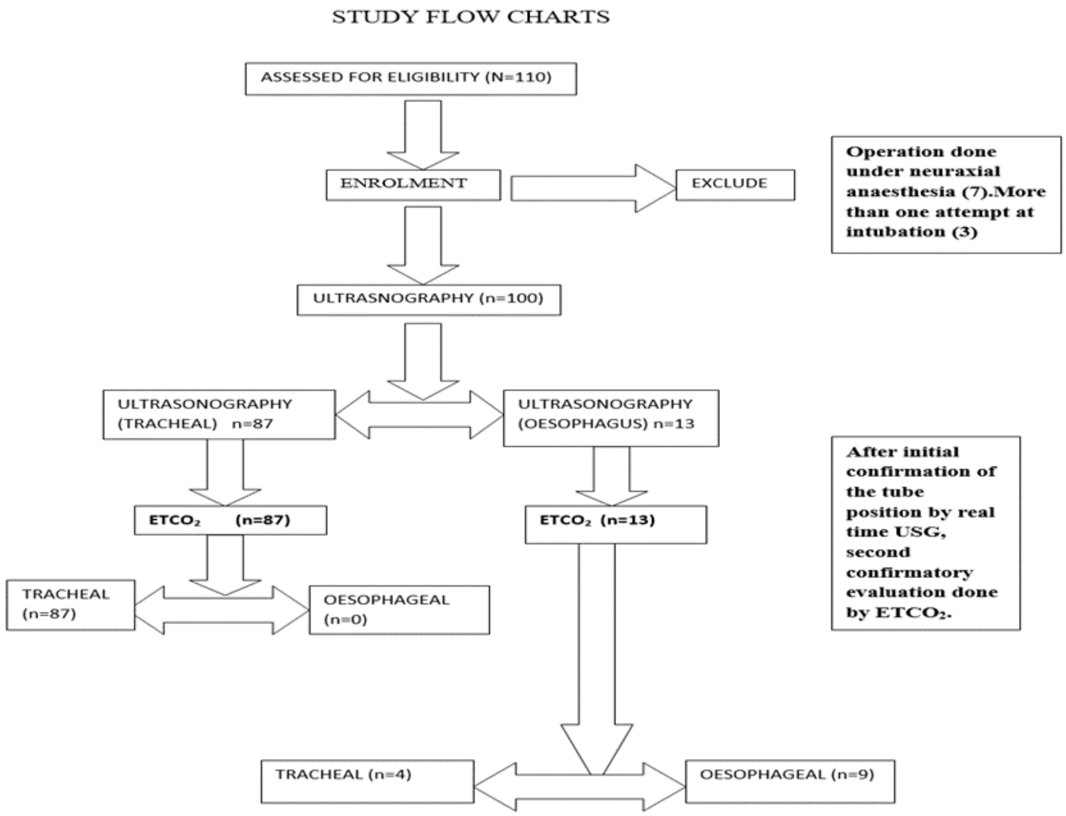

Diagram 1: Study flow chart

Table 3: Demographic data

Parameters	Values
Age*(yrs.)	41.25±7.76
Sex (F/M)	34/100
Height*(cm)	157.44±8.31
Weight*(kg)	57.28±16.43
BMI*(kg/m 2)	22.79±4.19

Data expressed as mean ± SD, as a group is a single and observational study, comparison not done. Sex is expressed in ratio.

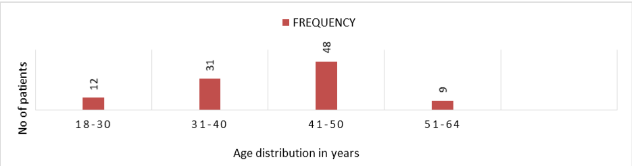

Figure 2: Distribution of age

The mean time of real-time evaluation was 12.94 sec with SD 2.5 sec. Sensitivity was 95% (95% CI:88-98%), specificity was 100% (95% CI: 62-100%), positive predictive value and negative predictive value was 100% (95% CI:94-100%) and 69% (95% CI:38-89%) respectively. Kappa value calculated value was 0.8 i.e. strong associations between the two tests in our study. For any test results probability of a positive result was 0.87 and a negative result was 0.13. For any particular test result, the probability of a true negative was 0.69 and a false negative was 0.30.

Table 4: USG time (Second.)

Number of values	100
Minimum	8
25% Percentile	12
Median	13
75% Percentile	14
Maximum	20
Mean	12.94
Std. Deviation	2.506
Std. Error of Mean	0.2506

Cohen Kappa coefficient[28] is a numerical evaluation of inter-test agreement for categorical data. K= $(P_o - P_e)/1 - P_e$

Table 5: Test results

Position of ETT	Gold standard test (Waveform capnography)		Total
	ETT in trachea	ETT in the oesophagus	
New test (Real-time USG) ETT in the trachea	87	0	87
ETT in the oesophagus	4	9	13
Total	91	9	100

Table 6: Modified presentation of the findings of different test results

		Test B		Total
		Yes	No	
Test A	Yes	p (87)	q (0)	p+q (87) rmm1
	No	r(4)	s(9)	r+s (13) rmm2
		p+r (91) cmm1S	q+s(9) cmm2	p+q+r+s(100)

Each 100 patients were evaluated separately by subsequent two tests, of which one gold standard and one newly prescribed test, i.e., waveform capnography and ultrasonography subsequently. A total of 87 observations are positive (tracheal intubation) by both tests.

So, observe population agreement is P_o = p+s / N=87+9/100= 0.96. Expected agreement

$$= \frac{\left\{\left(\frac{cmm1*rmm1}{n}\right)+\left(\frac{cmm2*rmm2}{n}\right)\right\}}{n}$$

$$= \frac{\left(91*\frac{87}{100}+9*\frac{13}{100}\right\}}{100}$$

=0.80, then

$K= (P_o\text{-}P_e)/1\text{-}P_e = \frac{(0.96-0.80\}}{1-0.8} = 0.8$

Table 7: Haemodynamic parameters

Parameters	Pre-procedure	Post procedure	P Value
Heart rate (Beat/min)	76.9 ±6.91	82.2± 6.83	0.001
Systolic BP (mm of Hg)	126.7±9.58	130 ±8.40	0.001
Diastolic BP (mm of Hg)	76.35 ±8.23	78.52 ±8.12	0.06
MEAN BP (mm of Hg)	92±11.46	94±11.77	0.05

Parameters are expressed in mean ± standard deviation on the same study population, Paired T-tests were used. Although heart rate and blood pressure change statically significant, but clinically insignificant.(p-Value <0.005)

4. Discussion

Different preliminary techniques are employed to confirm appropriate ETT positions. Various methods include the direct visualization of the glottis, observing bilateral chest movements, auscultation of the chest wall as well as epigastrium, and observing abdominal distension· However, each method has different drawbacks.[26,27,29–41] Definite confirmation methods such as capnography, oesophageal detector device, and chest radiography are frequently used to confirm ETT position.[38,40] Capnography and capnometry might give false-positive or false-negative results. Numerous recent studies reveal that ultrasound can identify oesophageal and endotracheal intubation.[7,19,25,36] A total of 110 patients of either sex, age between 18-65 years, ASA PS grade I and II, scheduled for elective endotracheal intubation followed by general anaesthesia in Orthopaedics, upper abdominal, and urological surgeries. All the study subjects were tested serially by upper airway ultrasonography and waveform capnography, then the test results of ultrasonography were compared with the capnography, and the kappa value[28] was calculated. Pre- and post-procedure haemodynamic parameters (Non-invasive) were recorded and the mean and standard deviation were calculated but no statistical comparison was done. There is a slight change in post-procedure mean heart rate (82±6.82 Vs 76±6.90). The mean BP was 92±11.46 pre-procedure to 94±11.77 post-procedure at two minutes. Test sensitivity of real-time upper airway ultrasonography was 95% specificity 100%, positive predictive value 100% and negative predictive value 69%. Kappa value 0.8 implies a strong correlation between the US and capnographic tube position estimation. Confidence limit in a particular confidence interval (95% CI), probability and likelihood ratio calculated, for any particular test result, probability of a positive test is 87% and negative is 13%. The probability of a true positive is 100% and a false positive 0%. For any particular test the probability of a true negative is 69% and false is 30%. The conventional likelihood ratio for the positive test was infinity and for the negative test, it was 4%. M Singh et al[4] in their study demonstrated the use of USG for the delineation of the anatomy of the airway. Tsung et al.[32] show the dynamic anatomic relationship of the oesophagus and trachea on sonography.[33] Frequency of identification of empty oesophagus was another study.[41] Drescher et al[40] confirm tracheal or oesophageal ETT placement in a small number of cadavers using USG. Rosenstein et al[42] showed that less exposed examiners can easily read transverse views of USG images. Muslu et al[32] studied the role of USG in the rapid identification of Oesophagus and tracheal intubation in adults and found USG is a fast and effective technique in this regard. Werner et al[19] determine the precision of real-time ultrasonography for tracheal and oesophagus ETT placement. Marciniak et al[43] describe the characteristics of the ultrasonographic finding of the paediatric airway during tracheal intubation Ma et al[34] Performed dynamic and static assessments of ETT position in a cadaver. Dynamic scanning resulted in 97% sensitivity and 100% specificity for oesophageal ETT placement. Static scanning resulted in 51% sensitivity and

91% specificity.

Park et al[39] concluded that the combination of trans cricothyroid membrane USG and sonographic lung-sliding sign could yield the highest sensitivity and specificity. Milling et al.[20] assess the efficacy of identifying oesophageal intubation with trans-tracheal ultrasonography. Chou et al[44] intheir observational study determine the concordance between the tracheal rapid ultrasound and quantitative waveform capnography and found tracheal ultrasound has high sensitivity and specificity for confirming ETT placement. Abbasi et al[25] conducted a study to compare the static and dynamic phases of ultrasonographic confirmation of endotracheal intubation. Adi et al[22] in their study compare ultrasonography to waveform capnography for verifying the position of ETT after intubation (static phase).

There were some limitations of our study. The study population could have been larger to obtain significant secondary outcomes. There is always a high probability that the intubation would be endotracheal intubation instead of oesophageal intubation. We have adopted convenience methods in sampling which may contribute to selection bias and therefore the performance of ultrasonography techniques. The actual prevalence of unwanted oesophageal intubation in the setting of planned operation is much less than our results. In our study, the prevalence of oesophageal intubation was raised intentionally for the evaluation of oesophageal intubation, after keeping all emergency airway management equipment in hands. In emergencies, intended endotracheal intubation results in accidental oesophageal intubation in up to 17% of patients.[45–47]

During intubation, the probe was displaced for the accommodation of the blade of the laryngoscope in some cases. The image quality was compromised to some extent due to some movement from laryngoscopy. We also found some false negative results.

5. Conclusion

Patients receiving general anaesthesia with endotracheal intubation require immediate preliminary and definitive verification of proper tube position. Ultrasonography is a sensitive screening evaluation tool with good sensitivity, specificity and positive predictive value. There is a strong association between the result finding with capnography. There are several limitations of our study such as anatomical distortion can impair image quality; our study was conducted in a controlled environment so the chance of sensitivity is high. The incidence of oesophageal intubation remained high.

6. Source of Funding

None.

7. Conflict of Interest

None.

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