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Research Article

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Accuracy of Bedside Upper Airway Ultrasonography *vs.* Standard Auscultation for Assuring the Location of Endotracheal Tube after Tracheal Intubation: Comparative Study Controlled by Quantitative Waveform Capnography

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Abstract

Objectives: To estimate the accuracy and rapidity of bed-side upper airway ultrasonography (UA-US) versus standard auscultation (SA) for confirmation of endotracheal tube (ETT) position.

Patients and methods: 107 patients underwent tracheal intubation for maintenance of general anesthesia. Position of ETT was confirmed by chest auscultation for the presence of breath sounds on both sides, and by UA-US using 9–12 MHz linear US transducer that was placed transversely on the neck anteriorly and superior to the suprasternal notch to visualize the ETT in the tracheal transverse and longitudinal views. The data obtained were compared to findings on using waveform capnography (WC). Time to define ETT position was determined. Study outcomes included determination of ETT position; tracheal or esophageal, accuracy of diagnosis and time taken till confirming the diagnosis.

Results: With comparison to WC findings, UA-US revealed sensitivity, specificity and accuracy rates of 97%, 71.4% and 95.3% while that for SA were 93.6%, 53.9% and 88.8%, respectively with significantly higher specificity and accuracy rates for UA-WC versus SA. Time required for confirmation of ETT position was significantly shorter with WC (9.16 ± 0.69 sec.) compared to SA and UA-US with significant difference in favor of UA-US (11.14 ± 1.3 *vs.* 13.5 ± 2.15 sec).

Conclusion: Confirmation of ETT position using UA-US or WC is very important because of the high false result depending on SA alone. UA-US using bed-side equipment is a simple, accurate and fast method than SA compared to WC as a gold standard, so it is recommended to be one of the important theater equipments whenever possible

Keywords: Endotracheal tube; Position; Ultrasonography; Capnography; Standard auscultation

Introduction

Mastering skill of endotracheal intubation to secure airway plays an important role in many settings [1] and confirmation of correct endotracheal tube (ETT) position immediately after intubation for general anesthesia has been one of the most challenging issues of airway management [2].

Confirmation of correct placement of ETT should be done rapidly [3] for early detection of esophageal intubation through a reliable method [4] as tube malposition is associated with various serious adverse outcomes [3].

Multiple methods were used over decades for verification of ETT position, end tidal carbon dioxide was found to be the most appropriate for identifying esophageal intubation [5]. However, there are reports assuring the greater accuracy of the esophageal detector device especially in emergency settings [6]. Capnography was documented to be the best reliable method for fast detection of ETT position [7].

Clinicians utilize auscultation of breath sounds to verify correct ETT placement. However, anesthesia providers often delay timely charting of ET intubation and this latency may result in decreased efficacy of clinical decision support systems [8]. Bedside ultrasonography had been widely used for preliminary diagnoses especially in bedridden patients [9] and in emergency medicine [10] and to aid for diagnostic decision making in emergency department [11].

Aim of Work

The current study aimed to assess accuracy and rapidity of bed-side upper airway ultrasonography (UA-US) versus standard auscultation (SA) for confirmation of endotracheal tube (ETT) position after tracheal intubation.

- **Setting:** University Hospital, Aswan, Egypt
- **Design:** Comparative double-blinded study

Patients and Methods

The current study was conducted since Oct 2016 till Oct 2017. The study protocol was approved by the Local Ethical Committee and all enrolled patients signed written fully informed consent to participate in the study.

Inclusion criteria included adult patients of ASA grade I and II and were assigned for general anesthesia with endotracheal intubation. Exclusion criteria included presence of severe neck trauma, neck mass, scar of previous neck surgery, anatomic neck distortion, limited neck extension, abnormal airway anatomy and obesity. Patients need emergency intubation or with high risk of aspiration and severe cardiac, pulmonary, hepatic, or renal disease were excluded from the study.

Patients were examined the night before surgery for determination of demographic data, clinical assessment for assurance of inclusion and exclusion criteria. Preoperatively, baseline hemodynamic data including heart rate (HR), blood pressure measures; systolic (SBP), diastolic (DBP) and mean arterial pressure (MAP) were non-invasively determined. Also, arterial peripheral oxygen saturation was determined using pulse oximetry.

All patients received the same anesthetic protocol including premedication using intravenous (IV) midazolam 2 mg, induction of anesthesia by fentanyl 2 µg/kg and propofol 2 mg/kg followed by atracuraium 0.5 mg/kg to facilitate tracheal intubation. Patients were maintained on controlled mask ventilation with 100% O_2 until adequately relaxed and then endotracheal tube was inserted within 3-5 min.

Induction of anesthesia and intubation were applied by an anesthetist who was blinded about the results of testing the accuracy of tube position. This anesthetist was responsible for auscultatory confirmation of ETT position by the presence of breath sounds sought on both sides by auscultation on the infra-clavicular and infra-axillary areas and were classified into definite, doubtful or absent.

Time taken for auscultatory confirmation was defined as the time elapsed from beginning to the end of auscultation. Also, this anesthetist was responsible for recording blood pressure and heart rate readings and O_2 saturation immediately, 5 min and 15 min after intubation.

Another anesthetist was responsible for performing upper airway US (UA-US) to ascertain the position of ETT; tracheal or esophageal and time elapsed since probe positioning till giving a decision about the tube position was given is determined. UA-US was performed using SonoScape US machine (China).

A 9-12 MHz linear ultrasound transducer was placed transversely on the neck anteriorly and superior to the suprasternal notch before intubation. Immediately after intubation, the transducer probe was used to visualize the ETT in the tracheal longitudinal and transverse views. The probe was then moved to the left to look at the esophagus to assure whether it was empty or distended by the tube.

The obtained results were compared to the positive result of quantitative waveform capnography (WC) using Dräger Fabius® plus XL (Germany). WC was considered as the gold standard for confirmation of ETT position.

A positive result on WC was determined by a 3rd anesthetist who was blinded about the results of SA and UA-US and was set as the detection of appropriate exhaled CO_2 that must be >30 mmHg after at least 5 breaths, with a typical CO_2 waveform. Time used by WC to assure tracheal intubation was also determined.

Study outcomes

- The detection of ETT position; tracheal or esophageal
- The accuracy of diagnosis using either SA standard auscultatory method or UA-US in comparison to WC.
- Time taken till confirming the diagnosis

Statistical analysis

Sample size was calculated using the standard nomogram proposed by Kraemer and Thiemann [12] and a sample size of ≥ 100 patients was determined to be sufficient to detect a difference at 5% significance level and give the trial 80% power [13].

Obtained data were presented as mean ± SD, ranges, numbers and percentages. Results were analyzed paired t-test and Chi-square test (X^2 test). Test diagnostic validity characters; namely sensitivity, specificity and accuracy were calculated. Statistical analysis was conducted using the IBM SPSS (Version 23, 2015) for Windows statistical package. P value <0.05 was considered statistically significant.

Results

The study included 126 patients; 19 patients were excluded and 107 patients were enrolled in the study (Figure 1). Enrollment data of studied patients are shown in Table 1.

All patients showed significantly increased HR and blood pressure measures immediately and 5 min after intubation compared to baseline measures. Fifteen minutes after heart rate and blood pressure measures were significantly lower compared to baseline measures (Table 2).

Auscultatory confirmation of ETT position assured proper tracheal intubation in 94 patients (87.9%) with definitely sought breath sounds, but suspected aberrant ETT position in 13 patients (12.1%) as doubtfully sought breath sounds in 10 patients and absent breath sounds in three patients.

On the other hand, UA-US detected tracheal position of ETT (Figure 2) in 99 patients (92.5%), and esophageal position of ETT (Figure 3) in 8 patients (7.5%). Considering WC, as a gold standard for comparison, defined proper tracheal position of ETT (Figure 4) in 100 patients (93.5%) and esophageal position of ETT (Figure 5) in 7 patients (6.5%), (Table 3).

Evaluation of diagnostic validity of auscultatory confirmation of ETT position versus findings of WC showed that auscultatory confirmation showed sensitivity and specificity rates of 93.6% and 53.9%, respectively with an accuracy rate for defining proper ETT position of 88.8%.

On contrary, UA-US confirmation of proper ETT position versus WC findings showed sensitivity and specificity rates of 97% and 71.4%, respectively with an accuracy rate of 95.3% with significantly higher specificity and accuracy rates versus auscultatory confirmation (Figure 6).

Furthermore, UA-US confirmation of ETT position allowed significantly ($p<0.001$) faster detection of ETT position than auscultatory confirmation (11.14 ± 1.3 *vs.* 13.5 ± 2.15 s), despite both modalities consumed significantly ($p<0.001$) longer time till confirmation of ETT position in comparison to time required using WC (9.16 ± 0.69 s) for detection of ETT (Figure 7).

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Data			**Findings**
Age (years)	<30 years	Frequency	19 (17.8%)
		Mean (± SD)	23.9 ± 2.1
	30-40	Frequency	30 (28%)
		Mean (± SD)	35.5 ± 2.3
	>40-50	Frequency	26 (24.3%)
		Mean (± SD)	45.6 ± 2
	>50	Frequency	32 (29.9%)
		Mean (± SD)	53.5 ± 1.4
	Total	Mean (± SD)	41.4 ± 10.9
Gender	Male		68 (63.6%)
	Female	39 (36.4%)	
Body mass index data	Weight (kg)		75.1 ± 6.7
	Height (cm)	170 ± 3.3	
	BMI (kg/m^2)	<25	52 (48.6%)
		>25	55 (51.4%)
		Mean (± SD)	26 ± 2.2
ASA grade	I		86 (80.4%)
	II	21 (19.6%)	
Data are presented as mean ± SD & numbers; percentages are in parenthesis; BMI: Body Mass Index; p>0.05: Indicates non-significant difference.			

Table 1: Patients' enrollment data.

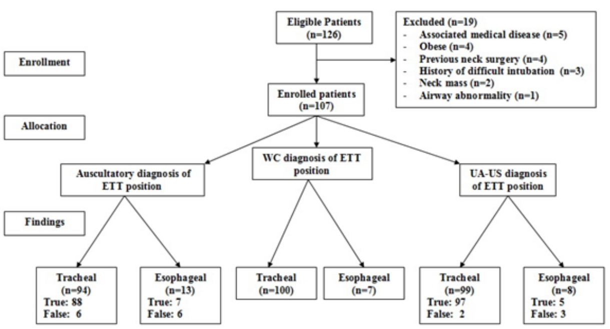

Figure 1: Flow Chart of the Study.

Data		**Findings**
HR (beats/min)	Baseline	84.6 ± 5.6
	Immediate after intubation	89.3 ± 6.7*
	5 min after intubation	92.2 ± 5.6*
	15 min after intubation	80.4 ± 8.4*
SBP (mmHg)	Baseline	115.6 ± 8.5
	Immediate after intubation	127.1 ± 8.9*
	5 min after intubation	97.6 ± 9.1*
	15 min after intubation	103.8 ± 7.2*
DBP (mmHg)	Baseline	75.5 ± 3
	Immediate after intubation	77.2 ± 3.5*
	5 min after intubation	79.6 ± 5*
	15 min after intubation	76.5 ± 3.9*
MAP (mmHg)	Baseline	88.9 ± 3.3
	Immediate after intubation	93.8 ± 3.4*
	5 min after intubation	85.6 ± 4.7*
	15 min after intubation	86.2 ± 3.6*
SaO_2 (%)	Baseline	97.5 ± 1.6
	Immediate after intubation	96.4 ± 3*
	5 min after intubation	97.9 ± 1.2*
	15 min after intubation	98.3 ± 0.5*
Data are presented as mean ± SD; HR: Heart rate; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; MAP: Mean Arterial Pressure; SaO_2: Arterial Oxygen Saturation; *: indicates significant difference *vs.* baseline value.		

Table 2: Patients' hemodynamic and arterial oxygen saturation data determined immediately, 5 min and 15 min after intubation compared to preoperative findings.

Value		**Auscultatory**	**UA-US**	**WC**
Positive	Total	94 (87.9%)	99 (92.5%)	100 (93.5%)
	True Positive	88 (93.6%)	97 (98%)	
	False Positive	6 (6.4%)	2 (2%)	
Negative	Total	13 (12.1%)	8 (7.5%)	7 (6.5%)
	True Negative	7 (53.8%)	5 (62.5%)	
	False Negative	6 (46.2%)	3 (37.5%)	
Data are presented as numbers; percentages are in parenthesis; UA-US: Upper Airway Ultrasonography; WC: Waveform Capnography.				

Table 3: Evaluation of diagnostic findings by auscultatory and UA-US confirmation of ETT position versus WC confirmation.

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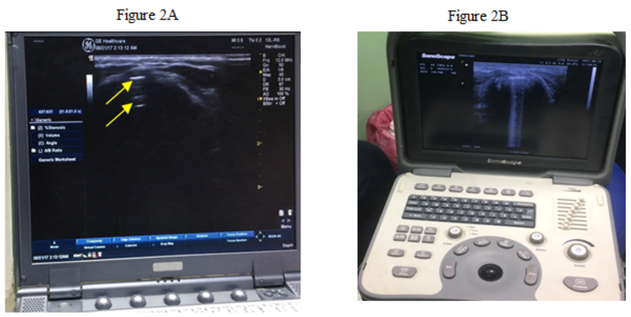

Figure 2: A) UA-US tracheal horizontal view showing two hyperchoic lines which mean that ETT is inside the trachea; B) UA-US tracheal vertical view showing two symmetrical hyperchoic lines which mean that ETT is inside the trachea.

Figure 3: UA-US tracheal horizontal view showing two hyperchoic lines inside the esophagus which appeared dilated on the left side (Yellow Arrow) with absence of intratracheal lines (Red Arrow).

Figure 4: Shows positive end-tidal CO_2 quantitative WC which means correct tracheal placement of ETT.

Figure 5: shows negative end-tidal CO_2 quantitative WC which means esophageal placement of ETT.

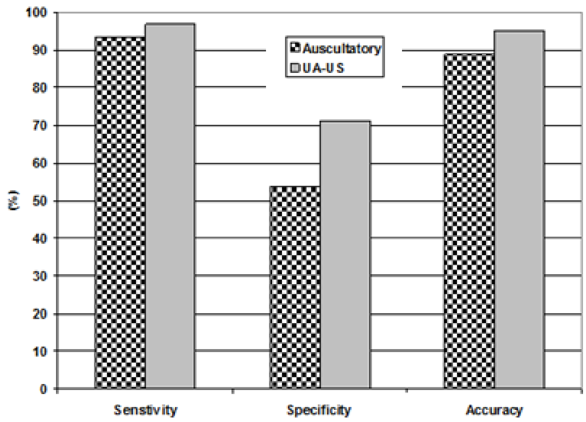

Figure 6: Diagnostic validity characters of auscultatory *vs.* UA-US confirmation of ETT position *vs.* WC.

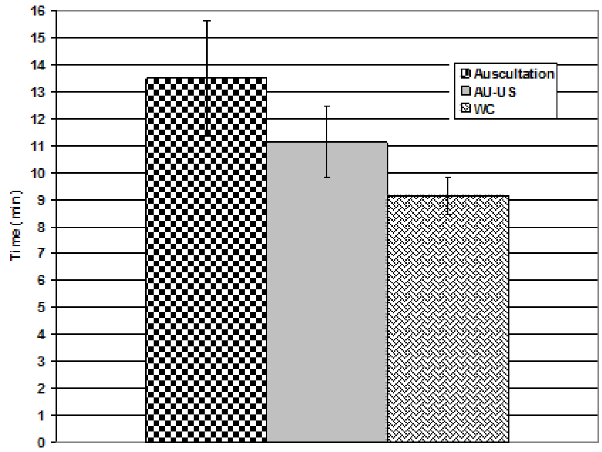

Figure 7: Mean time take till confirmation of ETT position.

Discussion

The current study tried to evaluate the accuracy of upper airway ultrasonography (UA-US) for detection of endotracheal tube (ETT) position; tracheal or esophageal in comparison to auscultatory confirmation. Quantitative waveform capnography (WC) was used as a gold standard for comparison. In line with the reliance on WC, Langhan et al. [14] documented that WC use had significantly increased overtime and its use during intubation was not associated with esophageal intubation or occurrence of cardiac arrest. Also, Scoccimarro et al. [15] reported that WC improves the time to intubation and first pass success rates through more consistent and expedient means of detecting optimal intubating conditions. Moreover, Silvestri et al. [16] approved the reliability of WC for verifying ETT location during low-perfusion states such as cardiac arrest, and suggested that WC showed no false negatives or positives, thus indicating 100% sensitivity and specificity.

In comparison to WC findings, auscultatory confirmation of ETT position showed sensitivity and specificity rates of 93.6% and 53.9%, respectively with an accuracy rate for defining proper ETT position of 88.8%, while UA-US showed sensitivity and specificity rates of 97% and 71.4%, respectively with an accuracy rate of 95.3% for confirmation of proper ETT position, with significant difference versus auscultatory method.

In line with the reported figures for diagnostic validity of UA-US for confirmation of ETT position, Alonso Quintela et al. [9] reported that US appears to be as effective as capnography for identifying ETT and may be useful wherever capnography is less reliable as during cardiopulmonary resuscitation. Thereafter, Das et al. [17] reported that transtracheal US is a useful tool to confirm endotracheal intubation with sensitivity and specificity rates of 98% in both emergency and elective intubation. Also, Tessaro et al. [18] assured that US visualization of a saline-inflated ETT cuff at the suprasternal notch is accurate and rapid modality to confirm the insertion depth of ETT in children with sensitivity of 98.8% and specificity of 96.4%.

Recently, Masoumi et al. [4] found WC detected appropriate tracheal placement in 100% of patients, while in comparison US detected tracheal intubation in 93% and esophageal intubation in 7% with sensitivity, specificity, and positive and negative predictive values for detecting appropriate ETT tracheal placement of 98.9%, 100%, 100% and 85.7%, respectively. Moreover, Lahham et al. [19] performed real-time transverse tracheal sonography during intubation to evaluate correct ETT placement and detected correct tracheal placement in 94.4% of patients, while 5.6% of intubations were interpreted as esophageal, and concluded that US conferred sensitivity and specificity rates of 98.5% and 75%, respectively.

The reported superiority of UA-US over auscultatory confirmation of ETT position goes in hand with Ramsingh et al. [20] reported that sensitivity and specificity rates of US for differentiating tracheal versus bronchial intubations were 93% and 96% *vs.* 66% and 59% for auscultation and the accuracy for identification of tracheal versus bronchial intubation was 95% versus 62% with significant difference in favor of US. Also, Zamani Moghadam et al. [21] evaluated the diagnostic accuracy of US in ETT placement confirmation compared to a combination of 4 clinical confirmation methods and found tracheal US had excellent sensitivity (>90%) and good specificity (80-90%) for confirming ETT placement. Moreover, Abhishek et al. [2] documented that both capnography and upper airway USG may be used as primary procedures for the confirmation of ETT placement.

As another support for the superiority of US over auscultatory confirmation of ETT position, Álvarez-Díaz et al. [22] compared trans-thoracic lung US and clinical method in confirming the position of double-lumen tube in thoracic anesthesia and found the sensitivity and specificity of US was 98.6% and 52.9%, while that of the clinical method was 84.5% and 41.1% with significant difference in favor of US. Recently, Rajan et al. [23] assessed the efficacy of US sliding lung sign versus standard auscultation for confirming ETT placement in normal, overweight and obese surgical patients and concluded that US confirmation of ETT placement is superior in accuracy compared to auscultatory method.

Furthermore, UA-US allowed significantly faster detection of ETT position than auscultatory confirmation, despite of the significantly longer time consumed by both modalities compared to time required using WC. In line with these findings, Pfeiffer et al. [24,25] documented that verification of ETT placement with US is as fast as auscultation alone and faster than the combination of auscultation and capnography, even in obese patients [23]. Thereafter, Alonso Quintela et al. [9] reported despite US was slower than capnography for identifying ETT, US is as effective and quicker than X-ray for assessment of ETT insertion depth, and it may contribute to decrease the routine use of X-ray after tracheal intubation. Recently, Rajan et al. [23] documented that US confirmation of ETT placement is superior in speed compared to auscultatory method. Also, Thomas et al. [26] reported that US confirmed ETT placement with comparable sensitivity and specificity to quantitative WC and clinical methods, but it yielded results considerably faster than the other two modalities.

Conclusion

It can be concluded that confirmation of ETT position using either UA-US or WC is a mandatory requirement because of the high false diagnosis depending on standard auscultatory confirmation alone. Using bed-side UA-US is an easy, accurate and fast method than standard auscultation compared to WC as a gold standard, so it is suggested to be one of the essential theater equipments whenever possible.

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