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The Egyptian Journal of Bronchology (2023) 17:16
https://doi.org/10.1186/s43168-023-00190-w

The Egyptian Journal of Bronchology

RESEARCH

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The diagnostic accuracy of an inclusive three-window ultrasonography assessment for the rapid authentication of endotracheal tube position in RICU

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Abstract

Background Assurance of proper endotracheal tube (ETT) location is crucial immediately after intubation as undiagnosed esophageal intubation can be catastrophic. The primary purpose for this study is to determine the diagnostic accuracy of to evaluate the accuracy of an inclusive three-window ultrasonography assessment for the rapid authentication of endotracheal tube position in the intensive care unit (RICU) with reference to Co_2 monitors (capnography) (the gold standard technique), The study included 100 patients who needed emergency intubation in the ICU of Aswan university hospital. Upon entrance to ICU, intubations was done by the residents and collective bedside three-windows ultra-sonography (tracheal, lung, diaphragmatic ultra-sonography) was carried out instantly after intubation Subsequently, the correct position of the endotracheal tube was established by the resident investigator via the use a capnometer.

Results Waveform capnography revealed endotracheal intubation in 80 cases (80%) and esophageal intubation in 20 cases (20%). However, trans-tracheal ultra-sonography (TUS) was able to detect endotracheal intubation in 78 cases (78%) and esophageal intubation in 22 cases (22%) patients. SLS detected only 17 esophageal intubations from 20 cases detected by CO2 detectors. DUS was able to detect proper endotracheal intubation in 77 cases (77%) and esophageal intubation in 23 cases (23%). However, it detected only 17 esophageal intubations from 20 cases detected by Co_2 detectors.

Conclusions Ultra-sonography, as recently introduced practice for validation of correct endotracheal tube location has both high accuracy and safety profile and can be used as a primary authentication technique.

Trial registration NCT05747248

Keywords Capnography, Endotracheal intubation, Ultrasonography

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Introduction

Nowadays, endotracheal intubation is considered a fundamental management procedure during emergency resuscitation. Assurance of proper endotracheal tube (ETT) location is crucial immediately after intubation as undiagnosed esophageal intubation can be catastrophic. Moreover, there was a reported incidence of unrecognized ETT misplacement during endotracheal intubation, ranged from 2.9 to 16.7% and is a common cause of morbidity and mortality in emergency intubations [1].

Straight imagining of the ETT passing through the vocal cords can be virtually used, however it is not always promising, especially if laryngoscopy is challenging. The alternative methods of confirmation including (observation of chest rising after intubation and both lungs auscultation) are varying in their degree of accuracy. Nevertheless, over 50% of one lung intubations may proceed undiagnosed by chest auscultation [2].

Waveform capnography was approved as the gold standard technique for the fundamental realization of ETT position [3]. Recent guidelines recommended constant waveform Co_2 monitoring in addition to clinical evaluation as the most accurate measures to confirm the accurate position of an endotracheal tube (ETT). However, end-tidal carbon dioxide ($ETCo_2$) measurement requires a minimum of five "breathing cycles" for validation, which can lead to gastric insufflation and numerous complications if the ETT was falsely set in the esophagus, also capnography cannot discriminate between main tracheal and endobronchial placement of endotracheal tube [4]. Furthermore, quantifiable capnography, (the rationale for authorization of endotracheal intubation), is undependable in cardiac arrest patients [5].

Ultrasound is a simple, real-time, and less invasive diagnostic method that is commonly used in the ICU. A previous report demonstrated that ETT placement with ultrasound is more rapidly than the usual technique of auscultation and capnography and is as quick as lung auscultation alone [6].

The primary aim for this study was to evaluate the diagnostic validity of an inclusive three-window ultrasonography assessment for the rapid authentication of endotracheal tube position in the respiratory intensive care unit (RICU) with reference to Co_2 monitors (capnography) (the gold standard technique). A secondary outcome was to estimate the elapsed time before validation of endotracheal tube location.

Patients and methods

This prospective observational study was carried out in the intensive care unit (ICU) of Aswan University Hospital during the period from December 2021 to October 2022.

Inclusions criteria

The study included 100 patients who required emergency intubation in the ICU of Aswan university hospital.

Exclusions criteria

Patients less than 18 years old, a strenuous intubation history, anatomical neck deformities, atypical airway anatomy, pleural pathologies, surgical emphysema, or lung disorders that might disturb the study technique were excluded from the study.

Procedure

Upon entrance to ICU, Intubations was done by the residents using a cuff endotracheal tube with a caliber from 7 to 7.5 mm and collective bedside ultra-sonography was carried out instantly after intubation by the investigator who was not concerned in the patients' care and not informed about the capnography results.

A SonoScape ultrasound (Model: A5, SonoScape (China) Co, Ltd.) was used for TUS, a 9–12 MHz linear probe was used. The probe was located transversely on the anterior neck entirely above the suprasternal notch promptly after intubation, and then the transducer was displaced to the left to assess whether the esophagus was empty or ETT inflated. The ETT was clarified as "endotracheal" if only a single hyperechoic air-mucosa (A-M) interface with a comet-tail artifact was noticed or "intra-esophageal" if an additional A-M interface (double-tract sign) (Figs. 1, 2 and 3).

To detect *SLS* over both lungs, another 3.75 MHz curvilinear probe was placed horizontally on both sides, Images were taken within the 3th to 5th intercostal spaces, alongside the mid axillary line. A positive SLS implied lung expansion with ventilation. On the base of the presence or absence of the sliding lung sign on both sides of the chest, a distinction of endotracheal tube location was made, existence on both sides of the chest was

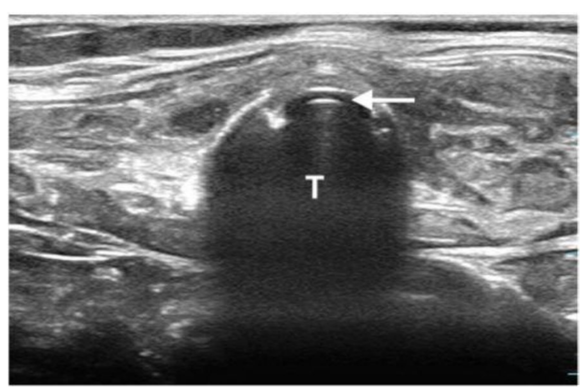

Fig. 1 Sonographic image of tracheal intubation

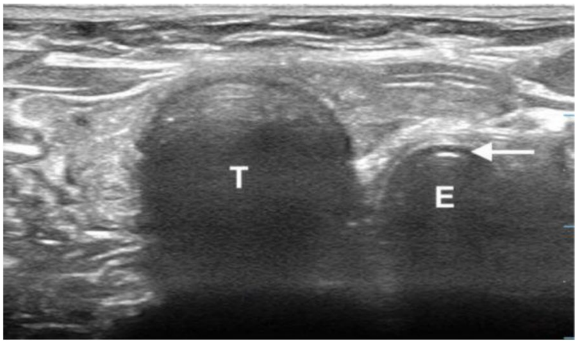

Fig. 2 Sonographic image of esophageal intubation

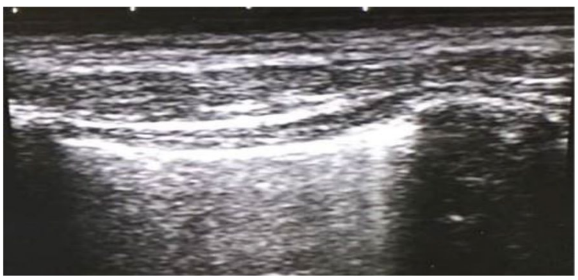

Fig. 3 Sliding lung sign

presumed to indicate tracheal intubation. SLS existence on the right side only was assumed to claim right main stem bronchial intubation. Finally, non-existence of SLS on either side was acknowledged to denote esophageal intubation [7].

Diaphragm ultrasonography was done with the use of a 3.5-MHz curved probe, the probe was situated in the right upper quadrant of the abdomen, accurately below the edge of the ribs with a 45° angle toward the chest near the mid-clavicular line. The probe will toward the right side of the patient. During positive pressure via ventilation with bag (inspiratory phase), diaphragm motion toward the abdomen was registered as an intratracheal intubation. In contrast, the observation of diaphragm motion toward chest or non-significant motion was be in favor of esophageal intubation [8].

Subsequently, the correct location of the endotracheal tube was established by the resident investigator via the use a capnometer (Scio Four, Drager, Germany), a positive result of capnography was defined as the detection of exhaled CO2 (> 4 mm Hg) after at least five breathing cycles with a characteristic CO2 waveform as shown in Fig. 4. The interval from the end of the endotracheal tube insertion to the time when the investigator elucidated the sonographic results and

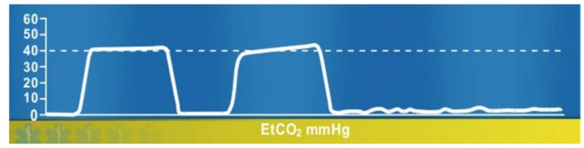

Fig. 4 Normal capnogram waveform performed in this study

Table 1 Comparison of demographic and clinical characteristics of the study population according to the capnography results

	Tracheal intubation ($n = 80$)	Esophageal intubation ($n = 20$)	*p* value
Age (years) (mean ± SD)	55.28 ± 13.3	54.45 ± 14.7	0.809
BMI (kg/m2) (mean ± SD)	26.05 ± 2.7	25.45 ± 2.8	0.376
Sex	*N* (%)	*N* (%)	
Male	41 (74.5)	14 (25.5)	0. 132
Female	39 (86.7)	6 (13.3)	
Medical diagnosis			
Cardiac problems	4 (80.0)	1 (20.0)	0.219
Cerebrovascular problems	5 (83.3)	1 (16.7)	
GIT problems	3 (100.0)	0 (0.0)	
Metabolic problems	12 (92.3)	1 (7.7)	
Pleural problems	2 (50.0)	2 (50.0)	
Pulmonary problems	43 (74.1)	15 (25.9)	
Others	11 (100.0)	0 (0.0)	

Data were expressed as mean ± SD and number (%)

BMI Body mass index

to the time of appropriating the results of capnography were estimated. A data gathering sheet was marked down to document the patients' demographics, capnography results, ultrasonography results, and the time passing to confirm tube position.

Statistical analysis

Date analysis were done using SPSS (Statistical Package for Social Science) software program version 25.0 (SPSS Inc., Chicago, IL, USA). *P* value considered statistically significant if < 0.05.

Results

Comparison of demographic and clinical characteristics of the study population according to capnography results into tracheal intubation group and esophageal intubation group was illustrated in Table 1. Endotracheal intubation was detected in 80 cases (80%), while esophageal intubation was detected in 20 cases (20%). There was no significant difference between the two groups as regard

Table 2 Comparison of the transtracheal ultrasonography (TUS) results with the continuous capnography waveform results

TUS results	Capnography results				Total
	Tracheal positive		Esophageal negative		
	n	(%)	*N*	(%)	
Tracheal (positive)	**TP = 76**	**95.0%**	FP = 2	10.0%	78
Esophageal (negative)	FN = 4	5.0%	**TN = 18**	**90.0%**	22
Total	80		20		100

Data are expressed as number (%)

TUS Tracheal ultrasonography, *TP* True positives, *FP* False positives, *FN* False negatives, *TN* True negatives

Text in bold indicates *p*-values <0.001

age, BMI, sex, and medical diagnosis (P value > 0.05) (Table 1).

Table 2 showed the comparison of the transtracheal ultrasonography (TUS) results with the continuous capnography waveform results where waveform capnography detected endotracheal intubation in 80 cases (80%) and esophageal intubation in 20 cases (20%). However, tracheal ultrasonography was able to detect endotracheal intubation in 78 cases (78%) and esophageal intubation in 22 cases (22%) patients. TUS detected 18 esophageal intubations from 20 cases detected by CO2 detectors and 2 detected as positive (false positive), however it did not detect four out of 74 tracheal intubations detected by CO2 detectors (false negatives).

Table 3 illustrate that ultra-sonographic SLS was able to detect proper endotracheal intubation in 78(78%), esophageal intubation in 22 cases (22%). However, SLS detected only 17 esophageal intubations from 20 cases detected by CO2 detectors and 3 cases detected as positive (false positive); however, it did not detect 5 out of 80 tracheal intubations detected by CO2 detectors (false negatives).

Table 4 demonstrated that comparison of the combined TUS and ultra-sonographic SLS results with the capnography results where the combined TUS and ultra-sonographic SLS results were able to detect proper endotracheal intubation in 84 cases (84%), esophageal intubation in 16 cases (22%). However, it detected only 15 esophageal intubations from 20 cases detected by CO2 detectors and 5 cases were detected as positive (false positive), however it did not detect one case out of 80 tracheal intubations detected by CO2 detectors (false negatives).

Table 5 demonstrated that comparison of DUS results with the capnography results where DUS was able

Table 3 Comparison of ultra-sonographic (SLS results) results with the continuous capnography waveform results

SLS	*Capnography results*				Total	*P* value
	Tracheal positive		Esophageal negative			
	n	(%)	*n*	(%)		
Present (bilaterally)	TP = 75	93.8%	FP = 3	15.0%	78	< 0.001[a]
Absent (either bilaterally or unilaterally)	FN = 5	6.2%	TN = 17	85.0%	22	
Total	80		20		100	

SLS Sliding lung sign, data are presented as number and percentage (%) (*n* No. of patients, *TP* True positives, *FP* False positives, *FN* False negatives, *TN* True negatives)

[a] Fisher's exact test

Table 4 A comparison of the combined TUS and ultra-sonographic SLS results with the capnography results

Combined TUS and SLS	*Capnography results*				Total	*P* value
	Tracheal positive		Esophageal negative			
	n	(%)	*n*	(%)		
Tracheal (positive)	TP = 79	98.8%	FP = 5	25.0%	84	< 0.001[a]
Esophageal (negative)	FN = 1	1.2%	TN = 15	75.0%	16	
Total	80		20		100	

TUS Tracheal ultrasonography, *SLS* Sliding lung sign; data are presented as number and percentage (%) (*n* No. of patients, *TP* True positives, *FP* False positives, *FN* False negatives, *TN* True negatives)

[a] Fisher's exact test

Table 5 A comparison of DUS results with the capnography results

DUS	*Capnography results*				Total	*P* value
	Tracheal positive		Esophageal negative			
	n	(%)	*n*	(%)		
Tracheal (Positive)	TP = 74	92.5%	FP = 3	15.0%	77	< 0.001[a]
Esophageal (Negative)	FN = 6	7.5%	TN = 17	85.0%	23	
Total	80		20		*n* = 100	

DUS Diaphragm motion ultrasonography; data are presented as number and percentage (%) (*n* No. of patients, *TP* True positives, *FP* False positives, *FN* False negatives, *TN* True negatives

[a] Fisher's exact test

Table 6 The diagnostic test performance of TUS, SLS, and DUS in the confirmation of ETT position

	Sensitivity	Specificity	PPV	NPV	Accuracy	AUC	SE	95% Confidence interval
TUS	95.0%	90.0%	97.4%	81.8%	94.0%	0.925	0.042	0. 844–0.999
SLS	93.8%	85.0%	96.2%	77.3%	92.0%	0.900	0.049	0. 797–0.990
Combined TUS and SLS	98.8%	75.0%	94.0%	93.8%	94.0%	0.901	0.059	0.753–0.985
DUS	92.5%	85.0%	96.1%	74.0%	91.0%	0.921	0.042	0. 830–0.994

Data are presented as number (%). *TUS* Tracheal ultrasonography, *SLS* Sliding lung sign, *DUS* Diaphragm motion ultrasonography, *AUC* Area under the curve, *NPV* Negative predictive value, *PPV* Positive predictive value

Table 7 Comparison of the mean time used to confirm the correct position of endotracheal tube ETT by ultrasonography and capnography

Variable	Mean ± SD (in seconds)	*P* value
Total time of ultrasonography	27.51 ± 2.68	**0.044**
Capnography time	34.50 ± 5.47	
Difference in time (ultrasonography-capnography)	7.0 ± 223	

Data are presented as mean ± SD

Text in bold indicates *p*-values 0.044

to detect proper endotracheal intubation in 77 cases (77%), esophageal intubation in 23 cases (23%). However, it detected only 17 esophageal intubations from 20 cases detected by CO2 detectors and 3 cases were detected as positive (false positive), however it did not detect 6 cases out of 80 tracheal intubations detected by CO2 detectors (false negatives).

Statistical calculations of the diagnostic test performance of TUS, SLS and DUS in the confirmation of ETT position were shown in Table 6. The combined TUS and SLS had the highest sensitivity while DUS had the lowest sensitivity, while TUS had the highest specificity and combined TUS and SLS had the lowest specificity.

The comparison of the mean time used to confirm correct placement of endotracheal tube ETT by ultrasonography and capnography is demonstrated in Table 7. It was noticed that the mean time of ultrasonography was significantly shorter than the mean time of capnography (P value = 0.044).

Discussion

Currently endotracheal intubation is considered a fundamental management procedure during emergency resuscitation. Assurance of proper endotracheal tube (ETT) location is crucial immediately after intubation as undiagnosed esophageal intubation can be catastrophic. The primary purpose of this study was to determine the diagnostic validity of an inclusive three-window ultrasonography assessment for the rapid authentication of endotracheal tube position in the intensive care unit (RICU) with reference to Co_2 monitors (capnography) (the gold standard technique). A secondary outcome was to determine the elapsed time before authentication of the accurate endotracheal tube position.

Our study showed that the comparison of (TUS) results with the continuous capnography waveform results where waveform capnography revealed endotracheal intubation in 80 cases (80%) and esophageal intubation in 20 cases (20%). However, TUS was able to detect endotracheal intubation in 78 cases (78%) and esophageal intubation in 22 cases (22%) patients. TUS distinguished 18 esophageal intubations from 20 cases detected by Co2 sensors and 2 noticed as positive (false positive); however, it did not detect four out of 74 tracheal intubations detected by Co2 detectors (false negatives). Concomitant with our results, Kabil et al. [9] on their study on forty cases disclosed that ultrasound detected tracheal intubation in 35 cases (97.22% of all patients with true tracheal intubation). Only one patient with tracheal intubation was detected by ultrasound as esophageal (2.78%). Moreover, all patients with esophageal intubation ($n = 4$) were appropriately detected by ultrasound as esophageal intubation. Similarly, Masoumi et al. [10] summarized that, from their total 100 cases, there was 93 cases (93%) had true positive results (tracheal intubation), and seven cases (7%) had true negative results (esophageal intubation). Out of which, 6 (85.7%) patients had negative waveform capnography reports, which was in favor of esophageal intubation, and the rest of them ($n = 1$; 14.3%) had undergone appropriate tracheal intubation based on positive waveform capnography.

We found that that direct localization of intubation by TUS had (95.0%) sensitivity, (90.0%) specificity, (97.4%) positive predictive value and (81.8%) negative predictive value to confirm the correct intubation with area under the curve was (0.925 and $P < 0.001$). In harmony with our results, Chen et al. [11] showed (75.0%) sensitivity, with (100%) specificity. Similarly, Fahmy and Kinawy [12], disclosed that the TUS use for authorization of ETT location showed sensitivity of)95.95%(, specificity of)83.33%(, PPV of)98.6%(, NPV of)62.5%(, and accuracy of (95%). Furthermore, Gottlieb et al. [13] results showed that the sensitivity and specificity of the static assessment technique in defining the ETT positions were [93.6% and 98.3%, correspondingly]. Chou et al. [14] pointed to the high efficacy of USG in the detection of esophageal intubation. In addition, it can be used as additional evidence with high sensitivity and specificity for the evaluation of the airway, definitely in many units where the capnometry is unavailable and, if obtainable, may be untrustworthy. Das and Choupoo [15], found that the mutual sensitivity and specificity of ultrasonography for recognition of appropriate ETT location were (98%, respectively). Sun et al. [16], found a closely excellent negative likelihood ratios in evaluating endotracheal tube location using TUS with the following results [the sensitivity (98.9%), specificity 100%, PPV (100%), and NPV (85.7%), correspondingly]. Adi et al. [17] found that there was a very good accordance between the bedside TUS and waveform capnography with their results [sensitivity (98%), specificity (100%), PPV (100%), and NPV (75.0%)]. Another study presented that TUS is a desirable and appreciated tool for the evaluation of appropriate endotracheal intubation, with a sensitivity (96.2%) and specificity (100%) with PPV and NPV [100 and 69.6%, correspondingly] [18].

Regarding SLS, we found that the ultrasonographic SLS was able to detect proper endotracheal intubation in 78 cases (78%), esophageal intubation in 22 cases (22%). However, SLS detected only 17 esophageal intubations from 20 cases detected by Co_2 detectors and 3 cases detected as positive (false positive). In harmony with our results, Bernard, et al. [19] demonstrated that in 16 cases, the ultrasonographic lung-sliding sign correctly identified lung intubation as confirmed with a flexible bronchoscope with one false-positive). Similarly, Fahmy and Kinawy [12], summarized that the ultra-sonographic SLS was able to detect proper endotracheal intubation in 69 cases (86.3%), esophageal intubation in 6 cases (7.5%) and right main stem bronchial intubation in 5 cases (6.2%) cases. SLS correctly detected all six esophageal intubations; however, its presence on the right side and absence on the left was noticed in 5 cases out of 74 tracheal intubations (false negatives) denoted right main stem intubation and ETT was taken out till positive lung sliding gained bilaterally. Furthermore, they demonstrated that SLS accurately identified esophageal placement, but was less accurate in identifying tracheal intubation compared to capnography.

We found that the sensitivity of SLS is (93.8%) while, specificity is (85%) and the AUC is (0.90) which is highly accurate. In accordance with our results, Amin et al. [20] disclosed that the use of pleural USG for confirmation of ETT placement in their study showed sensitivity of 89.5%, specificity of 50.0%, PPV of 97.1% NPV of 20.0%, and accuracy of 87.5%. Correspondingly, Fahmy and Kinawy [12], summarized that the use of pleural USG for confirmation of ETT placement in their study showed sensitivity of 93.24%, specificity of 100%, PPV of 100% NPV of 54.5%, and accuracy of 93.75%, and overall accuracy was 93.75%. Álvarez-díaz et al. [21] confirmed that the sensitivity of the ultrasound was 98.6%, specificity was 52.9%. Furthermore, Sim et al. [22] in their study have described that the global validity of ultra-sonographic SLS for authenticating ETT location during emergent intubation was (88.7%).

We found that the combined TUS and ultrasonographic SLS results were able to detect proper endotracheal intubation in 84 cases (84%), esophageal intubation in 16 cases (22%). However, it detected only 15 esophageal intubations from 20 cases detected by CO2 detectors and 5 cases were detected as positive (false positive); however, it did not detect one case out of 80 tracheal intubations detected by CO2 detectors (false negatives). Furthermore, regarding the diagnostic test performance of the combined TUS and SLS in the confirmation of ETT position, we found that the sensitivity is 98.8% however, specificity is 75%, and the AUC is 0.90 which is highly accurate. In harmony with our results, Fahmy and Kinawy [12], found that on combining TUS and SLS, the sensitivity and negative predictive values raised to 100% and the diagnostic accuracy rise to (98.75%). Moreover, Rahul et al. [23] found that the diagnostic accuracy of the US method was 100% (20/20) and that of the standard method 95% (19/20), with a p value of 1.0. The sensitivity and PPV of the US method was 100% (CI 79.9–100%), and the standard method had a 100% (CI 79.1–100%) sensitivity and 95% (CI 73.1–99.7%) PPV.

Regarding diaphragmatic ultrasonography, we found that DUS was able to detect proper endotracheal intubation in 77 cases (77%), esophageal intubation in 23 cases (23%). However, it detected only 17 esophageal intubations from 20 cases detected by Co_2 detectors and 3 cases were detected as positive (false positive), however it did not detect 6 cases out of 80 tracheal intubations detected by Co_2 detectors (false negatives), Furthermore, we summarized that that indirect localization of the tube by diaphragmatic U/S had 92.5% sensitivity and 85.0% specificity to confirm the correct intubation with area under the curve was 0.921 and $P < 0.001$. This result was concomitant with Hosseini et al. [8] who found that diaphragm Ultrasound appropriately identified 11 out of 12 esophageal intubations with a sensitivity of [92%] (95% CI = 62–100) but misidentified one esophageal intubation as tracheal.

It was noticed that the mean time of ultrasonography was considerably shorter than the mean time of capnography (P value = 0.044). In accordance, Fahmy and Kinawy [12], found that the total ultrasonography time was substantially less than that of capnography ($P < 0.001$) and the mean variance was 5 s in favor of ultrasound. Similarly, Lahham, et al. [24] summarized that three-window POCUS (tracheal, lung and diaphragmatic ultrasonography) was accomplished on average 25 min faster than plain chest X-rays (95% CI 6.2–43.9 min, $P = 0.005$).

Our study had several limitations: first, its small sample size which was not representative to the whole population. Moreover, we did not sufficiently investigate esophageal intubations due to small number of esophageal intubations detected by our study. Second, ultrasonography is acknowledged to be operator dependable procedure. Finally, TUS may not be feasible for each intubation challenge. The existence of a huge neck swellings, abnormal upper airway anatomy, soft tissue air, or substantial neck edema can make imaging more difficult to detect ETT location. To ascertain our study results, Additional studies must be guided with multiple investigators and patient assortment must be planned as successively to decline selection bias.

Conclusions

Endotracheal intubation (EI) is a crucial technique in airway management. It is important to verify the correct location and depth of insertion of ETT after each intubation attempt to avoid serious complications. Ultrasonography, as recently introduced practice for validation of correct endotracheal tube location has both high accuracy and safety profile and can be used as a primary authentication technique.

Abbreviations

ETT	Endotracheal tube
RICU	Respiratory intensive care unit
TUS	Trans tracheal ultrasonography
SLS	Sliding lung sign
DUS	Diaphragmatic motion ultrasonography
ETCO2	End-tidal carbon dioxide
BMI	Body mass index
USG	Ultrasonography
ETI	Endotracheal intubation

Acknowledgements

None.

Authors' contributions

IGS was the principal investigator, formulated the idea, and wrote the first draft of discussion. MA collected the data, formulated the results, and edited the final draft and revision. SS was responsible for methodology and statistical analysis. The manuscript has been read and approved by all the authors.

Funding

No financial support was needed.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The Research Ethics Committee at the Faculty of Medicine, Aswan University, has approved the study (IRB number: 425/12/19) and all patients provided written informed consent before participation.

Consent for publication

The manuscript has been read and approved by all the authors.

Competing interests

The authors declare that they have no competing interests.

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Received: 5 January 2023 Accepted: 7 March 2023
Published online: 17 March 2023

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