Review Article

Prediction of endotracheal tube size in the pediatric age group by ultrasound: A systematic review and meta-analysis

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Abstract

Anatomical differences in the airway in pediatric patients, compared to adults pose many challenges during endotracheal intubation, such as selecting the proper sized endotracheal tube (ETT) during intubation. Our primary objective was to assess how accurate is ultrasound (US) co-relation in comparison to standard age-based formulas in pediatric patients. Meta-analysis was registered in PROSPERO 2020, CRD42020220041. Online literature available in PubMed, Cochrane, and Embase, Goggle scholar was searched from year 2000 till November 30, 2020, using relevant Mesh terms, ('airway US' OR (('airway'/exp OR airway) AND ('US'/exp OR US))) AND ('endotracheal intubation'/exp OR 'endotracheal intubation') AND ('pediatric'/exp OR pediatric)" to Predict endotracheal tube size/placement in pediatric age (neonate till 18 years) by the US. Bibliographic cross-references of selected publications were further manually screened. The full texts of each article were studied, once the abstract was found appropriate independently by two reviewers. A total of 48 papers published between 2010 and 2020 were identified as relevant and read in detail. Average numbers of patients were 86 and total numbers of patients were 1978. Most of the studies included pediatric patients posted for elective surgeries under general anesthesia and excluded emergency procedures, known laryngeal or tracheal pathology, high-risk patients, recent upper respiratory tract infections or allergy to ultrasound gel. A total of 18 independent correlations were analyzed. Final combined r value calculated from all the included articles was 0.824 (95% CI 0.677, 0.908) with a $P < 0.00001$ {strong co-relation ($r > 0.80$)}. Q statistic of 756.484, and I^2 statistics of 97.53% showed a large degree of heterogeneity in the effect size across the studies. Use of US for upper airway in pediatric patients is an effective modality and can effectively predict endotracheal tube size estimations in comparison to standard age-based or height-based formulae in the pediatric age group. US is a non-invasive, cost-effective, portable, and reproducible technique as compared to CT and MRI. It also takes less time with increasing expertise and experience.

Keywords: Airway US, airway USG, cricoid cartilage diameter, cuffed endotracheal tube, endotracheal intubation, pediatric, point of care US, subglottic diameter, tracheal tube positioning, traditional formulas, uncuffed endotracheal tube, US assessment of airway, US imaging

Introduction

Pediatric patients, because of their anatomical differences[1] in the airway compared to adults pose many challenges during endotracheal intubation. One such challenge is, in selecting the proper sized endotracheal tube (ETT) required for intubation. If ETT is too small it may result in inadequate ventilation, unreliable end-tidal gas estimation, leakage of anesthetic gases into the operating room environment, and an increased risk of aspiration. If a large ETT is used it may lead to upper airway complications like ulceration, local ischemia, scar formation, and also increased risk for subsequent subglottic stenosis and post-extubation stridor. The use of age-based formulas, such as those of Cole and Motoyama[2,3] to estimate optimal ETT size

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has been traditionally employed since many years. Formulas for the prediction of appropriate ETT size have also been based on patient weight and height. However, none of these formulas are fully reliable. Thus repeated laryngoscopies are required to identify the appropriately sized tube for individual patients. Recent reports suggest the US can help determine the diameter of the subglottic[4] upper airway in healthy young adults and pediatric patients. However, the extent to which the US can help predict optimal ETT size in pediatric patients remains to be determined. The more advanced methods such as CT scan and MRI[5,6] are expensive and impractical. The authors sought to answer the research question if USG can effectively predict endotracheal tube size adequately as compared to existing methods of identification in pediatric patients.

Objective

Our main objective was to answer our research question as to how accurate is the US in assessing ETT size compared to conventional methods. The primary objective was to see if USG estimation co-related with standard age-based formulas in the pediatric age group.

Secondary objective-whether USG predicts ETT size and depth assessment in pediatric age group accurately.

Registration and protocol

This meta-analysis was conducted in accordance with Preferred Reporting Items for Systematic reviews and Meta-analyses.[7] The protocol was registered with PROSPERO 2020, CRD42020220041, registered on 10th December 2020 and Available from: https://www.crd.york.ac.uk/prospero/display_record.php?I = CRD42020220041

Material and Methods

To better systemize, this review was carried out under the preferred reporting items for systematic review and meta-analysis (PRISMA) guidelines. We used PICOS (population, intervention, control, and outcome study) design to include potential studies in this review [Table 1]. Online literature available in PubMed, Cochrane, and Embase, Goggle scholar was searched from year 2000 till November 30, 2020, using relevant Mesh terms, ('airway US' OR (('airway'/exp OR airway) AND ('US'/exp OR US))) AND ('endotracheal intubation'/exp OR 'endotracheal intubation') AND ('pediatric'/exp OR pediatric)". The current study only used published literature data, and no institutional review board approval was required. We restricted the search to articles published in the English language. Research question- Whether USG reliably predicts ET size in the pediatric age group?

Online literature was searched for studies that evaluated the efficacy of US in assessing endotracheal tube depth identification in pediatric age groups as compared to conventional methods using medical subject heading (MeSH) terms. Online literature available in PubMed, Cochrane, and Embase, Goggle scholar was searched from 2000 till November 30, 2020 by two independent observers, using relevant Mesh terms, ('airway US' OR (('airway'/exp OR airway) AND ('US'/exp OR US OR USG))) AND ('endotracheal intubation'/exp OR 'endotracheal intubation') AND ('pediatric'/exp OR pediatric OR pediatric)". The search was limited to human studies published in the English language in PubMed, Cochrane, and Embase, Google scholar searched from 2000 till 30th November 2020. Bibliographic and references of selected publications were further manually screened. The search strategy included all articles which have been peer-reviewed. The full texts of each article were studied once the abstract was found appropriate by two independent reviewers (B.G and P.A.) in an un-blinded standardized manner.

For each intervention, meta-analysis, systematic reviews were considered first, followed by randomized controlled trials, observational studies, and then case series or reports, if no better evidence was available. The criteria for study selection are listed in Table 1.

Study Identifications and selection

Two independent reviewers evaluated the potentially relevant articles on the basis of the inclusion and exclusion criteria. Articles were included if they met the following criteria:

Inclusion criteria

1. Investigation of the relationship between ultrasound-guided estimation of endotracheal tube size or depth estimation in pediatric population

Table 1: PICO Worksheet

Question	Search strategy
Population	Paediatric age group patients, preterm neonates till 18 years ASA I-II Both males and females
Intervention	USG prediction of endotracheal tube size/ placement
Comparison	Weight based/height based/COLE measurement/ body surface area/little finger breadth
Outcome	Primary objective- USG co-relation estimation with standard age-based formulas in the paediatric age group. Secondary objective- USG prediction of Endotracheal tube size and depth assessment in pediatrics
Study design	Randomized controlled trials, Observational studies, Case series and Case report
Describe the period of the study	Approximate 3 months

2. Research article published in the peer-reviewed journals.

Exclusion criteria- Studies were excluded if they did not use the US for identification of endotracheal tube identification or study methods, outcomes or results were not adequately identified/described in individual studies. Articles without sufficient information for calculation of correlation coefficient were excluded from meta-analysis. The decision on the suitability of a study for our analysis was compared by two authors (B.G. and P. A.). Discrepancies were resolved by discussion and disagreements were resolved by consensus [Table 2].

Data extraction- Data were extracted by two investigators independently from the full-text article of each included study into a Microsoft Excel spreadsheet (Microsoft Inc., USA), using a standardized data extraction form and the extracted contents included the following:

1. From each study the following data were extracted: year and country of publication, study design, patient demographic profile,
2. Type of US used, site of application, the position of the patient, formulas used, diameters compared (Outer Diameter/Inner Diameter),
3. Outcome studied and any complications reported.

Analysis

We analyzed the following outcome parameters about airway US- prediction of endotracheal tube size, endotracheal tube depth assessment, success at first intubation. Correlations were analyzed independently; a comprehensive meta-analysis tool was used and the Pooled correlation coefficient and the sample size were entered for respective studies, The program computed the effect size and Fisher's Z transformation of the correlation for each study. The transformation from correlation to Fisher's Z is given by $\rightarrow FisherZ = 0.5 * Log\left(\frac{1+Correlation}{1-Correlation}\right) \rightarrow$ and $SE_{FisherZ} = \frac{1}{\sqrt{N-3}}$

The comprehensive meta-analysis program provided the combined effect and confidence limits for both fixed and random effects models, and weights for both the fixed effect and the random-effects models. Meta-analysis was then computed from the results and displayed by the software. Observed correlations were pooled and corrected for sampling error using a mixed-effects model. The mean observed (r) correlation and corresponding confidence intervals were also calculated. The pooled correlation coefficient between ultrasound estimation of endotracheal tube size as compared to traditional methods was calculated according to the values of correlation coefficients obtained in each individual study. Correlation coefficient values were converted by Fisher's r-to-z transformation to obtain approximately normally distributed z values to further calculate 95% CIs. The mixed-effects model was used for the pooled analysis in this study. Correlations were classified as poor (correlation coefficient $r < 0.20$), average ($r = 0.20–0.39$), moderate ($r = 0.40–0.59$), significant ($r = 0.60–0.79$), and strong ($r > 0.80$). The heterogeneity of r values between studies was tested by calculating Q statistic and the inconsistency index (I^2). $P < 0.05$ or $I^2 > 50\%$ indicated the presence of heterogeneity. The Q statistic reflected the total amount of variance in the meta-analysis while the I^2 value indexes the proportion of variance that is due to between-study differences and unlike the Q statistic; it is not sensitive to the number of studies considered. I^2 values range from 0 to 100% and it has been suggested that values of 25, 50, and 75% indicate low, moderate, and higher heterogeneity, respectively. $P < 0.05$ was considered statistically significant. Mantel-Haenszel Chi-square test: expressed as the mean difference with 95%CI was used for continuous data. For dichotomous data - Inverse Variance was used and expressed as risk ratio with 95%CI. The ROBINS-E tool (Risk Of Bias In Non-randomized Studies - of Exposures) was used to assess risk of bias, as summarized in table.

Results

At stage one; the search strategy yielded a total of 12, 702 papers. After scanning abstracts and titles using the specified inclusion criteria, 48 papers were identified as relevant and read in detail, the substantial exclusions at this stage were due to a large number of studies that had not assessed ultrasonography in the pediatric age group or were not translated in the English

Table 2: Criteria for Study selection

Previous Review	None available
Exposure of interest	The paediatric age group for elective procedures under general anesthesia
The geographic location of the study	Worldwide
Language	English/translation in English was available
Participants	Paediatric age group (birth till 18 years)
Peer review	Peer-reviewed articles only
Reported outcomes	ETT size estimation in the paediatric age group utilizing Ultrasonography
Type of publication	Peer reviewed published articles (Randomized control trials, observational studies, case series, and case report)

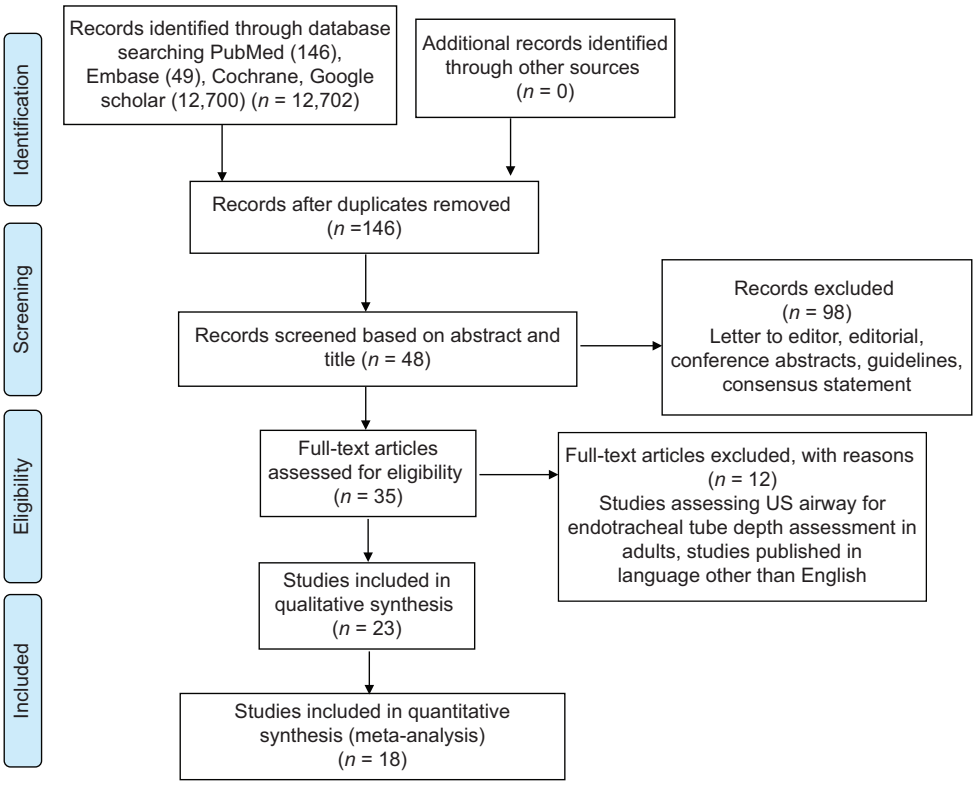
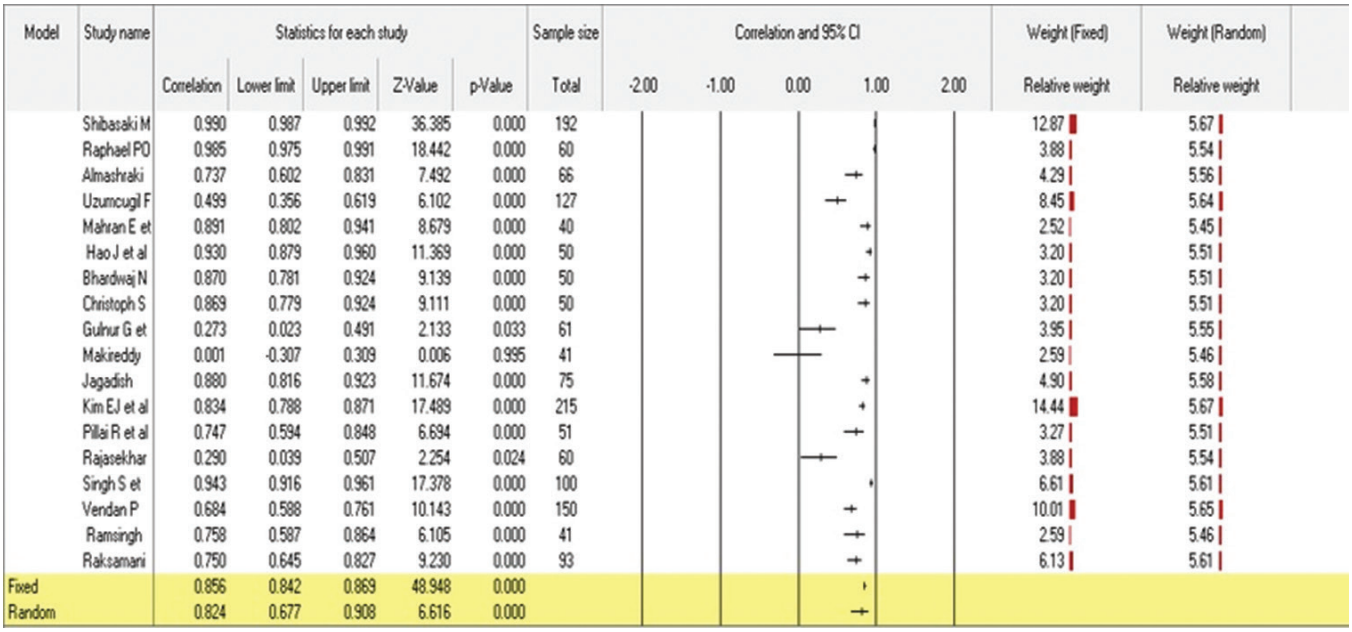


Figure 1: PRISMA 2009 Flow Diagram



Model	Study name	Statistics for each study					Sample size	Correlation and 95% CI	Weight (Fixed)	Weight (Random)
		Correlation	Lower limit	Upper limit	Z-Value	p-Value	Total	-2.00 -1.00 0.00 1.00 2.00	Relative weight	Relative weight
	Shibasaki M	0.990	0.987	0.992	36.385	0.000	192		12.87	5.67
	Raphael PO	0.985	0.975	0.991	18.442	0.000	60		3.88	5.54
	Almashraki	0.737	0.602	0.831	7.492	0.000	66		4.29	5.56
	Uzumcugil F	0.499	0.356	0.619	6.102	0.000	127		8.45	5.64
	Mahran E et	0.891	0.802	0.941	8.679	0.000	40		2.52	5.45
	Hao J et al	0.930	0.879	0.960	11.369	0.000	50		3.20	5.51
	Bhardwaj N	0.870	0.781	0.924	9.139	0.000	50		3.20	5.51
	Christoph S	0.869	0.779	0.924	9.111	0.000	50		3.20	5.51
	Gulnur G et	0.273	0.023	0.491	2.133	0.033	61		3.95	5.55
	Makireddy	0.001	-0.307	0.309	0.006	0.995	41		2.59	5.46
	Jagadish	0.880	0.816	0.923	11.674	0.000	75		4.90	5.58
	Kim EJ et al	0.834	0.788	0.871	17.489	0.000	215		14.44	5.67
	Pillai R et al	0.747	0.594	0.848	6.694	0.000	51		3.27	5.51
	Rajasekhar	0.290	0.039	0.507	2.254	0.024	60		3.88	5.54
	Singh S et	0.943	0.916	0.961	17.378	0.000	100		6.61	5.61
	Vendan P	0.684	0.588	0.761	10.143	0.000	150		10.01	5.65
	Ramsingh	0.758	0.587	0.864	6.105	0.000	41		2.59	5.46
	Raksamani	0.750	0.645	0.827	9.230	0.000	93		6.13	5.61
Fixed		0.856	0.842	0.869	48.948	0.000				
Random		0.824	0.677	0.908	6.616	0.000				

Figure 2: Forest plot for weight correlation and Heterogeneity

language. The selected studies were published between 2010 and 2020, average numbers of patients were 86 and total numbers of patients were 1978. Age group varied between neonates till 17 years of age group. Most of the studies included pediatric patients posted for elective surgeries under general anesthesia and excluded emergency procedures, known laryngeal or tracheal pathology, high risk patients, recent upper respiratory tract infection, or allergy to ultrasound gel, as summarized in Table 3. Majority of studies were observational studies, and few were randomized controlled trials, as listed in Table 3. RCTs were manually screened for random sequence generation, and allocation concealment (selection bias). Detection bias and participation bias, was assessed based on blinding of participants and observer's assessment; however,

a pooled analysis of bias was not done, as majority of studies published were prospective observational studies, as listed in Table 3. Majority of studies estimated their sample size based on power varying between 80-95% at a 5% significance level or pilot estimation/convenience sampling as summarized. Majority of studies used high resolution linear probe ultrasound, and ultrasound was performed by either experienced anesthesiologist or radiologist, as summarized in Table 4. Position of patients, and traditional method used for estimation of tube size is summarized in Table 4.

Observations of Meta-analysis

A total of 18 independent correlations were analyzed [Figure 1]. Figure 2 reflects correlations, respectively, and include the study details, sample size (N), each study r, the mean weighted (r), and 95% confidence intervals (CIs). Characteristics of the Studies Contributing Data to systematic review are summarized in Tables 3 and 4. The data provided by the finally chosen 18 studies met the standard of meta-analysis, as reflected in Figure 2. Final combined r value calculated from all the included articles was 0.824 (95% CI 0.677, 0.908), with a $P < 0.00001$ {strong co-relation ($r > 0.80$)}. Results of heterogeneity test indicated the presence of marked heterogeneity among studies, (I^2 97.78%, $P < 0.001$). Forest plot for weight correlation of all 18 studies is summarized in Figure 2. The Q statistic of 756.484, and I^2 statistics of 97.53% showed a large degree of heterogeneity in the effect size across the studies [Figure 2].

Discussion

We systematically studied and evaluated the use of US for the assessment of ETT size in the pediatric age group Table 3.[4-6,9-30] We wanted to examine whether the US measurements give us a reasonable enough idea of the size of the ETT to be inserted, whether there is any co-relation of US with the traditional formulas. Additional information was also gathered regarding the impact of the US learning curve, ease of insertion of the ETT, depth of insertion of the ETT, utility of the US to detect correct placement, any effect of the US on the ETT exchange rates, whether the real-time US reduced the need for repeated laryngoscopy and thus avoided airway trauma.

The current gold standard test to confirm proper ETT location in critically ill patients is chest radiography; however, this is mostly performed later after ventilation has started. Performing chest radiography often involves patient manipulation and X-ray film positioning that may be associated with the possibility of ETT displacement and even dislocation.[5] A further restriction is encountered during cardiopulmonary resuscitation (CPR), which renders chest x-ray impracticable due to interruption of chest compression[6] In addition to the above; there is also a risk of prolonged exposure to radiation in critically ill patients.[10] The optimum size of the ETT may be chosen from the calculation of the tracheal diameter on the chest radiography.[5] However, the tracheal diameter on the chest radiography does not necessarily represent the subglottic diameter, the narrowest portion of the pediatric larynx.

The advantages of ultrasound over X-rays[31] include: (i) lack of radiation; (ii) less handling, especially in critically ill infants; (iii) the potential for determining the ETT location in the delivery room, particularly for early delivery of surfactants; and (iv) early detection of malposition complications. Ultrasound drawbacks are (i) a need for advanced expertise and qualified personnel (ii) difficulties in correctly recognizing anatomical landmarks and (iii) a lack of widespread availability.

On the other hand, the MRI scan can provide additional information on the anterior–posterior measurement of the tracheal diameter.[19] The anterior–posterior diameter cannot be visualized using ultrasound because the acoustic shadow produced by the air column obscures the location of the posterior wall of the trachea. MRI offers high-quality images that allow accurate measurements of the larynx. Therefore, MRI is regarded as a non-invasive gold standard method for the measurement of subglottic diameter. In clinical settings, however, high-quality laryngeal images of CT and MRI cannot be routinely done due to high cost and feasibility. Ultrasound can be a viable technique for airway abnormalities, but it is an operator-dependent technique, and predictive value depends on experience despite the suggestion that it is an easy-to-learn technique.[4] Khalesi N *et al.*[32] reported that the ETT was visualized by the US in all new-borns tested. Overall, the Kappa value showed a very strong agreement to confirm the correct location of the tracheal tube position (Kappa coefficient 0.72, P value < 0.001). The mean time taken to confirm the position of the ETT was US 4 minutes and CXR was 20 minutes. The US needs limited preparation and does not require total immobility or sedation. The advantages of the US therefore lie in its feasibility, protection, and lower time requirements compared to chest radiography and MRI.

Basic understanding of US mechanics, transducer selection, body habitus, and probe orientation, and a better understanding of airway anatomy contribute to the accuracy of US perception. The sub-glottis, bound by the full cartilaginous ring of the cricoid cartilage, was long assumed to be the narrowest portion of the pediatric larynx. However, a recent study described the narrowest portion of the vocal cord and sub-vocal cord levels in unparalyzed children.[21] However, consistent estimation of the tracheal diameter at that level; in all patients is difficult due to

Table 3: Characteristics of the Studies

Authors	Year of study	Type of study	*n*	Age group	Sample size estimation	Inclusion criteria	Exclusion criteria	Robins tool to assess risk of bias[8]	Level of evidence
Shibasaki M *et al.*[4]	2010	observational study	192	1 month -6 years	based on pilot estimation	surgery under GA	known or suspected to predispose them to laryngeal or tracheal pathology	moderate	II
Raphael PO *et al.*[9]	2016	observational study	60	2-15 years	-	ASA I, II, Elective surgeries under GA	ASA grade III and IV, emergency surgeries, patients with known pulmonary and cardiovascular problems, and patients with facial abnormalities and or anticipated difficult intubation	Moderate	II
Alyousef S *et al.*[10]	2018	prospective study	66	<15 years	90% power, alpha value convenience sampling	<15 years who were intubated	high-risk patients, who could be affected by losing lung de recruitment during cuff deflation, patients on high-frequency ventilation, requiring high PEEP (` 10cm H_2O), severe pulmonary hypertension, active pulmonary hemorrhage, patients with high intracranial pressure, neck masses, scars, difficult airway, difficult in performing USG neck.	low	II
Uzumcugil F *et al.*[11]	2018	prospective study	127	24 to 96-month	power of 95% at a 5% significance level	(ASA) physical status grade I-II patients, undergoing elective surgical procedures (6-month period)	known or suspected laryngeal or tracheal pathologies or syndromes characterized by airway anomalies or difficult airways	moderate	II
Mahran E *et al.*[12]	2019	prospective cohort	40	2-10 years	80% power and 5% significance level	ASA class≤II, Mallampati airway classes I and II, scheduled for surgery away from the head and neck	Known allergy to US gel.	Low	II
Jianhong Hao *et al.*[13]	2020	prospective	50	5-12 years	not mentioned	scoliosis surgery	neck trauma, throat disorders, or an anticipated difficult airway	low	II
Bhardwaj N *et al.*[14]	2020	observational study	50	2-6 years	power of 80%, the alpha error of 5%, mean difference of 0.5 mm, and a standard deviation of 1	cases under GA	not mentioned	low	III
Altun D *et al.*[15]	2016	prospective randomized	50	1 to 10 years	not mentioned	general anesthesia with endotracheal intubation	previous histories of tracheal and laryngeal pathologies, such as tracheostomy, pharyngeal surgery with anatomical airway abnormalities and anticipated difficult airway, American Society of Anesthesiologists III-IV patients with unstable cardiopulmonary conditions and patients with body mass indices above the 85th %ile (overweight) and below the 5th %ile (underweight)	low	II
Altun D *et al.*[16]	2017	prospective randomised	152	1-10 years		general anesthesia for adenotonsillectomy	Information could not be retrieved	Moderate	II
Schramm C *et al.*[17]	2012	observational study	50	≤5 years	consecutive patients	written informed consent signed by the legal guardians of the child, elective surgery or procedures requiring endotracheal intubation	missing informed consent and allergy to the US gel.	low	II

Contd...

Table 3: Contd...

Authors	Year of study	Type of study	*n*	Age group	Sample size estimation	Inclusion criteria	Exclusion criteria	Robins tool to assess risk of bias[8]	Level of evidence
Gupta k *et al.*[18]	2012	Prospective observational	112	3-18 years	consecutive patients	general anesthesia with endotracheal intubation.	The respiratory disease that might cause airway narrowing, pre-existing laryngeal or tracheal pathology, any lesion that could cause airway deformity due to fibrosis or difficult airway	Low	II
Gulnur G *et al.*[19]	2018	prospective, randomized, single-blind	61	2-17 years	-	ASA I-II	Facial or respiratory tract anomalies, failure to give informed consent, anticipated difficult airway, and having a history of US gel allergy	low	II
Makireddy R *et al.*[20]	2019	observational study	41	2-6 years	alpha of 95% and power of 80%.	ASA I-II, elective surgeries under GA	laryngeal or tracheal pathology, anticipated difficult airway, neck mass, children at risk of aspiration, or those with unstable cardiopulmonary condition	Moderate	III
Sutagatti JG *et al.*[21]	2017	prospective clinical observational study	75	1-14 years	power 80%, CI 95%	elective surgery under general anesthesia with oro-tracheal intubation	anticipated difficult airway, delayed milestones, pre-existing laryngeal or pharyngeal pathology, unstable cardiopulmonary conditions or presence of any neck mass	moderate	II
Kim EJ *et al.*[22]	2013	prospective	215	1-72 months	age-based	under GA	-	Low	II
Pillai R *et al.*[23]	2018	prospective observational	51	1 day to 5 y	appropriate formula	children <5 years of age with congenital heart defects for cardiac surgery	Anticipated difficult airway and parental refusal	Moderate	II
Rajasekhar M *et al.*[24]	2018	observational study	60	6 months-8 y	not mentioned	either sex, scheduled for elective surgery under general anesthesia (GA) requiring oral endotracheal intubation	ASA III and above, suffering from any respiratory disease that might cause airway narrowing, pre-existing laryngeal or tracheal pathology, any lesion that could cause airway deformity due to fibrosis, and anticipated difficult airway	Moderate	II
Singh S *et al.*[25]	2019	prospective	100	12-60 months		ASA I, II	upper respiratory tract infection, tracheal and laryngeal pathology, ASA III-V. Patients in whom SGA was inserted and patients requiring mechanical ventilation.	moderate	II
Kayashima K *et al.*[26]	2018	case report	1	7y	not applicable	down syndrome		-	IV
Gnanaprakasam *et al.*[27]	2016	a prospective randomized parallel-group	150	2-6y	pilot study	ASA I, II	recent URTI, Anticipated difficult airway, mass/ ulcer	Low- moderate	II
Ramsingh D *et al.*[28]	2020	observational study	41	birth to 10 y	based on pilot estimation	children aged from birth to 10 years and general anesthesia with a cuffed TT	Emergency procedures, patients with known airway anomalies, and parents/guardians who were non-English- or non-Spanish-speaking.	low	II
Bae *et al.*[29]	2011	observational study	141	<8 y	McNemar test-alpha error 0.05 and beta error of 0.2.	Age<8 y scheduled for elective surgery	Anticipated difficult airway, presence of a neck mass, and unstable cardiopulmonary condition.	Moderate	III
Raksamani K *et al.*[30]	2018	RCT	93	1-6y	Random selection	l and 6 years old undergoing elective surgery under general anesthesia	Emergency procedures	low	I

ASA - American society of anesthesiologists, GA - General anesthesia, US - Ultrasound, USG - Ultrasonography PEEP - Positive end expiratory pressure, RCT - Randomised controlled trial, URTI - upper respiratory tract infections

Table 4: Type of US used, patient head position, measured parameters, and type of ETT used

Authors	Type of US used	Patient's head position during ultrasonography	USG done by	Traditional method used and comparison made	Measured parameter	Type of endotracheal tube used
Shibasaki M *et al.*[4]	B mode (SonoSite 180, SonoSite Inc. Japan)	Neutral position	Experienced anesthesiologists	prediction of size based on age and height	outer diameter	both were compared
Raphael PO *et al.*[9]	a high-resolution linear probe of US machine (GE healthcare venue 40)	Supine		prediction of size compared to age		
Alyousef S *et al.*[10]	high-frequency 10-13 MHz, linear array probe, M turbo US machine (Sonosite, Inc, Bothell, WA) linear array probe	Supine	experienced well trained PICU physician with extensive training	proper position of ETT	ETT depth studied	Endotracheal tube depth was estimated
Uzumcugil F *et al.*[11]	40 mm linear probe, 12-7 MHz, Titan, Sonosite, Bothell, WA, USA	Supine	experienced anesthesiologists	prediction of uncuffed tube size based on age	outer diameter	uncuffed
Essam Mahran *et al.*[12]	high-resolution B-mode US (SonoSite®, Global Technology, USA) with a linear probe of small footprint, (38 mm length, frequencies 6-13 MHz).	Supine and Sniffing head position	one of two authors	prediction of size compared to age	ID	uncuffed
Jianhong Hao *et al.*[13]	linear 7-15- MHz probe	horizontal with slight extension	two anesthesiologists, then average reading was taken	prediction of size in congenital scoliosis	ID	both were compared
Bhardwaj N *et al.*[14]	The subglottic diameter was determined by using a high-resolution linear probe (40 mm length, frequencies 6-13 MHz) of USG machine	Supine	experienced anesthesiologist	prediction of size compared to age and little finger diameter	OD	Uncuffed
Altun D *et al.*[15]	subglottic airway transverse diameter in the brightness (B) mode using the linear probe (range, 4.5-13 MHz) of the USG device (GE Healthcare LOGIQ e)	supine and neutral head position		investigate the first attempt success of ultrasonography (USG) in pediatric patients		cuffed
Altun D *et al.*[16]	subglottic airway transverse diameter	supine and neutral head position		prediction of size based on age and height		
Schramm C *et al.*[17]	6- to 13-MHz hockey stick probe Slax connected to the portable US system Micromax or M-Turbo (SonoSite, Bothell, WA, USA)		Experienced anesthesiologist	prediction of uncuffed tube size based on age		uncuffed
Gupta k *et al.*[18]	High-resolution B-mode ultrasonography (Toshiba-Apilo) with the linear probe of a small footprint (40 mm length, frequencies 7 to 15 MHz)			prediction of size based on age and height		
Gulnur G *et al.*[19]	(Siemens, Acuson X150, 13-5 Hz linear probe, CA, USA)	Neutral position	same surgeon who was trained by an experienced radiologist for two-weeks	prediction of size compared to age	outer diameter	uncuffed
Makireddy R *et al.*[20]	A 5-13 Hz linear US probe (S-ICU, Sonosite Fujifilm Corporation)	a neutral position with neck slightly extended	not mentioned	prediction of size compared to age and Cole formula70.7%	OD was estimated with USG then correlated with ID	uncuffed
Jagadish G Sutagatti *et al.*[21]	high-resolution B mode USG (Philips, IU-22, the United States of America) with a linear probe (5-12 MHz and 7-15 MHz)	Sniffing	radiologist	prediction of size based on age and height	outer diameter	both were compared
E J Kim *et al.*[22]		mid cricoid cartilage level		prediction of size compared to age-based formula	outer diameter	cuffed

Contd...

Table 4: Contd...

Authors	Type of US used	Patient's head position during ultrasonography	USG done by	Traditional method used and comparison made	Measured parameter	Type of endotracheal tube used
Pillai R *et al.*[23]	Linear array high-frequency transducer (GE L818i) with a 25 mm hockey stick footprint	the lower border of the cricoid cartilage	Anesthesiologist with US experience.	prediction of size compared to age and Cole formula	Outer diameter	Both cuffed and uncuffed
Man Rajasekhar *et al.*[24]	The US was done with linear probe (frequency 7-15 MHz) and measurements were taken in B-mode.	Supine	radiologist	little fingerbreadth and USG co-relation with OD	outer diameter	uncuffed
Shubhi Singh *et al.*[25]	high-resolution B mode ultrasonography with a small footprint linear probe having frequencies 7 to 15 MHz and length 40 mm	sniffing	radiologist	age, height, weight-based formulas and diameter of right and left little finger	OD	Uncuffed
Kayashima K *et al.*[26]	short-axis view of cricoid was obtained before intubation using US apparatus equipped with L12-2 Mhz probe (L441, Noblus, Hitachi Aloka Medical Ltd., Tokyo, Japan)	supine	radiologist	Prediction of size of endotracheal tube	OD	cuffed
Gnanaprakasam *et al.*[27]	high-resolution B mode linear USG using small footprint probe HST15-8/20(Frequency range of 15-8 MHZ) of sonix Tablet (ultrsonix, Analogic Corporation, Massachusetts, USA)	subglottic diameter at the cricoid region was measured, sniffing	Senior anesthetist unaware of the group	glottic diameter at the cricoid better than modified COLE formula	OD and ID both compared	Uncuffed
Ramsingh D *et al.*[28]	high-frequency linear probe (13-6 MHz) Sonosite X Porte, Fiji film X site	Supine	four physician examiners (two pediatric anesthesiology fellows, one anesthesiology resident, and one research fellow) performed the POCUS examinations	Fluoroscopy		
Bae *et al.*[29]	high-frequency linear probe	mid cricoid level, in a neutral position		Compared to the Age-based formula	ID	Uncuffed
Raksamani K[30]	high-frequency linear probe	measurement of the transverse subglottic diameter in the supine position during apnoea		a modified Cole formula was used to select the ETT size, while in group US measurement of the subglottic diameter		

**OD - outer diameter, ID - internal diameter*

distorted ultrasonic representation of the vocal cord. As a result, several authors calculated subglottic diameter at the lower edge of the hypo-echoic cricoid cartilage. This measure reflected a valid and consistent value that could be compared between patients. The subglottic diameter is calculated using a high-resolution US computer linear probe mounted on the midline of the anterior neck with the head extended and neck flexed during mask ventilation. The subglottic tracheal diameter measured was used to pick an endotracheal tube of similar outer diameter in the studies done by Shibasaki M *et al.*,[4] Uzumcugil *et al.*,[11] Bhardwaj N *et al.*,[14] Gollu G *et al.*,[19] Kumar A *et al.*[33] The endotracheal tube with an outer diameter often less than the measured tracheal diameter was chosen to avoid damage to the airways. These measurements were conducted when manual ventilation was momentarily halted to mitigate variations in tracheal diameter as reported by Raphael P *et al.*[9]

There is a strong link between the subglottic transverse diameter determined by the U.S. and the outer ETT. Shibasaki M *et al.*[4] selected the optimum size of the ETT based on traditional age formulas for cuffed and un-cuffed tubes. Tubes have been replaced when required until a successful clinical match has been achieved. Using ultrasonography, the subglottic upper airway diameter was determined before tracheal intubation. A regression equation was built between the subglottic upper airway diameter and the outer diameter of the ETT, which was finally chosen. They found that age and height-based formula can only reliably predict 35% of the cuffed ETT size and 60% of the uncuffed tube size compared to ultrasonography (98 and 96% respectively. Kim EJ *et al.*[22] found a strong correlation between the outer diameter of the ETT at the subglottic stage and the real outer diameter of the ETT and proposed a formula to select the right size of the ETT in infants. Pillai R *et al.*[23] used a minimal transverse diameter of subglottic airway (MTDSA) measurements. They found that the age-based formula showed poor correlation (27.5%) compared to MTDSA (87.8%) in predicting the bestfit ETT. However, Bae JY *et al.*[29] suggested that ultrasound-based estimation is a better alternative to age-based formulas, but it was not reliable for the prediction of appropriate ETT size. They reported correct size prediction by the US in only 60% of cases. Equivocal results were reported by Makireddy R *et al.*[20] They reported that there was no difference in the number of correct predictions of ETT size by US measurement, universal formula, and locally derived formula. Few limitations of US as suggested by Bae JY *et al.*[29] were that it measures only transverse diameter at one level, OD change according to the manufacturer, measurements are subject to variation and hence it leads to an inappropriate estimation of size in 40% cases. Final combined *r* value calculated from the Meta-analysis of all included studies is 0.824 (95% CI 0.677, 0.908), with a $P < 0.00001$ {strong co-relation ($r > 0.80$)}.

Although several methods have been suggested to verify the position of the ETT, there is no single confirmatory approach that is suitable in any case. Capnography is considered a quality of treatment for the primary verification of the position of the ETT. Upper airway ultrasound may also be useful in cases involving cardiovascular arrest, bronchial constriction, or in situations where Capnography or ETCO2 may be defective. The location of the ETT in the trachea is seen as two hyperechoic lines that are defined as a double lumen" or double lumen" symbol. Alyousef S *et al.*[10] concluded that ultrasonography was found to be a more feasible; Safe and comparatively faster alternative approach for evaluating the correct location of ETT in the trachea of patients with PICU by using a saline-filled ETT cuff with high sensitivity and specificity, with a sensitivity of 91.67%, the specificity of 83.33% and positive predictive value of 93.62%. Related research has been performed by Tessaro *et al.*[34] (Trust study) in patients with pediatric elective surgery with high sensitivity (98.8%) and high specificity (96.4%) of the US technique in detecting the proper position of saline-filled cuffed ETT. The intratracheal ETT location was also confirmed ultrasonographically by Gollu *et al.*[19]

The superiority of the US as opposed to the traditional age-based formula has been confirmed by many authors including Bae JY *et al.*[29] and Schramm *et al.*,[17] except that the ability to predict correct ETT size differs between the two studies by 60% and 48%, Formulas based on age, such as those of Cole and Motoyama,[2,3] are widely used. However, the agreement rate for age-based pediatric ETT size selection using the Cole formula was as low as 47–77% in previous studies.[17,29] On the opposite, the US has been extremely predictive. Besides, age-based formulations typically predict greater sizes than clinically optimal, often two or even three sizes. To compensate for individual growth differences, others proposed that the patient's length-based technique (e.g., Broselow tape)[35] should be chosen in 90% of patients.). Bae JY *et al.*[29] reported 31%, Schramm C *et al.*[17] reported 24%, Shibasaki M *et al.*[4] reported 60%, and Daugherty *et al.*[36] reported 43.2% precision for accurate age estimates. Shibasaki M *et al.*[4] used tube size based on (1) uncuffed tubes, with Cole formulas: ID (inner diameter) in mm 0.25× (age in years) plus 4; (2) cuffed ETTs in children aged 2 years or older, with Motoyama formulas: ID in mm 0.25× (age in years) plus 3.5; (3) cuffed ETTs in children younger than 2 years, with Khine formulas: ID in mm 0.25× (age in years) plus 3.5; Tube size was considered to be ideal when tracheal leakage was observed at an inflation pressure of between 10–20 cm H2O with either uncoated

tubes or deflated tubes. Raphel PO *et al.*[9] used-Motoyama was the age-based formula (for more than 2 years) used. ID in mm = 0.25× (year age) +3.5. Uzumcugil *et al.*[11] used Data on age (years and months), body weight, and body height (measured the day before surgery) were collected from records, and BSA was estimated using the formula {BSA (m2) = approximate[weight (kg)×height (cm) 3,600–1]}. Weight-and height-for-age%ages were determined using growth charts and concluded BSA had a right estimate rate of 40.2%.

The size of the ETT was determined for each patient based on the updated age-based formula of Cole (age/4 + 4) by Essam Mehraj *et al.*[12] Bhardwaj N *et al.*[14] used ETT size as per age-based formula was determined based on age-based formula (2-6 yr) (Penlington formula)[37] ID in mm = age (yr)/3 + 3.5 and the small finger diameter was measured using a Vernier calliper. Gollu G *et al.*[19] used the scale of the ETT according to the child's age by Cole [ID (mm) =0.25× (age in years) +4], Motoyama [ID (mm) =0.25× (age in years) +3.5], and Khine [ID (mm) =0.25× (age in years) +3]. Makireddy R *et al.*[20] provided an equation for predicting ETT ID based on US measurements as (0.63 × U/S measured diameter) – 0.36 and OD as (0.87 × U/S measured diameter) – 0.47. Formula-derived age to predict ETT ID was + 3.75 (0.25 × Age) and + 5.17 (0.34 × Age) for ETT OD. They concluded that there was no strong connection between height and weight and the final ETT OD. Shubhi Singh *et al.*[25] used age-dependent formula (Age + 16)/4, body length based formula [2 + length (in cms.)/30], multivariate Formula (2.44 + age in year ×0.1 + height in cm × 0.02 + weight in kg × 0.016.), fifth right and left finger diameter calculated as the anterior to the posterior diameter of the distal digit with the calliper at the nearest 0.1 mm.

Mayasuki S *et al.*[1] compared both cuffed and uncuffed tubes and stated that the rate of agreement between the expected ETT size based on the ultrasonic measurement and the clinically selected final ETT size was 98% for cuffed ETTs and 96% for uncuffed ETTs. Paul o Raphel *et al.*[9] compared the internal diameter to the approximate U.S. diameter. Alyousef S *et al.*[10] were using cuffed tubes. Uzumcugil *et al.*[11] studied the outer diameter of uncuffed ETTs. Demet Altun *et al.*[15,16] compared ID with a subglottic diameter measured by ultrasound. The correlation between the US and traditional formulae.

Final combined *r* value calculated from all the included articles was 0.824 (95% CI 0.677, 0.908). Essam Mahran *et al.*[12] found that the calculated ETT size by age formula was closely associated with the size measured by the U.S. (Pearson correlation 0.913). Schramm C *et al.*[17] concluded that the minimal transverse diameter of the subglottic airway (MTDSA) was strongly correlated with the outer diameter of the ETT in children under 5 years of age ($r = 0.869$, $R^2 = 0.754$). The rate of agreement between clinically optimal and US-directed endotracheal tubes was 98% in children 3–18 years of age as stated by Gupta K *et al.*[18] ($P < 0.001$). Sutagatti JG *et al.*[21] concluded that USG predicted an acceptable ETT size ($P < 0.05$) better than the physical indices based on formulas for cuffed and uncuffed tubes. The age-based formula predicted well the clinically used ETT size ($P = 0.58$) and the height-based formula did not correlate with the clinically used tube size ($P = 0.0002$ – a statistically significant value). EJ Kim *et al.*[22] concluded that the OD-ETT at subglottic diameter (SD) was associated with the actual OD-ETT outside the trachea ($R^2 = 0.635$), demonstrating the validity of the ultrasound measurement; also, the US-mediated SD displayed a clear correlation with the actual OD-ETT $R^2 = 0.834$). US-mediated SD and biographical data (age, height, and weight) showed little correlation in children under 12 months of age but a strong correlation (age, height) in children over 12 months of age ($P < 0.01$). The age-based formula showed a weak correlation (27.5% compared to MTDSA (87.8%) in predicting the best-fit ETT. Using US MTDSA measurements to direct the collection of ETT sizes is a healthy and reliable approach for the pediatric cardiac population. The coefficient of concordance between the US-guided subglottic diameter (USGD) and the small finger width (LFB) for 6 months to 8 years with the OD of the ETT was found to be 0.29 (0.13–0.41) and 0.46 (0.29–0.6) respectively. They concluded that neither the USGD nor the LFB could be used as a reliable method to predict the OD of the ETT. Singh S *et al.*[25] found a mild association of best fit Endotracheal tube with endotracheal tube size by age-dependent formula ($r = 0.743$), body length based formula ($r = 0.683$), right small finger-based formula ($r = 0.587$), left little finger-based formula ($r = 0.587$) and multivariate formula ($r = 0.741$). There was a good ultrasound correlation ($r = 0.943$). Singh *et al.*[28] found a clear association between POCUS measurements and fluoroscopic measurements, $r = 0.7575$, 95% CI [0.8638,0.5866], $P < 0.001$). Uzumcugil F *et al.*[11] enrolled one-hundred-four patients and analyzed the associations between the right ETT-OD (determined by the leak test) and the outcome parameters. Cole formula, ultrasonography, and BSA had similar accurate estimates. All three parameters had higher underestimation rates as age increased; all three parameters had their lowest estimated rates in patient's ≥72 to ≤96 months of age. Jianhong Hao *et al.*[13] verified the use of US in scoliosis patients and concluded that

US is a reliable method for predicting the size of ETT in pediatric patients with thoracic or lumbar scoliosis.

Demet Altun *et al.*[15,16] investigated the first successful attempt of ultrasonography (USG) in pediatric patients to predict the acceptable size of the cuffed endotracheal tube (ETT) and concluded that the success rate of the first attempt with USG was 86%, and the subglottic diameter measured with USG was a reliable predictor in the estimate of the appropriate pediatric size of the ETT. Bae JY *et al.*[29] recorded 60% progress in selecting the right uncuffed size of the ETT. Schramm *et al.*[17] also researched uncuffed ETT and had a lower success rate (48%) in the younger population. Shibasaki M *et al.*[4] obtained higher performance (98%) for cuffed tubes when the regression equation was extended to specifically measured subglottic diameters.

Mukadder Orhan-Sungur *et al.*[38] observed a reasonable and unacceptable failure rate of 20 and 40% respectively, for 16 residents who had completed 30 US jobs each. They stated that the overall success rate for determining the correct endotracheal tube size was 77.5%. Ultrasonography is an operator-dependent technique that is reasonably easy to understand. A total of approximately 15 procedures are required for operators to obtain accurate and reproducible measurements. Another issue about ultrasonic measurements is that age-dependent physiological calcification of the larynx produces an acoustic shadow. However, as calcification starts to occur in laryngeal cartilage during the third decade of life, ultrasonography can be applied with few problems in the pediatric age group.

Limitations

Our meta-analysis was based only on published studies which provided *r* values or raw data which can be used to calculate *r* values. Other articles which only report positive or negative results without specific data were excluded from this analysis. In addition, this study was restricted to articles published or translated in English, which would cause publication bias. Most of the studies included pediatric patients posted for elective surgeries under general anesthesia and excluded emergency procedures, known laryngeal or tracheal pathology, high risk patients, recent URTI or allergy to ultrasound gel, clinical utility of US needs to be determined in patients posted for emergency and high risk patients. Other limitation was that we did not include studies which used the US for performing various procedures in the pediatric age group such as percutaneous dilatational tracheostomy, insertion of the supraglottic airway, and cricothyroidotomy. Publication bias was not checked using regression test for funnel plot asymmetry and egger's test.

Strength of Meta-analysis- We used the fixed and random-effects model to reduce heterogeneity. Therefore, the results of this study are reliable, as Grade B recommendations, owing to consistent findings from type II, III and IV level of evidence studies.

Suggestions for future research-Use of US will help minimize airway related complications, lesser incidence of postoperative sore throat by selecting the most appropriate sized tube will aid early extubation which is still not explored.

Conclusion

U.S. usage for upper airways in the pediatric age group is an important modality and can accurately predict endotracheal tube size estimates as opposed to normal age-based or height based formulas in the pediatric age group. The US is a non-invasive, cost-effective, compact, and reproducible technique. It also takes less time with improved knowledge and experience. With encouraging results from the current data, there is a potential for US airways to be integrated into standard care pediatric airway measurement, endotracheal tube size estimate, depth assessment and proper positioning, and imaging/monitoring procedures The US is a very useful modality, currently underutilized, and can prove to be an indispensable tool for airway management in near future. It can help correctly identify the size of ETT required, depth of insertion, minimize intubation attempts, and confirm correct placement. US can be utilized while tackling normal as well as difficult airways in operation theatres as well as ICU.

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Conflicts of interest

There are no conflicts of interest.

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