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

Bhavna Gupta, Pallavi Ahluwalia1
Assistant Professor, AIIMS, Rishikesh, Uttarakhand, 1Department of Anaesthesia, Teerthanker Mahaveer Medical College, Moradabad, Uttar Pradesh, India

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 I2 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 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 to estimate optimal ETT size...
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 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 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 correlates 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. 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, Google 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 OR USG)) AND (‘endotracheal intubation’/exp OR ‘endotracheal intubation’) AND (‘pediatric’/exp OR pediatric 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.

| 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

\[
Z = \frac{1}{\sqrt{3N}} \times \ln \left( \frac{1 + \text{Correlation}}{1 - \text{Correlation}} \right)
\]


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-

\[
Z = 0.5 * \ln \left( \frac{1 + r}{1 - r} \right)
\]

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 \(F\) 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. \(F\) 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
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 F 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 3.14  6  29  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.33 A further restriction is encountered during cardiopulmonary resuscitation (CPR), which renders chest x-ray impracticable due to interruption of chest compression.66 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.35 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-rays31 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.34 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 | Level of evidence |
|-------------------|---------------|---------------|-----|-----------|------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-----------------------------------|--------------------|
| Shibasaki M et al. | 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.  | 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.  | 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 H2O), 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. | 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.    | 2019          | prospective cohort | 40  | 2-10 years | 80% power and 5% significance level | ASA class ≤ II, Mallampati artery classes I and II, scheduled for surgery away from the head and neck | Known allergy to US gel.                                                              | Low                 | II                 |
| Jianhong Hao et al. | 2020         | prospective study | 50  | 5-12 years | not mentioned           | scoliosis surgery                                                                  | neck trauma, throat disorders, or an anticipated difficult airway                 | Low                 | II                 |
| Bhardwaj N et al.  | 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                 | II                 |
| Altun D et al.     | 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.     | 2017          | prospective randomised | 152 | 1-10 years | not mentioned           | general anesthesia for adenotonsillectomy                                          | Information could not be retrieved                                                | Moderate             | II                 |
| Schramm C et al.   | 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...
| Authors          | Year of study | Type of study | n   | Age group | Sample size estimation | Inclusion criteria                                                                 | Exclusion criteria                                                                 | Robins tool to assess risk of bias | Level of evidence |
|------------------|---------------|---------------|-----|-----------|------------------------|------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|----------------------------------|-------------------|
| Gupta k et al.   | 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.  | 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. | 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. | 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.    | 2013          | prospective    | 215 | 1-72 months | age-based              | under GA                                                                          | -                                                                                  | Low                             | II                |
| Pillai R et al.  | 2018          | prospective    | 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. | 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.   | 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. | 2018        | case report    | 1   | 7y         | not applicable        | down syndrome                                                                    | -                                                                                  | IV                              |                  |
| Gnanaprakasam et al. | 2016      | a prospective randomized parallel-group study | 150 | 2-6y       | pilot study            | ASA-I, II                                                                         | recent URTI, Anticipated difficult airway, mass/ ulcer                            | Low- moderate                    | II                |
| Ramsingh D et al. | 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.       | 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. | 2018       | RCT            | 93  | 1-6y       | Random selection       | 1 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
| 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                                        | Experenced anesthesiologists                                             | 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                                                                                        |                    |                                 |
| 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. [5] | 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 | prediction of size based on age and height                                                                   |                    |                                |
| Altun D et al. [16]     | subglottic airway transverse diameter                                                             | supine and neutral head position              | Experienced anesthesiologist                                              | prediction of uncuffed tube size based on age                                                               |                    | uncuffed                       |
| 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) | Supine                                        | Prediction of size compared to age                                         | prediction of size based on age and height                                                                   |                    |                                |
| 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) | Supine                                        | Prediction of size compared to age                                         | 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 | Radiologist                                                               | Prediction of size compared to age and Cole formula 70.7%                                                  | OD was estimated with USG then correlated with ID | uncuffed                       |
| Jagadish G 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                                      | Prediction of size compared to age based on age and height                | Prediction of size compared to age and height                                                                 | outer diameter     | both were compared             |
| EJ Kim et al. [22]      |                                                                                                   | mid cricoid cartilage level                   | Prediction of size compared to age based on age and height                | Prediction of size compared to age based on age and height                                                  | outer diameter     | cuffed                         |

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.               | 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.         | 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.           | high-resolution B mode ultrasonography with a small footprint linear probe having frequencies 7 to 15 MHz and length 40 mm | supine                                      | radiologist                  | age, height, weight-based formulas and diameter of right and left little finger | OD | Uncuffed |
| Kayashima K et al.            | 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.          | high-resolution B mode linear USG using small footprint probe HST15-8/20(Frequency range of 15-8 MHZ) of sonix Tablet (ultrasonix, Analogic Corporation, Massachusetts, USA) | supine                                      | 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.             | high-frequency linear probe (13-6 MHz) Sonosite X Porte, Fiji film X site        | supine                                      | four physician examiners (two pediatric anesthesia fellows, one anesthesiology resident, and one research fellow) performed the POCUS examinations | Fluoroscopy        |                              |
| Bae et al.                    | high-frequency linear probe                                                      | mid cricoid level, in a neutral position      | Compared to the Age-based formula |                              | ID | Uncuffed |
| Raksamani K                   | 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.[13] “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 uncuffed 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.[23] 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 ET CO2 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.[14] (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 precise. 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.\textsuperscript{[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.\textsuperscript{[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
\(\text{BSA (m}^2) = \text{approximate [weight (kg) \times height (cm) }
3,600 – 1] \). 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.\textsuperscript{[12]} Bhardwaj N et al.\textsuperscript{[14]} used ETT
size as per age-based formula was determined based on
age-based formula (2-6 yr) (Penlington formula)\textsuperscript{[15,16]} ID
in mm = age (yr)/3 + 3.5 and the small finger diameter
was measured using a Vernier calliper. Gollu G et al.\textsuperscript{[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.\textsuperscript{[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.\textsuperscript{[23]} 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.\textsuperscript{[11]} 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.\textsuperscript{[9]} compared
the internal diameter to the approximate U.S. diameter.
Alyousef S et al.\textsuperscript{[10]} were using cuffed tubes. Uzumcugil
et al.\textsuperscript{[11]} studied the outer diameter of cuffed ETTs. Demet
Altun et al.\textsuperscript{[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.\textsuperscript{[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.\textsuperscript{[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.\textsuperscript{[18]} \((P < 0.001)\). Suragatti JG
et al.\textsuperscript{[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 \((P = 0.0002 – a \text{ statistically significant value})\).
EJ Kim et al.\textsuperscript{[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.\textsuperscript{[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.\textsuperscript{[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.\textsuperscript{[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.\textsuperscript{[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.[40] 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 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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