Assessment of the Endotracheal Tube Tip Position by Bedside Ultrasound in a Pediatric Intensive Care Unit: A Cross-sectional Study

Seenivasan Subramani[1], Narayanan Parameswaran[2], Ramesh Ananthkrishnan[3], Shilpa Abraham[4], Muthu Chidambaram[5], Ramachandran Rameshkumar[6], Mahadevan Subramanian[7]

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Abstract

Introduction: The chest X-ray (CXR) is the standard of practice to assess the tip of the endotracheal tube (ETT) in ventilated children. In many hospitals, it takes hours to get a bedside CXR, and it has radiation exposure. The objective of this study was to find the utility of bedside ultrasound (USG), in assessing the ETT tip position in a Pediatric Intensive Care Unit (PICU).

Methods: It was a prospective study conducted in the PICU of a tertiary care center involving 135 children aged from 1 month to 60 months, requiring endotracheal intubation. In this study, the authors compared the position of the ETT tip by the CXR (gold standard) and USG. The CXR was taken in children to assess the correct position of the tip of ETT. The USG was used to measure the distance between the tip of ETT and the arch of the aorta, thrice in the same patient. The mean of the three USG readings was compared with the distance between the tip of the ETT and carina in CXR.

Results: The reliability of three USG readings was tested by absolute agreement coefficient in intraclass correlation (ICC), 0.986 (95% CI: 0.981–0.989). The sensitivity and specificity of the USG in identifying the correct position of the ETT tip in children when compared to CXR were 98.10% (95% CI: 93.297–99.71%) and 50.0% (95% CI: 31.30–68.70%), respectively.

Conclusion: In ventilated children <60 months of age, identifying the tip of ETTs by bedside the USG has good sensitivity (98.10%) but poor specificity (50.0%).

Keywords: Bedside ultrasound, Children, Endotracheal tube tip position.

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Highlights

- In children <60 months of age, to assess the tip of the ETT, the USG has good sensitivity but poor specificity.
- Further studies are recommended before USG could be advised as a bedside tool in assessing the ETT tip position in children.

Introduction

Endotracheal intubation and mechanical ventilation are common procedures in PICUs all over the world. After intubation, it is very important to fix the ETT in the correct depth in the trachea, mid-way between vocal cords and carina, more precisely between the upper border of the first thoracic vertebra (T1) and lower border of the second thoracic vertebra (T2) (at the level of the medial end of clavicles). There are several formulae to calculate the depth of insertion in infants and older children, both oral and nasal routes.[1–6] Despite these formulae, malpositions of the ETT either close to vocal cords or close to the carina, or even in one of the bronchi are not uncommon.[7–12]

For assessing the proper depth of the ETT insertion, currently, the CXR is the gold standard.[1,10,13] Chest X-rays are done frequently in intensive care units (ICUs) only to confirm the position of the ETT tip, as the migration of the tip is a common problem. But in many hospitals, it takes a few hours to get a bedside CXR. In addition, it has the risk of radiation exposure. Portable USG is available in most ICUs at present, as USG-guided placement of central venous lines

[1]Department of Pediatric Intensive Care, Madras Medical College, Chennai, Tamil Nadu, India

[2,6]Department of Paediatrics, Jawaharlal Institute of Postgraduate Medical Education & Research, Puducherry, India

[3]Department of Radiodiagnosis, Jawaharlal Institute of Postgraduate Medical Education & Research, Puducherry, India

[4]Department of Pediatrics, Believers Church Medical College, Thiruvalla, Kerala, India

[5]Division of Pediatric Critical Care, Department of Pediatrics, Jawaharlal Institute of Postgraduate Medical Education & Research, Puducherry, India

[7]Director, Sri Venkateshwaraa Medical College Hospital & Research Centre, Ariyur, Puducherry, India

Corresponding Author: Narayanan Parameswaran, Department of Paediatrics, Jawaharlal Institute of Postgraduate Medical Education & Research, Puducherry, India, Phone: +91 9443458850, e-mail: drnarayananp@gmail.com

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is increasingly the standard of care. In addition, point-of-care USG is being used for lung USG, assessing preload status, myocardial function in shock, etc. Thus, intensive care physicians have adequate exposure to the use of point-of-care USG. It is noninvasive and has no radiation exposure. Hence, it makes sense to investigate the role of portable USG in assessing the ET tube position. Ultrasound was used to identify the tip of ETT as early as 1986 by Slovis et al.[14] However, this technique was not widely used. In this study, we assessed the ETT tip position by bedside USG and compared it with the CXR.

Methods

Study Population and Setting

This prospective observational cross-sectional study was carried out in a 19 bedded tertiary care PICU from October 2016 to June 2018. The unit is a mixed PICU receiving medical and surgical patients aged 1–144 months. The institute's ethical committee approved the study and informed written consent was obtained from parents/legally acceptable representatives.

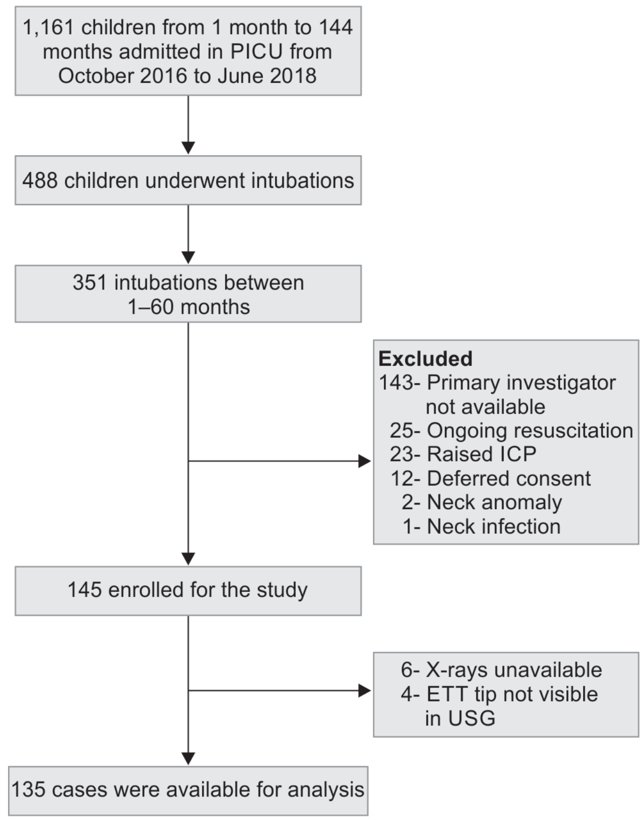
Consecutively, children aged 1–60 months who had undergone endotracheal intubation and were treated in PICU were eligible for the study. Children with hemodynamic compromise necessitating ongoing resuscitative measures, raised intracranial pressure, airway anomalies, right aortic arch, tumors, or any swellings in the neck that would distort the airway anatomy, extensive skin infections/sub-cutaneous emphysema in the anterior aspect of the neck were excluded. If the time interval between USG and CXR was >6 hours, we thought the chances of the migration of ETT were higher. Hence, if it was >6 hours or if it was <6 hours, but the ETT position was suspected to have migrated, before taking CXR or USG, patients were not enrolled.

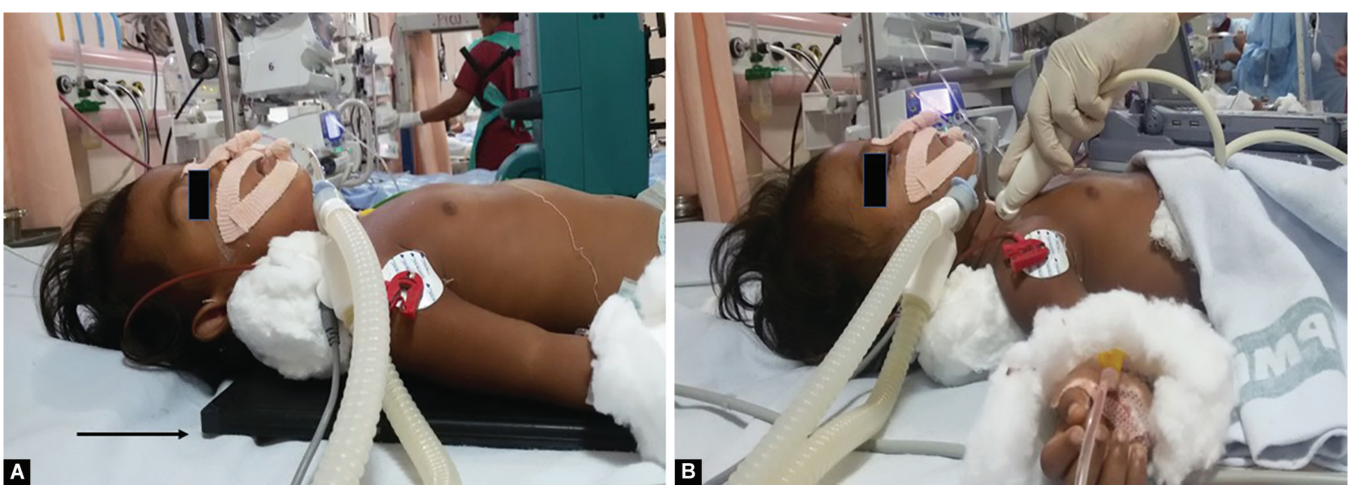
We used point-of-care USG with a micro convex 8 MHz probe [GE ultrasound, General Electric (GE) Health Care, Milwaukee, United States of America (USA)] for evaluating the ETT tip position. primary investigator (SS) was trained was trained by a faculty (RA) in the department of radiodiagnosis to visualize the ETT and aortic arch for 2 months before the start of the study. By that time, the primary investigator was adequately trained to assess the ETT tip position independently.

Study Method

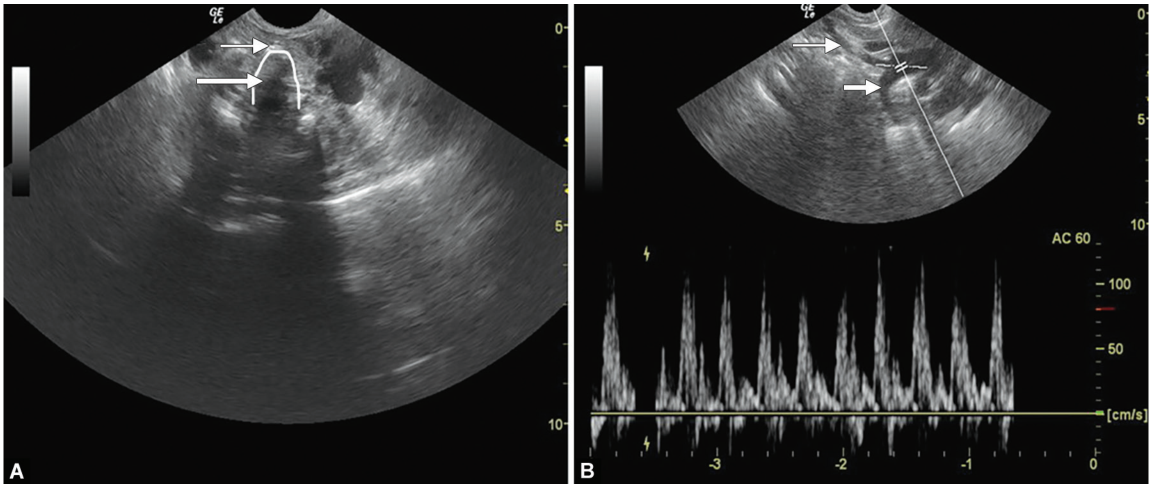
In our study, we used both cuffed and uncuffed ETT. Ultrasound was performed after intubation, in every new patient, with the mild extension of the neck as in the same position used for performing the X-ray (keeping the X-ray cassette would cause mild extension of the neck, Flowchart 1). The first step in the USG examination was to check laterality of the arch of the aorta. Children with the right-sided aortic arch were excluded, as the arch would be located in

Flowchart 1: Flow diagram showing screening, eligibility and available for analysis; ETT, endo tracheal tube; ICP, intra cranial pressure; USG, ultrasound





Figs 1A and B: (A) Showing the position of neck while taking CXR (Black line arrow showing the X-ray cassette; (B) Showing the position of neck while taking the USG. Note the probe is kept in the right supraclavicular area to visualize the ETT



Figs 2A and B: USG images of trachea and arch of aorta from the neck (A) USG showing bullet sign formed by ETT (line arrow at the apex) and posterior air column in trachea (solid arrow), showing that ETT is inside trachea. The trace of the air column looks like a bullet-"Bullet sign"; (B) USG showing arch of aorta (solid arrow) and left common carotid artery (line arrow). Note the pulsatile wave form of aortic arch in pulse wave doppler

a much higher position in these children and may not correspond to the level of the carina. The probe was kept in the suprasternal notch and the presence of the ETT inside the trachea was assessed (transverse view). The ETT would be seen as a round echogenic body with a dark shadow posteriorly, and it is known as the "bullet sign" (trachea, Fig. 1A). The bullet sign along with the absence of double rings (trachea and esophagus) confirmed the position of the ETT inside the trachea. Then, the probe was tilted inferiorly to look for the arch of the aorta (longitudinal view parallel to the trachea). The aortic arch was usually seen as hyperlucent vasculature showing arterial pulsations in pulse wave doppler (Fig. 1B).

The USG probe was kept in the right supraclavicular area to visualize the ETT in the longitudinal view. The ETT tip was visualized in the same plane of the aortic arch. A gentle to-and-fro (longitudinal) movement of 2–3 mm was done to visualize the ETT tip easier. The distance between the ETT tip and the superior border of the aortic arch was measured in millimeters (Fig. 2A). The measurements were repeated thrice in each patient to rule out any artifacts mimicking the ETT. The vital signs were recorded before and after the study procedure. Complications like hypoxia, change in heart rate, and increase in sedation requirement were anticipated and recorded, if any.

The results of the USG were interpreted by the primary investigator independent to that of a CXR. However, if the ETT tip was found in malposition in the USG, the decision to adjust it was not taken until the same was confirmed by the CXR. But, if the clinical situation warranted adjusting the tube, the tube was adjusted and the case was excluded.

All enrolled children in the study underwent digital CXR (anteroposterior view) as part of routine management. The distance between the ETT tip and the carina was measured in millimeters (Fig. 2B) through picture archiving and communication system images (software detail of X-ray). The CXRs were interpreted by co-investigator (RA), in a blinded manner, independent of the results of the USG. The ETT tip is considered in the correct position if it is within 5 mm (above or below) from the medial end of clavicles in infants from 1 to 12 months of age. For children from 13 to 60 months, the ETT tip is in the correct position if it is within 10 mm (above or below) from the medial end of the clavicle (Unit Protocol).

Sample Size Calculation

The sample size estimation was attempted using the statistical formula for estimating the sensitivity of a diagnostic test. The expected sensitivity of the USG for assessing the correct ET tube tip position compared to the CXR was taken as 90%.[1] Sample size was estimated at 5% absolute precision with a 95% confidence interval. To assess the specificity, patients with the migrated position in the CXR were treated as a true negative. It was expected from previous studies that only 5–10% of the cases would be with the migrated tube position.[15] Using the above data, the sample size was calculated as 126.

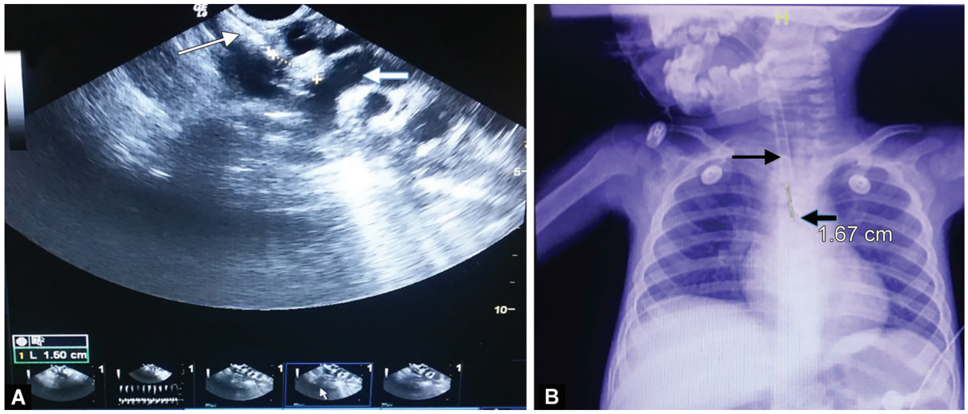
Statistical Analysis

Continuous data were presented as mean (standard deviation) or median (interquartile range) based on the distribution of data and the proportion as number (percentage). Test–retest reliability of the USG was measured by the average measurement, absolute agreement, two-way mixed-effects model ICC. The agreement between the X-ray and the USG was measured by consistency coefficient by ICC. Sensitivity and specificity of the USG were calculated based on whether the USG picks up the correct position of the ETT tip and the migrated position of the ETT tip compared to the CXR.[16–19] Similarly, positive and negative predictive values and accuracy were calculated. Samples with missing data will be excluded. Statistical Package for Social Sciences (SPSS) 20.0 software (SPSS Inc., Chicago, Illinois) was used for data analysis.

Results

Patient Characteristics

After the screening of 488 intubated patients, 145 were enrolled but 135 were available for analysis (Fig. 3). The baseline characteristics of analyzed patients were depicted in Table 1. Children with weight for age <–2 and –3 *Z*-score contributed to 65.9% and 51.11% of the study population, respectively. Similarly, the proportion of children with length/height for age <–2 and –3 *Z*-scores were 43.7% and 29.6%, respectively. The most common size of ETTs were 3.5 mm (32.6%) and 4 mm (34.1%) since our study population was predominantly infants (Table 2).



Figs 3A and B: USG image of ETT and corresponding CXR image; (A) USG image showing the distance between the tip of ETT and superior border arch of aorta. Line arrow shows the ETT and solid arrow shows the arch of aorta; (B) CXR showing the distance between the tip of ETT (line arrow) and carina (solid arrow)

Table 1: Baseline characteristics

Characteristics	*Study children (N = 135)*
Age (in months, median, IQR)	5 (3,13)
Weight (in kg, mean, SD)	6.3 (3.5)
Length (in cm, mean, SD)	67.2 (16.3)
PRISM III-12 (median, IQR)	14 (10,18)
Patient category (*n*, %)	
Medical	110 (81.5)
Surgical (cardiac)	12 (8.9)
Surgical (noncardiac)	7 (5.2)
Trauma/Burns	6 (4.4)

IQR, inter quartile range; PRISM, pediatric risk of mortality; SD, standard deviation

Table 2: ETT size used and their fixation lengths

S. No.	*ETT size (internal diameter in mm)*	*n (%)*	*Fixation length range (cm)*
1	2.5	1 (0.7)	8
2	3.0	22 (16.3)	8–11
3	3.5	44 (32.6)	8.5–15
4	4.0	46 (34.1)	9–15
5	4.5	19 (14.1)	10–15
6	5.0	2 (1.5)	15
7	5.5	1 (0.7)	16
	Total	**135 (100)**	–

Main Results

In our study, we were able to visualize the ETT tip during 97% of the examinations. The ETT tip was not present in the correct position in 30 (22.22%) children. The reliability of three USG readings in our study population (1–60 months of age), tested by absolute agreement coefficient in ICC, was 0.986 (95% CI: 0.981–0.989), and the Cronbach's alpha value was 0.986. The agreement between X-ray and USG, measured by consistency coefficient by the ICC, was 0.783 (95% CI: 0.694–0.846). The sensitivity of the USG in identifying the correct position of the ETT tip in children from 1 month to 60 months of age, when compared to CXR, was 98.10% (95% CI: 93.29–99.27%). The specificity was 50.0% (95% CI: 31.30–68.70%). Positive predictive value was 87.29% (95% CI: 82.75–90.77%), and negative predictive value was 88.24% (95% CI: 64/48–96.87%). The accuracy was 86.92% (95% CI: 79.89–92.19%).

Subgroup Analysis

Subgroup analysis was also done for infants (1–12 months and 13–60 months, separately). The reliability of the three USG readings in infants (1–12 months of age), tested by absolute agreement coefficient in ICC, was 0.981 (95% CI: 0.973–0.986), and the Cronbach's alpha value was 0.981. The agreement between the X-ray and the USG in 1–12 months, measured by consistency coefficient by the ICC, was 0.809 (95% CI: 0.714–0.873). The sensitivity and specificity of the USG in identifying correct position of the ETT tip in children from 1 month to 12 months of age, when compared to the CXR, were 97.50% (95% CI: 91.26–99.70%) and 52.63% (95% CI: 28.86–75.55%). Positive and negative predictive values were 89.66% (95% CI: 84.35–93.31%) and 83.33% (95% CI: 54.39–95.45%), respectively. The accuracy was 88.89% (95% CI: 80.89–94.32%).

The reliability of three USG readings in children from 13 to 60 months of age, tested by absolute agreement coefficient in the ICC, was 0.995 (95% CI: 0.991–0.997), and the Cronbach's alpha value was 0.995. The agreement between the X-ray and the USG in 13–60 months of age, measured by consistency coefficient by the ICC, was 0.712 (95% CI: 0.435–0.853). The sensitivity and specificity of the USG in identifying the correct position of the ETT tip in children from 13 to 60 months of age, when compared to the CXR were 100% (95% CI: 85.75–100%) and 45.45% (95% CI: 16.75–76.62%), respectively. Positive and negative predictive values were, respectively, 80% (95% CI: 69.99–87.28%) and 100%. The accuracy was 82.86% (95% CI: 66.35–93.44%).

The adverse effects during the USG were minimal. Coughing was the most common adverse effect found in 11.1% of the patients compared to 5.9% while taking the CXR (*p*-value: 0.13, not significant). Further, additional bolus doses of sedatives were required in 8.1% and 3.7% of the study population, respectively, during the USG study and the CXR (*p*-value: 0.12, not significant). There were no serious adverse events like accidental extubation or hemodynamic compromise observed during the USG or CXR study.

Discussion

Our study evaluated the utility of the USG in assessing the ETT tip in infants and small children. There are many methods reported in the literature to assess the position of the ETT tip by the USG.[15,20–23] In adults, neither it is easy to visualize the carina nor the ETT tip by the USG. Hence, the cuff of the ETT filled with saline, which serves as a contrast media during the USG, was used as an indirect measure to predict the correct position of the ETT tip. In these studies, either fibro-optic bronchoscopic visualization of the carina and the ETT tip or cuff–carina distance was used as reference standard to compare the USG measurements.[21]

In neonates, many authors were able to visualize the ETT tip in the USG. But the carina could not be seen in the USG as air column acts as a poor contrast medium. Hence, the anatomical equivalents of the carina namely, the right pulmonary artery[22,23] and the arch of the aorta[14,15,24] were harnessed as surrogates for the carinal position in the USG by various studies. These blood vessels could be visualized easily in the USG with both gray scale and color doppler and confirmed by the pulse wave doppler. The CXR was used in all previous studies as the gold standard to compare their findings in the USG.[15,22–24] To date, there are no studies in children (other than neonates) to harness the utility of the USG in assessing the tip of the ETT. In our study, we were able to visualize the ETT tip in the USG. Superior border of the arch of the aorta was taken as anatomical equivalent of the carina, and the distance between ETT tip and aortic arch was measured. This distance was compared with the ETT tip–carina distance in the CXR.

Najib et al.[22] and Dennington et al.[23] measured the ETT tip to the right pulmonary artery (anatomical equivalent of carina) in the USG. They compared the ETT tip to the right pulmonary artery distance in the USG with the ETT tip–carina distance in the CXR. They concluded that the USG and CXR have similar accuracy in assessing the ETT tip-to-carina in neonates requiring endotracheal intubation.

Dennington et al. measured the distance from the ETT tip to the carina in the CXR and the ETT tip to the right pulmonary artery in the USG in 30 neonates. The ETT was visualized by the USG in all newborns examined. They observed a good correlation ($r^2 = 0.68$) between the ETT tip-to-carina distance on the USG and CXR. There was no clinical deterioration during the examination, which was completed within 5 minutes. Similarly, we did not find any significant adverse effects except for coughing and increase in sedation requirement during the procedure but statistically not significant.

Sethi et al.[15] measured the distance between the ETT tip and superior border of the arch of the aorta in neonates and compared it with the ETT tip to the carina distance in the CXR.[15] They had visualized the ETT tip in 49 out of 53 neonates, where in four of them, the tube was too high to be seen in the thorax. They found that the ETT tip would be in the correct position if the ETT tip was between 0.5 and 1 cm from the superior border of the arch of the aorta. Our rates of visualizing the ETT tip (97%) was comparable to Sethi et al (92%). Our study is similar to that of Sethi et al. in using the arch of the aorta as landmark in the USG. Singh et al. conducted a similar study in neonates, taking the arch of the aorta as a reference point and measured the distance between the ETT tip and the arch of the aorta in the USG.[24] This distance was compared with the ETT tip to the carina distance in the CXR to check whether the ETT tip was optimally placed or not. Their approach was similar to our study. A review by Jaeel et al. found that the ETT tip was visible in more than 80% of the patients, and the USG findings correlated to the CXR in 73–100%.[25]

We measured the distance between the ETT tip and the superior border of the aortic arch thrice in the same patient. In 135 patients enrolled, the ICC absolute agreement co-efficient, to determine the reliability of three USG readings, was 0.986. We had a higher number of patients with the ETT tip in the incorrect position 30 (22.22%). This may be due to the higher proportion of malnourished children in our study population, and we used age-based formula for the selection of the ETT size and hence fixation length.

We made sure that both CXR and USG were done with the same neck position, as flexion or extension of the neck would cause the ETT tip to move downward and upward, respectively, thereby altering the measurements. In addition, in all children, we placed the probe in the suprasternal notch (transverse view) only to check whether the ETT was inside the trachea or not (bullet sign) and subsequently moved the probe to the supraclavicular area to measure the ETT tip–carina distance. The measurement of the ETT tip–carina distance by the USG from the suprasternal notch would require hyperextension of the neck in small infants, which can lead to the movement of the ETT tip away from the carina and errors of comparison of the CXR and USG readings. The measurement of the ETT tip–carina distance from supraclavicular area avoids hyperextension thereby preventing errors.

The sensitivity of the USG was good (98%), but the specificity was poor (50%). The sensitivity was comparable in subgroups [1–12 months (97.5%) and 13–60 months (100%)]. In addition, we observed that it was easier to visualize the ETT tip in the USG in infants when compared to more than 12 months of age. All four patients, in whom we were unable to visualize the tip of the ETT, were more than 12 months old. When the ETT tip was in the incorrect position (most of the time too above clavicular ends), we found technically challenging in identifying the ETT tip in the USG. That could be the reason for the poor specificity found in our study. We recommend further studies to explore the utility of the USG in assessing the ETT tip position. If found useful, with no additional cost and manpower, the USG could be a convenient way of assessing the ETT tip position within minutes at the bedside.

Strengths and Limitations

Our study has many strengths. Our study was one of the few studies to visualize the tip of the ETT in children in assessing the depth of insertion of the ETT by bedside USG. The sensitivity of the USG in our study was good (98%). Our sample size was comparatively larger (n = 135) when compared to previous studies. By taking three measurements in the same patient, it was possible to calculate the test–retest reliability of the USG, which was excellent. The agreement between the USG and CXR by the ICC was good (0.783).

There are a few limitations in our study. We could not assess the ETT tip position with the USG and CXR simultaneously due to logistic reasons (availability of X-ray technician). During the time interval between the USG and CXR, the ETT might have migrated in a few patients. Interobserver variability was not assessed as all measurements were made by the first author himself. In addition, we found that the specificity of the USG in assessing the correct position of the ETT tip was low.

It is also pertinent to point out that the CXR gives a lot of additional information when compared to the USG. Other than the identification of the ETT tip, information regarding lung fields, size and shape of the heart shadow, mediastinum, bones, liver, fundus of stomach, diaphragm, etc., can be gleaned from the CXR. In that sense, the overall information available from the CXR is more than that of the USG in most situations.

Conclusion

The study concludes that bedside USG has good sensitivity in assessing the tip of the ETT in children <60 months of age but poor specificity. Though promising, further studies are required to establish the exact role of the USG in assessing the position of the ETT in children.

Authors' Contributions

SS: Study concept, design, measurement of USG readings, NP: Study concept, design, and administrative support. RA: CXR readings, technical support, and training. MC and SM: Statistical analysis and technical support. SA and RR: Critical revision. MC, SM, SA, and RR: Study supervision.

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Orcid

Seenivasan Subramani https://orcid.org/0000-0002-3269-1702
Narayanan Parameswaran https://orcid.org/0000-0002-8297-5789
Ramesh Ananthakrishnan https://orcid.org/0000-0002-1404-6400
Shilpa Abraham https://orcid.org/0000-0001-7968-596X
Muthu Chidambaram https://orcid.org/0000-0002-4962-2463
Ramanchandran Rameshkumar https://orcid.org/0000-0002-1911-3473
Mahadevan Subramanian https://orcid.org/0000-0002-3052-6949

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