Paediatrica Indonesiana

p-ISSN 0030-9311; e-ISSN 2338-476X; Vol.65, No.5 (2025). p.431-7; DOI: https://doi.org/10.14238/pi65.5.2025.431-7

Original Article

Comparative diagnostic accuracy of ultrasound and chest radiography in endotracheal tube tip localization

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Abstract

Background Endotracheal intubation is a life-saving intervention, and accurate placement of the endotracheal tube (ETT) is crucial in pediatric patients due to anatomical variability. Ultrasound offers a practical and safe alternative to chest X-ray (CXR) for verifying ETT placement.

Objective To compare the diagnostic accuracy of ultrasound compared to CXR in localizing the ETT tip in pediatric patients.

Methods A cross-sectional study was conducted from January to April 2025 in the Pediatric Intensive Care Unit and Cardiac Intensive Care Unit at Dr. Cipto Mangunkusumo Hospital. The study included children aged 1 month to 18 years intubated with either cuffed or uncuffed ETTs. A CXR was performed immediately after intubation, followed by ultrasound within 24 hours. ETT position was assessed based on CXR findings and tracheal ring alignment on ultrasound.

Results A total of 89 patients were enrolled. Ultrasound demonstrated sensitivity of 88.6%, specificity of 73.7%, overall accuracy of 85.4%, positive predictive value (PPV) of 92.5%, and negative predictive value (NPV) of 63.6%. The area under the receiver operating characteristic curve (AUC) was 0.811. The positive likelihood ratio (LR+) was 3.37, and the negative likelihood ratio (LR–) was 0.16. Multivariate analysis identified ultrasound as a significant predictor of accurate ETT placement [odds ratio (OR) 7.75; 95%CI 1.29 to 4.74; P<0.001].

Conclusion Ultrasound is a feasible, reliable and accurate alternative to CXR for verifying ETT tip positioning in pediatric intensive care settings. **[Paediatr Indones. 2025;65:431-7; DOI: https://doi.org/10.14238/pi65.5.2025.431-7]**.

Keywords: *endotracheal tube localization; ultrasound; chest X-ray; diagnostic accuracy*

Endotracheal intubation remains a critical intervention in pediatric intensive care, routinely employed in emergency scenarios requiring rapid airway stabilization. The clinical success of intubation is contingent upon accurate placement of the endotracheal tube (ETT), as malposition can result in serious complications, including hypoventilation, unintentional endobronchial intubation, atelectasis, and barotrauma.[1] To mitigate these risks, confirming ETT placement promptly and precisely is essential. The current gold standard for verifying ETT tip location is chest radiography (CXR), with optimal placement typically visualized between the second and fourth thoracic vertebrae. Despite its diagnostic reliability, CXR presents several drawbacks, especially within the pediatric population, where the cumulative risks of radiation exposure, procedural delays, and potential ETT displacement during patient handling pose critical concerns.[1,2]

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Submitted June 13, 2025. Accepted November 14, 2025.

In response to these limitations, emerging evidence has positioned bedside ultrasound as a compelling, non-invasive alternative for confirming ETT positioning. Unlike CXR, ultrasound enables real-time, dynamic visualization of anatomical structures, is free of ionizing radiation, and allows repeated assessments without compromising patient safety. Techniques such as suprasternal notch imaging, tracheal ring assessment, and three-point ultrasonography have demonstrated noteworthy efficacy in localizing the ETT tip with a high degree of accuracy. Reported sensitivity in neonatal and pediatric cohorts ranges between 93% and 98%, with accuracy rates from 95% to 98%.[1-3]

Nonetheless, the specificity of ultrasound in identifying precise ETT placement varied among studies, a discrepancy largely attributed to differences in sonographic approach, anatomical diversity in younger patients, and operator experience. Depending on the imaging method being used - be it suprasternal, tracheal ring, or pleural sliding views - specificity figures have fluctuated broadly from 50% to 100%.[6-8] In particular, the three-point ultrasonography technique - an innovative protocol incorporating multiple anatomical landmarks - has been shown to achieve a diagnostic accuracy of up to 97.4%.[3] Likewise, suprasternal approaches have achieved accuracy rates as high as 98%, with near-perfect specificity in some studies.[4,5] A recent meta-analysis focusing on neonatal populations reported a pooled sensitivity of 93.4% (95%CI 90.4 to 95.75%) and a successful ETT identification rate of 96.8%.[1]

Beyond diagnostic accuracy, ultrasound offers pronounced advantages in terms of timeliness and procedural safety. Average scan duration typically ranges between 2 to 3 minutes - markedly shorter than the over 10-minute timeframe often required for CXR confirmation. This time efficiency is particularly advantageous in acute or hemodynamically unstable cases, where rapid decision-making is paramount. Moreover, ultrasound obviates radiation exposure - a key benefit in neonates and infants who are uniquely susceptible to the long-term effects of ionizing radiation. Its bedside application also reduces the risk of accidental tube dislodgment by eliminating the need for patient transport or repositioning.[1,9]

Despite these compelling advantages, ultrasound remains underutilized for ETT confirmation, particularly in scenarios involving uncuffed ETTs. These tubes are commonly employed in pediatric airway management due to concerns of potential mucosal injury from cuffed devices. Notably, much of the existing literature disproportionately emphasizes cuffed ETTs, thereby neglecting the specific challenges and clinical nuances associated with uncuffed tube placement. This evidentiary gap highlights the critical need for further investigations comparing the diagnostic performance of ultrasound and CXR across both cuffed and uncuffed ETT populations. Such research is essential for validating ultrasound's broader applicability and reinforcing its role as a frontline tool in ensuring safe, effective airway management within pediatric intensive care environments.[2,3,7]

To address the underrepresentation of uncuffed ETT cases in the current literature on ETT placement confirmation, this study compares the diagnostic performance of ultrasound and CXR for both cuffed and uncuffed ETT placements in pediatric intensive care, unlike prior studies that have often excluded uncuffed tubes or lacked robust analysis. In this study, we aimed to assess the diagnostic accuracy of ultrasound in verifying ETT tip position in pediatric patients, with CXR serving as the reference standard. Utilizing multivariate statistical modeling and clinical decision analysis, our investigation was designed to quantify the diagnostic accuracy and reproducibility of ultrasound confirmation under routine clinical conditions. Particular attention was given to ensuring methodological rigor and minimizing operator-dependent variability, thereby enhancing the generalizability of findings across diverse healthcare environments.[1,4,6]

Methods

A cross-sectional study was conducted in the Pediatric Intensive Care Unit (PICU) and Cardiac Intensive Care Unit (CICU) of Dr. Cipto Mangunkusumo Hospital, Jakarta, from January to April 2025. Participants included children aged 1 month to 18 years, all of whom were intubated with either cuffed or uncuffed ETTs and received mechanical ventilation. Following intubation, CXR was immediately performed to confirm the ETT position. Ultrasound examination was conducted as early as possible and no later than

24 hours following endotracheal intubation, to ensure the accurate verification of ETT tip position.

The objective of confirmation imaging was to verify that the ETT was properly positioned within the trachea, with the tip located between the second and fourth thoracic vertebrae (Th2-Th4), as confirmed by CXR. A tip above Th2 was classified as too shallow, while a tip deeper than Th4 was considered too deep. Ultrasound was employed to assess the ETT position by visualizing the tracheal rings. Proper ETT placement was defined as the tip being located between the fifth and sixth tracheal rings. This approach enabled a direct comparison between ultrasound and CXR in confirming ETT positioning.

We included all intubated patients in the PICU and CICU who underwent both an immediate CXR and a laryngeal ultrasound within 24 hours after intubation. Patients who had undergone prior repositioning or malposition of the ETT, required neck immobilization, died before completing the examination, or had self-extubated were excluded. The study was approved by the Ethics Committee of Universitas Indonesia/Dr. Cipto Mangunkusumo Hospital.

We recorded the demographic and clinical characteristics of subjects such as age, sex, nutritional status, indication for intubation, comorbidities, length of PICU stay, duration of mechanical ventilation. The primary outcome was to assess the position of the ETT tip relative to the tracheal rings using ultrasound, while the secondary outcome focused on the diagnostic accuracy of both ultrasound and CXR. Diagnostic performance metrics, including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), likelihood ratios (LR), receiver operating characteristics (ROC) curve analysis to determine area under the curve (AUC), and Youden index, were calculated to evaluate the diagnostic performance of ultrasound with CXR as the reference standard.

Ultrasound examination was performed with the patient in a supine position following intubation. A linear or hockey-stick transducer (5-10 MHz) was used, with the transducer positioned on the anterior neck, perpendicular to the skin at the level of the sternal notch. The transducer was adjusted until the ETT tip was located, and the position of the tracheal rings at the tip was assessed. Confirmation of the ultrasound findings was conducted by a second evaluator to ensure accuracy. The ETT position identified by ultrasound was cross-validated with the CXR results, which were reviewed by a radiologist. Agreement between ultrasound results from the first and second evaluator were then tested for its interrater reliability by computing Cohen's kappa.

Data analysis was performed using *Python-based software*, with multivariate logistic regression and nomogram models to examine the relationship between various factors and ultrasound diagnostic performance. A minimum required sample size of 89 patients was determined based on preliminary calculations, ensuring a robust analysis of diagnostic accuracy across the study population.

K-fold cross-validation was implemented to enhance result robustness, partitioning the dataset into multiple subsets for repeated training and testing, minimizing reliance on any single fold and ensuring a generalized evaluation of ultrasound's diagnostic performance. Bootstrapping was applied to generate resampled datasets, enabling the estimation of confidence intervals and evaluation of variability in key diagnostic metrics. Nested cross-validation was utilized for hyperparameter optimization within each fold, refining the ultrasound model's performance while preventing overfitting. Feature importance analysis assessed the contribution of factors, such as patient demographics, to the accuracy of ultrasound against CXR, ensuring a comprehensive, unbiased evaluation of ultrasound as a diagnostic tool in pediatric intensive care.

Results

Of 108 mechanically-ventilated pediatric patients, 89 met the inclusion criteria. The remaining 19 patients were excluded for various reasons: 3 patients died before completing the examination, 6 self-extubated during the sampling period, and 10 underwent ETT repositioning after CXR but before ultrasound examination. The study flowchart is shown in **Figure 1**. Of the 89 subjects, 77 were confirmed to have correct ETT tip positions by CXR.

The demographic and clinical characteristics of subjects are detailed in **Table 1**. The majority of patients were aged between 1 and 5 years (95.5%), with smaller proportions being under 1 year (1.1%) or older than 5 years (3.4%). Sex distribution was nearly balanced, with 50.6% male and 49.4% female participants. Nutritional status was predominantly normal (55.1%), followed by undernourished (18%) and poor (12.4%). The median ETT size was 5 mm, reflecting the specific need of the pediatric population. Respiratory failure was the most common indication

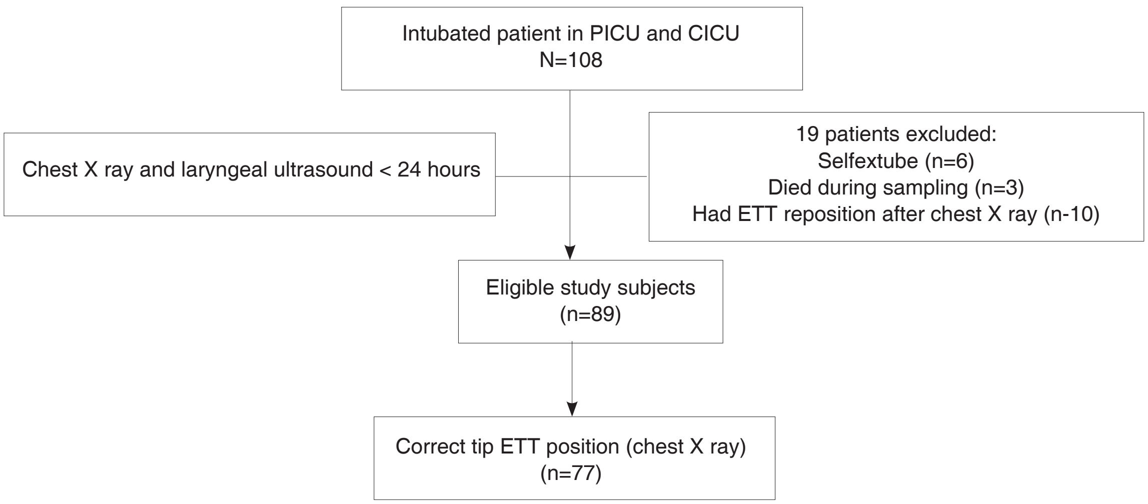

Figure 1. Study flow chart

Table 1. Characteristics of subjects

Characteristics	(N=89)	95%CI
Age, n(%)		
< 1 year	17 (19.1)	11.5 to 28.8
1-5 years	33 (37.1)	27.1 to 48.0
> 5 years	39 (43.8)	33.3 to 54.7
Gender, n(%)		
Male	45 (50.6)	39.8 to 61.3
Female	44 (49.4)	38.7 to 60.2
Nutritional status, n(%)		
Poor	13 (14.6)	8.0 to 23.7
Undernourished	41 (46.1)	35.4 to 57.0
Normal	26 (29.2)	20.1 to 39.8
Overweight	9 (10.1)	4.7 to 18.3
Median ETT size, mm	5	-
Indication for intubation, n(%)		
Respiratory failure	19 (21.3)	13.4 to 31.3
Circulatory failure	5 (5.6)	1.8 to 12.6
Metabolic disorder	10 (11.2)	5.5 to 19.7
Neurological disorder	4 (4.5)	1.2 to 11.1
Post-operative	49 (55.1)	44.1 to 65.6
Other	2 (2.2)	0.3 to 7.9
Type of ETT, n(%)		
Uncuffed	26 (29.2)	20.1 to 39.8
Cuffed	63 (70.8)	60.2 to 79.9
Outcomes within 48 hrs, n(%)		
Transferred to another ward	42 (47.2)	36.5 to 58.1
Remained in PICU/CICU	44 (49.4)	38.7 to 60.2
Deceased	3 (3.4)	0.7 to 9.5

for intubation (55.1%), followed by post-operative recovery (25.8%) and circulatory failure (7.9%). A majority of patients (64%) were intubated with uncuffed tubes, while 36% received cuffed tubes. Within 48 hours post-intubation, 43.8% of patients were transferred to another ward, 40.4% remained in the PICU/CICU, and 9% died.

The diagnostic performance of ultrasound in confirming ETT tip position, as reflected by the ROC curve, is presented in **Figure 2**. The ROC curve demonstrates an AUC of 0.82, reflecting good diagnostic discrimination between true positive and false positive results. The sensitivity of ultrasound was 80.5%, with a specificity of 83.3%. These sensitivity and specificity values yielded a positive likelihood ratio (LR+) of 4.83 and a negative likelihood ratio (LR-) or 0.234. The overall accuracy, combining both sensitivity and specificity, was 80.9%, highlighting a high rate of correct diagnoses. The PPV and NPV were 96.9% and 40%, respectively. Youden Index was 0.639.

Final logistic regression analysis to confirm the diagnostic value of ultrasound in verifying ETT tip placement showed an overall accuracy of 84.3% and a Brier score of 0.12, indicative of well-calibrated predictive performance. The ultrasound variable was identified as a statistically significant predictor of correct ETT positioning on CXR (coefficient=1.57; P=0.031), reflecting a strong positive association. Calibration was found to be optimal, as evidenced by a Hosmer-Lemeshow P value of 1.0, with calibration slope and intercept values further confirming model fit. External validation through bootstrapping (AUC=0.821) and cross-validation (AUC=0.816) yielded consistent discrimination metrics, supporting the generalizability and stability of the model. Assessment of the agreement between the first and second ultrasound evaluator resulted in a Cohen's kappa of 0.818 (95% CI 0.651 to 0.949), indicating good interrater reliability. These findings reinforce the reliability, clinical relevance, and statistical robustness of ultrasound as a real-time diagnostic tool.

Discussion

This study analyzed a cohort of 89 mechanically ventilated pediatric patients, representing a clinically relevant sample of critically ill children within the intensive care setting. Exclusion criteria, including death before both the index and reference tests were

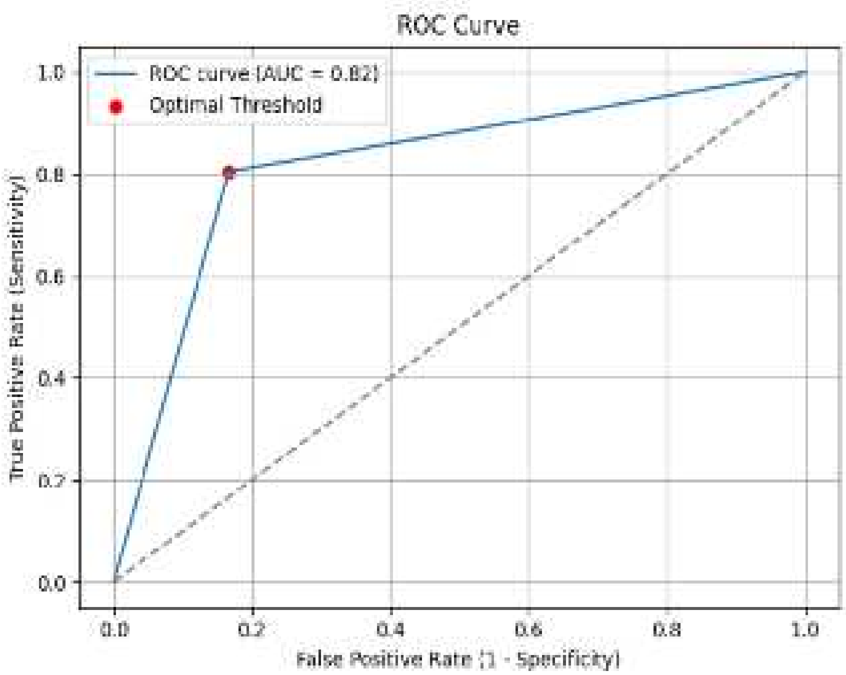

Figure 2. ROC curve

done, self-extubation, and ETT repositioning, were applied to ensure the validity and generalizability of findings.[2,9] The demographic profile, predominantly children aged 1 to 5 years (95.5%), with a balanced sex distribution and a median ETT size of 5 mm, aligns with established pediatric airway literature.[6,7] Furthermore, the predominance of uncuffed ETTs (64%) reflects contemporary clinical practice, particularly in neonates and infants, where concerns over mucosal injury from cuffed ETTs persist.[12]

The diagnostic performance of ultrasound in confirming ETT tip placement demonstrated a sensitivity of 80.5% and specificity of 83.3%, resulting in an overall accuracy of 80.9%, compared to CXR as the gold standard. These values are consistent with prior studies reporting ultrasound sensitivity ranging between 71% and 98%, and specificity spanning 50% to 100%, depending on the technique and patient characteristics.[1,2,6,10] For instance, a study documented sensitivities from 92 to 98% with near-perfect specificity using suprasternal notch and tracheal ring visualization, similar to our findings.[9] Similarly, a meta-analysis revealing a pooled sensitivity of 93.4% (95% CI 90.4 to 95.8%) and a successful ETT identification rate of 96.8%, further validating the diagnostic capability of ultrasound.[1]

Our PPV of 96.9% and Cohen's kappa of 0.818 was in line with results from a previoius study reported a PPV of 100% and a kappa of 0.822, confirming the reliability of positive ultrasound findings.[10] However, our NPV was relatively low (40%), indicating that a negative ultrasound result should be interpreted with caution, especially in ambiguous cases. Similar limitations were noted by two previous studies, reinforcing the need for selective confirmatory imaging.[9,13] This diagnostic gap was further highlighted by the study's moderate Youden Index (0.639) and likelihood ratios (LR+ = 4.83; LR− = 0.234), suggesting that ultrasound is a strong confirmatory tool, but a modest exclusionary one.[9,10,13]

Logistic regression analysis confirmed the significance of ultrasound as a predictor of accurate ETT placement (coefficient=1.57; P=0.031). The model demonstrated robust performance with an overall accuracy of 84.3%, a low Brier score (0.12), and a perfect Hosmer-Lemeshow test result (P=1.0), indicating excellent model calibration. Bootstrapping and cross-validation procedures produced consistent AUCs of 0.821 and 0.816, respectively, underscoring the model's reproducibility and reliability across diverse pediatric ICU populations.[1,6]

In terms of operational efficiency, ultrasound exhibited notable advantages. A study reported average examination times of 3.2 minutes for both term and preterm infants,[9] substantially shorter than the average 12.6-minute delay associated with CXR confirmation.[13] On the other hand, a study demonstrated that trained nursing staff can reliably perform USG exams, highlighting its potential for scalable, bedside implementation in intensive care settings.[13]

Nevertheless, limitations inherent to USG must be acknowledged. The relatively low NPV and operator dependence underscore challenges in consistently visualizing anatomical landmarks, particularly in patients with neck edema or anatomical variations.[13,14] The importance of anatomical landmarks and weight-based depth formulas has been emphasized to enhance imaging reliability and interpretative accuracy.[12] Therefore, USG should be integrated as a complementary modality alongside clinical assessment and selective CXR confirmation, rather than serving as a wholesale replacement, to optimize patient safety and diagnostic accuracy.[11,12]

In conclusion, USG demonstrates high diagnostic accuracy and clinical reliability in the assessment of ETT tip placement, with performance metrics comparable to CXR. Its advantages - including rapid bedside application, absence of radiation exposure, and minimal risk of tube displacement - support its use as a complementary tool to CXR for airway verification in pediatric critical care settings.

Conflict of interest

None declared.

Acknowledgements

This work was supported by the staff of Pediatric Emergency and Critical Care Division, Child Health Department, Faculty of Medicine Indonesia University/Cipto Mangunkusumo Hospital. We would especially like to than the Pediatric Emergency and Intensive Care Medicine and Integrated Cardiac Services teams of Cipto Mangunkusumo Hospital for their assistance in data collection.

Funding acknowledgment

The authors received no specific grants from any funding agency in the public, commercial, or not-for-profit sectors.

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