ORIGINAL RESEARCH PAPER

Prediction of post-extubation stridor using ultrasound measurement of subglottic airway diameter

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ABSTRACT

Background: Post-extubation stridor (PES) is a common complication in children in the pediatric intensive care unit (PICU). Despite the evaluation of various predictive tests, no single method has consistently demonstrated strong predictive value for PES. We evaluated the diagnostic utility of subglottic diameter ultrasonography for predicting PES within 48-h post-extubation in children.

Material and methods: The prospective observational study in university-affiliated PICU was done in children aged 1 month to 15 years who successfully passed a spontaneous breathing trial (SBT) and were scheduled for extubation were enrolled between January 2024 and January 2025. During SBT and cuff deflation, subglottic ultrasonography was performed at a peak inspiratory pressure (PIP) of 15 cmH_2O, and the subglottic ratio (SR) and intracricoid peritubular free space (IPFS) were calculated. Leak percentage was calculated as the ratio of the difference between inspiratory and expiratory volumes over inspiratory volume at each PIP level.

Results: PES occurred in 33 of 176 (18.75%) patients. In children aged ≥1 year, SR was significantly associated with PES (adjusted OR, 3.78; 95% CI: 1.28–12.21). An SR <1.30 showed 70% sensitivity, 65% specificity, and 66% accuracy. IPFS <2.08 mm demonstrated 80% sensitivity, 65% specificity, and 68% accuracy. A leak percentage <36.77% at 25 cmH_2O yielded 80% sensitivity, 47% specificity, and 53% accuracy. AUC values for SR, IPFS, and leak percentage were 0.664, 0.691, and 0.648, respectively.

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Conclusion: Among the evaluated parameters, IPFS showed the highest diagnostic performance for predicting PES, slightly outperforming the subglottic ratio in patients aged ≥1 year.

Key words: pediatric, post-extubation stridor, ultrasonography, subglottic ratio, intracricoid peritubal free space, leak percentage

Introduction

Ventilator liberation and extubation constitute the most challenging aspects of care in the pediatric intensive care unit (PICU). The extubation process can be complicated by post-extubation airway obstruction, often resulting from laryngeal or subglottic edema, which clinically presents as post-extubation stridor (PES) (1) Approximately 8.5–51% of pediatric patients may experience stridor following extubation (2). According to the American Thoracic Society 2017 guidelines, the cuff leak test (CLT) is a commonly used method to predict PES in adults; however, its utility in pediatric populations remains controversial (3, 4). In the literature, CLT has been performed in two ways. The leak percentage indicates that expiratory tidal volumes are significantly reduced compared to inspiratory tidal volumes (leak percentage 10–20% or leak volume range 110–140 mL in adults) (5). The second assessment was based on the presence of an audible leak during expiration, after cuff deflation. In adults, the leak percentage showed a moderate to high predictive value, with reported sensitivities of 67% and specificities of 86–99%. However, pediatric studies have demonstrated a much lower diagnostic performance, with sensitivities ranging from 27% to 55% and specificities between 35% and 81% (3, 6). Consequently, there are no reliable tools for predicting PES in pediatric patients. Moreover, in some studies, the leak percentage did not reliably correlate with extubation outcomes in children. Ultrasonography is increasingly used in ICUs due to its simplicity and lack of radiation exposure. Many studies have demonstrated the efficacy of laryngeal and subglottic diameter ultrasonography in predicting PES in adults (7); however, few studies have been conducted in children (1, 2). The objectives of this study were to evaluate the diagnostic accuracy of subglottic diameter ultrasonography in predicting PES and to compare the diagnostic accuracy of the subglottic ratio (SR), intracricoid peritubal free space (IPFS), and leak percentage.

Material and Methods

Study design and population

This prospective observational study was conducted in the eight-bed PICU of Songklanagarind Hospital, a university-affiliated teaching hospital in Thailand. This study was approved by the Human Research Ethics Unit, Faculty of Medicine, Prince of Songkla University (REC.66-470-1-1), during the study period from January 12, 2024, to January 31, 2025. The study was registered with the Thai Clinical Trials Registry under the identification number TCTR20250516001. Eligible participants included endotracheally intubated and mechanically ventilated children aged 1 month to 15 years who successfully completed a spontaneous breathing trial according to the institutional protocol and were scheduled for extubation within 2 h. The attending physician in the PICU made decisions regarding extubation. The exclusion criteria were preexisting laryngeal or tracheal pathologies, or the presence of equipment or skin lesions over the anterior neck that contraindicated the application of an ultrasound probe. Informed consent was obtained from legal guardians, and assent was obtained from patients aged ≥8 years upon enrollment. Diagnostic procedures were performed 2 h prior to

extubation. Intraoral suctioning was performed in all patients. In patients with cuffed endotracheal tubes (ETTs), the cuff was deflated prior to the procedure whereas patients intubated with uncuffed ETTs underwent this procedure without additional preparation.

Diagnostic tests

Ultrasonographic measurement of subglottic diameter

Patients were maintained on spontaneous-mode ventilation with a peak inspiratory pressure (PIP) of 15 cmH_2O and PEEP of 5–6 cmH_2O, and positioned with the neck in neutral alignment. Subglottic diameter measurements were obtained using high-resolution B-mode ultrasonography with a linear probe (40 mm footprint, frequency range 7–15 MHz) and a thyroid imaging preset. Imaging was performed immediately below the cricoid cartilage by a well-trained pediatric pulmonology fellow. The cricoid cartilage, the anatomical landmark for airway ultrasound, was visualized as a hypoechoic, semicircular, and curvilinear structure. The fellow collected three sonographies of the subglottic airway per patient. These images were independently reviewed by two investigators—a pediatric intensivist and a pediatric radiologist—who were blinded to the patient outcomes. The subglottic diameter is defined as the transverse distance between the inner margins of the cricoid cartilage (8). US was performed as previously described (Figure 1) (2). Interobserver reliability for subglottic diameter measurement was high, with an intraclass correlation coefficient (ICC) of 0.92 (95% CI: 0.86–0.95). SR was calculated by dividing the measured subglottic diameter by the outer diameter of the endotracheal tube (as specified by the manufacturer). The IPFS was calculated as the difference between the subglottic and outer diameters of the endotracheal tube. Increased SR and IPFS indicated a narrow airway diameter.

Leak test and leak percentage

After recording the airway ultrasound image, a leak test was immediately performed. At a PIP of 15 cmH_2O, the pulmonologist recorded inspiratory and expiratory tidal volumes for 6–10 breaths. The test was terminated upon the identification of a positive leak, which was defined as a reduction in expiratory tidal volume that exceeded 20% of the inspiratory volume, or the presence of an audible leak sound. If the test result was negative, the PIP was sequentially adjusted to 20, 25, or 30 cmH_2O. For a positive result, the PIP at which the leak was first identified was recorded.

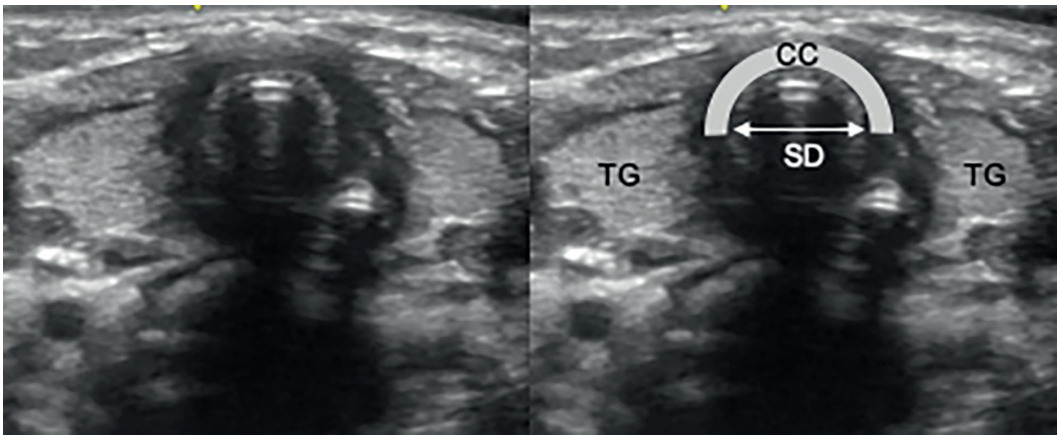

Figure 1. Ultrasound image of the cricoid cartilage: a hypoechoic, semicircular structure with the posterior surface defined by a hyperechoic tissue–air interface. The transverse distance between the hyperechoic inner margins of the cricoid cartilage represents the subglottic diameter, which was calculated by dividing the subglottic diameter by the outer diameter of the endotracheal tube. The intracricoid peritubal free space is denoted by the difference between the subglottic diameter and the outer diameter of the endotracheal tube. TG: thyroid gland.

Outcome measurement

Post-extubation care was provided by a PICU physician according to the patient's respiratory condition. Using the Downes croup score (9), clinical PES was assessed by bedside nurses at 0, 6, 24, and 48 h post-extubation, as per standard nursing protocols. The type of respiratory support used was documented immediately after extubation and again at 6 h and 48 h. PES, other extubation outcomes, and overall PICU outcomes were evaluated and recorded. Data were collected from the hospital information system, including baseline characteristics (age, sex, underlying diseases, hemodynamic status, and steroid use before extubation) and intubation-related details (indication, type and size/outer diameter of endotracheal tube, number of intubation attempts, intubation performer, and duration of intubation).

Statistical analysis

The sample size was calculated based on an expected area under the ROC curve (AUC) of 0.80 (1) for subglottic ultrasonography and a reported PES incidence of 33.8% (10). With 90% power and a significance level (α) of 0.05, the estimated sample size was 137. To account for potential dropouts, the final sample size was increased to 176. Data from the record forms were digitized using the Kobo Toolbox and analyzed using R Studio (version 4.4.1). Descriptive statistics included frequencies and percentages for categorical variables and mean ± standard deviation (SD) or median with interquartile range (IQR) for continuous variables, depending on normality. Between-group comparisons were undertaken using the chi-square test for categorical variables and the Student's *t*-test or Mann–Whitney *U* test for continuous variables, as appropriate. Risk factors for PES were identified using multivariate logistic regression, incorporating variables that were significant in the univariate analysis. The diagnostic performances of the subglottic diameter ratio, IPFS, and leak percentage were assessed using ROC curves. The threshold of statistical significance was set at $p < 0.05$. significant. The optimal cutoff value for each test was determined using the Youden Index.

Results

A total of 184 patients who successfully completed the institutional weaning protocol and underwent extubation were included. We excluded eight patients: one owing to the lack of guardian consent, two owing to preexisting laryngeal lesions, and five who were already included in the study but underwent subsequent extubation during the study period. A total of 176 patients were included in the final analysis (Figure S1). The incidence of PES was 18.75% (33 of 176 patients). There were no significant between group differences in the patient characteristics between the PES and non-PES groups, except for body weight. Patients who developed PES had a significantly lower median body weight of 8.8 (IQR: 4.5–13.7) kg compared to those without PES ($p = 0.04$, Table 1). Although patients with PES had a longer duration of intubation (median 53.0 h [IQR: 23.1–98.3]) compared to those without PES [27.2 h [IQR: 11.9–106.8]), the difference was not statistically significant. There were no statistically significant differences in SR and IPFS between patients with and without PES in the overall population. However, the leak percentages at PIP 25 and 30 cmH_2O were significantly lower in the PES group ($p = 0.03$, Table 2). In the subgroup of patients aged <1 year, the SR was significantly higher ($p = 0.03$) in the PES group (1.36 ± 0.13) as compared to the non-PES group (1.24 ± 0.11). Among patients aged ≥1 year, the SR, IPFS, and leak percentage at PIP 25 cmH_2O were significantly lower in the PES group compared to those without PES ($p = 0.02$, 0.01, and 0.04, respectively; Table 2). Multivariate regression analysis in patients aged ≥1 year identified subglottic diameter ratio as the only significant independent factor associated with PES, with an adjusted odds ratio of 3.78 (95% CI: 1.28–12.1; $p = 0.02$; Table 3). ROC curves and Youden's Index were used to evaluate diagnostic performance and identify the optimal cutoff points for each test (Table S1), and specifically for children aged ≥1 year (Table 4). The AUCs for SR, IPFS, and leak percentage at 25 cmH_2O were 0.664, 0.691, and 0.648, respectively (Figure 2).

Table 1. Characteristics of the study population.

Variables	No PES (N=143)	PES (N=33)	*P*-value
A. Patient characteristics			
Age, n (%)			0.36
<1 year	45 (31.5)	13 (39.4)	
≥1 years	98 (68.6)	20 (60.6)	
Female (%)	69 (48.3)	10 (30.3)	0.09
BW (kg) [median (IQR)]	***13.8 (6–24.9)***	***8.8 (4.5–13.7)***	***0.04***
U/D (%)	112 (78.3)	28 (84.8)	0.55
Respiratory disease	6 (4.2)	1 (3.0)	
Cardiovascular disease	53 (37.1)	16 (48.5)	
Neurological disease	23 (16.1)	2 (6.0)	
Others	30 (20.)	9 (27.3)	
Admission PRISM score [median(IQR)]	5 (0.2,9)	3 (2,5)	0.28
Steroid administration before extubation, n (%)	67 (46.9)	14 (42.4)	0.79
B. Intubation process			
Indication for intubation (%)			0.72
Respiratory failure	38 (26.6)	8 (24.2)	
Cardiac support	11 (7.7)	3 (9.1)	
Airway protection	10 (7)	4 (12.1)	
Postoperative/procedure	84 (58.7)	18 (54.5)	
Cuffed endotracheal tube (%)	117 (81.8)	28 (84.8)	0.87
Emergency intubation (%)	59 (41.3)	15 (45.5)	0.86
Intubator (%)			0.77
Resident	28 (19.6)	6 (18.2)	
Fellow/staff	4 (2.8)	2 (6.1)	
Anesthesiologist	83 (58)	18 (54.5)	
Unknown	28 (19.6)	7 (21.2)	
Intubation attempt [median (IQR)]	1 (1,1)	1 (1,1.75)	0.06
Intubation duration >48 h, n (%)	57 (39.9)	17 (51.5)	0.30

Abbreviations: IQR = interquartile range; PRISM = The Pediatric Risk of Mortality.

Discussion

Ultrasound assessment of the airway diameter is an emerging tool that complements traditional methods. All tests showed moderate diagnostic accuracy. The optimal cutoff for IPFS differed from that reported in previous studies (2, 7, 11) likely due to variations in patient age, intubation duration, and ETT type. In this study, the SR was also evaluated, offering a practical approach applicable across various age groups and ETT sizes. However, SR did not outperform IPFS, and the two measures were correlated. In children aged <1 year, the SR and IPFS were higher in the PES group, which was unexpected. Several postulates have been proposed for this purpose. Poor ossification of the cricoid cartilage complicates subglottic

Table 2. Diagnosis test results comparing patients with and without post-extubation stridor.

Variables	**No PES**	**PES**	
Total population	**N=143**	**N=33**	***P*-value**
Subglottic ratio	1.32 (1.23–1.42)	1.3 (1.18–1.4)	0.34
Intracricoid peritubal free space (mm)	2.02 (1.27–2.9)	1.8 (1.14–2.02)	0.05
Leak percentage (%)			
Pressure 15	26.59 (10.06–48.38)	21.98 (5.99–33.7)	0.10
Pressure 20	30.21 (12.21–48.75)	26.32 (5.71–35.71)	0.07
Pressure 25	*32.31 (18.89–49.89)*	*26.32 (8.45–35.71)*	*0.03*
Pressure 30	*33.46 (21.31–51.02)*	*27.78 (9.41–35.71)*	*0.03*
Age <1 year	**N=45**	**N=13**	
*Subglottic ratio**	*1.28 (0.11)*	*1.36 (0.13)*	*0.03*
Intracricoid peritubal free space (mm)*	1.41 (0.59)	1.71 (0.69)	0.13
Leak percentage (%)			
Pressure 15	17.02 (9.09–35.94)	11.96 (3.92–33.7)	0.57
Pressure 20	24.00 (8.57–39.2)	17.43 (7.14–33.7)	0.10
Pressure 25	25.00 (7.14–42.47)	23.53 (5.77–33.7)	0.50
Pressure 30	25.6 (12.5–42.47)	23.53 (7.41–33.7)	0.37
Age ≥1 year	**N=98**	**N=20**	
Subglottic ratio	*1.35 (1.25–1.46)*	*1.25 (1.17–1.33)*	*0.02*
Intracricoid peritubal free space (mm)	*2.46 (1.87–3.18)*	*1.6 (1.07–2.03)*	*0.01*
Leak percentage (%)			
Pressure 15	31.50 (11.76–56.83)	22.84 (8.37–33.33)	0.11
Pressure 20	33.33 (18.85–57.5)	29.10 (5.17–35.92)	0.07
Pressure 25	*33.61 (21.26–57.5)*	*29.10 (11.33–35.92)*	*0.04*
Pressure 30	34.65 (23.5–58.42)	30.43 (17.54–35.92)	0.05

All data are reported as percentage in median ± IQR. *Abbreviation:* IQR = interquartile range.

Table 3. Multivariate analysis variables associated with post-extubation stridor in patients aged ≥1 year.

Variables	**Crude OR (95% CI)**	**Adjusted OR (95% CI)**	***P*-value**
Subglottic ratio ≤1.3	**4.67 (1.7–14.25)**	**3.78 (1.28–12.21)**	**0.02**
Leak percentage ≤36.77%	3.75 (0.88–14.68)	2.10 (0.41–9.81)	0.36
Body weight (kg)	0.96 (0.91–1.00)	0.96 (0.91–1.01)	0.12
Intubation duration >48 h	1.53 (0.57–4.06)	2.17 (0.59–8.72)	0.25
No steroid given before extubation	1.22 (0.46–3.29)	1.53 (0.45–5.59)	0.50
Cuffed ETT	0.49 (0.10–3.64)	0.91 (0.13–10.00)	0.93
Indication for intubation			0.96
Cardiac support	1.44 (0.18–8.97)	1.54 (0.14–12.77)	
Airway protection	1.15 (0.14–6.96)	1.54 (0.15–13.52)	
Postoperative/procedure	1.25 (0.39–4.85)	1.59 (0.13–17.41)	
Emergency intubation	0.91 (0.33–2.4)	0.84 (0.09–7.18)	0.88

Abbreviations: OR = odd ratio; ETT= endotracheal tube.

Table 4. Diagnostic performance of tests for post-extubation stridor in those aged ≥1 year.

Cutoff	Subglottic ratio	Intracricoid peritubal free space (mm)	Leak percentage at PIP 25 cmH_2O
	1.30	2.08	36.77%
Sensitivity	0.70	0.80	0.80
Specificity	0.65	0.65	0.47
Positive Likelihood Ratio (LR+)	2.02	2.31	1.52
Negative Likelihood Ratio (LR–)	0.46	0.31	0.42
Accuracy	0.66	0.68	0.53
AUROC	0.664	0.691	0.648

Abbreviations: AUC = Area under the ROC curve; IPFS = Intracricoid peritubal free space; PES = Post-extubation stridor; LR+ = Positive likelihood ratio; LR– = Negative likelihood ratio; PIP = Peak inspiratory pressure.

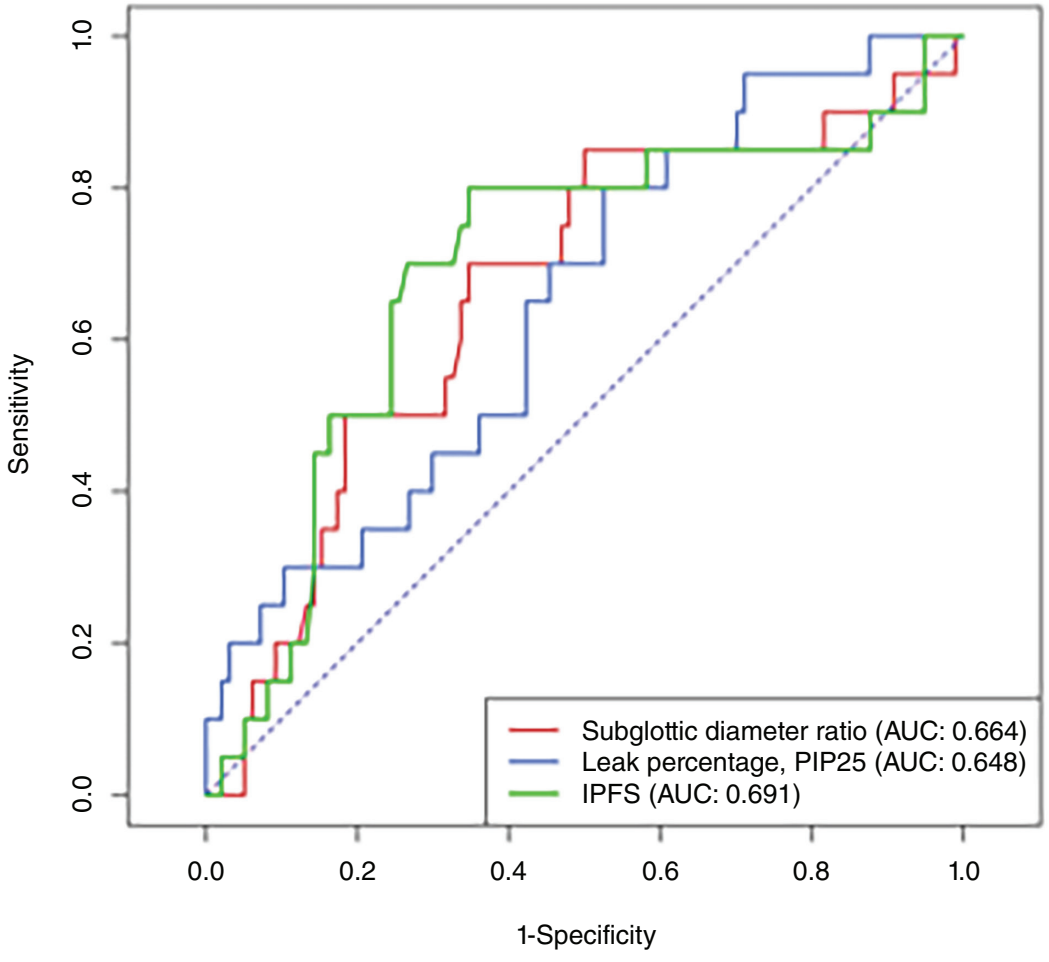

Figure 2. Receiver operating characteristic curves for predicting post-extubation stridor in children aged ≥1 year. The curves illustrate the diagnostic performance of three tests in predicting post-extubation stridor: subglottic ratio, intracricoid peritubal free space, and leak percentage at peak inspiratory pressure of 25 cmH_2O.

diameter measurements (8). Furthermore, the funnel-shaped pediatric airway may render transverse diameter measurements insufficient to represent the true cross-sectional area (12). In children aged ≥1 year, IPFS showed the highest diagnostic performance for predicting PES, and slightly surpassed the performance of the SR. Both measurements can be obtained using subglottic ultrasonography and are more feasible than leakage percentage testing. They require less patient cooperation, lower PIP, and are simpler to calculate and interpret. In contrast, the leak test exhibited the lowest performance and could cause discomfort owing to its higher PIP and longer test duration. Historically, cuffed ETTs have been believed to increase the risk of laryngeal edema and mucosal injury owing to the funnel shape and relatively narrow subglottic diameter of the pediatric airway. However, recent studies have demonstrated that when properly sized and monitored, cuffed ETTs do not increase the incidence of airway complications compared with uncuffed tubes (12). Therefore, the 2020 Pediatric Advanced Life Support guidelines recommend using cuffed ETTs as the standard of care for pediatric patients (13). Consistently, this study also found no significant difference in the incidence of PES between ETT types. The moderate predictive accuracy of all tests could stem from the relatively low incidence of PES, which may reduce the statistical power; PES is not solely caused by subglottic edema, but may also result from laryngeal involvement (11, 14). Both the IPFS and SR focus only on the airway diameter at the subglottic level. Future research should explore combined measurements of the laryngeal and subglottic areas, as well as dynamic airway changes, to improve predictive accuracy. The incidence of PES in this study was 18.75%, which is consistent with the incidence of 8.5–51% in previous reports, likely due to differences in patient age across studies (1, 15, 16). The only significant factor associated with PES was lower body weight, consistent with El Amrousy et al. (1) Most patients with PES had mild severity, with a Croup score of 2, and none of these patients required reintubation. Lower severity may reflect routine monitoring of cuff pressure during intubation per institutional protocol, with fewer intubation attempts and shorter intubation duration (11). Moreover, 80% of the patients were intubated with a microcuff ETT, which is known to reduce the risk of PES (17). The CLT is widely used in adults; however, its predictive accuracy in children is limited. In the present study, the leak percentage was significantly lower in the PES group. However, when the optimal cutoff point (36.77% at PIP 25 cmH_2O), the predictive accuracy remained moderate, which was consistent with the result of a previous study (3). Furthermore, performing this test can prove uncomfortable for children because of the application of high PIP, and the need for calculations makes it a less practical approach at the bedside. The strengths of this study include its prospective observational design and relatively large pediatric sample size, which added valuable data to a limited evidence base. This study employed a pragmatic bedside approach using ultrasound, and the findings were interpreted by a pediatric radiologist to enhance its clinical applicability. Moreover, we evaluated multiple diagnostic parameters, including novel SR, to predict PES. Nonetheless, this study had some limitations. This study was conducted at a single center, which may have limited the generalizability of the results. While the high level of training of our ultrasound operator minimized measurement variability, it may also limit the external validity of the results in broader practice. Moreover, most PES cases were mild, which may have influenced the predictive performance of the tests. Finally, the study may have lacked sufficient power to detect all significant associations owing to the relatively low incidence of PES.

Conclusion

Among the evaluated tests, IPFS was the most practical and effective method for predicting PES in patients aged ≥1 year. However, as PES can occur at multiple airway levels, future studies should aim to improve predictions by incorporating combined laryngeal and subglottic cross-sectional area assessments and dynamic airway evaluations.

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Ethics Approval: This study complied with the principles of the Declaration of Helsinki and was approved by the Institutional Ethics Committee of the Faculty of Medicine, Prince of Songkla University (REC.66-470-1-1).

Consent to Participate: All patient information was de-identified, and informed consent was obtained from legal guardians, and assent was obtained from patients aged ≥8 years upon enrollment.

Consent to Publish: The authors affirm that participants provided informed consent for publication.

Data Availability: All data supporting the findings of this study are available in the paper and Supplementary Information.

Competing Interests: The authors have no relevant financial or non-financial interests to disclose.

Declaration on the Use of AI: The authors did not use artificial intelligence-assisted technologies in the writing process or for the generation of any figures or data presented in this study.

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Supplementary files

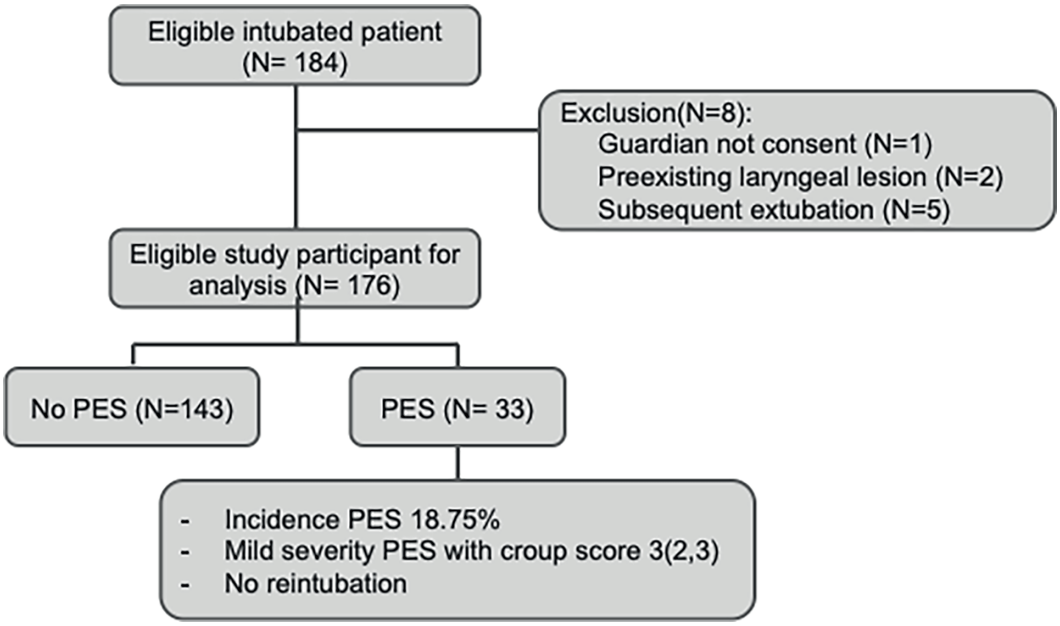

Figure S1. Flowchart depicting patient enrollment and the study population. The flowchart illustrates the process of enrollment of pediatric patients in the study. Of the 184 intubated patients screened, 8 were excluded due to lack of consent (n=1), preexisting laryngeal lesions (n=2), and subsequent extubation (n=5). A total of 176 patients were included in the final analysis. Post-extubation stridor occurred in 33 patients (18.75%), all of whom had mild symptoms (croup score 3 [IQR 2, 3]) and did not require reintubation.

Table S1. Diagnostic performance of tests for post-extubation stridor in all age groups.

Cutoff	Subglottic ratio	Intracricoid peritubal free space (mm)	Leak percentage at PIP 30 cmH_2O
	1.36	2.08	36.77%
Sensitivity	0.70	0.82	0.82
Specificity	0.42	0.49	0.43
Positive Likelihood Ratio (LR+)	1.20	1.60	1.43
Negative Likelihood Ratio (LR–)	0.72	0.37	0.42
Accuracy	0.47	0.55	0.50
AUROC	0.554	0.609	0.625

Abbreviations: AUC = Area under the ROC curve; IPFS = Intracricoid peritubal free space; PES = Post-extubation stridor; LR+ = Positive likelihood ratio; LR– = Negative likelihood ratio; PIP = Peak inspiratory pressure.