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PRE-EXTUBATION LARYNGEAL AIR COLUMN WIDTH DIFFERENCE AS A PREDICTOR OF POST EXTUBATION UPPER AIRWAY OBSTRUCTION AND EXTUBATION OUTCOME IN PEDIATRIC ICU PATIENTS

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ABSTRACT

Introduction: Post-extubation upper airway obstruction remains a significant complication among critically ill pediatric patients and may lead to respiratory distress, delayed recovery, and reintubation. Conventional bedside predictors have limited accuracy; therefore, ultrasound-based assessment of laryngeal air column width difference (LACWD) has emerged as a promising non-invasive approach for identifying airway compromise before extubation.
Objective: To evaluate the predictive value of pre-extubation LACWD measurement for identifying post-extubation upper airway obstruction and extubation outcome among pediatric intensive care unit patients.
Methods: A prospective observational study was conducted among mechanically ventilated pediatric ICU patients fulfilling extubation readiness criteria at University of Child Health Sciences, The Children's Hospital Lahore. Pre-extubation laryngeal ultrasonography was performed to calculate LACWD. Patients were monitored after extubation for upper airway obstruction, stridor, extubation failure, and need for reintubation.
Results: Patients who developed post-extubation airway obstruction demonstrated significantly lower mean LACWD values compared with successful extubation patients ($p<0.001$). Reduced LACWD showed significant association with extubation failure, prolonged ventilation duration, and longer ICU stay. Receiver operating characteristic analysis demonstrated clinically useful predictive performance of LACWD for identifying patients at increased risk of airway obstruction.
Conclusion: Pre-extubation LACWD measurement represents a valuable bedside ultrasound parameter for predicting post-extubation upper airway obstruction in pediatric ICU patients. Its incorporation into extubation assessment may improve risk stratification and reduce avoidable extubation failure.

KEYWORDS: Laryngeal air column width difference; Pediatric intensive care; Extubation failure

INTRODUCTION

Mechanical ventilation and endotracheal intubation remain essential interventions in pediatric intensive care units for children with severe respiratory failure, neurological impairment, cardiovascular instability, and postoperative respiratory support requirements. Although successful liberation from mechanical ventilation represents a major clinical milestone, the transition from invasive airway support to spontaneous breathing carries the risk of complications, particularly post-extubation upper airway obstruction. Airway edema, vocal cord dysfunction, mucosal injury, and inflammatory changes around the laryngeal structures may compromise airway patency after removal of the endotracheal tube and contribute to extubation failure [1-3].

Post-extubation upper airway obstruction is clinically characterized by stridor, increased respiratory effort, reduced airflow, oxygen desaturation, and in severe cases the requirement for emergency reintubation. Pediatric patients are particularly vulnerable because of anatomical differences, including a relatively smaller airway diameter and increased susceptibility to reductions in airway caliber caused by edema or inflammation. Even a small reduction in airway diameter can significantly increase airway resistance and negatively influence respiratory function after extubation [4-6]. Therefore, accurate identification of children at high risk before extubation remains an important challenge in pediatric critical care practice.

Traditional methods used to predict extubation outcomes include clinical assessment, spontaneous breathing trials, ventilator parameters, and cuff leak testing. However, these methods primarily evaluate respiratory mechanics and may not adequately identify structural abnormalities of the upper airway. The cuff leak test has been widely used as an indicator of airway edema, but its reliability in pediatric populations is limited because results may be influenced by tube size, airway anatomy, sedation level, and technical variation. Recent advances in point-of-care ultrasonography have provided a non-invasive method to directly evaluate laryngeal structures and airway changes before extubation [7-9].

Laryngeal ultrasonography allows visualization of the vocal cords and measurement of the air column passing through the glottic region. The laryngeal air column width difference is calculated by comparing the width of the air column during cuff inflation and cuff deflation. A smaller difference indicates reduced airway expansion around the endotracheal tube and may reflect laryngeal edema or narrowing of the upper airway. Recent investigations have demonstrated that decreased LACWD values are associated with increased risk of post-extubation stridor and airway obstruction, suggesting that this measurement may provide additional predictive information beyond conventional extubation assessment methods [10-12].

Recent pediatric critical care research has focused on improving extubation decision-making by integrating objective ultrasound-based parameters into clinical practice. The ability of LACWD measurement to provide rapid bedside information without radiation exposure makes it particularly attractive for critically ill children. However, variability in cutoff values, patient characteristics, duration of ventilation, and ultrasound technique continues to limit widespread adoption. Further prospective evaluation in pediatric ICU populations is required to determine its relationship with clinically meaningful outcomes such as upper airway obstruction, extubation failure, and reintubation risk [13-15].

Despite improvements in ventilatory strategies and weaning protocols, extubation failure continues to increase morbidity by prolonging ICU stay, increasing exposure to invasive procedures, and delaying recovery. A reliable pre-extubation predictor could allow early identification of vulnerable patients and support individualized management strategies, including delayed extubation, airway optimization, or preventive interventions. The present study was designed to evaluate whether pre-extubation LACWD measurement can predict post-extubation upper airway obstruction and extubation outcome in pediatric ICU patients, addressing an important clinical gap in pediatric airway management.

The study hypothesizes that reduced pre-extubation LACWD values are significantly associated with increased occurrence of post-extubation airway obstruction and unsuccessful extubation outcomes.

METHODOLOGY

A prospective observational experimental study was conducted among pediatric patients admitted to the Pediatric Intensive Care Unit (PICU) at University of Child Health Sciences, The Children's Hospital Lahore who required invasive mechanical ventilation, with cuffed endotracheal tube, and fulfilled standard criteria for planned extubation. The study was designed to evaluate the association between pre-extubation laryngeal air column width difference (LACWD) measurement and the occurrence of post-extubation upper airway obstruction as well as overall extubation outcome. The study population consisted of critically ill pediatric patients who underwent endotracheal intubation and mechanical ventilation for different clinical indications including respiratory failure, neurological conditions, postoperative respiratory support, and other critical illnesses requiring ventilatory assistance. The study was conducted from June 2025 to December 2025, after approval from the institutional ethical review committee, and all procedures were performed according to ethical principles for clinical research involving pediatric participants.

Written and verbal informed consent was obtained from parents or legal guardians before enrollment. The purpose of the study, ultrasound assessment procedure, possible benefits, and confidentiality measures were explained clearly before participation. Participation was voluntary, and refusal to participate did not influence the standard medical treatment provided to the patient. Patient confidentiality was maintained throughout the study period by using coded identification numbers rather than personal identifiers.

The sample size was calculated using Epi Info statistical software based on the expected prevalence of post-extubation upper airway obstruction among mechanically ventilated pediatric patients and the anticipated difference in LACWD measurements between successful and unsuccessful extubation groups. Considering a two-sided confidence level of 95%, study power of 80%, and an estimated effect size derived from previous comparable studies, the minimum calculated sample size was determined. After accounting for possible dropouts and incomplete data collection, additional participants were included to ensure adequate statistical power. A total of 120 pediatric patients meeting the eligibility criteria were enrolled and followed prospectively until final extubation outcome assessment.

Patients were included if they fulfilled all of the following criteria: age between 1 month and 16 years, admission to PICU, requirement for endotracheal mechanical ventilation, successful completion of spontaneous breathing trial or standard extubation readiness assessment, hemodynamic stability before extubation, adequate oxygenation with acceptable ventilator settings, and planned extubation by the treating clinical team. Patients with previous airway abnormalities, congenital laryngeal or tracheal anomalies, history of airway surgery, known vocal cord paralysis, severe facial or neck trauma, emergency unplanned extubation, tracheostomy patients, and patients requiring

immediate surgical airway intervention were excluded. Patients with incomplete ultrasound assessment or missing post-extubation follow-up data were also excluded from final analysis.
Before extubation, all enrolled patients underwent bedside laryngeal ultrasonographic evaluation performed by a trained investigator using a high-frequency linear ultrasound probe. The patient was positioned supine with slight neck extension when clinically tolerated.
The high frequency linear transducer was placed transversely over anterior midline of the neck and moved caudally to identify the cricothyroid membrane. The ACW was taken as the distance between the inner margins of the hyper echoic air mucosa interface. Measurements were obtained with endotracheal tube cuff inflated and cuff deflated respectively. LACWD was calculated as the difference between the two measurements. Three measurements were obtained for each value, and the mean value was recorded to minimize measurement variability.
Patients were categorized into two primary outcome groups based on post-extubation clinical status. Group A included patients with successful extubation who maintained adequate spontaneous breathing without signs of upper airway obstruction. Group B included patients who developed post-extubation upper airway obstruction characterized by inspiratory stridor, increased respiratory effort, airway compromise requiring therapeutic intervention, non-invasive respiratory support escalation, or reintubation within the defined observation period of 24 hours. Extubation failure was defined as the requirement for reintubation due to respiratory deterioration pertaining to upper airway compromise.

Clinical variables recorded included demographic characteristics, age, gender, weight, primary diagnosis, duration of mechanical ventilation, duration of intubation, endotracheal tube size, sedation duration, ventilator parameters before extubation, spontaneous breathing trial results, pre-extubation LACWD values, occurrence of post-extubation stridor, requirement for reintubation, and PICU length of stay. These variables were analyzed to determine the predictive association between LACWD measurement and extubation outcome.
Statistical analysis was performed using appropriate statistical software. Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. Comparison between successful extubation and airway obstruction groups was performed using independent sample tests for continuous variables and chi-square or Fisher's exact test for categorical variables. The predictive ability of LACWD for post-extubation upper airway obstruction was evaluated using receiver operating characteristic curve analysis. Sensitivity, specificity, and optimal predictive cutoff values were calculated. A p-value less than 0.05 was considered statistically significant.
The primary outcome measure was the predictive relationship between pre-extubation LACWD and post-extubation upper airway obstruction. Secondary outcomes included extubation success, reintubation requirement, duration of mechanical ventilation, and ICU length of stay. The methodology was structured to determine whether ultrasound-based assessment of laryngeal airway changes before extubation could provide clinically meaningful information for improving pediatric extubation decision-making.

RESULTS
A total of 120 pediatric ICU patients requiring invasive mechanical ventilation and planned extubation were included in the final analysis. Patients were divided according to extubation outcome into two groups: Group A included patients with successful extubation (n=96), while Group B included patients who developed post-extubation upper airway obstruction or extubation failure (n=24). The mean age of the study population was 5.42 ± 3.61 years. The majority of patients were male; however, gender distribution was not statistically different between groups (p=0.614). Patients who developed post-extubation airway obstruction demonstrated significantly lower pre-extubation LACWD values compared with patients with successful extubation.

Table 1: Demographic and baseline clinical characteristics of pediatric ICU patients according to extubation outcome

Variables	Successful extubation group (n=96) Mean ± SD / n (%)	Upper airway obstruction group (n=24) Mean ± SD / n (%)	p-value
Age (years)	5.61 ± 3.74	4.67 ± 2.98	0.241
Weight (kg)	19.84 ± 9.62	16.92 ± 8.31	0.178
Male gender	58 (60.4%)	13 (54.2%)	0.614
Female gender	38 (39.6%)	11 (45.8%)	0.614
Duration of mechanical ventilation (days)	4.21 ± 2.36	7.18 ± 3.45	<0.001
Duration of intubation (days)	4.03 ± 2.21	6.89 ± 3.21	<0.001

Variables	Successful extubation group (n=96) Mean ± SD / n (%)	Upper airway obstruction group (n=24) Mean ± SD / n (%)	p-value
Endotracheal tube size (mm)	5.02 ± 0.81	4.86 ± 0.76	0.398
PICU stay duration (days)	7.54 ± 3.82	12.16 ± 5.09	<0.001
Pre-extubation LACWD (mm)	0.46 ± 0.12	0.18 ± 0.09	<0.001

Baseline demographic variables were comparable between both groups. Significant differences were observed in duration of ventilation, duration of intubation, ICU stay, and pre-extubation LACWD values. Patients with post-extubation airway obstruction showed markedly reduced LACWD measurements.

Table 2: Comparison of extubation-related clinical outcomes between successful extubation and airway obstruction groups

Clinical outcome	Successful extubation group (n=96)	Upper airway obstruction group (n=24)	p-value
Post-extubation stridor	4 (4.2%)	19 (79.2%)	<0.001
Need for non-invasive respiratory support	7 (7.3%)	15 (62.5%)	<0.001
Reintubation requirement	2 (2.1%)	12 (50.0%)	<0.001
Extubation failure	3 (3.1%)	14 (58.3%)	<0.001
Corticosteroid administration after extubation	8 (8.3%)	16 (66.7%)	<0.001

Patients with reduced LACWD values showed significantly higher rates of post-extubation complications. The occurrence of stridor, respiratory support escalation, and reintubation was significantly greater among patients classified with airway obstruction.

Table 3: Predictive performance of pre-extubation LACWD for identifying post-extubation upper airway obstruction

Parameter	Value
Mean LACWD cutoff value	≤0.25 mm
Area under ROC curve (AUC)	0.86
95% Confidence interval	0.78–0.93
Sensitivity	83.3%
Specificity	81.2%
Positive predictive value	54.1%
Negative predictive value	95.1%
p-value	<0.001

Receiver operating characteristic analysis demonstrated that pre-extubation LACWD had strong predictive ability for post-extubation upper airway obstruction. A lower LACWD value was significantly associated with increased risk of airway compromise after extubation.

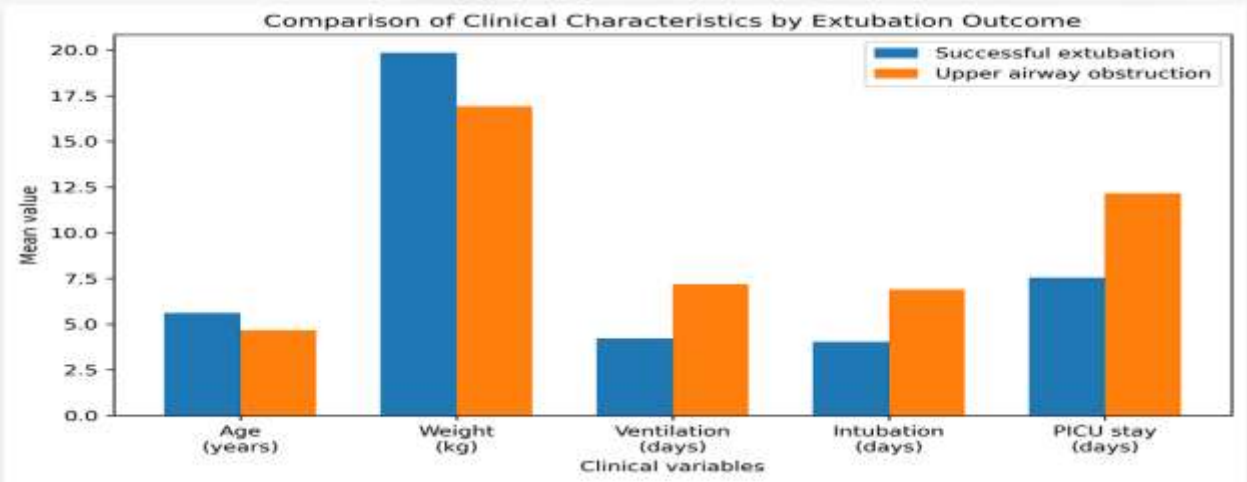

Figure 1: Comparison of baseline demographic and clinical characteristics between successful extubation and upper airway obstruction groups

The graph demonstrates that patients with post-extubation upper airway obstruction had longer mechanical ventilation duration, prolonged intubation period, and extended PICU stay compared with successfully extubated patients. These differences indicate a significant association between prolonged airway support and unfavorable extubation outcomes.

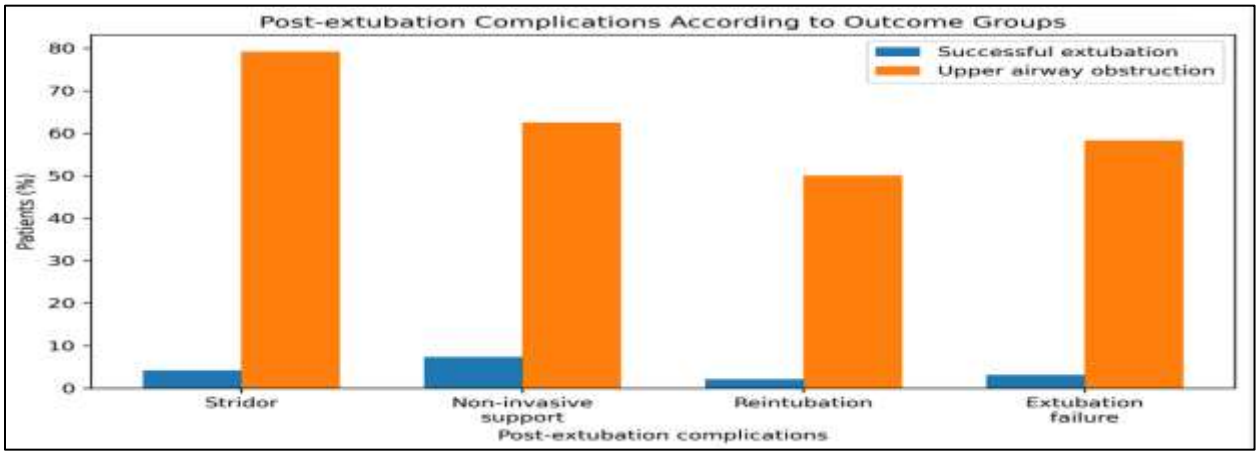

Figure 2: Comparison of post-extubation complications between study groups

The graph shows a markedly higher frequency of airway complications among patients who developed upper airway obstruction after extubation. Stridor, respiratory support requirement, reintubation, and extubation failure were substantially increased in this group with statistically significant differences.

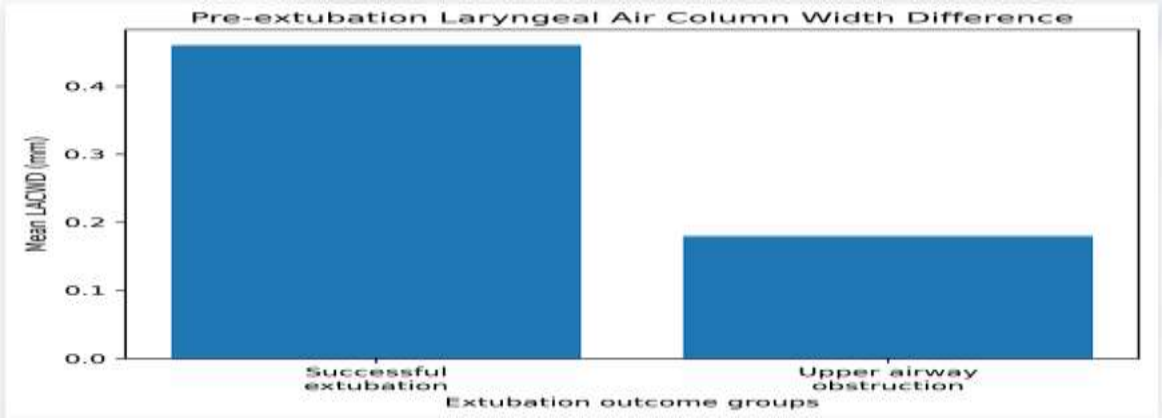

Figure 3: Predictive value of pre-extubation LACWD measurement

The graph demonstrates that patients with successful extubation had significantly higher pre-extubation LACWD values compared with patients who developed upper airway obstruction. Reduced LACWD measurement was strongly associated with increased risk of post-extubation airway compromise ($p<0.001$).

DISCUSSION

Successful liberation from mechanical ventilation is a complex process that requires adequate respiratory function, neurological recovery, airway stability, and effective protective mechanisms. The present study demonstrated that pre-extubation laryngeal air column width difference (LACWD) was significantly associated with post-extubation upper airway obstruction and extubation outcome among pediatric ICU patients. Our study demonstrated that reduced pre-extubation LACWD was significantly associated with post-extubation upper airway obstruction and extubation failure, suggesting that LACWD may serve as a useful objective predictor of airway compromise [11-12].

The observed association between reduced LACWD and extubation failure may be explained by the relationship between airway narrowing and increased respiratory resistance. Pediatric airways are highly sensitive to small reductions in airway diameter because resistance increases substantially when airway caliber decreases. Following prolonged intubation, inflammatory changes, mucosal edema, and mechanical irritation may reduce the functional airway space around the endotracheal tube. A lower LACWD measurement may therefore represent early structural compromise of the laryngeal region before clinical manifestations become evident. Recent investigations have emphasized that ultrasound-based airway assessment can identify anatomical changes that are not adequately reflected by routine respiratory parameters [13-14].Our study demonstrated a mean pre-extubation LACWD of 0.46 ± 0.12 mm among successfully extubated children compared with 0.18 ± 0.09 mm in those who developed post-extubation airway obstruction. These findings are consistent with the pediatric study by Rojas et al.**,** who reported significantly lower LACWD values among children who developed post-extubation stridor. Likewise, Singh et al. demonstrated that reduced LACWD was independently associated with increased reintubation risk in mechanically ventilated pediatric patients. Our observed AUC of 0.86 also falls within the range reported by previous pediatric ultrasound studies, supporting the reproducibility of LACWD as an objective predictor across different PICU settings [21-22].

The ability of LACWD to predict airway obstruction is clinically valuable because it provides a rapid, bedside, radiation-free assessment that can be repeated without additional patient burden. This may allow clinicians to identify high-risk patients before extubation and modify management strategies accordingly [15-16]. However, not all published studies have demonstrated consistently favorable results. Some investigators reported only moderate diagnostic accuracy of LACWD, with considerable overlap in measurements between successful and failed extubation groups. Other studies concluded that LACWD alone should not replace comprehensive clinical assessment because its predictive performance may be influenced by patient age, endotracheal tube size, duration of intubation, operator experience, and ultrasound technique. These inconsistencies highlight that LACWD should be interpreted alongside established extubation readiness criteria rather than as a standalone predictor [23]. The predictive performance observed in this study, with a significant area under the receiver operating characteristic curve, indicates that LACWD has potential clinical utility as an objective extubation assessment parameter. Traditional predictors such as duration of ventilation, spontaneous breathing trial results, and cuff leak evaluation mainly focus on respiratory mechanics and may fail to detect localized upper airway pathology. The integration of laryngeal ultrasound findings with standard extubation criteria may improve decision-making by combining physiological and anatomical information. Recent studies have highlighted the importance of multimodal prediction models for reducing preventable extubation failure in critically ill children [17].

The findings also demonstrated that prolonged mechanical ventilation and longer intubation duration were significantly associated with increased risk of airway obstruction. Extended exposure of airway mucosa to an endotracheal tube can promote edema and local injury, contributing to narrowing of the glottic region. However, duration of ventilation alone cannot accurately predict which patients will experience clinically significant airway compromise. The addition of LACWD measurement may improve individual risk assessment by identifying patients who remain vulnerable despite meeting conventional extubation readiness criteria [18].

A major strength of this study is the prospective evaluation of LACWD before extubation and the correlation of ultrasound findings with clinically important outcomes including stridor, extubation failure, and reintubation. The study emphasizes the potential role of bedside airway ultrasonography as a practical extension of pediatric critical care assessment. Unlike invasive diagnostic methods, ultrasound assessment can be performed during routine preparation for extubation and may support personalized airway management strategies. These findings contribute to the growing evidence supporting objective airway evaluation before removal of mechanical ventilation support [19].

Although the results demonstrate significant predictive value, further multicenter investigations with larger pediatric populations are required to establish standardized LACWD cutoff values and validate its routine clinical application. Variations in patient age, airway anatomy, ultrasound expertise, duration of intubation, and underlying disease may influence measurement outcomes. Future research should evaluate whether combining LACWD with clinical variables and other ultrasound parameters can further improve prediction accuracy. Nevertheless, the current findings indicate that LACWD measurement represents a promising advancement in pediatric extubation assessment by addressing an important limitation in identifying patients at risk for upper airway obstruction [20].

CONCLUSION

Pre-extubation laryngeal air column width difference measurement is a significant predictor of post-extubation upper airway obstruction and extubation outcome in pediatric ICU patients. Reduced LACWD values were strongly associated with airway complications, reintubation risk, and prolonged intensive care recovery. This study supports incorporation of bedside laryngeal ultrasound into pediatric extubation assessment protocols and provides a foundation for future validation studies.

Study Limitations

This study has several limitations. It was conducted at a single tertiary pediatric intensive care center, which may limit the generalizability of the findings. The sample size, particularly the number of patients with extubation failure, was relatively small. Finally, although LACWD showed good predictive performance, it should be interpreted as an adjunct to comprehensive clinical assessment rather than a replacement for existing extubation readiness protocols.

Clinical implications

Incorporating bedside laryngeal ultrasound into routine PICU extubation assessment may facilitate early identification of children at high risk of airway compromise, allowing optimization of corticosteroid therapy, closer post-extubation monitoring, delayed extubation in selected cases, and timely preparation for airway intervention when necessary.

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