การวัดปริมาตรลมรั่วรอบท่อช่วยหายใจเพื่อทำนายการเกิดภาวะอุดกั้นทางเดินหายใจส่วนบนภายหลังถอดท่อช่วยหายใจในผู้ป่วยเด็ก

ประวิทย์ เจตนชัย พ.บ.*,**, จริยา พจน์ทวีเกียรติ พ.บ.*
*หน่วยโรคระบบการหายใจและเวชบัดวิกฤต กลุ่มงานกุมารเวชศาสตร์ สถาบันสุขภาพเด็กแห่งชาติมหาราชินี ถนนราชวิถี แขวงทุ่งพญาไท เขตราชเทวี กรุงเทพฯ 10400
**วิทยาลัยแพทยศาสตร์ มหาวิทยาลัยรังสิต แขวงทุ่งพญาไท เขตราชเทวี กรุงเทพฯ 10400

Measurement of Leak Volume as a Diagnostic Predictor of Post-extubation Stridor in Pediatric Patients

Pravit Jetanachai, M.D.*,**, Jariya Pojthaveekiet, M.D.*
*Division of Respiratory Diseases and Critical Care, Department of Pediatrics, Queen Sirikit National Institute of Child Health, Ratchawithi Road, Thung Phaya Thai, Ratchathewi, Bangkok 10400, Thailand
** College of Medicine, Rangsit University, Thung Phaya Thai, Ratchathewi, Bangkok 10400, Thailand
Corresponding Author: Pravit Jetanachai (E-mail: dr.pravitj@gmail.com)
(Received: 28 January, 2025; Revised: 24 March, 2025; Accepted: 10 July, 2025)

Abstract

Background: Endotracheal intubation can cause post-extubation stridor (PES). PES can prolong the hospital stay length and is linked to high mortality and morbidity, especially, if re-intubation is essential. Leak volume (LV) test is a simple method to detect upper airway edema. **Objective:** We aimed to evaluate the effectiveness of percent leak volume (PLV) and LV in predicting PES. **Methods:** Before extubation, expired tidal volume (VTe) and inspired tidal volume (VTi) were observed for 6 respiratory cycles during positive pressure ventilation. The average of the 6 VTi and 6 VTe values were recorded. LV was the difference between average VTi and average VTe. The conversion of the ratio of LV to average VTi into percentage was defined as PLV. Both LV and PLV were assessed to indicate cut-off values in predicting PES. **Results:** Among 77 patients, 39 patients (50.6%) developed PES. Both LV and PLV showed a significant decrease in patients with PES. ROC analysis indicated that LV at cut-off value < 18.34 ml gave a sensitivity of 82.1% and specificity of 57.9%, whereas PLV < 13.83% yielded 79.5% sensitivity and 57.9% specificity, for PES prediction. PLV and LV showed an area under the ROC curve of 0.770 ($p < .001$, 95%CI: 0.665, 0.874) and 0.706 ($p = .01$, 95%CI: 0.59, 0.821) respectively. **Conclusion:** LV and PLV could be used as a predictor of PES in pediatric patients.

Keywords: Post-extubation stridor, Leak volume, Percent leak volume, Laryngeal edema

บทคัดย่อ

ภูมิหลัง: การใส่ท่อช่วยหายใจอาจทำให้เกิดภาวะอุดกั้นทางเดินหายใจส่วนบนภายหลังถอดท่อช่วยหายใจตามมาได้ ซึ่งภาวะดังกล่าว ส่งผลเสียทำให้ผู้ป่วยต้องรับการรักษาในโรงพยาบาลนานขึ้น มีความเสี่ยงต่อการเกิดทุพพลภาพและการเสียชีวิตเพิ่มมากขึ้น โดยเฉพาะในรายที่ต้องใส่ท่อช่วยหายใจกลับเข้าไปใหม่ การวัดปริมาตรลมรั่วรอบท่อช่วยหายใจเป็นวิธีที่ง่ายในการบอกถึงการบวมของทางเดินหายใจส่วนบน **วัตถุประสงค์:** เพื่อประเมินประสิทธิผลของการวัดปริมาตรลมรั่วรอบท่อช่วยหายใจในการทำนายการเกิดภาวะอุดกั้นทางเดินหายใจส่วนบนภายหลังถอดท่อช่วยหายใจ **วิธีการ:** ก่อนถอดท่อช่วยหายใจจะมีการวัด tidal volume ในช่วงหายใจออกและ tidal volume ในช่วงหายใจเข้า ในรอบการหายใจเข้าและออก 6 ครั้ง ระหว่างการใช้เครื่องช่วยหายใจแรงดันบวก บันทึกค่าเฉลี่ยของ tidal volume ในช่วงหายใจเข้าและค่าเฉลี่ย tidal volume ในช่วงหายใจออกทั้ง 6 ครั้ง ค่าปริมาตรลมรั่วรอบท่อช่วยหายใจ (leak volume; LV) คือ ผลต่างระหว่างค่าเฉลี่ยของ tidal volume ในช่วงหายใจเข้าและค่าเฉลี่ยของ tidal volume ในช่วงหายใจออก ค่าเปอร์เซ็นต์ของปริมาตรลมรั่วรอบท่อช่วยหายใจ (percent leak volume; PLV) คือ อัตราส่วนระหว่าง LV ต่อค่าเฉลี่ย tidal volume ในช่วงหายใจเข้า นำค่า LV และ PLV มาประเมินทางสถิติเพื่อหาค่าจุดตัดในการทำนายการเกิดภาวะอุดกั้นทางเดินหายใจส่วนบนภายหลังถอดท่อช่วยหายใจ **ผล:** ในผู้ป่วย 77 ราย, ผู้ป่วย 59 ราย (50.6%) เกิดภาวะอุดกั้นทางเดินหายใจส่วนบนภายหลังถอดท่อช่วยหายใจ ค่า LV และ PLV มีค่าต่ำกว่าอย่างชัดเจนในผู้ป่วยที่มีภาวะอุดกั้นทางเดินหายใจส่วนบนภายหลังถอดท่อช่วยหายใจ จากการวิเคราะห์ ROC พบว่า จุดตัด LV < 18.34 มิลลิลิตร มีความไว 82.1% และความจำเพาะ 57.9% ในขณะที่จุดตัด PLV < 13.83% มีความไว 79.5% และความจำเพาะ 57.9% จากพื้นที่ใต้กราฟ ROC ของ PLV และ LV ที่ 0.770 ($p < .001$, 95%CI: 0.665, 0.874) และ 0.706 ($p = .01$, 95%CI: 0.59, 0.821) ตามลำดับ **สรุป:** ค่าปริมาตรลมรั่วรอบท่อช่วยหายใจและค่าเปอร์เซ็นต์ของปริมาตรลมรั่วรอบท่อช่วยหายใจ อาจนำมาใช้การทำนายการเกิดภาวะอุดกั้นทางเดินหายใจส่วนบนภายหลังถอดท่อช่วยหายใจในผู้ป่วยเด็ก

คำสำคัญ : ภาวะอุดกั้นทางเดินหายใจส่วนบนภายหลังถอดท่อช่วยหายใจ, ค่าปริมาตรลมรั่วรอบท่อช่วยหายใจ, ค่าเปอร์เซ็นต์ของปริมาตรลมรั่วรอบท่อช่วยหายใจ, ภาวะกล่องเสียงบวม

Introduction

The prevalence of post-extubation stridor (PES) in children ranges from 3.5-30.2%[1-2]. PES may increase the risk of adverse outcomes and prolong the length of pediatric intensive care unit (PICU) stay, especially if reintubation is required. At present, it is difficult to predict which patients will develop PES after extubation. Cuff leak test (CLT) is a simple method to predict PES but many studies have questioned the applicability of CLT as a routine test because of varied specificity and sensitivity[3]. The presence or absence of an audible air leak from an air leak test (ALT) has a low sensitivity in predicting PES in pediatric patients[4]. We assessed the cut-off value of percent leak volume (PLV) and leak volume (LV) in predicting PES.

We also evaluated the efficacy of PLV and LV in predicting PES in pediatrics.

Material and method

We conducted this prospective, observational study in the PICU of Queen Sirikit National Institute of Child Health between January 2019 and January 2020, with patients aged from 1 month to 15 years old who were intubated for more than 24 hours and met the criteria of extubation. Exclusion criteria were patients with congenital upper airway anomalies, unplanned extubation, a requirement of a tracheostomy tube and death before trial of extubation.

The measurement of LV was performed immediately before extubation. To measure the LV, the patient was suctioned intraorally and intratracheally, and put on pressure control mode. The endotracheal tube (ETT) cuff was deflated in the patient who was intubated with cuffed ETT. The patient was ventilated with

FiO_2 40%, peak inspiratory pressure to deliver tidal volume (V_T) at 8-10 cc/Kg, mechanical rate at 20 breaths/minute, and inspiratory time depending on age (infant: 0.5 second, toddler: 0.-0.7 second, small child: 0.7-0.8 second, child 0.8-1 second and adolescent 1-1.2 seconds). Inspiratory and expiratory V_T were determined. Both inspiratory and expiratory V_T were observed over the 6 respiratory cycles. The average of the 6 V_T in both inspiration and expiration was calculated. LV was the difference between average inspiratory V_T and average expiratory V_T. PLV was obtained by the following formula:

$$PLV = \frac{\text{average inspiratory } V_T - \text{average exspiratory } V_T}{\text{average inspiratory } V_T}$$

The signs and symptoms of PES were evaluated immediately in patients after extubation. Patients were considered to have PES if respiratory distress with whistling, inspiratory grunting, or high-pitched wheezing localized in the trachea or larynx that developed in 24 hours after extubation and needed medical intervention beyond humidified oxygen treatment, such as steroid nebulization, adrenaline nebulization, non-invasive positive pressure ventilation or reintubation.

Statistical analysis

Continuous data were described by mean and standard deviation and the proportion (%) was applied to describe categorical data. The Chi-square test, independent t-test, or Mann-Whitney U test are used to analyze the data. ROC curve was constructed and the area under the curve was used to find the optimal cut-off value of LV and PLV to predict PES. The findings were considered significant at a p-value < .05.

Results

Seventy-seven cases were assessed and their demographic and baseline characteristics are presented in Table 1.

Table 1 Characteristics of study patients

	Patients with PES (n = 39)	Patients without PES (n = 38)	p-value
Age (years), median (IQR)	0.83 (0.33, 2.67)	2.63 (1.08, 7.67)	.001*
Gender: Male, n (%)	24 (61.5)	24 (63.2)	.883
Body weight (kilograms), median (IQR)	7.5 (4.9, 13.3)	10 (9, 22)	.003*
Intubation with cuffed ETT, n (%)	18 (46.2)	21 (55.3)	.424
Duration of intubation (hours), median (IQR)	116.92 (65.5, 183.5)	83.63 (46, 144.33)	.109
Steroids before extubation, n (%)	20 (51.3)	22 (57.9)	.560

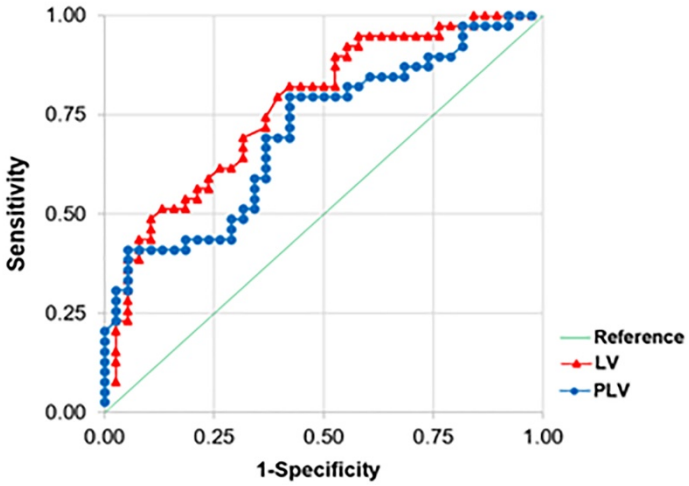
PES occurred in 39 (50.6%) of 77 included patients. Eight patients (10.3%) needed to be reintubated within one hour due to upper airway obstruction.

LV showed a significant difference between the two groups (p = .007). Patients with PES had a mean LV of 14.04±14.22 ml, in comparison with patients without PES who had a mean LV of 95.12±21.92 ml. The mean PLV of patients with PES was 11.3±7.41%, in comparison with patients without PES was 16.6±15.02%, with a significant difference (p = .06). The comparison of LV and PLV between patients with PES and patients without PES is demonstrated in Table 2.

Table 2 Leak volume and percent leak volume of patients with or without PES

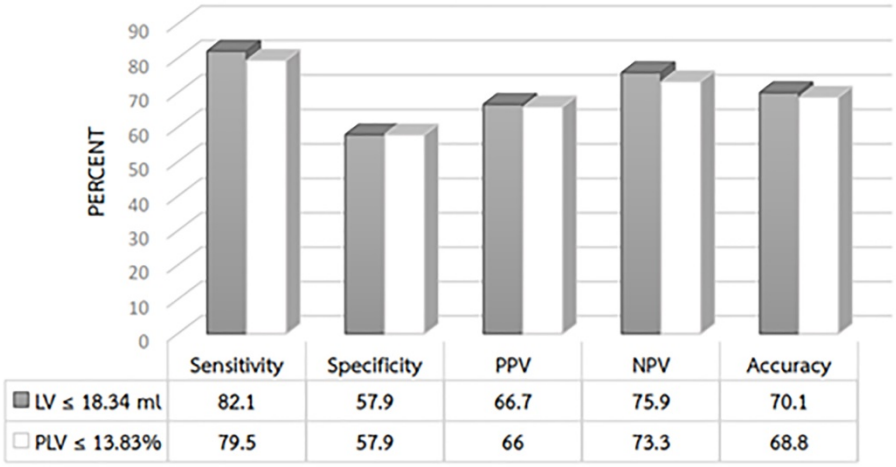
	Patients with PES (n = 39)	**Patients without PES (n= 38)**	**p-value**
LV (ml)	14.04±14.22	95.12±21.92	.007
PLV (%)	11.3±7.41	16.6±15.02	.006

From the ROC curve, the diagnostic ability of LV and PLV in the detection of PES showed that LV < of 18.34 ml had 82.1% sensitivity, 57.9% specificity, 66.7% PPV, 75.9% NPV, and 70.1% accuracy. PLV < 13.83% had a specificity of 57.9%, sensitivity of 79.5%, PPV of 66%, NPV of 73.3%, and accuracy of 68.8% at cut-off value of < 13.83% (Fig. 1 and Fig. 2).



Test	Cut-off	AUC	95%CI	p-value
LV	≤ 18.34 ml	0.770	(0.665, 0.874)	< 0.001
PLV	≤ 13.83 %	0.706	(0.59, 0.821)	0.001

Figure 1. ROC curve for the predictive value of LV and PLV in predicting PES



	Sensitivity	Specificity	PPV	NPV	Accuracy
LV ≤ 18.34 ml	82.1	57.9	66.7	75.9	70.1
PLV ≤ 13.83%	79.5	57.9	66	73.3	68.8

Figure 2. Comparison of sensitivity, specificity, PPV, NPV and accuracy between cutoff value of LV and PLV in predicting PES

Discussion

PES as a life-threatening complication can occur immediately following extubation. The risk factors of PES in pediatric patients include young age, prolonged mechanical ventilation, prolonged intubation, multiple intubation attempt and larger endotracheal tube[5]. PES may need treatment ranging from nebulization using racemic epinephrine to reintubation considering its severity. Several studies have estimated the incidence of PES, reporting the incidence range of 3.5-30.2%[1-2]. The incidence of PES in the present study was 50.6%, which is higher than in other studies. The high variance among these investigations may be due to the number of days on mechanical ventilation and ETT, various underlying medical conditions, airway edema degree, and using steroids before extubation[6]. We also found that the median age in patients with PES is smaller than the patients without PES and patients with PES have lower body weight when compared to patients without PES.

Identification of patients at risk for PES is of great importance. Most studies about leak volume in predicting PES are involved in adults, so we would like to know the results of the study in children. We proposed the measurement of LV and PLV as a simple method to predict the occurrence of PES in pediatric patients. LV and PLV are the quantitative assessments to measure the air leak around the ETT. We reported LV ≤ 18.34 ml as the threshold value for predicting PES in our study patients; the sensitivity was 82.1%, the specificity was 57.9%, PPV was 66.7%, NPV was 75.9% and the accuracy was 70.1%. PLV ≤ 13.83% yielded 79.5% sensitivity, 57.9% specificity, 66.0% PPV, 73.3% NPV, and 68.8% accuracy for predicting PES.

Theoretically, when there is no laryngeal edema, there is an air leak around the ETT. In contrast, laryngeal edema can cause airway narrowing and decrease expiratory flow into the upper airway, suggesting potential airway obstruction after extubation[7]. The lesser the LV and PLV, the higher the risk for PES. The LV and PLV were significantly lesser in the PES group than in the non-PES group. This study supports the use of LV and PLV as a simple method to predict PES in pediatric patients. It does not require expensive or sophisticated instrumentation. The other causes of air leak around the ETT are improper tube positioning and insertion the smaller endotracheal tube[8]. In this study, we use age-based and length-based formulas to determine the correct ETT size and verify the proper placement with auscultation and chest X-ray.

Several tests have been proposed for the

evaluation of risk for PES. Following the report by Mhanna et al.[9], they conducted a retrospective review of 105 PICU patients who performed an ALT prior to extubation. They found that the ALT at > 20 mmHg is a more sensitive predictor of PES in older patients (> 7 years) compared to younger patients (< 7 years). ALT measurement requires positive pressure to generate an audible air leak around ETT which may be affected by interobserver variability and head positioning[10-11].

Laryngeal ultrasonography including laryngeal air column width difference measurement has been reported as a reliable method to predict the risk of PES. Results from the study by Amrousy et al.[12] indicated that laryngeal air column width difference at a cut-off point < 0.8 mm had high sensitivity in predicting PES. Although laryngeal ultrasound is an appropriate tool for predicting PES because it has a very good correlation with bronchoscopic images, proper training and experience are required to ensure accurate measurement of air column width[13].

LV and PLV are simple, non-invasive and reliable methods in predicting PES in pediatric patients

Limitations of this study include the small number of pediatric patients and most of them were young children.

Conclusion

Patients with PES had significantly smaller LV and PLV than those without PES. LV and PLV prior to extubation can identify a patient at increased risk for PES.

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