ORIGINAL ARTICLE

Laryngeal Ultrasonography and Percent Leak Volume in Predicting Post-Extubation Stridor in The Pediatric Intensive Care Unit Patients

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Background: Endotracheal tube intubation can be associated with laryngeal edema, which may present as post-extubation stridor (PES). PES may prolong length of stay in pediatric intensive care unit, particularly if reintubation was necessary.

Objective: To evaluate the efficacy of laryngeal ultrasonography and percent leak volume (PLV) in predicting PES in pediatric patients.

Materials and Methods: A prospective study of 43 pediatric patients admitted to pediatric intensive care unit was conducted. Laryngeal ultrasonography was performed to measure air column width (ACW) within 24 hours after intubation. Within four hours before extubation, laryngeal ultrasonography was repeated. Air column width ratio (ACWR) was calculated by ACW before extubation divided by ACW after intubation. PLV was calculated by the difference between inspiratory and expiratory tidal volume divided by inspiratory tidal volume. Both of ACWR and PLV were analyzed to determine the optimal cut-off value for predicting PES.

Results: Twenty-two patients (51%), developed PES. Receiver operating characteristics curve (ROC) analysis showed that ACWR at cut-off point ≤0.94 had a sensitivity of 72.7%, specificity of 61.9%, positive predictive value (PPV) of 66.7%, and accuracy of 67.4% in predicting PES. A cut-off point of PLV of less than 9.74% had 59.1% sensitivity, 57.1% specificity, 59.1% PPV, and 58.1% accuracy in predicting PES. ACWR and PLV had an area under the ROC curve (AUC) of 0.722 (p=0.013, 95% CI 0.56 to 0.87) and 0.602 (p=0.253, 95% CI 0.43 to 0.77), respectively.

Conclusion: ACWR measured by laryngeal ultrasonography of 0.94 or less may be helpful in predicting PES. ACWR is more accurate than PLV in predicting PES.

Keywords: Laryngeal ultrasonography; Percent leak volume; Post-extubation stridor

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Post-extubation stridor (PES) from laryngeal edema is one of the common complications of prolonged endotracheal tube (ETT) intubation. PES can lead to extubation failure and prolonged length of stay in pediatric intensive care unit (PICU) if airway obstruction was severe and reintubation was necessary. Prolonged intubation leads to an increase in morbidity and mortality[1]. Therefore, it is important to assess airway patency before extubation. Cuff leak test has been proposed as a simple method in predicting PES in adult patients, but the accuracy of cuff leak test is controversial[2]. There were previous studies about air leak test (ALT) in predicting PES in pediatric patients. In 2002, Mhanna et al.[3] studied on pediatric patients with endotracheal tube intubation. They defined a positive ALT as the presence of an audible air leak at an inspiratory pressure of 20 mmHg. They suggested that ALT had a low sensitivity when used as a screening test to predict PES in young children younger than seven years, where as in older children that are seven years or older, ALT may predict PES. In 2008, Wratney et al.[4] studied 59 pediatric patients who were intubated. They found that air leak pressure of 30 cmH_2O or more before extubation was not associated with a greater likelihood for PES. Currently, there are no tests with high positive predictive value to identify the patients at risk of PES, so it is necessary to identify the test that is accurate in predicting PES in pediatric patients. Ding et al.[5] demonstrated that the air column width

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(ACW) measured by laryngeal ultrasound was a potential predictor of PES. The primary objective of the present study was to evaluate the efficacy of air column width ratio (ACWR) in predicting PES in pediatric patients. The authors also secondarily assessed the accuracy of ACWR in comparison to percent leak volume (PLV) in predicting PES.

Materials and Methods

The present study was approved by Ethical Approval Committee of Queen Sirikit National Institute of Child Health, Reference Number: REC 026/2562.

Patients

After received approval by the Institutional Ethics Committee, informed consents were collected from patients' parents, this prospective study was then carried out on children aged between 1 month and 15 years who were intubated and admitted into PICU, Queen Sirikit National Institute of Child Health. Patients less than eight years of age were intubated with uncuffed ETT, while patients of eight years or older were intubated with cuffed ETT.

Inclusion criteria included patients who require intubation and mechanical ventilation for a minimum of 24 hours and met the criteria of extubation. Patients were excluded from the present study were known for congenital upper airway anomalies or upper airway obstruction, history of neck or larynx surgery, unplanned extubation, a requirement of a tracheostomy tube, more than three attempts of intubation, and death before the trial of extubation.

Laryngeal ultrasound

Patients were in supine position with neck extension. Laryngeal ultrasound was performed with ALOKA, ProSound Alpha 6 machine (Tokyo, Japan) with 10 MHz linear probe for the measurement of ACW by one investigator and the investigator did not know the results of PLV. The probe was placed on longitudinal view to find the cricothyroid membrane. Then it was rotated to transverse view to identify the vocal cord (Figure 1). ACW is defined as the width of air passing through the vocal cord (Figure 2). The ACW were measured within 24 hours after intubation and within four hours before extubation, the measurement was repeated. Both measurements of ACW after intubation and before extubation were recorded three times consecutively, and the average values were calculated. ACWR is the average of ACW before extubation divided by the average of ACW after intubation. In patients intubated with cuffed ETT, the ETT balloon was deflated before ultrasound examination.

Figure 1. Ultrasound probe in transverse view to demonstrate vocal cord.

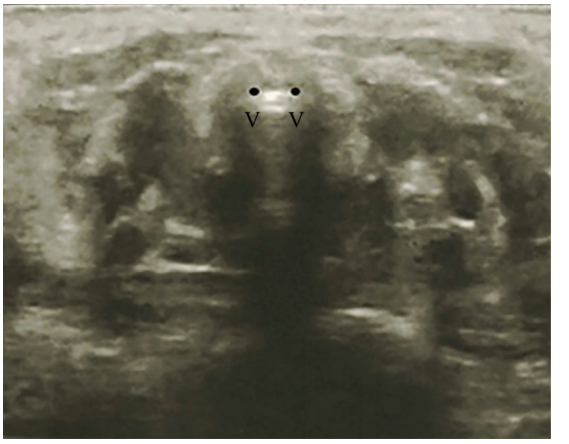

Figure 2. Ultrasound image of laryngeal air column, ACW is the distance between the two dots, V: vocal cord.

Percent leak volume

Before extubation, oral and ETT suction were done. In patients intubated with cuffed ETT, the ETT balloon was deflated. Then the mechanical ventilator was set to pressure control mode. Patients were ventilated with FiO_2 40%, peak inspiratory pressure to deliver tidal volume (V_T) at 8 to 10 cc/Kg, mechanical rate at 20 breaths per minute, and inspiratory time depends on age with infant at 0.5 second, toddler at 0.6 to 0.7 second, small child at 0.7 to 0.8 second, child at 0.8 to 1 second, and adolescent

Table 1. Patients' characteristics and correlated variables to PES and without PES

Variables	PES (n=22)	Without PES (n=21)	p-value
Male; n (%)	11 (50.0)	14 (66.7)	0.268
Age (years); median (IQR)	1.25 (0.5, 3)	2.08 (1.08, 9)	0.080
Intubated with cuffed ETT; n (%)	7 (31.8)	12 (57.1)	0.095
Use of steroid before extubation; n (%)	15 (68.2)	11 (52.4)	0.289
Duration of intubation (days); median (IQR)	3.91 (2.52, 7.01)	4.96 (1.92, 6.33)	0.894
Downes' score after extubation; median (IQR)	4 (3, 6)	0 (0, 0)	<0.001*

PES=post-extubation stridor; ETT=endotracheal tube; IQR=interquartile range

Table 2. Comparison of PLV, ACW (after intubation), ACW (before extubation), and ACWR between patients with PES and patients without PES

Variables	PES (n=22)	Without PES (n=21)	p-value
PLV (%); median (IQR)	8.15 (2.96, 16.27)	10.28 (4.42, 27.46)	0.253
ACW (after intubation) (mm); mean±SD	2.96±0.95	3.42±0.95	0.120
ACW (before extubation) (mm); mean±SD	2.55±0.8	3.23±0.91	0.014*
ACWR; mean±SD	0.87±0.1	0.94±0.05	0.006*

PES=post-extubation stridor; PLV=percent leak volume; ACW=air column width; ACWR=air column width ratio; IQR=interquartile range; SD=standard deviation

at 1 to 1.2 seconds[6].

Inspiratory and expiratory V_T were determined. Both inspiratory and expiratory V_T were observed over six respiratory cycles. The average of the 6 V_T in both inspiration and expiration were recorded. PLV was obtained by the following formula:

$$PLV = \frac{\text{Average inspiratory } V_T - \text{Average expiratory } V_T}{\text{Average inspiratory } V_T}$$

Twenty-four hours following extubation, patients were observed for signs and symptoms of PES and the severity of PES was assessed by using Downes' score[7]. PES is defined as the presence of respiratory distress by inspiratory grunting, whistling, or high-pitched wheezing localized in trachea or larynx that was developed 24 hours following extubation, and required medical intervention beyond humidified oxygen therapy, including steroid nebulization, adrenaline nebulization, non-invasive positive pressure ventilation, or reintubation[8].

Statistical analysis

Data were analyzed by using Stata Statistical Software, version 17 (StataCorp LLC, College Station, TX, USA). Descriptive statistics, such as median and interquartile range or mean and standard deviation, were shown for all continuous variables such as age, duration of intubation, Downes' scores after extubation, PLV, ACW after intubation, ACW before extubation, and ACWR. Categorical data such as gender, number of patients intubated with cuffed ETT, and the number of patients who received steroid before extubation were shown as relative frequency (percentage). Comparisons between patients with PES and patients without PES were made utilizing both parametric and non-parametric approaches, namely, paired t-test and two-sample Mann-Whitney U test for continuous variables and two-sample chi-square test for categorical variables.

ROC curve was constructed with the area under curve analysis performed to detect optimal cutoff value of PLV and ACWR to predict PES. The p-value of less than 0.05 were considered as statistically significant.

Results

Between November 2018 and April 2019, 43 patients were enrolled. Twenty-five patients were males (58%), and eighteen patients were females (42%). The median age was 1.83 (IQR 0.5, 5.75) years. The median duration of intubation was 4.81 (IQR 2.46, 6.58) days. Twenty-six patients received systemic steroid before extubation. Comparison of demographic and characteristic data between patients with PES and patients without PES were represented in Table 1.

There was no significant difference regarding gender, age, used of cuffed ETT, used of steroid before extubation, and duration of intubation. However, there was a statistically significant difference in Downe's score after extubation between patients with PES and patients without PES.

In Table 2, median PLV was 8.15 (IQR 2.96,

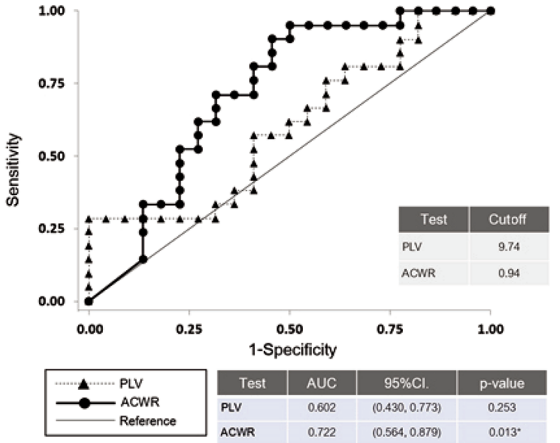

Figure 3. ROC curve for the predictive value of ACWR and PLV in predicting PES.

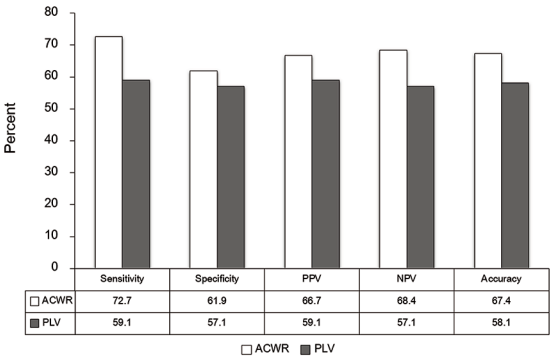

Figure 4. Comparison of sensitivity, specificity, PPV, NPV, and accuracy between cutoff value of ACWR and PLV in predicting PES.

16.27) and 10.28 (IQR 4.42, 27.46) in patients with PES and patients without PES, respectively (p=0.077). Average ACW after intubation was 2.96±0.95 mm and 3.42±0.95 mm in patients with PES and patients without PES, respectively (p=0.120). Average ACW before extubation was 2.55±0.8 mm and 3.23±0.91 mm in patients with PES and patients without PES, respectively (p=0.014). ACWR was 0.87±0.1 mm and 0.94±0.05 mm in patients with PES and patients without PES, respectively (p=0.006).

AUC of PLV was 0.602 (p=0.253, 95% CI 0.430 to 0.773) with cutoff value of 9.74% or less. PLV had a sensitivity of 59.1%, specificity of 57.1%, positive predictive value (PPV) of 59.1%, negative predictive value (NPV) of 57.1%, and accuracy of 58.1%. The optimal cutoff value in predicting PES of ACWR at 0.94 or less showed AUC of 0.722, 72.74% sensitivity, 61.9% specificity, 66.7% PPV, 68.4% NPV, and 67.4% accuracy (Figure 3, 4).

Discussion

The incidence of PES in the present study is 51%, which is higher than in the other pediatric studies at 3.5% to 30.2%[9,10]. This occurrence could be explained by the study's population, which mostly consisted of young children. The small size of airway in young children increases the risk of PES when compared to older children.

In the present study, patients with PES had significantly lower ACW before extubation and lower ACWR compared to those without PES (p=0.014 and 0.006, respectively). This may represent the laryngeal edema and predicting the development of PES. ROC curve analysis showed that ACWR at cutoff point of less than 0.94 gave a sensitivity of 72.7%, specificity of 61.9%, PPV of 66.7%, NPV of 68.4%, and accuracy of 67.4%. ACWR also had AUC of 0.722 (p=0.013, 95% CI 0.56 to 0.87). This means that ACWR identified by laryngeal ultrasound is an effective test in predicting PES and guiding the decision on prophylactic steroids.

ROC curve analysis of PLV showed that a cutoff point of less than 9.74% gave a sensitivity of 59.1%, specificity of 57.1%, PPV of 59.1%, NPV of 57.1%, and accuracy of 58.1%. PLV also has AUC of 0.602 (p=0.253, 95% CI 0.43 to 0.77). There was a difference between the diagnostic accuracy of PLV and ACWR in predicting PES.

From the present study, the ACWR had higher sensitivity, specificity, PPV, NPV, and accuracy in predicting PES compared with PLV. ACWR is more accurate than PLV in predicting PES because of direct visualization of laryngeal morphology. ACW can be quantified by laryngeal ultrasound and represents the space around ETT, which may reflex the change of air leak and air flow in patients who develop PES[5,11]. There are many factors affecting the accuracy of PLV, such as compliance of respiratory system, occlusion of ETT by secretion, and expiratory time[12,13]. The evaluation of ACWR by laryngeal ultrasound is not affected by the mentioned confounding factors.

Results from this study are in concordance with Ding et al., Venkategowda et al., and Sutherasan et al. The study done by Ding et al.[5] focused on the accuracy of laryngeal ultrasound in predicting PES in 51 adult intubated patients. They mentioned that patients with PES had lower ACW and ACWD, which is the ACW difference between balloon-cuff inflation and balloon-cuff deflation, compared with patients without PES. Venkategowda et al.[14] studied on 72 intubated adult patients and concluded that ACWR determined by laryngeal ultrasound of 0.8 or less

had a potential ability to predict PES. There was a difference in the cutoff value of ACWR in predicting PES between adult and pediatric patients because the airway in children is smaller in diameter. Sutherasan et al.[15] studied on 101 intubated adult patients and found that ACWD at cutoff value 1.6 mm or greater gave sensitivity of 0.706 and specificity of 0.702, which aids in the prediction of successful extubation regarding laryngeal edema. The present study also corresponds with that of Amrousy et al.[16]. In their study on 400 children, they found that ACWD of less than 0.8 was helpful in predicting PES in pediatric patients intubated with cuffed ET tube. The present study uses ACWR, which is a different parameter to investigate the efficacy in predicting PES because the authors studied patients intubated with cuffed and uncuffed ETT.

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

Conclusion

ACWR measured by laryngeal ultrasound is a simple, non-invasive, and reliable method in predicting PES in pediatric patients. ACWR at 0.94 or less is more accurate than PLV in predicting PES.

What is already known on this topic?

Laryngeal ultrasonography is a less invasive method of examining the larynx in children. It can evaluate laryngeal morphology, which has a potential ability to predict PES in intubated patients.

What this study adds?

Laryngeal ultrasonography should be considered before extubation as a tool to predict or exclude the significant laryngeal edema.

Conflicts of interest

The authors declare no conflict of interest.

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