RESEARCH PAPER

Stress Index in Pediatric Critical Illness: A Tool from Ventilator Graphics

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ABSTRACT
Background: Mechanical ventilation may result in ventilator-induced lung injury (VILI), primarily due to alveolar overdistension and tidal recruitment. The stress index, which is derived from the pressure-time curve during constant-flow ventilation, functions as a non-invasive instrument for detecting these detrimental patterns. While it has been validated for adults, its use in pediatric patients has not been thoroughly investigated. Objective: The objective of this study is to assess the practicality and clinical significance of visually assessing the stress index among children with acute lung injury or ARDS who are on mechanical ventilation. Design: This was a prospective cohort study involving 50 pediatric patients receiving mechanical ventilation in a tertiary ICU. Intervention: During volume-controlled ventilation, a 5-second end-expiratory occlusion was conducted. Measurements: The stress index was visually assessed by examining the pressure-time curve displayed on the ventilator and categorized as linear, downward concavity (suggesting tidal recruitment), or upward concavity (indicating overdistension). Ventilator settings and clinical outcomes were documented. Results: The visual assessment revealed that 60% of patients had a linear curve, 20% had downward concavity, and 20% had upward concavity. The overall mortality rate was 68%. Patients exhibiting upward concavity showed significantly higher peak inspiratory pressure, driving pressure, plateau pressure, and oxygenation index ($p<0.05$). Logistic regression analysis identified peak inspiratory pressure, mean airway pressure, plateau pressure, as well as driving pressure as key predictors of poor outcomes in those with upward concavity. Conclusion: The visual assessment of the stress index is a straightforward and feasible tool for pediatric critical care. An upward concavity pattern, which indicates overdistension, correlates with poorer ventilator parameters and clinical outcomes. Utilizing this visual assessment could assist in implementing lung-protective ventilation strategies and minimizing barotrauma in children.
Keywords: stress index; barotrauma; pediatrics; mechanical ventilation
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BACKGROUND:

Mechanical ventilation is a cornerstone in PICU, essential for sustaining life for children with acute respiratory failure, compromised airway integrity, or significant ventilation-perfusion mismatch. It acts as a bridge for recovery in various life-threatening disorders. Ventilation involves delivery of pressure breaths to the lungs, overcoming the mechanics of spontaneous breathing. Observing parameters, as lung compliance, airway resistance, and the interplay of pressure, volume, and flow dynamics is essential to minimizing potential complications including ventilator-induced lung injury (VILI), barotrauma, and hemodynamic instability. (Pham T et al.,2017). The two primary mechanisms of VILI are tidal recruitment as well as alveolar overdistention (Rocco PR et al.,2012). The stress index is a parameter that can be used to identify injurious mechanical ventilation by analyzing the structure of the pressure time curve during constant flow volume ventilation. This may signify tidal overdistension or tidal recruitment, which are two principal causes of VIDI (Cruces et al., 2023).

It Is a non-invasive tool used in mechanical ventilation to assess lung mechanics. A linear rise in pressure (constant compliance, stress index 1) indicates sufficient alveolar recruitment without over-distension (Caballero et al., 2022). Its development necessitated specialized hardware and software and is not a commonly utilized parameter in commercial ventilators. Another option is to observe the pressure-time curve visually during mechanical ventilation for signs of concavity. When the shape is concave upwards, it can suggest tidal overdistension; when it's concave downwards, it can indicate tidal recruitment; and

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when it's straight line, it can represent non-injurious ventilation (Jaramillo et al., 2022). Visual examination of the pressure-time curve on the ventilator screen is a straightforward and dependable method for evaluating SI at the bedside in an adult research. The objective of our study is to evaluate the potential for stress index to be implemented in pediatric ICU.

PATIENT AND METHOD:

This prospective cohort study conducted during the year 2025 on fifty mechanically ventilated patients admitted to the PICU of tertiary care hospital. Children having acute lung injury along with/OR acute respiratory distress syndrome (ARDS), sedated as well as mechanically ventilated were included and details about age, sex, diagnosis, ventilatory parameters including pressure of inspiration (PIP), positive end expiratory pressure (PEEP), mean airway pressure (MAP), driving pressure, plateau pressure, tidal volume with calibrated flow sensor, measuring oxygenation index (OI) were recorded.

Subsequently, transitioning to volume control mode, while maintaining the same observed tidal volume achieved throughout pressure control ventilation, showed no leaks over a two-hour period. The parameters for evaluating the pressure-time curve throughout constant flow ventilation (SI) were documented as reported by Sun et al. The absence of spontaneous breathing efforts in the child was confirmed by careful observation of flow as well as paw tracings. A 5-s end-expiratory occlusion was conducted, and the ventilator screen displaying flow-time as well as Paw-t waveforms was frozen to guarantee that the screen contained the complete breath shortly prior to the occlusion,

Reevaluation of the pressure-time curve throughout constant flow ventilation following modification. SI was evaluated through visual inspection of the ventilator waveforms on the pressure-time curve displayed on the ventilator screen. The assessment subsequently classified the pressure-time curve as linear, exhibiting downward concavity, or displaying upward concavity, with the aim of identifying optimal lung inflation, tidal recruitment, as well as alveolar overdistension, respectively (Sun et al.,2018).

Stastical analysis:

The resulting data will be entered on the computer using the Microsoft Office Excel program for Windows on a weekly basis at the end of each working day, then data will be coded and entered in an excel sheet, then will be analyzed utilizing SPSS (Statistical Package for the Social Sciences) program. Numerical data will be presented as mean, SD, as well as range, and will be compared utilizing paired analysis. Non-parametric data will be represented as median as well as interquartile range then analyzed using the Mann-Whitney test. The chi-square test will be employed for the comparison among prior to and following the intervention data. The Mann-Whitney U test, also known as the Wilcoxon test, will be employed for quantitative data. P-value will be considered significant if less than quantitative data) will be used. P-value will be considered significant if less than 0.05

Sample size:

Clin calc online power / sample size calculator was used. The following assumptions were applied: 40% of the population would have satisfactory initial SI; of those who would not, 50% would achieve this after intervention . The calculated minimum sample size of a power of 80% & alpha error of 0.05 was 42. Allowing for incomplete assessment, the planned sample size is 50 subjects.

RESULTS:

Fifty pediatric patients on mechanical ventilation participated in this prospective cohort research. Detailed demographic and clinical information regarding the participants is presented in Table 1. The cohort's mean age was 2.54 years, with a SD of 3.32 years, comprising 20 males as well as 30 females. The leading cause of respiratory failure in these patients was meningitis, accounting for 36% of cases, followed by isolated respiratory failure at 30%, multisystem organ failure at 22%, and pneumonia with congenital heart disease at 12%. Inotropic support was necessary for 64% of the patients, and the overall mortality rate was 68%.

The pressure-time curve throughout constant flow ventilation was visually assessed to categorize the stress index. A linear curve was seen in 30 patients (60%), while 10 patients (20%) exhibited a downward concavity, and another 10 patients (20%) showed an upward concavity. Ventilator settings for the entire group are summarized in Table 2, with a mean PIP of 21.51 cm H_2O, mean airway pressure (MAP) of 11.36 cm H_2O, PEEP of 6.10 cm H_2O, driving pressure (ΔP) of 15.40 cm H_2O, plateau pressure of 17.46 cm H_2O, expired tidal volume (Vte) of 9.73 ml/kg, and oxygenation index (OI) of 6.43.

Table 3 compares the ventilator settings and clinical information among the three categories of stress index. Patients with an upward concavity, which suggests tidal overdistension, were older (mean age 6.71 years) compared to those with linear or downward concavity curves (p=0.041). There were also notable differences in sex distribution, reasons for ventilation, and the use of inotropic medications. Ventilator parameters such as PIP, MAP, PEEP, ΔP, plateau pressure, driving pressure, and OI showed significant variations across the groups ($p<0.05$), with the upward concavity group consistently having higher values.

A binary logistic regression analysis was conducted to determine predictors of poor outcomes in patients with an upward concavity stress index, as shown in Table 4. Significant predictors identified included PIP (OR 0.679, p=0.035), MAP (OR 0.975, p=0.047), plateau pressure (OR 1.072, p=0.046), and driving pressure (OR 0.936, p=0.027). However, PEEP, ΔP, Vte, and OI did not emerge as significant predictors in this analysis.

Table 1: Clinical characteristics and outcome of the study group.

Demographic data	**No.**	**%**
Sex		
Male	20	40.0
Female	30	60.0
Age (years)		
Min. – Max.	0.2 – 14.0	
Mean ± SD.	**2.54** ± 3.32	
Median	1.00	
System failure		
Meningitis and respiratory failure	18	36.0
Pneumonia and Congenital heart disease	6	12.0
Respiratory failure	15	30.0
MSOF	11	22.0
No inotropes	18	36.0
Inotropes	32	64.0
State of Stress index curve		
Linear curve	30	60.0
Downward concavity	10	20.0
Upward concavity	10	20.0
Outcome		
Died	34	68.0
Discharged	16	32.0

MOSF: multiple organ system failure

Table 2: ventilator parameters of the study group

	Mean ± SD.	**Median (IQR)**	**Min. – Max.**
PIP	21.51± 2.28	21 (17 – 25.5)	12 – 36
MAP	11.36 ± 0.99	11 (9 – 12)	6 – 24
PEEP	6.10 ± 0.26	6 (5 – 7)	5– 9
ΔP	15.40± 1.63	15 (12 – 18.5)	7– 30
P plateau	17.46± 1.83	16 (13 – 22.5)	9– 31
Vte	9.73± 0.42	9.6 (7.5 – 11)	5– 17
Driving pressure	11.18± 1.36	10 (8 – 15.5)	3– 23
OI	6.43± 0.48	4.2 (3.4 – 7.1)	1.69– 29.8

PIP: peak inspiratory pressure; MAP; mean airway pressure; PEEP:peak end expiratory pressure;P delt pressure; Vte: tidal volume at expiration; OI: oxygenation index.

Table (3): difference in ventilator parameters according to change in stress indices.

	Linear n=30(60%)	**Downward Concavity n=10 (20%)**	**Upward Concavity n=10 (20%)**	**p**
age				
Min. – Max.	0.2 – 12.5	0.2– 14.0	0.25 – 10.0	0.041*
Age Mean ± SD. (min-max)	1.59± 1.37	6.71± 1.39	2.50± 1.57	
sex				
males.	16(53.3%)	9(90%)	5(50%)	0.011*
females.	14(46.7%)	1(10%)	5(50%)	
cause of ventilation				0.026*
Meningitis and pneumonia	11(36.7%)	10(100%)	1(10%)	
Pneumonia and CHD	7 (23.3%)	0	0	
Respiratory failure	12 (40%)	0	9(90%)	
No inotropes.	10(33.3%)	7(70%)	1(10%)	
inotropes.	20(66.7%)	3(30%)	9(90%)	
PIP* Mean ± SD.(Min-	19.29 ± 1.45(15 – 29)	18. 5 ± 1.09 (12-	31.0 ± 2.91 (26-	

Max)		24)	36)	
MAP* Mean ± SD.(Min-Max)	7.0 ± 15.0	6.0 ± 11.0	13.0 ± 24.0	0.011*
PEEP*Mean ± SD (Min-Max)	5.85 ± 0.07 (5-8)	5.6 ± 0.07 (5-7)	7.44 ± 0.08 (6-9)	
ΔP Mean ± SD.	13.8± 1.75	12.9± 1.85	24.57± 1.75	0.031*
P plateau Mean ± SD(Min-Max)	16.47± 1.4(12-25)	13.6± 0.95 (9-8)	26.5± 0.99(23-31)	0.035*
Vte Mean ± SD.(Min-Max)	9.2± 0.39 (5.8-15)	13.32± 1.51(11-17)	8.25± 1.11(5-10)	0.167
Driving pressure Mean ± SD.(Min-Max)	10.28± 0.51(6-7)	7.33± 0.35(3-10)	18.87± 1.91(16-23)	0.036*
OI Mean ± SD. (Min-Max)	4.33± 0.04 (1.69-8.8)	4.16± 0.09 (1.7-13.5)	15.6± 1.41(7.2-30)	0.027*

PIP: peak inspiratory pressure; MAP; mean airway pressure; PEEP:peak end expiratory pressure; P delt pressure; Vte: tidal volume at expiration; OI: oxygenation index.

Table (4): Binary logistic regression analysis for relevant predictors of the outcome of patients with upward concavity according to stress index

Predictors	B	p-value	OR	95% CI	
				Lower limit	Upper limit
PIP	0.033	0.035*	0.679	0.783	0.965
MAP	0.024	0.047*	0.975	0.879	1.032
PEEP	0.344	0.532	0.856	0.754	1.765
ΔP	1.457	0.064	4.568	0.648	21.498
P plateau	0.023	0.046*	1.072	0.958	1.091
Vte	0.836	0.527	0.382	0.183	1.037
Driving pressure	0.735	0.027*	0.936	0.305	2.547
OI	0.594	0.745	0.875	0.372	2.832

PIP: peak inspiratory pressure; MAP; mean airway pressure; PEEP:peak end expiratory pressure;P delt pressure; Vte: tidal volume at expiration; OI: oxygenation index.

DISCUSSION

Mechanical ventilation poses a challenge for patients with ARDS because it worsens lung injury, which increases the risk of morbidity and mortality associated with the condition. Lung protective ventilation should be the primary focus of early detection and implementation of non-ventilatory as well as ventilatory measures to improve survival (Schneider and Johnson, 2022).

The stress index delineates the configuration of the dynamic pressure-time profile throughout constant flow inflation, which may aid in forecasting the mechanical stress required to mitigate ventilator-induced lung injury (VILI). (Pan et al., 2016). Evaluating respiratory mechanics is crucial for tailoring ventilator settings to reduce VILI. The examination of the dynamic airway pressure time (Paw-t) curve profile serves as a noninvasive, real-time technique for respiratory monitoring at the bedside (Sun et al., 2018).

In the present study, the predominant cause of acute lung injury was neurological insult in 36% of the cases followed by pneumonia in 30% then septic shock with MSOF in 22% and CHD with pneumonia in 12%. Mortality of acute lung injury was 68%. This is close to the study by Saragih et al as their mortality rate ARDS was 73.7%. (Saragih et al., 2024). No previous pediatric studies has investigated the SI in mechanically ventilated pediatric patients.

Our findings indicated that 60% of the cases exhibited a linear curve, 20% demonstrated downward concavity, and 20% displayed upward concavity. This aligns with the findings of Sun XM et al. (2018), who reported that 63% were linear, 27% were downward concave, and 10% were upward concave, as evaluated by the reference method.

Sun et al. (2018) also discovered that visual SI classification has a remarkable concordance with the reference approach, which employed off-line software fitting. The visual inspection method may effectively and reliably differentiate Paw-t curve shapes, facilitating the timely identification of potentially harmful ventilator settings at the bedside. In a study involving 20 children having ARDS, NEVE et al. demonstrated that analyzing the dynamic pressure/time curve throughout constant flow ventilation enables the identification of hyperinflation and correlates well with the findings from the static pressure/volume curve (NÈVE et al., 2000). Previous research by Schwartz et al. noted the necessity to carefully titrate mechanical ventilation, involving both driving pressure as well as PEEP. Our analysis also showed that driving pressure was related with worse patient outcome as well as an upward concavity of the curve. Driving pressure is often described as plateau pressure subtracted by PEEP and indicates lung compliance. The elements of driving pressure must be assessed under steady flow and in the absence of any exertion. Driving pressures over 15 cm H2O are linked to a heightened risk of postoperative respiratory problems as well as mortality (Schwartz et al.,2024)

Cruces indicated that the SI is assessed via visual inspection of ventilator waveforms among patients receiving volume-controlled ventilation (constant flow) without spontaneous breathing, with the pressure-time curve examined immediately from the ventilator display at the bedside. When the stress index is near 1 (0.9–1.1, straight curve), there is very little tidal hyperinflation. A higher stress index (>1.1, upward concavity) correlates with increased tidal hyperinflation (Cruces, 2023). This study revealed that the significant predictors of bad outcome in patients with alveolar hyperinflation or upward curve concavity were PIP, MAP, P plateau, and Driving pressure. Wongsurakiat P. et al. indicated that tidal overdistension is presently assessed by Pplat. Furthermore, it was shown that alveolar overdistension could still happen even when Pplat values were less than or equal to 30 cm H2O. Finding a Pplat value less than or equal to 30 cm H2O alone might not be enough to maximize survival from ARDS, highlighting the need to explore alternatives to the Pplat for lung protective strategies as well as patient outcomes (Wongsurakiat, P. and Yuangtrakul, N.,2019), Lung stress and strain are recognized as essential factors in the initiation and progression of VILI among critically ill individuals (Loring et al., 2010; Hurtado et al., 2020). Moreover, among adults with ARDS, elevated global strain during mechanical ventilation (MV) correlates with heightened mortality, while enhanced outcomes are observed among patients receiving low tidal volume (Vt) during MV, leading to diminished global strain (Cruces, 2023). **Conclusion:** Stress index is an easy tool that can help avoid barotrauma in pediatric invasive ventilation.

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