Description and Validation of a Novel Score (Flow Index) as a Clinical Indicator of the Level of Respiratory Support to Children on High Flow Nasal Cannula

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Abstract

This study's objective was to describe and validate flow index (flow rate × FiO_2/weight) as a method to report the degree of respiratory support by high flow nasal cannula (HFNC) in children. We conducted a retrospective chart review of children managed with HFNC from January 1, 2015 to December 31, 2019. Variables included in the flow index (weight, fraction of inspired oxygen [FiO_2], flow rate) and outcomes (hospital and intensive care unit [ICU] length of stay [LOS], escalation to the ICU) were extracted from medical records. Max flow index was defined by the earliest timestamp when patients FiO_2 × flow rate was maximum. Step-wise regression was used to determine the relationship between outcome (LOS and escalation to ICU) and flow index. Fifteen hundred thirty-seven patients met the study criteria. The median first and maximum flow indexes of the population were 24.1 and 38.1. Both first and maximum flow indexes showed a significant correlation with the LOS ($r = 0.25$ and 0.31, $p < 0.001$). Correlation for the index was stronger than that of the variables used to calculate them and remained significant after controlling for age, race, sex, and diagnoses. Mild, moderate, and severe categories of first and max flow index were derived using quartiles, and they showed significant age and diagnosis independent association with LOS. Patients with first flow index >20 and maximum flow index >59.5 had increased odds ratio of escalation to ICU (odds ratio: 2.39 and 8.08). The first flow index had a negative association with rapid response activation. Flow index is a valid measure for assessing the degree of respiratory support for children on HFNC.

Keywords

- ► acute respiratory failure
- ► children
- ► intensive care unit
- ► oxygen
- ► area under the curve
- ► adult respiratory distress syndrome

Introduction

High flow nasal cannula (HFNC) is increasingly utilized to provide noninvasive support to children with acute respiratory failure.[1,2] As the science behind HFNC matures and the evidence of its benefit accumulates,[3,4] it is also imperative to identify a scoring system to assess the level of respiratory support with HFNC. The score typically used to assess the degree of respiratory failure for intubated patients (oxygenation index)[5] would not apply for a patient on HFNC because of the absence of the essential variable of mean airway pressure. Saturation of peripheral oxygen/fraction of inspired oxygen ([SpO_2/FiO_2] S/F) ratio[6]

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has limited application for patients on HFNC as most patients are expected to have normal oxygen saturations. In adult literature, a scoring system of SpO_2/FiO_2 ratio/respiratory rate (ROX score) has been described to discriminate between patients who would succeed on HFNC (as described by the ability to avoid intubation).[7,8] However, the respiratory rate in children is a very unreliable indicator as it varies with age and periods of agitation.

HFNC provides two degrees of support to the patient, (1) the flow rate, which presumably provides positive end expiratory pressure and assists in lung expansion[9] and (2) FiO_2, which provides support with oxygenation. For children, weight also becomes an essential factor in determining the level of support. Thus, to accurately represent the respiratory support level, all three variables must be considered. This complexity creates an opportunity to develop a single score that would represent respiratory support to the patient.

We want to propose a new equation, which we would call the flow index. This equation includes the flow rate delivered to the patient in liters/minute multiplied by the fraction of inspired oxygen (percentage)/weight (kilograms) or ($FiO_2 \times$ flow rate/weight). We would like to describe this as a communication tool in describing the level of support to the patient and also for its ability to discriminate patients who may require escalation of care to the intensive care unit (ICU), intubation, or a call for a rapid response team (called as Pediatric Emergency Response Team [PERT] at our institution, which includes attending/senior pediatric resident, respiratory therapist, and charge nurse). This study's primary objective was to identify the association of the first and maximum flow index of a patient on HFNC with the severity of illness (using surrogate of hospital length of stay [LOS]). The secondary objective was to identify the sensitivity and specificity of a threshold value of the first and maximum flow index to predict care escalation to ICU and PERT.

Materials and Methods

In this monocentric retrospective study, we identified all children (0–17 years) who required HFNC therapy for respiratory support during their hospitalization at the Children's Hospital of Illinois/OSF Saint Francis Medical Centre in Peoria from January 1, 2015 to December 31, 2019. Children's Hospital of Illinois is a 136-bed tertiary referral hospital with a 16-bed pediatric intensive care unit (PICU). HFNC support is provided at all hospital floors. HFNC titration was performed by personnel trained in its management, according to the institution's protocol. The high flow rate ranged from 0.5 to 2 L/kg/minute, and it was adjusted based on work of breathing and blood gas if available. Hospital also has a robust PERT system, triggered by the Pediatric Early Warning score threshold[10] or nurse/parent concerns. All data were extracted by automated chart review from the electronic medical records. The study was reviewed and approved by the Institutional Review Board with a waiver of the informed consent.

Study Inclusion and Exclusion Criteria

Patients with congenital malformations of the circulatory system, severe sepsis with septic shock, chronic respiratory failure, obstructive sleep apnea, cerebral palsy, pulmonary hypertension, and tracheostomy were identified based on their respective International Classification of Diseases 9/10 (ICD 9/10) codes and excluded from the study. These patients were excluded as their expected titration of oxygen and flow rate may differ from titration in children, not with the aforementioned comorbidities. Patients who died during their hospitalization were excluded as the primary outcome variable was hospital LOS. Patients who had any missing variable required for the calculation of the flow index (FiO_2, flow rate, or the weight) and patients who had a gap of more than 24 hours between two chartings of the flow rate of HFNC were also excluded (as it was not possible to differentiate whether these patients had a gap of HFNC [stopped and then restarted], or if the charting was incomplete).

Study Variables

The variables extracted from the electronic medical records (EMR) included age (in months), sex, race (classified as African American, White, or others), body mass index, admitting diagnoses (subclassified into organ system categories, and further as diagnostic categories of asthma, pneumonia, and bronchiolitis), and patient's initial admitting unit (first nonemergency room department). In our institution, patients with asthma are treated with HFNC if they fail to respond to initial therapy with bronchodilators. It is used in conjunction with other therapies like continuous albuterol and steroids. The initiation or discontinuation of HFNC in asthmatics is based on clinical response and not on any objective score.

For the analysis, age was categorized as infant (<2 years), child (2 years to <12 years), and adolescent (12–17 years). The first and maximum recorded FiO_2 (in percentage) and the oxygen flow rate of HFNC (L/min) were extracted from respiratory charting in the EMR flow sheet. The outcome variables included hospital LOS, ICU LOS (for patients admitted to the ICU), intubation (yes/no), escalation of care (transfer to the ICU after initial admission to the general pediatric/intermediate care floors), PERT activation, and the duration of HFNC therapy. The exact timestamp of patient's arrival to the hospital, escalation to the intensive care unit, PERT activation, intubation, as well as timestamp of the first flow index calculation, and day/time during the patients HFNC therapy when the maximum value of the product of patients FiO_2 and flow rate was first recorded was also obtained. The unit for inclusion in the study was an admission. If the patient was admitted multiple times during the study, each admission was counted separately.

Statistical Analysis

Standard descriptive and comparative analysis were performed with data presented as mean ± SD or median with interquartile range (IQR) for continuous variables and number with percentage for categorical variables. Simple regression was used to determine the relationship between the outcome (LOS) and the individual components of the flow index, weight, FiO_2, oxygen flow rate, the product of flow rate and FiO_2, as well as the flow index itself, to determine the strength of the relationship. Flow index was also included in the step-wise multiple regression model to determine its significance after controlling for additional potentially confounding variables (age, gender, race, and diagnostic categories). Due to positively skewed data on LOS, all analysis of LOS was conducted after log transformation. The geometric mean LOS is reported due to the use of log transformation. In addition to examining the relationship between numeric flow index and the LOS, flow index was also grouped by quartiles to determine if a specific range of the score was related to the LOS (group one [green]; first quartile, group two [yellow]; second and third quartile, and group three [Red], fourth quartile). A separate analysis was conducted for the first and maximum flow index. For patients who were directly admitted to the ICU, the strength of association of ICU LOS with first and maximum flow index was calculated.

For patients who required escalation to the ICU, after admission to the general pediatric floor and patients who required PERT activation, analysis of the relationship between first and maximum flow index and the event's binary occurrence (escalation to ICU or PERT) was conducted by logistic regression. For this analysis, patients whose index was recorded (first or maximal) after the event (ICU transfer or PERT) were excluded. The R package "cutpoint" was used to determine the optimal flow index cutpoint, "threshold," for the classification of transfer or PERT by maximizing the sum of sensitivity and specificity. Because of the low numbers of adolescents in the high flow index category (only nine adolescents above the binary threshold of the high flow index for the first flow index and only one for the maximal flow index), adolescents were excluded from the analysis of the prediction of ICU transfer/PERT based on flow index. Least Absolute Shrinkage and Selection Operator (LASSO) and step-wise regression were used to select variables to include the flow index threshold in multivariate logistic regression on ICU transfer and PERT. Potential predictors included age group, admission diagnostic group, sex, and race. All statistical analysis was performed using the open-source statistical program R (v 4.0.0) and JMP Pro (v14.2, SAS Inc, Cary, North Carolina, United States), against a two-sided alternative hypothesis with a significance level of 5%.

Results

A total of 2,209 patients met the inclusion criteria during the study period (January 1, 2015 to December 31, 2019). Out of these patients, 672 were further excluded. A total of 1,537 patients were included in the analysis. Out of these patients, 352 (22.9%) were directly admitted to the ICU from the emergency department, and 270 (18.5%) patients required escalation to the ICU. One-hundred sixty-two patients (10.5%) required intubation and 288 (18.7%) patients had a PERT activation (►**Fig. 1**).

Study Demographics

The sample was 57% (873/1537) male and 64% (990/1527) Caucasian with a median age of 20 (IQR: 7, 60) months and a

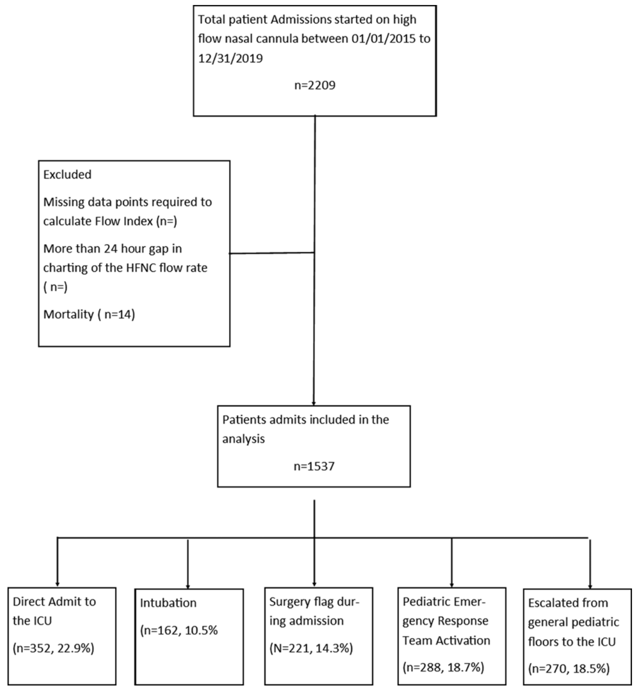

Fig. 1 Patient recruitment flowchart. ICU, intensive care unit.

median weight of 11.2 (IQR: 7.3, 18.8) kg. The median hospital and ICU LOS were 4.5 (IQR: 2.9, 7.3) days and 2.2 (IQR: 1.0, 5.1) days, respectively. The median duration of HFNC therapy was 45 (IQR: 23, 75) hours. The most common admitting diagnosis system was respiratory (80.6%). Among patients in the respiratory category, 230 (14.9%) had a diagnosis of asthma, 291 (18.9%) had bronchiolitis, and 104 (6.7%) had pneumonia. The whole study population's median first flow index was 24.1 (IQR: 13.5, 42.9) $L.min^{-1}.kg^{-1}$, while the median maximal flow index was 38.1 (IQR: 20.6, 64.8) $L.min^{-1}.kg^{-1}$ (►**Table 1**).

Relationship between Flow Index and Hospital/ICU Length of Stay

►**Table 2** shows the results of the simple linear regression between log-transformed hospital and ICU LOS and the first and maximum recorded weight (kg), FiO_2 (percentage), oxygen flow rate (L/min), FiO_2 multiplied by oxygen flow rate and the ($FiO_2 \times$ flow rate/weight). For hospital LOS, weight was not significantly related to the LOS. All other variables showed a significant positive relationship with the LOS, indicating that an increase in these variables would be associated with an increased LOS. Both the first and max flow index had a stronger correlation coefficient than the variables used to calculate them. The first flow index had a correlation coefficient of 0.25 ($p < 0.001$), and the maximum flow index having a correlation coefficient of 0.31($p < 0.001$). Among patients who had initial admission to the ICU, a similar relationship between the various components of the flow index and ICU LOS was observed. The first flow index had a correlation coefficient of 0.21 ($p < 0.001$), and the maximum flow index had a correlation coefficient of 0.27 ($p < 0.001$) with ICU LOS (►**Table 2**).

Table 1 Demographics of the study population

Category	Subcategory	Value
Continuous variables		
Age (mo)		20 (7, 60)
Weight (kg)		11.2 (7.3, 18.8)
Body mass index ($n = 1489$)		16.7 (15.0, 19.0)
ICU length of stay ($n = 693$) (d)		2.2 (1.0, 5.1)
High flow nasal cannula duration (h)		45 (23, 75)
Hospital length of stay (d)		4.5 (2.9, 7.3)
First flow index		24.1 (13.5, 42.9)
Maximum flow index		38.1 (20.6, 64.8)
Categorical variables		
Age	Neonate	82 (5.5%)
	Infant	749 (48.7%)
	Child	580 (37.7%)
	Adolescent	126 (8.1%)
Sex	Female	664 (43.2%)
	Male	873 (56.7%)
Race	Black	415 (27.0%)
	White	990 (64.4%)
	Other	132 (8.5%)
Diagnostic categories	Cardiology	85 (5.5%)
	Endocrine	6 (0.3%)
	GI	14 (0.9%)
	ID	82 (5.3%)
	Neurology	40 (2.6%)
	Oncology	23 (1.4%)
	Other	9 (0.5%)
	Renal	2 (0.1%)
	Respiratory	1239 (80.6%)
	Surgical	19 (1.2%)
	Toxicology	3 (0.1%)
	Trauma	15 (0.9%)

Abbreviations: GI, gastrointestinal; HFNC, high flow nasal cannula; ICU, intensive care unit; ID, infectious diseases.
Note: Values represent median (interquartile range) and frequency (percentage) as applicable. Neurology admission diagnosis included patients with seizure/encephalopathy as admission diagnosis who required HFNC for respiratory compromise.

The first and maximum flow indexes were included in the multivariate regression along with potential confounders of age, race, sex, and diagnostic categories (asthma, pneumonia, and bronchiolitis). LASSO and step-wise linear regression were used to eliminate variables that did not contribute to the model's performance. Both first and maximum flow indexes remained significantly associated with the increased hospital LOS after controlling for other variables. The first flow index relationship with hospital LOS was independent of age and diagnostic categories (impact of first flow index on the LOS was similar for each age group and diagnostic category). However, there was a significant positive ($p = 0.037$) interaction between maximum flow index and child age group. Infants (<2 years) had higher LOS than child age group (2–12 years), but the difference between LOS for infants and child decreased as flow index increased, until it reversed at a very high max flow index. (►**Supplementary Fig. S1** [online only]).

Table 2 Relationship between flow Index and its constituent variables with hospital LOS and ICU LOS

		R^2	R	*p*-Value
Hospital LOS	First value			
	Weight (kg)	0.00	0.00	0.897
	FiO_2	0.01	0.11	<0.001
	O_2 flow rate	0.02	0.13	<0.001
	FiO_2 * O_2 flow rate	0.02	0.13	<0.001
	Flow index	0.06	0.25	<0.001
	Max value			
	Weight (kg)	0.00	0.00	0.897
	FiO_2	0.02	0.14	<0.001
	O_2 flow rate	0.04	0.19	<0.001
	FiO_2 * O_2 flow rate	0.04	0.20	<0.001
	Flow index	0.09	0.31	<0.001
ICU LOS[a]	First value			
	Weight (kg)	0.00	0.00	0.971
	FiO_2	0.02	0.12	0.019
	O_2 flow rate	0.01	0.10	0.062
	FiO_2 * O_2 flow rate	0.01	0.11	0.034
	Flow index	0.04	0.21	<0.001
	Max value			
	Weight (kg)	0.00	0.00	0.971
	FiO_2	0.03	0.16	0.003
	O_2 flow rate	0.02	0.14	0.010
	FiO_2 * O_2 flow rate	0.03	0.18	0.001
	Flow index	0.07	0.27	<0.001

Abbreviations: FiO_2, fraction of inspired oxygen; ICU, intensive care unit; LOS, length of stay.
[a]Only for patients who had initial admission as ICU ($n = 352$).

Mean Length of Stay of Different Flow Index Categories

The first and maximum flow indexes were categorized into three subgroups based on quartiles. The cutoff point for the first flow index was green < 13 L.min^{-1}.kg^{-1}, yellow 13 to <43 L.min^{-1}.kg^{-1}, red > 43 L.min^{-1}.kg^{-1}, and the cutoff for the maximum flow index was green < 20 L.min^{-1}.kg^{-1}, yellow 20 to <64 L.min^{-1}.kg^{-1}, and red ≥ 64 L.min^{-1}.kg^{-1}. Results of simple linear

Table 3 Mean LOS of different flow index categories

	Threshold values	Geometric mean LOS	*p*-Value
First flow index			
Green	<13	4.09 (95% CI: 3.79, 4.42)	
Yellow	13 to <43	4.74 (95% CI: 4.50, 4.99)	0.002
Red	≥43	6.28 (95% CI: 5.83, 6.76)	<0.001
Max flow index			
Green	<20	3.68 (95% C:I 3.42, 3.96)	
Yellow	20 to <64	4.83 (95% CI: 4.59, 5.09)	<0.001
Red	≥64	6.65 (95% CI: 6.19, 7.14)	<0.001

Abbreviations: CI, confidence interval; LOS, length of stay.

regression on log-transformed LOS and first and maximum flow index categories are shown in ►**Table 3**. There was a statistically significant difference in the geometric mean LOS between green and yellow/red categories for both first and maximum flow index.

On multiple regression using the same control variables as described previously (age, race, sex, and diagnostic categories [asthma, pneumonia, and bronchiolitis] and using flow index category, rather than continuous flow index variable), the significant difference of green versus yellow/red categories persisted for both first and maximum flow index. No significant interactions were found between the first or maximum flow index category and other included predictors indicating that the impact of first and maximum flow index categories on LOS was independent of age and admitting diagnosis category of asthma/pneumonia or bronchiolitis.

Prediction of Transfer to ICU (Children 12 Years and Under)

A first flow index value > 20 $L.min^{-1}.kg^{-1}$ was significantly more likely to be associated with an ICU transfer (odds ratio [OR]: 2.4, 95% confidence interval [CI]: 1.7, 3.5) with area under the curve [AUC] of 0.60, a sensitivity of 71.7%, and a specificity of 48.8%. Patients with a first flow index >20 $L.min^{-1}.kg^{-1}$ were expected to have an ICU transfer rate of ~23.4% compared with 11.3% for those with the first flow index <20. Similarly, a maximum flow index greater than 59.5 $L.min^{-1}.kg^{-1}$ was significantly associated with an increased likelihood of being transferred to the ICU (OR: 7.6, 95% CI: 4.8, 12.5,) with an AUC of 0.73, the sensitivity of 65.9%, and specificity of 79.8%. Patients with the maximum flow index > 59.5 $L.min^{-1}.kg^{-1}$ had an ICU transfer rate of 25.9% compared with 4.4% for patients with the maximum flow index <59.5 $L.min^{-1}.kg^{-1}$ (►**Table 4** and ►**Supplementary Fig. S2** [online only]). Separate age group cutoffs (< 2 and 2–12 years) were also calculated and are provided in ►**Supplementary Table S1** (online only).

On multivariable LASSO regression, using additional variables of age group, race, sex, and diagnostic categories of asthma, bronchiolitis, or pneumonia, no other variables were found to contribute to the model's performance above having first flow index >20 $L.min^{-1}.kg^{-1}$ or maximum flow index >59.5 $L.min^{-1}.kg^{-1}$. In a logistic regression with a first flow index over 20 $L.min^{-1}.kg^{-1}$, age group, race, sex, asthma, bronchiolitis, and pneumonia as predictors, a first flow index over 20 $L.min^{-1}.kg^{-1}$ was the only variable found to be significantly associated with an increased likelihood of being transferred to the ICU (OR: 2.34, 95% CI: 1.62, 3.42, $p < 0.001$). Similar results were found when the maximum flow index over 59.5 $L.min^{-1}.kg^{-1}$ was included with age group, race, sex, asthma, bronchiolitis, and pneumonia. A flow index over 59.5 $L.min^{-1}.kg^{-1}$ was the only variable significantly related to an increased likelihood of a transfer to the ICU (OR: 8.08, 95% CI: 4.9, 13.7, $p < 0.001$).

Flow Index and PERT

All the variables associated with the first flow index, except weight, were significantly associated with a decrease in PERT's likelihood; however, the first flow index resulted in the highest AUC at 0.58. None of the components used to calculate the maximum flow index were significantly associated with PERT. The maximum flow index itself was also not significantly associated with PERT and produced an AUC of 0.50. The maximum flow index was excluded from further analysis since it did not show a significant relationship to PERT.

The first flow index had a negative association with the incidence of PERT. A first flow index below 31 was significantly more likely to be associated with PERT (OR: 2.54, 95% CI: 1.77, 3.71, $p < 0.001$) and produced an AUC of 0.59 with a sensitivity of 80.0% and a specificity of 38.8%. Inclusion of the

Table 4 Sensitivity and specificity of escalation to ICU (univariate) and activation of pediatric emergency response team (children 12 and under only)

	Threshold	OR	95% CI	*p*-Value	AUC	Sensitivity	Specificity
Escalation to the pediatric ICU after a general pediatrics admission							
First flow index	>20	2.4	1.7, 3.5	<0.001	0.60	71.7%	48.8%
Max flow index	>59.5	7.6	4.8, 12.5	<0.001	0.73	65.9%	79.8%
PERT activation							
First flow index	<31	2.5	1.7, 3.7	<0.001	0.59	80.0%	38.8%

Abbreviations: AUC, area under the curve; CI, confidence interval; ICU, intensive care unit; OR, odds ratio; PERT, Pediatric Emergency Response Team.
Patients in which the flow index was recorded after the event occurred were excluded. The sample size for ICU transfer and first flow index, 966; ICU transfer and maximum flow index, 878; PERT and first flow index, 939.

race, sex, and age group variables in LASSO regression increased the AUC to 0.64. (►Table 4)

Discussion

In this article, we have described a novel single metric (flow index) to characterize the degree of respiratory support by HFNC in children. We have shown that the flow index is a valid measure to assess disease severity (using hospital LOS as a surrogate marker). We have also categorized the first and maximum flow index values into mild, moderate, and severe categories (described as green, yellow, and red) and further identified the sensitivity and specificity of predicting escalation to ICU and PERT using flow index cutoffs.

Most prior studies on HFNC have focused on its ability to provide noninvasive respiratory support to children and adults.[1] HFNC has also been shown to decrease hospital LOS and requirement of intubation.[11] To the best of our knowledge, no study has investigated methods to quantify respiratory support provided by HFNC. The idea behind the flow index is relatively simple. It is also easy to calculate at the bedside and trend over time. It attempts to answer the question of whether a 10 kg patient who in the morning was on 10 L 30% and now on 6 L 50% is getting the same degree of respiratory support or less/more. The red, yellow, green categories of the flow index provide meaning to the flow index values. They are similar to the oxygenation index[12] and PaO_2/FiO_2[13] categorization of acute respiratory distress syndrome (ARDS). Flow index, as described, only provides information on the support patient is receiving and does not include any patient response variables like saturations or partial pressure of oxygen (PaO_2). This contrasts the flow index from the indexes mentioned earlier. While PaO_2 may vary between different patients, most patients on HFNC do not have arterial lines, and incorporating PaO_2 in the formula would limit its applicability. Even though some studies have shown S/F ratio to predict failure of HFNC therapy in the PICU,[14] in our hospital majority of patients on HFNC have normal saturations (as they are escalated to a higher level of support otherwise); thus, we could not compare flow index with S/F ratio or include patient saturations in the model.

We have used hospital and ICU LOS as surrogate markers for the severity of illness. However, LOS is a crude index for severity as it can be impacted by factors unrelated to the illness.[15] Patients with mortality were excluded from our analysis. Mortality in pediatric patients is very low,[16] and assessing the impact on mortality would require an extremely large dataset. Intubation can serve as a definitive end point for the failure of HFNC therapy. Unfortunately, intubation prediction could not be calculated in our study as precise intubation times were not reliably charted in our EMR.

The impact of age on the performance of the flow index deserves special mention. The score uses the denominator of weight. While the generally accepted practice of HFNC is to use 2 $L.min^{-1}.kg^{-1}$,[2] this is not always possible for older children. For example, it would be relatively common to use a 6 L/min flow rate for a 3 kg infant; it would be uncommon to use 100 L.min for a 50 kg adolescent. Thus, the flow index would be lower for older patients. The flow index category (of red/yellow/green), however, had a significant difference with the LOS even after controlling for age categories, so it would be applicable for all age groups.

The flow index value of 20 $L.min^{-1}.kg^{-1}$ for the first flow index and 59.5 $L.min^{-1}.kg^{-1}$ for the maximum flow index provides a cutoff for maximum AUC for the risk of ICU admission. Even though the OR for escalation to ICU using the cutoffs is high, sensitivity and specificity on linear scales are low. However, they are applicable for all age groups (12 and under) and diagnostic categories of bronchiolitis, asthma, and pneumonia. Thus, they can potentially be utilized as decision points for escalating care on patients on HFNC on general pediatric floors.

The negative association of the first flow index with the PERT call was an unexpected observation. Although PERT calls are based on various patient/provider factors,[17,18] one of the criteria is an escalation of patients' oxygenation or flow rate. Thus, if the patient was started on a very low degree of respiratory support (low-flow index) and required escalation, later on, the chances of him having a PERT call would be higher. This association, however, should be evaluated further in future studies.

Flow index, as described in our study, has several limitations. First, even though the flow index performs better than the individual component, the overall correlation of the flow index with the LOS is small. The flow index's discriminating ability diminishes with age, although the flow index categories maintain an independent association with LOS irrespective of the age categories. Second, as a retrospective study, HFNC protocol was not standardized, and there may be minor variations between different physicians in weaning and escalations of flow rate and FiO_2. Third, ideal body weight was not available to us and was not utilized in the model. While it may yield better model performance, it may have limited clinical utility as it is not readily available to clinicians. Obesity, in particular, can impact HFNC duration and was not evaluated in our study. Fourth, the score gives equal weightage to the flow rate in liters per minute and the FiO_2. It thus does not discriminate between hypoxemic and hypercapnic respiratory failure. For example, a patient with asthma might need a higher flow rate, but low FiO_2 than a patient with ARDS who may need both a higher flow rate and FiO_2. Thus, the patient's score with asthma and ARDS may not be comparable to assess the severity of illness. There could be bias in the score if the patient has mixed obstructive and restrictive component. Our study, however, showed that the association of flow index with the LOS and risk of ICU admission persisted even after controlling for the three main diagnostic categories. Finally, escalation to ICU and PERT is very hospital policy-sensitive parameters and may not have external validity.

Conclusion

Flow index ($FiO_2 \times$ flow rate/weight) can be used as a metric for rapid assessment and communication of the degree of respiratory support in children on high flow nasal cannula. Absolute and mild/moderate/severe categories have a significant association with the hospital LOS. A single value (flow index: FiO_2 flow/weight) is a valid measure of the degree of respiratory support to children on HFNC. High flow index is associated with worse outcomes and risk of ICU transfer. Further studies should look at independent validation in a different patient population and possibly including patient response variables like work of breathing/respiratory rate to increase its accuracy.

Note

This study has been accepted for oral presentation as “STAR research” for the 50th National Congress of the Society of Critical Care Medicine (SCCM), February 2 to 13, 2021. Abstract from this study has been accepted for presentation at the Virtual Pediatric Academic Society (PAS) meeting 2021.

Authors’ Contributions

S.T. conceptualized and designed the study, assisted in data extraction, supervised analysis and interpretation, and wrote the final manuscript. J.M. conducted the statistical analysis and interpretation and assisted in drafting the methodology and results. N.S. assisted in the design, literature search, and proposal development. L.M. extracted all the data from electronic medical records and its validation. All authors reviewed and approved the final manuscript as written.

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Conflict of Interest

None declared.

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