RESEARCH ARTICLE

Effect of a Hospital-wide High-Flow Nasal Cannula Protocol on Clinical Outcomes and Resource Utilization of Bronchiolitis Patients Admitted to the PICU

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ABSTRACT

OBJECTIVE: To assess the association of the introduction of a high-flow nasal cannula (HFNC) protocol with clinical outcomes and hospital charges of infants with bronchiolitis initially admitted to the PICU.

METHODS: We conducted a retrospective, nonrandomized, preintervention-postintervention study of infants with bronchiolitis initially admitted to the PICU for HFNC. We compared patients admitted in the 24 months before and after protocol initiation for HFNC use on the general wards. The primary outcome assessed was length of hospital stay (LOS), and the secondary outcomes included total hospital charges, intubation, and 30-day readmission. We conducted bivariate analysis using χ^2 test for categorical variables and Student's t test or Wilcoxon rank sum test for continuous variables.

RESULTS: Two hundred and ninety patients were admitted to the PICU on HFNC; 120 patients were admitted before and 170 admitted after the introduction of HFNC use on the general wards. Comparing the 2 groups, the median LOS was significantly reduced (4 days vs 3 days; $P < .001$), as was the median total hospital charges ($12 257 vs $9337; $P < .001$). After starting HFNC use on the wards, 30% of patients initially admitted to the PICU were ultimately transferred to the wards while still on HFNC. There was no difference in intubation rate or 30-day readmission between the 2 groups.

CONCLUSIONS: For bronchiolitis patients initially admitted to the PICU, initiating a guideline for HFNC use on the general pediatric wards is associated with reduced total hospital LOS and total hospital charges, with no difference in intubation rates or 30-day readmission.

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Bronchiolitis is the most common cause of hospitalization of infants <1 year old in the United States, and the cost of care for these infants is high.[1] High-flow nasal cannula (HFNC) therapy for infants with bronchiolitis is used in some centers around the United States, but its impact on outcomes and resource utilization is unclear. The mechanism of efficacy is explained variably in the literature, with multiple proposed mechanisms.[2] Recent studies of infants in the ICU setting noted increases in end-expiratory lung vol and slower respiratory rates among infants on HFNC.[3,4] Currently there are few data available to drive decision-making from an institutional level regarding whether to allow this therapy on the general wards. No study has looked at cost-related outcomes regarding this therapy nor how the therapy affects frequency or duration of care in the ICU. Two large reviews found that there were insufficient data to warrant a summary statement on the efficacy of this therapy.[5,6]

There is evidence that HFNC is effective at reducing intubation in the emergency department and ICU setting.[3,7,8] Additionally, safety for the therapy when used on the general wards has been demonstrated in several small studies.[9–12] However, as the cost savings, impact on length of stay, and other parameters are unclear, the AAP Bronchiolitis Guidelines from 2014 called for more research on the efficacy of HFNC in pediatric bronchiolitis.[13]

The objective of this study was to assess the association of the introduction of HFNC therapy on the general wards with clinical outcomes and resource utilization of children initially admitted to the ICU with bronchiolitis. Our primary outcome measure was total length of stay (LOS) for patients initially admitted to the PICU. Additionally, we sought to measure the association of total hospital charges, intubation rates, and 30-day readmission with the introduction of this new protocol for infants with bronchiolitis.

METHODS

Study Design and Participants

We conducted a retrospective, nonrandomized, preintervention-postintervention study of infants aged <24 months admitted to the PICU with a diagnosis of bronchiolitis to Hasbro Children's Hospital between April 1, 2010 and March 31, 2014. Hasbro Children's Hospital is a tertiary care facility located in Providence, Rhode Island. This site admits ~600 patients for bronchiolitis annually. It is the principal tertiary pediatric care center for the state of Rhode Island and bordering communities and serves a predominantly urban and suburban population.

HFNC Protocol

In March 2012, Hasbro Children's Hospital initiated an institutional protocol for HFNC use on the general wards. The protocol stated that a patient in the ICU on HFNC could be transferred to the general wards while continuing this therapy, a patient could be initially admitted to the wards on HFNC, or the therapy could be initiated for an established patient on the wards. It includes guidelines for indications, initiation, and weaning of HFNC.[14] Flow limitations based on patient age are recommended, above which attending and respiratory therapy discussion is warranted. Maximum flow for patients <6 months old is 8 L/minute, 6 months to 18 months is 12 L/minute, and patients ≥18 to 24 months the max flow is 15 L/minute. Ability to wean off HFNC is based on patient work of breathing, respiratory rate, and improvements in other clinical factors. Patients are able to begin transition off HFNC once those patients <18 months old are receiving 2 L/minute, and patients ≥18 months are receiving 4 L/minute, both while additionally requiring <40% fraction of inspired oxygen to maintain oxygen saturation ≥92% (Fig 1).

Data Collection

For the current study, we compared patients admitted to the PICU in the 24 months before and 24 months after the introduction of the HFNC protocol. The hospital billing database was used to identify patients who were admitted with bronchiolitis during the 2 study time periods, and data contained within the database was extracted electronically. Additionally, chart review was conducted by the primary researcher and 1 research assistant, each of whom were unblinded to the nature of the study.

Inclusion and Exclusion Criteria

All charts with any discharge diagnosis with *International Classification of Disease, Ninth Edition*, codes 466.19 (non–respiratory syncytial virus [RSV] bronchiolitis), 466.11 (RSV bronchiolitis), 786.03 (apnea), 465.9 (acute upper respiratory infection), and V73.99 (unspecified viral illness) were screened for inclusion by reviewers as part of a larger chart review of all patients with bronchiolitis. Patients were included in the current study if they were initially admitted to the PICU and received HFNC therapy in that setting. We defined high flow as >2 L/minute while using a heated humidification device, which is consistent with other studies.[3,15] We excluded patients >24 months of age, to reduce inclusion of nonbronchiolitis acute respiratory infections, as well as children hospitalized >21 days, to reduce inclusion of patients with a more complex course. We excluded infants <37 weeks' gestation as well as patients with specific diagnoses of chronic lung diseases, asthma, chromosomal abnormalities, heart disease, and neurologic diseases. This study was approved by the hospital's institutional review board.

Outcome Measures

The primary outcome assessed was LOS (in integer days) after initiation of general ward HFNC protocol. Secondary clinical outcomes including total hospital charges and potential adverse outcomes (intubation and 30-day readmission [yes/no]) were recorded by chart reviewers from documentation within the medical record. Total hospital charges were provided by institutional billing department and included charges for entire hospitalization.

Other Covariates

Demographic data including age, gender, and race/ethnicity were extracted electronically by the hospital billing database. Severity levels (1 = minor to 4 = extreme) for each patient encounter were obtained from All Patient Refined Diagnosis-Related Groups (APR-DRG) documentation provided by the billing department. The research team recorded insurance status (private, public, or uninsured) from the patient demographic sheet (completed by registration at the time

HFNC Initiation Guidelines

Age	Initial Settings	Limitations*	Considerations
<6 mo	Initial flow rate = 2 L/min, titrate to max 8 L/min; adjust FiO_2 to maintain O_2sat ≥92%†	Patient requires flow rates >8L/min	• Inititation of HFNC may occur on the wards, and patients may remain on the wards as long as clinical stability is established. • Higher flow rates may be needed on the basis of clinical judgment and patient disease process. • Once initial flow rate is established, wean FiO_2 to lowest % tolerated to maintain target O_2sat.
6–18 mo	Initial flow rate = 4LPM, titrate to max 12LPM	Patient requires flow rates >12L/min	
≥18 mo	Initial flow rate = 8LPM, titrate to max 15LPM	Patient requires flow rates >15L/min	

Indications for Use

- Patient with increased work of breathing; otherwise stable with no significant apnea or bradycardia.
- Reduce the work of breathing in patients with moderate to severe respiratory distress.
- Aid in transition from positive pressure ventilation (BIPAP/mechanical ventilation) to standard nasal cannula or room air.

HFNC Weaning Guidelines

Age	Weaning Guidelines	Considerations
<18 mo	Patient receiving 2L/min via HFNC and requires FiO_2 ≤40%, can transition to standard NC ≤1 L/min to maintain O_2sat ≥92%	• Weaning should be discussed during patient rounds. • Weaning of flow rate is based on work of breathing, RR, and improvements in Bronchiolitis Score.
≥18 mo	Patient receiving 4LPM via HFNC, and requires FiO_2 ≤40%, can transition to standard NC <=2LPM to maintain O_2sat ≥92%	

Special Considerations

- HFNC is not meant to substitute for patients requiring NIPPV (CPAP/BIPAP).
- Caution in patients with functional or anatomic bowel obstruction. Higher flows can cause abdominal distention.
- Caution placing patients with rapidly progressive respiratory distress or impending respiratory failiure on HFNC because they require close monitoring and assessment.
- If frequent adjustments in flow are required, it may be necessary to consider other means of respiratory support.

FIGURE 1 HFNC protocol for use on the general wards. BIPAP, biphasic positive airway pressure; CPAP, continuous airway pressure; FiO_2, fraction of inspired oxygen; NIPPV, noninvasive positive pressure ventilation; RR, respiratory rate. *Discussion with attending physician and respiratory therapy. †FiO_2 to be adjusted to maintain O_2sat ≥92% for each setting.

of admission). Reviewers examined patients' charted admission history and recorded secondhand smoke exposure (yes/no) if it was noted in the record. Chart reviewers also collected information on diagnostic testing in any clinical area (RSV [positive, negative, or not tested] and chest radiograph [yes/no]), therapeutic interventions of maximum HFNC rate (L/minute), total number of days of HFNC, and bronchodilator use (yes/no) at any time upon presentation or during admission.

Interrater Reliability

Ten percent of charts of patients on HFNC were randomly selected and reviewed by the 2 abstractors, each with 9 indicators per chart. Charts were considered discrepant if any indicator differed between abstractors. The Cohen's κ score for overall interrater reliability was 0.92 (95% confidence interval, 0.84–0.99), with a chart review agreement of 96%. Conflicting data were re-reviewed by both reviewers for final resolution.

Data Analysis

Using Stata version 12.1 (College Station, TX), descriptive statistics were calculated to characterize the overall study population. We reported counts and proportions for categorical variables, mean and 95% confidence interval for normally distributed continuous variables and medians and interquartile range (IQR) for skewed variables. We created 2 groups of patients to compare, those initially admitted to the PICU during the 24 months before the introduction of the HFNC protocol and those admitted to the PICU during the 24 months after the start of the protocol. We then conducted bivariate analysis using χ^2 test for categorical variables and Student's t test or Wilcoxon rank sum test for continuous variables. Results were considered significant if a 2-sided P value was $<.05$. Because we suspected some colinearity between total hospital charges and LOS, we conducted multivariate linear regression to test the association between total hospital charges between cohorts while controlling for LOS.

RESULTS

One hundred and twenty patients were initially admitted to the PICU in the 24 months before introduction of HFNC on the general wards ("before group") and 170 admitted in the 24 months after ("after group") (Fig 2).

The baseline characteristics of the 2 groups are presented in Table 1. There was no significant difference in age, gender, race, insurance status, and secondhand smoke exposure.

Table 2 summarizes unadjusted analysis including diagnostic testing, therapeutic interventions occurring in any clinical area during hospitalization, clinical outcomes, and total hospital charges. Comparing the 2 groups of bronchiolitis patients admitted to the PICU for HFNC, there was no significant difference in RSV positivity or bronchodilator use. Fewer patients had a

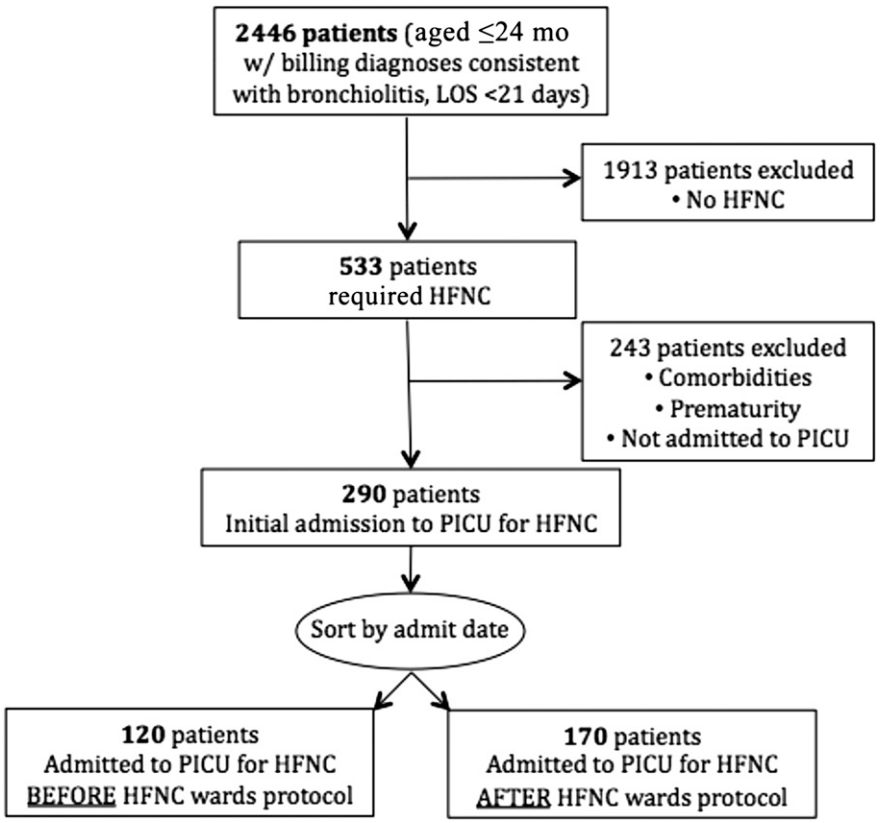

FIGURE 2 Chart selection study flow diagram.

chest radiograph in the group after HFNC was introduced on the wards.

In the unadjusted comparison of the 2 groups before and after introduction of HFNC on the general wards, the median total LOS for bronchiolitis patients admitted to the PICU was significantly reduced by 1 day (4 days, IQR 3–5 vs 3 days, IQR 2–4; $P < .001$). The median total hospital charges were also significantly reduced ($12 257, IQR $8365–$17 226 vs $9337, IQR $6882–$12 624; $P < .001$). Using multivariate linear regression, the significant difference in total hospital charges is no longer significant when controlling for LOS ($P = .39$), and no other independent variables were noted on our analysis.

Using APR-DRG severity levels, we found the after group had a significantly higher mean severity level (2.1 vs 1.6; $P < .001$). When controlling for illness severity using multivariable linear regression, LOS remained significantly shorter in the after group compared with before the HFNC protocol.

Of those patients requiring HFNC at any point during hospitalization, there was no difference in the proportion initially admitted to the PICU between the before and after groups (120/208 = 57.7% vs 170/325 = 52.3%; $P = .25$). In the 24 months after HFNC use on the wards, 30% (51/170) of patients initially admitted to the PICU were ultimately transferred to the wards while still on HFNC. Of these patients, 82.4% (42/51) were transferred to a hospitalist service. The mean age of these patients was 7.2 months, and the average flow rate upon transfer was 4.7 L/minute. There was no difference in the proportion of patients transferred back to the PICU between the 2 groups (5.0% vs 2.9%; $P = .37$).

After introduction of HFNC on the general wards, mean max flow rate (liters per minute) and mean number of days of HFNC were significantly less (9 vs 7.4 L/minute; and 2.4 vs 1.8 days, respectively; $P < .001$). There were no cases of pneumothorax or other complications from HFNC use on the general wards in this cohort. Additionally, there was no difference in intubation rate or 30-day readmission between the 2 groups, and there were no deaths in either group.

TABLE 1 Baseline Characteristics of Bronchiolitis Patients on HFNC Admitted to the PICU Before and After Implementation of HFNC on the General Pediatric Wards ($N = 290$)

	Before ($n = 120$)	After ($n = 170$)	P
Median age (mo)	4 (IQR 2–9)	7 (IQR 2–12)	.076
Male, *n* (%)	68/120 (56.7)	100/170 (58.8)	.71
Race, *n* (%)			.23
White	75/120 (62.5)	122/170 (71.8)	
Black	14/120 (11.7)	13/170 (7.6)	
Other	31/120 (25.8)	35/170 (20.6)	
Public insurance, *n* (%)	92/120 (76.7)	127/170 (74.7)	.70
Secondhand smoke exposure, *n* (%)	38/104 (36.5)	52/156 (33.3)	.59

DISCUSSION

Currently there is a paucity of available evidence for clinical outcomes of HFNC use in bronchiolitis. To date, our study is the second largest ($N = 290$) to investigate HFNC use in bronchiolitis and the first to examine its association with hospital LOS. Although patients initially admitted to the PICU for HFNC accounted for only half of the total bronchiolitis patients on HFNC in our institution, examining this cohort gives a concrete, easily comparable group in which to evaluate outcomes associated with a ward HFNC protocol. We found implementation of this protocol was associated with both reduced total LOS and total hospital charges for patients with bronchiolitis initially admitted to the PICU. Additionally, we found that weaning of HFNC was faster during the second time period when HFNC was available on the wards.

TABLE 2 Interventions Performed and Clinical Outcomes of Bronchiolitis Patients on HFNC Admitted to the PICU Before and After Implementation of HFNC on the General Pediatric Wards ($N = 290$)

	Before ($n = 120$)	After ($n = 170$)	P
Diagnostic testing, *n* (%)			
RSV positive	61/96 (63.5)	55/102 (53.9)	.17
Chest radiograph	94/119 (79.0)	109/170 (64.1)	.006
Therapeutic interventions			
Mean Max HFNC rate (L/min)	9.0 (SD 2.5 L) (95% CI 8.6–9.5)	7.4 (SD 2.2 L) (95% CI 7.0–7.7)	<.001
Mean days of HFNC	2.4 (SD 1.4) (95% CI 2.2–2.7)	1.8 (SD 1.4) (95% CI 1.6–2.0)	<.001
Intubation, *n* (%)	9/120 (7.5)	11/170 (6.5)	.73
Bronchodilator use, *n* (%)	101/120 (84.2)	137/170 (80.6)	.43
Clinical outcomes			
Median total LOS (d)	4 (IQR 3–5)	3 (IQR 2–4)	<.001
Median total hospital charges	$12 257 (IQR 8365–17 226)	$9337 (IQR 6882–12 624)	<.001[a]
APR-DRG severity level	1.6 (SD 0.6) (95% CI 1.5–1.7)	2.1 (SD 0.8) (95% CI 2.0–2.2)	<.001
Transfer to wards on HFNC, *n* (%)	0/120 (0)	51/170 (30.0)	<.001
Transfer back to PICU, *n* (%)	6/120 (5.0)	5/170 (2.9)	.37
30-d readmission, *n* (%)	11/120 (9.2)	13/170 (7.7)	.64

APR-DRG: 1 = minor to 4 = extreme. CI, confidence interval.
[a] Difference in total hospital charges is no longer significant after controlling for LOS.

The reduced total hospital charges are entirely attributed to the shorter total LOS in the after group. Although LOS is the main driver of reduced total hospital charges, it is nonetheless notable. The etiology of the reduced LOS in the after group is unclear. However, we found that after the introduction of an HFNC wards protocol, 30% of patients initially admitted to the PICU were transferred to the general wards while still requiring HFNC, with the majority (82.4%) to a hospitalist service. Although no study to date has compared patient outcomes between pediatric general wards and PICU management of bronchiolitis, we present evidence that general wards care is associated with lower LOS and lower total hospital charges for bronchiolitis patients initially admitted to the PICU after the availability of HFNC use on the general wards. The applicability of these findings to other diagnoses and methods of management in the 2 settings is unclear. A recent review article comparing pediatric hospitalist versus nonhospitalist systems of care in 11 studies found mixed results in LOS and cost,[16] but none of the reviewed studies compared HFNC management for bronchiolitis.

There were a greater number of overall patients in the after cohort, and therefore more patients who received HFNC therapy. Although this increased use may result in less ill patients being placed on HFNC, and thus explain the reduced LOS, we instead found that the after group had more severe bronchiolitis when comparing APR-DRG severity levels between the 2 groups, and the reduced LOS remained statistically significant when controlling for severity.

There are limitations to our study. A significant limitation of a single-site nonrandomized, preintervention-postintervention study design is difficulty in controlling for confounding variables. Although we compare some baseline patient demographic characteristics, there is the possibility the outcome differences could be explained by seasonal variation, patient level factors, or other unmeasured confounding variables. Additional limitations of a before and after assessment is the lack of control for secular trends, and the absence of controls for the intervention of interest.

We had more patients in the after group cohort (170 vs 120). A previous study found that increased inpatient prevalence of bronchiolitis is associated with a decrease in resource utilization.[17] Therefore, it is possible the increased volume in our after group may explain the reduced LOS via changes in PICU utilization rather than be simple artifact.

HFNC has been increasingly used in bronchiolitis because of its tolerance and ease of use but is restricted to the ICU setting in many pediatric hospitals. Our findings are generalizable only to hospitals that perform HFNC on the general wards, but our study may be relevant to institutions looking for more evidence to allow HFNC use on the general wards due to its association with decreased hospital LOS and hospital charges.

The patients in our study have the specific clinical condition of initial PICU admission. We did not compare all patients who were on HFNC at some time during hospitalization and therefore excluded those patients initially admitted to the floor and subsequently transferred to the PICU; thus, we cannot comment on that cohort.

We used APR-DRG severity levels to measure severity rather than patients' respiratory distress scores, which have been used in a recent study of ICU bronchiolitis management,[18] due to the inconsistent documentation of respiratory scores in our charts. The indications for intubation (ie, hypercapnia, respiratory fatigue, persistent apneas) were not recorded so we are unable to comment whether intubation was a subjective decision by individual intensivists or based on specific clinical factors.

LOS was measured in integer number of days. We were unable to measure LOS in actual time between admission and discharge, which may result in the difference in LOS being overstated. Additionally, we were unable to quantify total length of time in the PICU and therefore could not directly compare PICU LOS between the 2 groups or how PICU LOS contributed to overall hospital charges. We can hypothesize that the PICU LOS was greater in the before group because this group had significantly more days of HFNC, which before the wards protocol would need to occur solely in the PICU.

In terms of cost, it is difficult to address the true cost reduction because the value is multifactorial and includes payer, hospital, patient, and physician provider variables. We restricted cost analysis to the total billable hospital charges.

Although we showed reduced total LOS and hospital charges for bronchiolitis patients initially admitted to the PICU with the availability of HFNC on the general wards, more research is required to provide additional evidence of the patient outcomes and associated cost of HFNC use in bronchiolitis.

CONCLUSIONS

For bronchiolitis patients initially admitted to the PICU, initiating a guideline for HFNC use on the general pediatric wards is associated with reduced total hospital LOS and total hospital charges, with no difference in intubation rates or 30-day readmission.

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