

Clinical Efficacy of Heated Humidified High-Flow Nasal Cannula versus Conventional Oxygen Therapy in Children Aged 2–24 Months with Bronchiolitis: A Prospective Observational Study

Authors:

Abhishek Kumar¹, Yogesh Chandra¹, Krishan Kr Jha², Rizwan Haider³, Farhan Abdul Hai¹, Annpurna Adarsh¹, Shiwali Singh¹, Anjali Kumari¹

¹Junior Resident (Academic), Department of Pediatrics, Darbhanga Medical College & Hospital, Laheriasarai, Darbhanga, Bihar- 846003, India.

²Associate Professor, Department of Pediatrics, Darbhanga Medical College & Hospital, Laheriasarai, Darbhanga, Bihar- 846 003, India.

³Professor & H.O.D., Department of Pediatrics, Darbhanga Medical College & Hospital, Laheriasarai, Darbhanga, Bihar- 846 003, India.

*Corresponding Author:

Dr. Yogesh Chandra, Junior Resident (Academic), Department of Pediatrics, Darbhanga Medical College & Hospital, Laheriasarai, Darbhanga, Bihar- 846003, India.

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ABSTRACT

Background: Bronchiolitis remains a major cause of respiratory distress and hospitalization during the first two years of life. Heated humidified high-flow nasal cannula (HHHFNC) has emerged as a non-invasive alternative to conventional low-flow oxygen, but real-world evidence from ward-based settings remains valuable. **Methods:** This prospective observational hospital-based study included 200 children aged 2–24 months admitted with bronchiolitis. One hundred children received conventional oxygen and 100 received HHHFNC in addition to standard supportive care. Demographic features, baseline physiological parameters, clinical signs, oxygen response, treatment failure, duration of oxygen therapy, hospital stay, referral, and mortality were compared. Categorical variables were analyzed with the chi-square test and continuous variables with Student's t-test or analysis of variance; correlation and multivariable logistic regression were also performed. A two-sided p value below 0.05 was considered statistically significant. **Results:** The groups were similar in age, sex distribution, pulse rate, admission oxygen saturation, temperature, and illness duration. Both treatments rapidly improved mean SpO₂, with comparable values at 1 hour and 24 hours. Treatment failure was substantially lower with HHHFNC than with conventional oxygen (9.0% versus 22.0%; p=0.012), and recovery was correspondingly higher (91.0% versus 78.0%). Referral and mortality were also lower with HHHFNC, although these differences did not reach statistical significance. Oxygen therapy and hospital stay were longer in the HHHFNC cohort. Respiratory rate predicted treatment failure in the conventional oxygen group, while no baseline predictor was significant in the HHHFNC group. **Conclusions:** HHHFNC was associated with lower treatment failure and higher recovery than conventional oxygen in children hospitalized with bronchiolitis. Its benefits were observed across age, sex, and clinical-sign subgroups. Optimized weaning protocols may help reduce the longer treatment and observation periods observed in routine practice.

Keywords: bronchiolitis; child; high-flow nasal cannula; heated humidified oxygen; non-invasive ventilation; oxygen saturation; respiratory rate; treatment failure

1. INTRODUCTION

Acute bronchiolitis is one of the most common causes of respiratory illness and hospitalization during infancy.

The condition is characterized by inflammation of the small conducting airways, mucus production, epithelial injury, and transient airway obstruction. Clinical

manifestations may range from upper respiratory symptoms such as rhinorrhea and cough to tachypnea, wheezing, chest retractions, feeding difficulty, and hypoxemia [1,2]. Because infants have relatively narrow airways and limited physiological respiratory reserve, even moderate airway edema and mucus accumulation may result in clinically significant respiratory compromise [3,4].

Respiratory syncytial virus (RSV) is the leading viral cause of bronchiolitis, although other respiratory viruses, including rhinovirus, parainfluenza virus, influenza virus, adenovirus, and human metapneumovirus, may also contribute to the disease burden [2,17]. Several factors have been associated with more severe disease, including prematurity, low birth weight, chronic lung disease, congenital heart disease, immunodeficiency, exposure to tobacco smoke, and crowded living conditions [15,16,18–20]. Severe bronchiolitis can place substantial pressure on pediatric healthcare services, particularly in resource-constrained settings where seasonal admissions may challenge the availability of oxygen supplies, monitoring facilities, pediatric beds, and intensive care services [13,14].

Management of bronchiolitis is predominantly supportive. Adequate hydration, clinical monitoring, and correction of hypoxemia remain the principal components of treatment, while routine pharmacological therapy is not recommended for most infants [4,22–24]. Conventional oxygen therapy delivered through low-flow nasal cannulae or other standard oxygen-delivery devices is effective for many children with hypoxemia. However, conventional oxygen may provide limited respiratory support in children with substantial work of breathing or progressive respiratory distress [5,6,11].

Heated humidified high-flow nasal cannula (HHHFNC) therapy delivers a heated and humidified mixture of air and oxygen at relatively high flow rates through appropriately sized nasal prongs. High-flow therapy may improve mucociliary function, wash out nasopharyngeal dead space, reduce entrainment of room air, meet a greater proportion of inspiratory flow demand, and generate a degree of positive airway pressure that may help maintain airway patency and improve alveolar recruitment [28–34]. These physiological effects may reduce respiratory effort and potentially decrease the need for escalation to more intensive non-invasive or invasive respiratory support [7,8,29].

The use of HHHFNC has expanded beyond pediatric intensive care units to general pediatric wards. This is particularly relevant because many children with bronchiolitis require oxygen and close clinical monitoring without an immediate indication for intensive care. Previous randomized trials, observational studies, and systematic reviews have reported improvements in clinical outcomes and reductions in

treatment escalation with high-flow therapy compared with standard oxygen therapy, although the effects on oxygen duration and hospital length of stay have varied according to patient population, disease severity, treatment protocols, and clinical setting [6,7,35–42].

Despite increasing use of HHHFNC, evidence from routine ward-based practice in resource-conscious healthcare settings remains important. In particular, information regarding treatment failure, oxygen response, duration of oxygen therapy, hospital stay, and factors associated with treatment failure may help clinicians optimize the use of high-flow therapy.

Therefore, the present prospective observational study was conducted in a tertiary pediatric unit at Darbhanga Medical College and Hospital, Bihar, India, to compare the clinical efficacy of HHHFNC with conventional oxygen therapy in children aged 2–24 months hospitalized with bronchiolitis. The study evaluated treatment failure, recovery, oxygenation response, duration of oxygen therapy, hospital stay, referral, mortality, and clinical predictors of treatment failure.

2. MATERIALS AND METHODS

2.1 Study design and setting

This prospective, hospital-based observational study was conducted in the Department of Pediatrics, Darbhanga Medical College and Hospital, Laheriasarai, Bihar, India, over a two-year period. Children admitted to the pediatric inpatient unit with a clinical diagnosis of bronchiolitis were screened for eligibility and followed throughout their hospitalization.

The study compared two treatment cohorts: children who received conventional oxygen therapy and those who received heated humidified high-flow nasal cannula (HHHFNC) therapy in addition to standard supportive care. Treatment allocation was not randomized; the choice of respiratory support reflected clinical need and routine treatment practice.

2.2 Participants

Children aged 2–24 months who were admitted with clinically diagnosed bronchiolitis and required oxygen-supported inpatient care were considered eligible for participation. A total of 200 children were included in the study, comprising 100 children who received conventional oxygen therapy and 100 who received HHHFNC therapy.

Clinical features considered consistent with bronchiolitis included rhinorrhea, cough, dyspnea, tachypnea, wheezing, chest retractions, and reduced oxygen saturation. All participants were evaluated clinically at admission and monitored during hospitalization.

2.3 Inclusion criteria

Children were included if they met the following criteria:

- Age between 2 and 24 months.
- Clinical presentation consistent with bronchiolitis.
- Symptoms or signs of lower respiratory tract involvement, including cough, rhinorrhea, or dyspnea.
- Evidence of respiratory distress, including tachypnea, wheezing, chest retractions, or reduced oxygen saturation.
- Admission to the pediatric inpatient department with an indication for oxygen therapy.
- Written informed consent obtained from a parent or legal guardian.

2.4 Exclusion criteria

Children were excluded if they had any of the following:

- Structural deformity of the upper airway.
- Impending respiratory failure requiring immediate ventilatory support.
- Radiological evidence of pneumonia.
- Congenital pulmonary malformation.
- Chronic cardiovascular or chronic respiratory disease.
- Known immunodeficiency.
- A family history of asthma or atopy.

2.5 Sample size

The study included 200 children who fulfilled the eligibility criteria, with 100 participants in each treatment cohort.

For the observational prevalence-based sample-size estimation, the formula:

$$n = Z^2pq/d^2$$

was used, where **Z = 1.96**, **p = 0.70**, **q = 0.30**, and **d = 0.06**. Based on these assumptions, the required sample size was approximately 200 participants. This sample size was considered appropriate for the institutional admission pattern and for evaluating clinical outcomes associated with HHHFNC and conventional oxygen therapy in the study population.

2.6 Data collection and intervention

After obtaining informed consent, demographic and clinical information was recorded using a structured data collection format. Variables documented at admission included age, sex, duration of illness, respiratory rate, pulse rate, axillary temperature, peripheral oxygen saturation (SpO₂), chest retractions, and wheezing.

All children received standard supportive management according to clinical requirements, including hydration, monitoring, and oxygen therapy when indicated.

In the HHHFNC group, heated and humidified respiratory gas was delivered through appropriately sized pediatric nasal prongs. Flow rate and inspired oxygen concentration were adjusted according to the child's clinical condition and response to therapy.

Children in the conventional oxygen group received oxygen through standard low-flow oxygen-delivery devices according to clinical requirements.

Peripheral oxygen saturation was reassessed approximately 1 hour after initiation of treatment and again at 24 hours. During hospitalization, oxygen therapy duration, hospital length of stay, treatment failure, recovery, referral, and mortality were documented.

2.7 Outcomes

The principal efficacy endpoint was **treatment failure**.

Secondary outcomes included:

- Recovery from the acute illness.
- Referral to a higher level of care.
- Mortality.
- Change in SpO₂ after treatment initiation.
- Oxygen flow rate.
- Duration of oxygen therapy.
- Duration of hospitalization.
- Age-specific and sex-specific treatment responses.
- Treatment response according to the presence or absence of chest retractions and wheezing.
- Clinical and physiological predictors of treatment failure.

Subgroup analyses were performed according to age category, sex, baseline clinical characteristics, chest retractions, and wheezing.

2.8 Statistical analysis

Data were entered into a worksheet, verified, and analyzed using SPSS version 25.0. Continuous variables were expressed as mean $\pm$ standard deviation (SD), while categorical variables were summarized as frequencies and percentages.

Between-group comparisons of categorical variables were performed using the chi-square test. Continuous variables were compared using the independent-samples Student's t-test, as appropriate. One-way analysis of variance (ANOVA) was used when comparisons involved more than two groups.

Pearson correlation analysis was performed to examine relationships between selected physiological and treatment-related variables. Multivariable logistic regression was used to explore independent associations between baseline clinical variables and treatment failure. All statistical tests were two-sided, and a p value <0.05 was considered statistically significant.

2.9 Ethics approval and consent

The study was conducted in accordance with the institutional ethical requirements of Darbhanga Medical College and Hospital, Laheriasarai, Bihar, India. The investigation was approved by the Institutional Ethics Committee of the institution. Written informed consent

was obtained from the parents or legal guardians of all participating children before enrollment. Participant confidentiality was maintained throughout data collection, analysis, and reporting.

3. RESULTS

3.1 Baseline characteristics

The study included 200 children, with 100 in the conventional oxygen cohort and 100 in the HHHFNC cohort. Mean age was 12.99 ± 6.73 months with conventional oxygen and 13.30 ± 6.26 months with HHHFNC; the corresponding medians were both 13.5 months. Most children were aged 13–24 months in each group (Table 1; Figure 1).

Table 1. Age distribution of study patients.

Age range	Conventional oxygen (n=100)	HHHFNC (n=100)
2–6 months	22 (22.0%)	16 (16.0%)
7–12 months	27 (27.0%)	29 (29.0%)
13–24 months	51 (51.0%)	55 (55.0%)
Mean ± SD	12.99 ± 6.73	13.30 ± 6.26
Median	13.5	13.5
Range	2–24	2–24

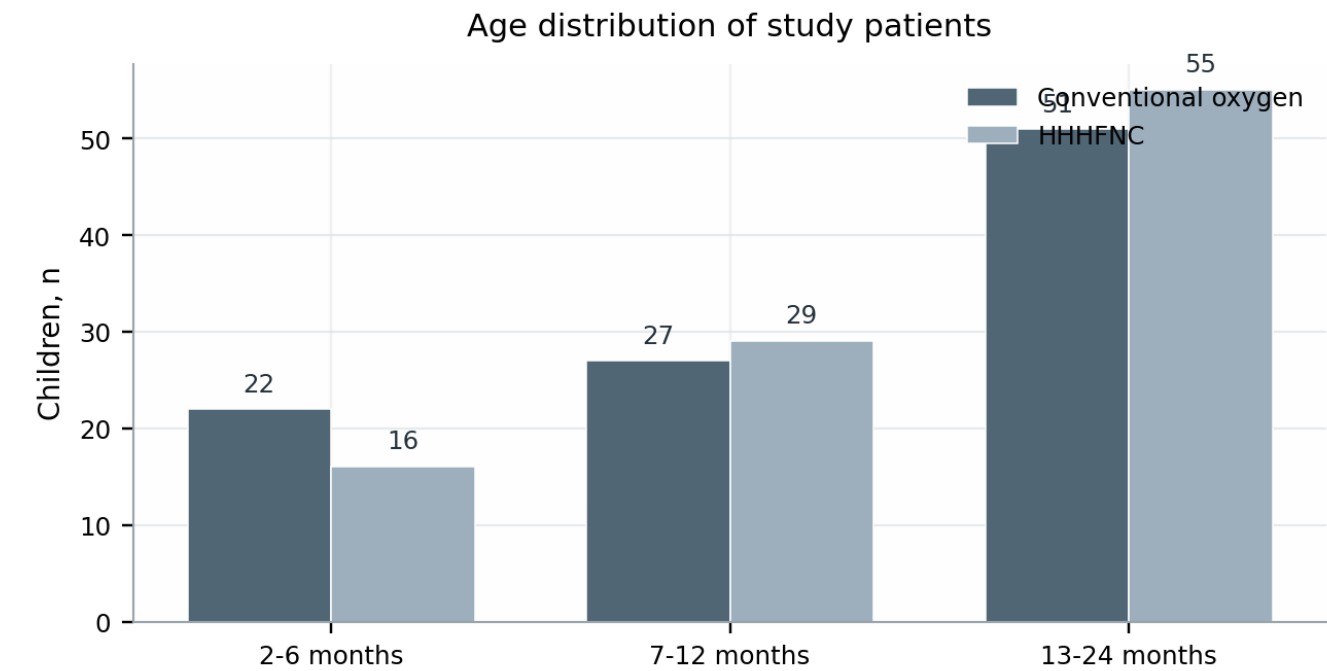


Figure 1. Age distribution of study patients.

A slight male preponderance was present in both groups: 55.0% of children receiving conventional oxygen and 51.0% receiving HHHFNC were male (Table 2; Figure 2).

Table 2. Sex distribution of study patients.

Sex	Conventional oxygen (n=100), n (%)	HHHFNC (n=100), n (%)
Male	55 (55.0%)	51 (51.0%)
Female	45 (45.0%)	49 (49.0%)
Total	100 (100.0%)	100 (100.0%)

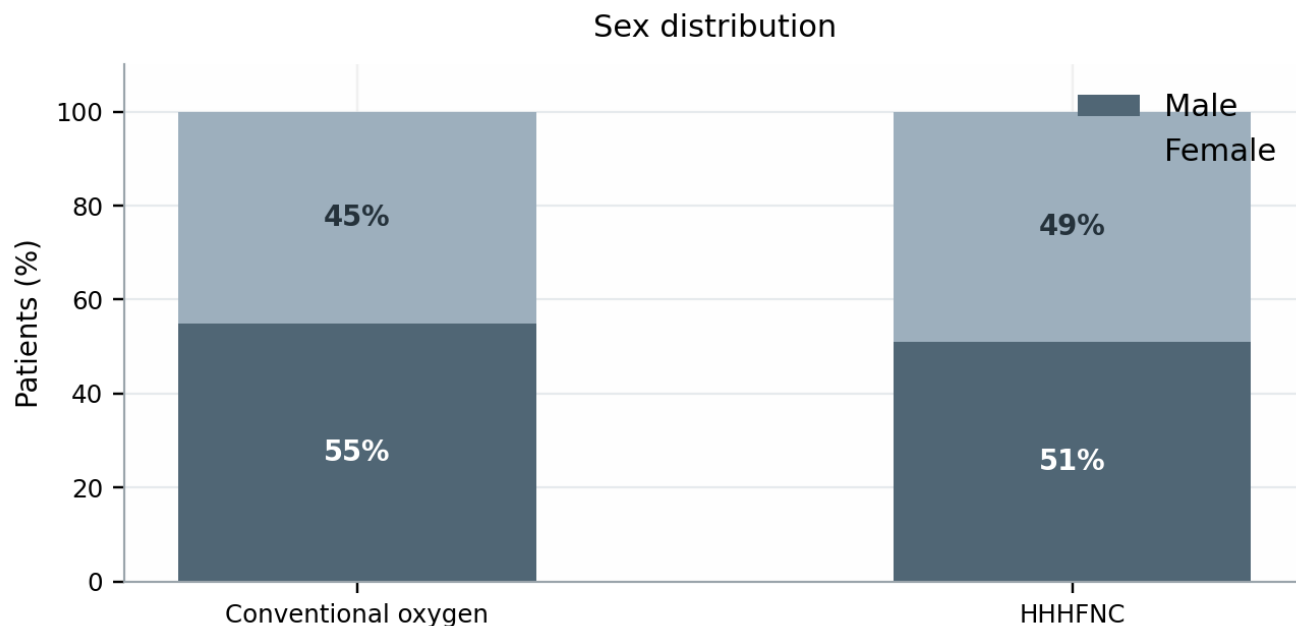


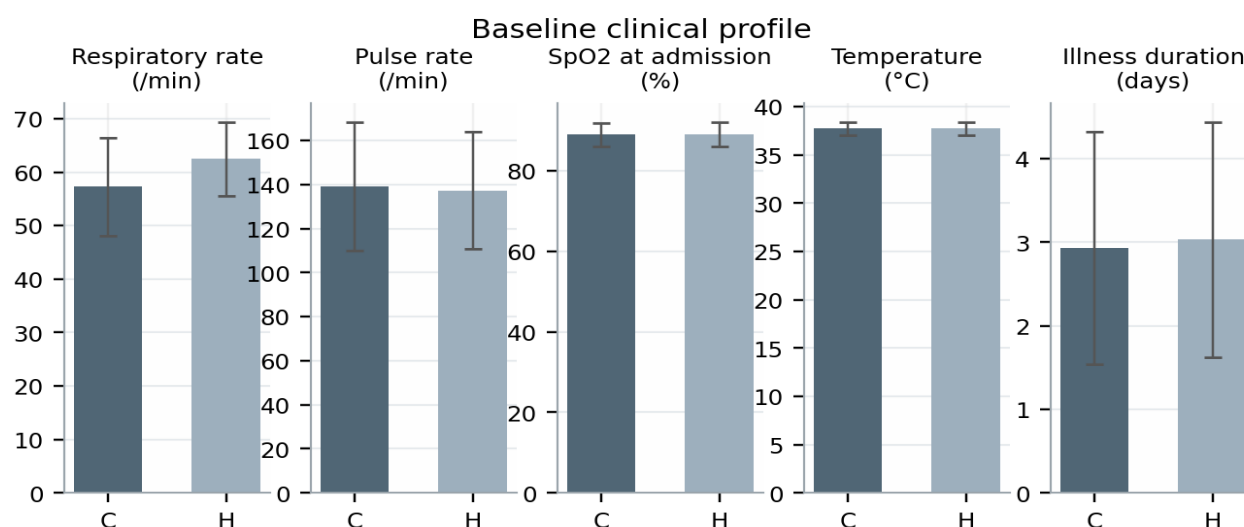
Figure 2. Sex distribution by treatment group.

Baseline respiratory rate, pulse rate, SpO₂, axillary temperature, and illness duration were broadly comparable between the groups. The HHHFNC cohort had a somewhat higher mean respiratory rate, but the difference did not meet the prespecified threshold for statistical significance in the baseline table (Table 3; Figure 3).

Table 3. Baseline clinical characteristics.

Parameter	Conventional oxygen, mean	HHHFNC, mean ± SD	P value
Respiratory rate (/min)	57.28 ± 9.14	62.48 ± 6.91	0.062
Pulse rate (/min)	139.17 ± 29.20	137.25 ± 26.55	0.624
SpO ₂ at admission (%)	88.98 ± 3.01	89.11 ± 3.06	0.768
Axillary temperature (°C)	37.73 ± 0.68	37.75 ± 0.67	0.845
Day of illness	2.93 ± 1.39	3.03 ± 1.41	0.612

Note. Values are mean ± SD.



C, conventional oxygen; H, heated humidified high-flow nasal cannula. Bars show mean values; error bars show SD.

Figure 3. Baseline clinical profile. C, conventional oxygen; H, HHHFNC. Bars show mean values; error bars show SD.

Chest retractions were recorded in 52.0% of the conventional oxygen cohort and 54.0% of the HHHFNC cohort. Wheezing was present in 54.0% and 49.0%, respectively (Table 4; Figure 4).

Table 4. Distribution of clinical signs.

Clinical sign	Conventional oxygen, n (%)	HHHFNC, n (%)
Chest retractions - present	52 (52.0%)	54 (54.0%)
Chest retractions - absent	48 (48.0%)	46 (46.0%)
Wheezing - present	54 (54.0%)	49 (49.0%)
Wheezing - absent	46 (46.0%)	51 (51.0%)

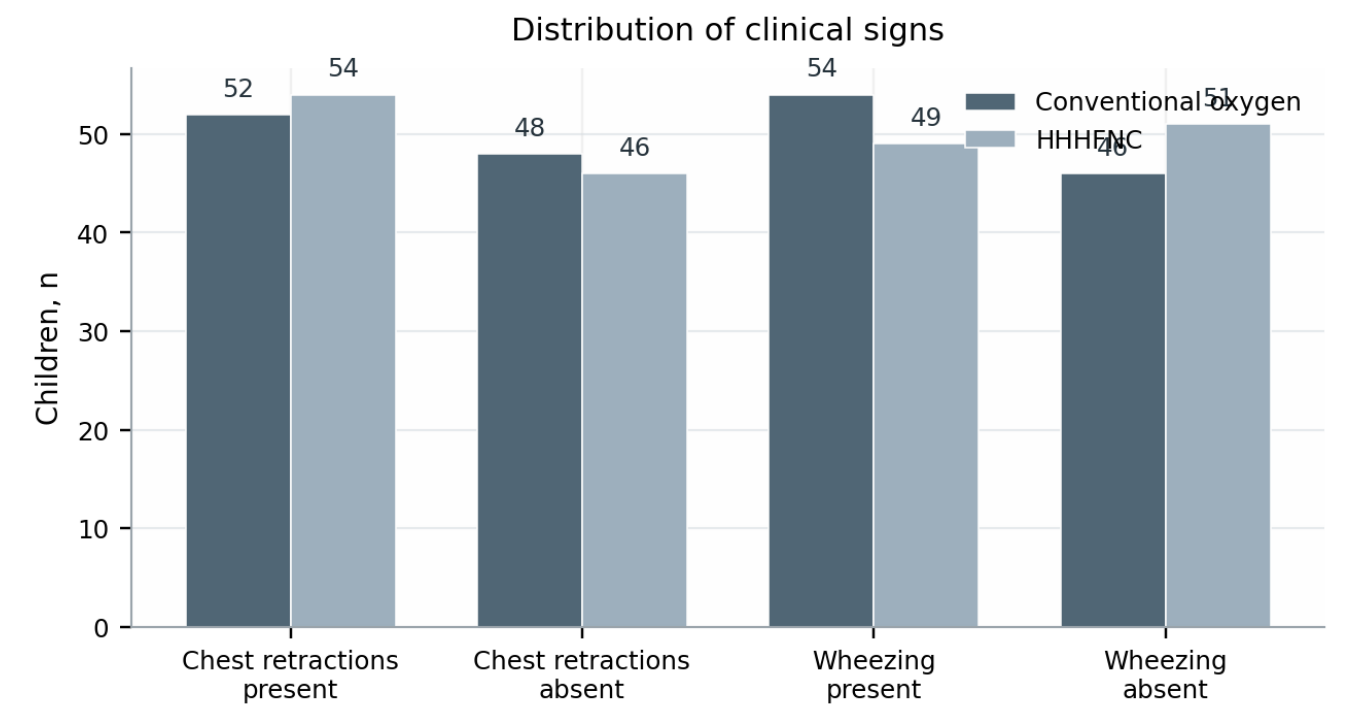


Figure 4. Distribution of clinical signs among treatment groups.

No participant had SpO2 below 85% at admission. Moderate hypoxemia was present in 38.0% of children receiving conventional oxygen and 40.0% of those receiving HHHFNC; 27.0% in each group had SpO2 above 92% (Table 5; Figure 5).

Table 5. Severity stratification at admission.

Severity level	Conventional oxygen, n (%)	HHHFNC, n (%)
Severe (<85%)	0 (0.0%)	0 (0.0%)
Moderate (85–88%)	38 (38.0%)	40 (40.0%)
Mild (88–92%)	35 (35.0%)	33 (33.0%)
Normal (>92%)	27 (27.0%)	27 (27.0%)

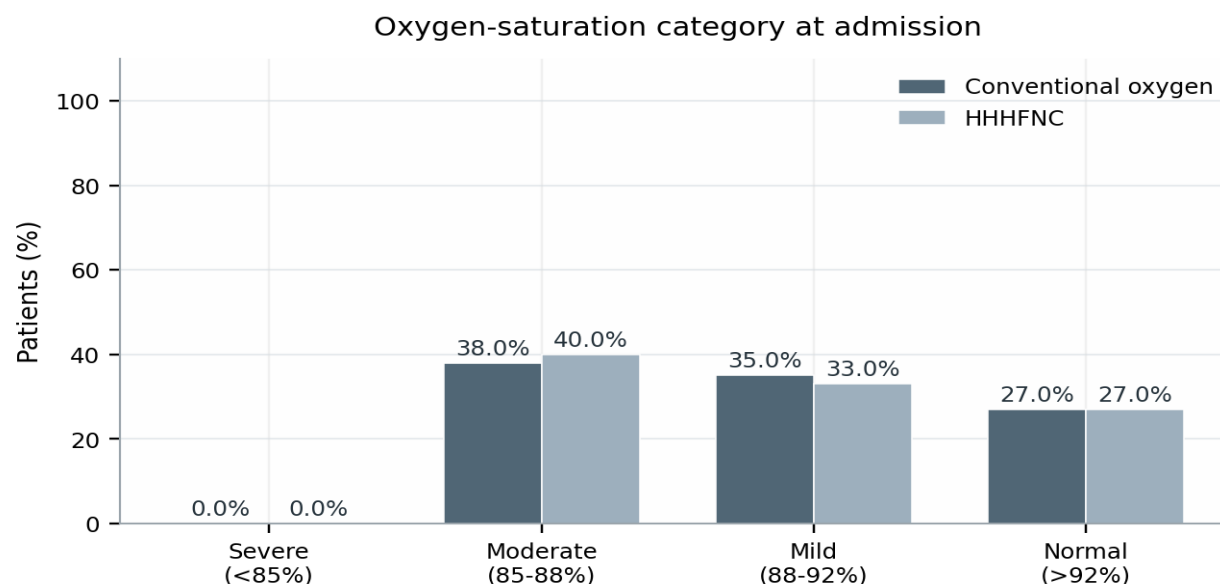


Figure 5. Oxygen-saturation category at admission.

3.2 Oxygen response

Mean oxygen flow was nearly identical in the two groups. Following treatment initiation, mean SpO₂ increased from 88.98% to 94.69% after 1 hour and to 95.42% after 24 hours with conventional oxygen. Corresponding values in the HHHFNC group were 89.11%, 94.41%, and 95.36% (Table 6; Figures 6A and 6B).

Table 6. Oxygen flow and saturation response.

Parameter	Conventional oxygen	HHHFNC	P value
Oxygen flow rate (L/min), mean $\pm$ SD	5.79 $\pm$ 2.35	5.78 $\pm$ 2.36	0.8993
Oxygen flow rate, median	5.8	5.7	—
Low flow ($\leq$ 4 L/min)	27 (27.0%)	29 (29.0%)	—
Medium flow (4–7 L/min)	40 (40.0%)	36 (36.0%)	—
High flow ($>$ 7 L/min)	33 (33.0%)	35 (35.0%)	—
SpO ₂ at admission (%)	88.98 $\pm$ 3.01	89.11 $\pm$ 3.06	0.6347
SpO ₂ after 1 hour (%)	94.69 $\pm$ 2.71	94.41 $\pm$ 2.85	0.8110
SpO ₂ after 24 hours (%)	95.42 $\pm$ 2.37	95.36 $\pm$ 2.26	0.6127

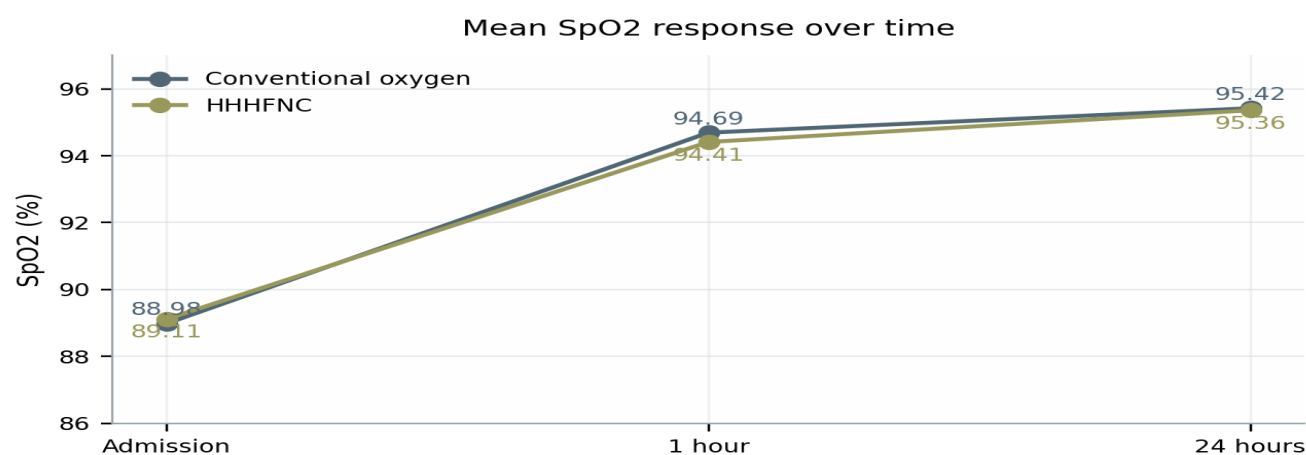


Figure 6A. Mean SpO₂ response over time.

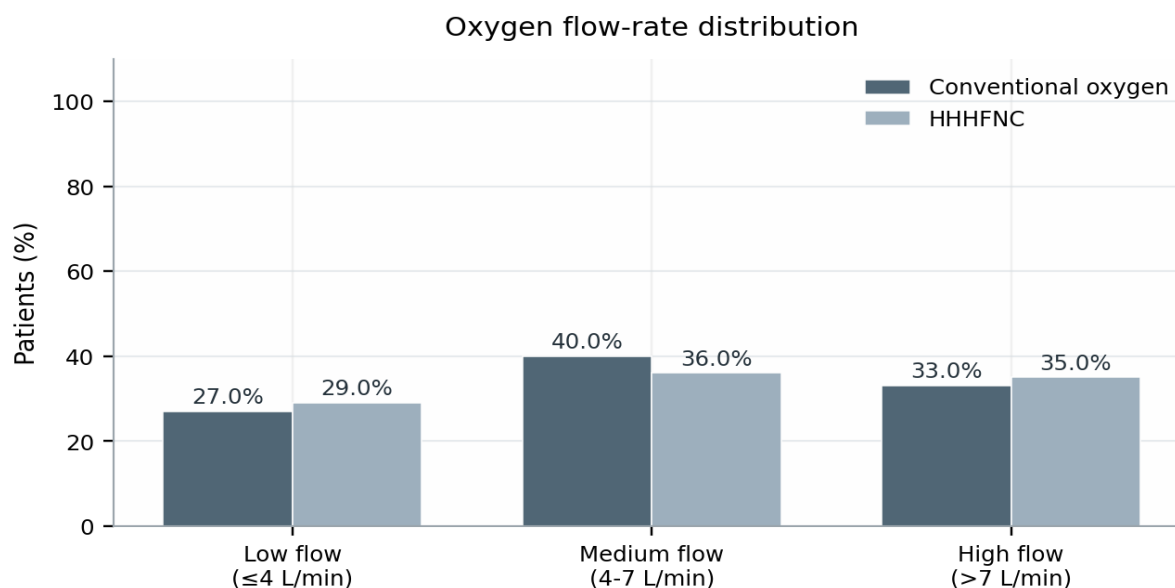


Figure 6B. Distribution of oxygen flow rate.

3.3 Treatment outcomes and resource use

Treatment failure occurred in 22 children receiving conventional oxygen but in only 9 receiving HHHFNC ($p=0.012$). Recovery followed the same pattern, while referral and mortality were numerically lower in the HHHFNC cohort (Table 7; Figure 7). Mean oxygen duration and hospital stay were both longer with HHHFNC (Table 8; Figure 8).

Table 7. Treatment failure and final outcomes.

Outcome	Conventional oxygen, n (%)	HHHFNC, n (%)	P value
Treatment failure - no	78 (78.0%)	91 (91.0%)	0.012
Treatment failure - yes	22 (22.0%)	9 (9.0%)	—
Final outcome - recovered	78 (78.0%)	91 (91.0%)	0.012
Final outcome - referred	16 (16.0%)	8 (8.0%)	0.078
Final outcome - expired	6 (6.0%)	1 (1.0%)	0.056

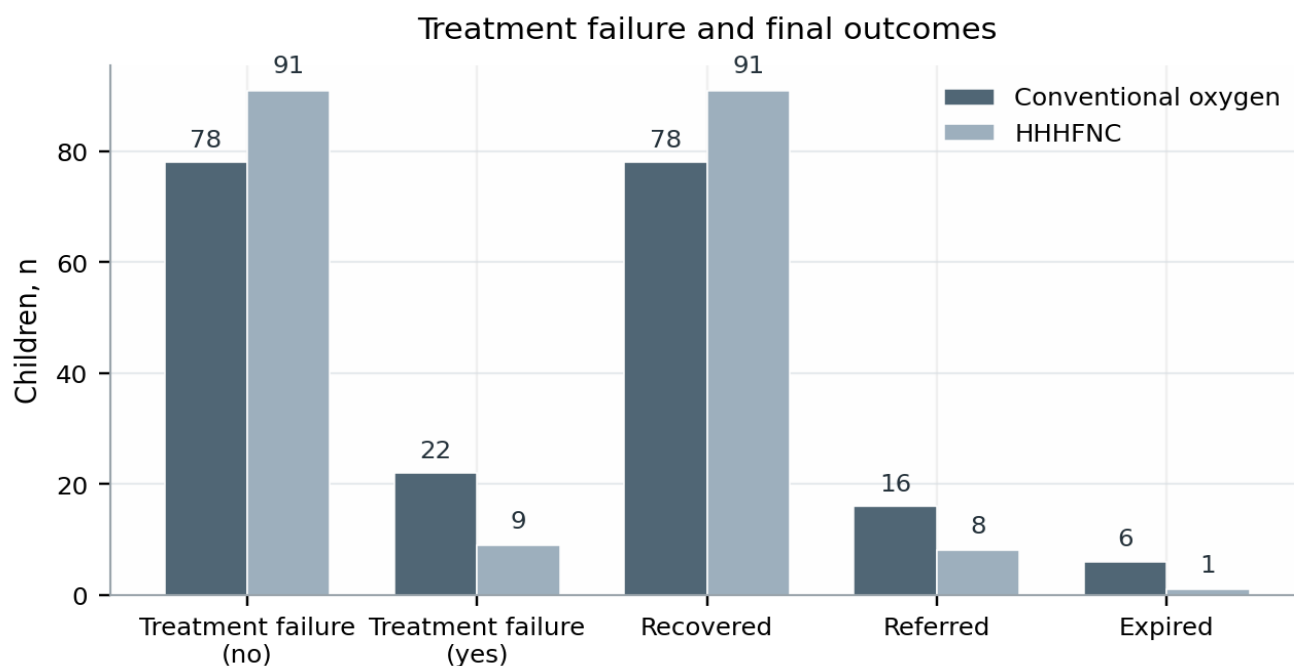
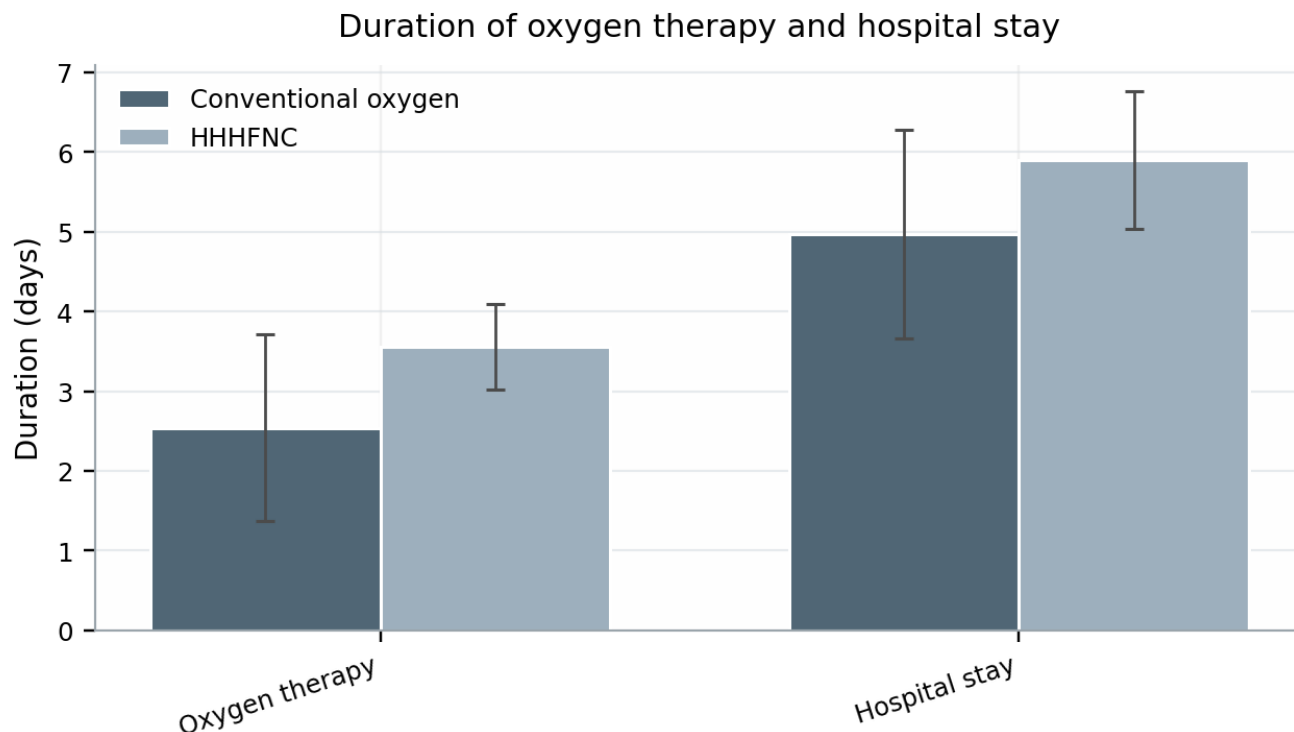


Figure 7. Treatment failure and final outcomes.

Table 8. Duration of oxygen therapy and hospital stay.

Parameter	Conventional oxygen	HHHFNC	P value
Oxygen therapy duration (days), mean $\pm$ SD	2.54 $\pm$ 1.17	3.56 $\pm$ 0.54	<0.001
Oxygen therapy duration, median (range)	3 (1–5)	4 (3–5)	—
Hospital stay (days), mean $\pm$ SD	4.97 $\pm$ 1.31	5.90 $\pm$ 0.86	<0.001
Hospital stay, median (range)	5 (2–8)	6 (4–8)	—

**Figure 8. Duration of oxygen therapy and hospital stay. Bars show mean values; error bars show SD.**

3.4 Subgroup, correlation, and regression analyses

Respiratory rate was higher in the HHHFNC cohort within each age stratum, while pulse rate and admission SpO₂ did not differ meaningfully by age. Treatment failure remained numerically lower with HHHFNC across all age categories, with the largest subgroup contrast observed at 13–24 months (Table 9; Figure 9).

Table 9. Age-stratified comparison of clinical parameters.

Parameter	Age group	Conventional oxygen	HHHFNC	P value
Respiratory rate (/min)	2–6 months	58.5 $\pm$ 9.8	63.1 $\pm$ 7.2	0.034
	7–12 months	56.9 $\pm$ 9.2	62.4 $\pm$ 6.8	0.008
	13–24 months	56.8 $\pm$ 8.9	62.2 $\pm$ 6.9	0.008
Pulse rate (/min)	2–6 months	136.8 $\pm$ 28.5	135.2 $\pm$ 28.4	0.820
	7–12 months	138.9 $\pm$ 30.1	138.6 $\pm$ 25.8	0.966
	13–24 months	140.2 $\pm$ 29.4	136.8 $\pm$ 26.2	0.622
SpO ₂ at admission (%)	2–6 months	89.2 $\pm$ 2.8	89.4 $\pm$ 2.9	0.777
	7–12 months	88.6 $\pm$ 3.2	88.9 $\pm$ 3.1	0.700
	13–24 months	89.0 $\pm$ 3.0	89.2 $\pm$ 3.1	0.791
Treatment failure rate (%)	2–6 months	13.6%	12.5%	1.000
	7–12 months	14.8%	6.9%	0.669
	13–24 months	27.5%	9.1%	0.111

Note. Values are mean $\pm$ SD unless otherwise indicated.

Age-stratified clinical parameters

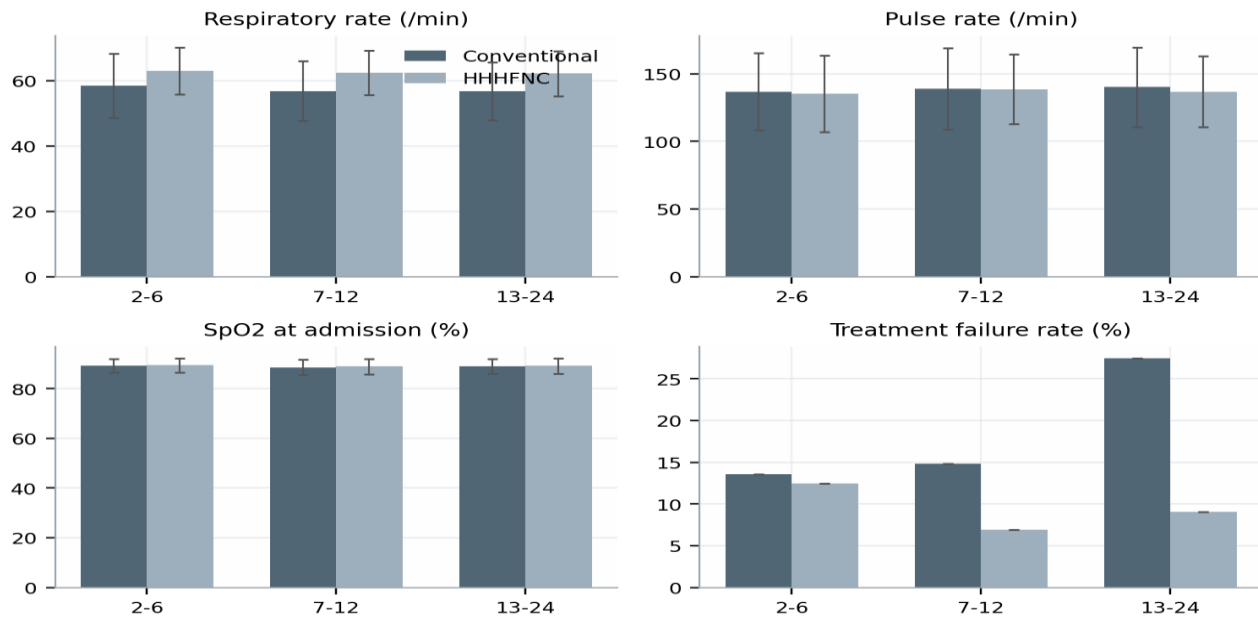


Figure 9. Age-stratified clinical parameters. CO, conventional oxygen; HF, HHHFNC. Bars show mean values; error bars show SD.

Oxygen duration correlated positively with hospital stay in both cohorts, with a stronger coefficient in the conventional oxygen group. Respiratory rate correlated with oxygen flow in the conventional group but not in the HHHFNC group (Table 10; Figure 10).

Table 10. Correlation coefficients by variable pair.

Variable pair	Conventional oxygen (r)	HHHFNC (r)
Age vs pulse rate	0.044	0.052
SpO2 vs O2 flow rate	-0.067	-0.124
O2 flow vs O2 duration	0.145*	0.089
O2 duration vs hospital stay	0.791***	0.612***
Respiratory rate vs O2 flow	0.259**	0.183

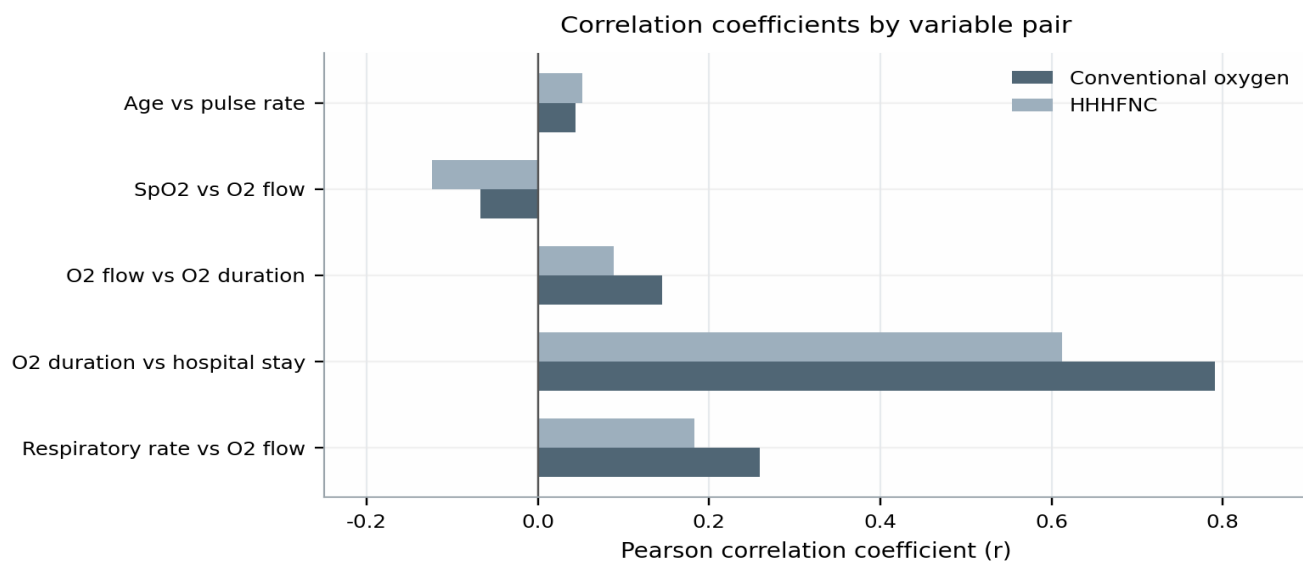


Figure 10. Correlation coefficients by variable pair.

In the conventional oxygen cohort, each one-breath-per-minute increase in respiratory rate was associated with approximately 4% higher adjusted odds of treatment failure. No measured baseline variable was a statistically significant predictor in the HHHFNC cohort (Table 11; Figure 11).

Table 11. Multivariable logistic regression analysis.

Predictor	Conventional oxygen, OR	P value	HHHFNC, OR (95% CI)	P value
Age (months)	1.035 (0.969–1.105)	0.057	0.952 (0.852–1.064)	0.943
Respiratory rate (/min)	1.041 (0.981–1.105)	<0.001	0.968 (0.914–1.025)	0.987
SpO2 at admission (%)	0.989 (0.868–1.128)	0.129	0.945 (0.815–1.095)	0.110
O2 flow rate (L/min)	0.862 (0.717–1.037)	0.096	0.788 (0.658–0.944)	0.223
Chest retractions	0.778 (0.346–1.745)	—	0.892 (0.412–1.932)	—

Note. OR, odds ratio; CI, confidence interval. Dashes indicate values not reported in the source table.

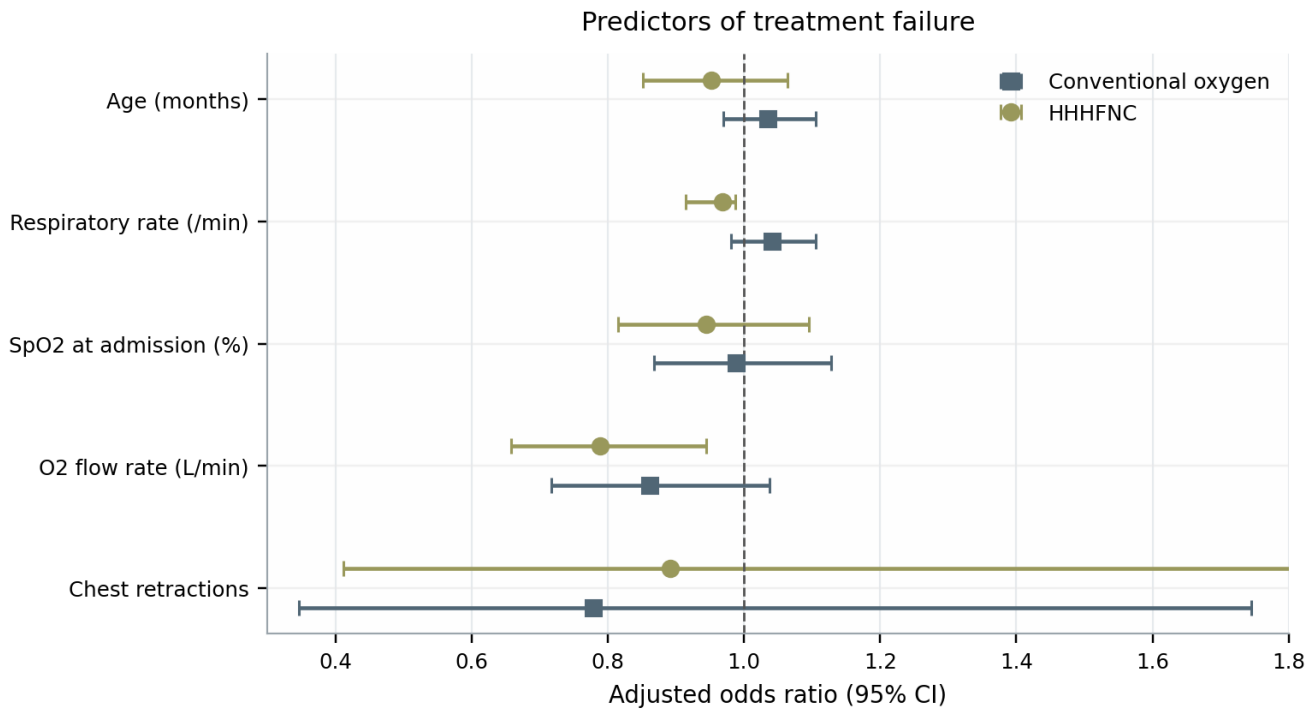


Figure 11. Forest plot of adjusted predictors of treatment failure.

3.5 Sex, clinical phenotype, and oxygenation response

Within the conventional oxygen cohort, boys had higher recorded age, respiratory rate, oxygen duration, and hospital stay than girls. These differences were not observed in the HHHFNC cohort (Table 12; Figure 12).

Table 12. Sex-wise comparison across treatment groups.

Parameter	Conventional oxygen,	P	HHHFNC, male/female	P
Age (months)	13.61 ± 6.47 / 12.94 ± 6.16	0.045	13.18 ± 6.28 / 13.43 ± 6.28	0.7
Respiratory rate (/min)	62.91 ± 7.26 / 62.82 ± 6.93	0.026	62.35 ± 7.12 / 62.61 ± 6.74	0.7
Pulse rate (/min)	137.24 ± 29.35 / 139.34 ± 22.65	0.735	136.24 ± 27.82 / 138.33 ± 25.18	0.3
SpO2 at admission (%)	89.13 ± 3.05 / 89.26 ± 3.05	0.745	89.22 ± 3.12 / 89.00 ± 3.02	0.7
O2 flow rate (L/min)	5.84 ± 2.40 / 5.81 ± 2.19	0.518	5.73 ± 2.42 / 5.84 ± 2.31	0.5
O2 duration (days)	2.62 ± 1.14 / 2.48 ± 1.18	0.047	3.61 ± 0.54 / 3.51 ± 0.54	0.9
Hospital stay (days)	5.16 ± 1.37 / 4.83 ± 1.23	0.026	5.96 ± 0.87 / 5.84 ± 0.86	0.9
Treatment failure rate	23.6% / 20.0%	0.353	9.8% / 8.2%	0.9

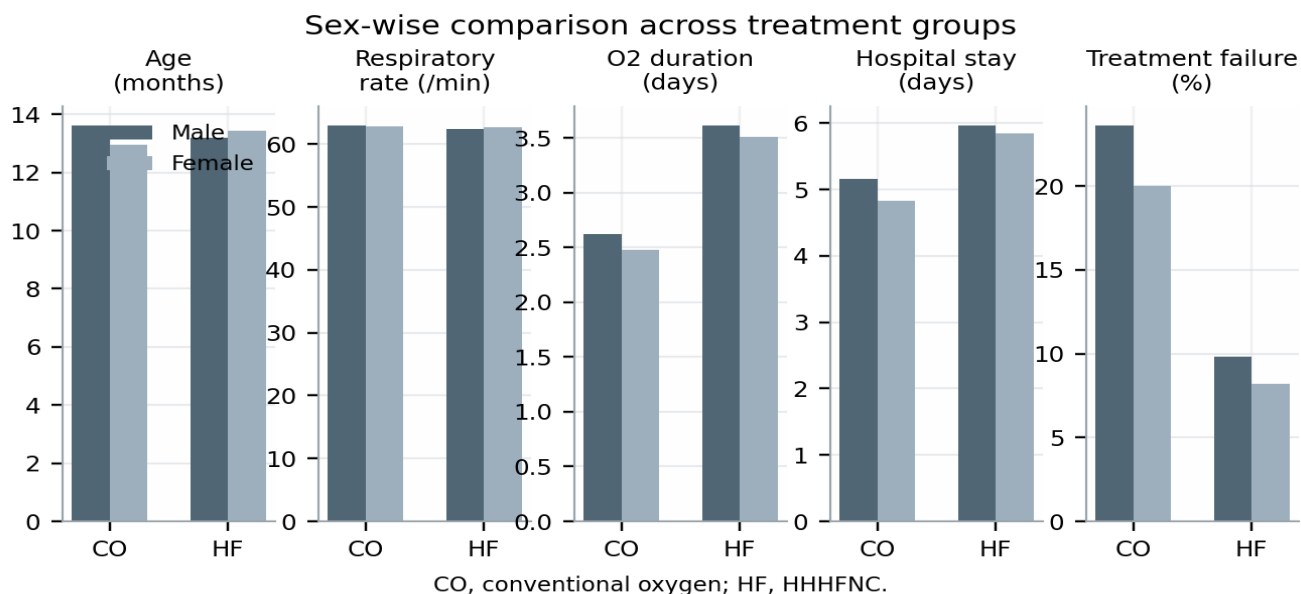


Figure 12. Sex-wise comparison across treatment groups. CO, conventional oxygen; HF, HHHFNC.

HHHFNC was associated with lower treatment failure both when chest retractions or wheezing were present and when they were absent. The largest absolute reduction occurred among children without chest retractions (Table 13; Figure 13).

Table 13. Treatment failure by physical examination findings.

Clinical sign	Conventional oxygen, treatment failure rate	HHHFNC, treatment failure rate
Chest retractions - present	12.5%	9.3%
Chest retractions - absent	16.7%	8.7%
Wheezing - present	14.9%	8.2%
Wheezing - absent	14.1%	9.8%

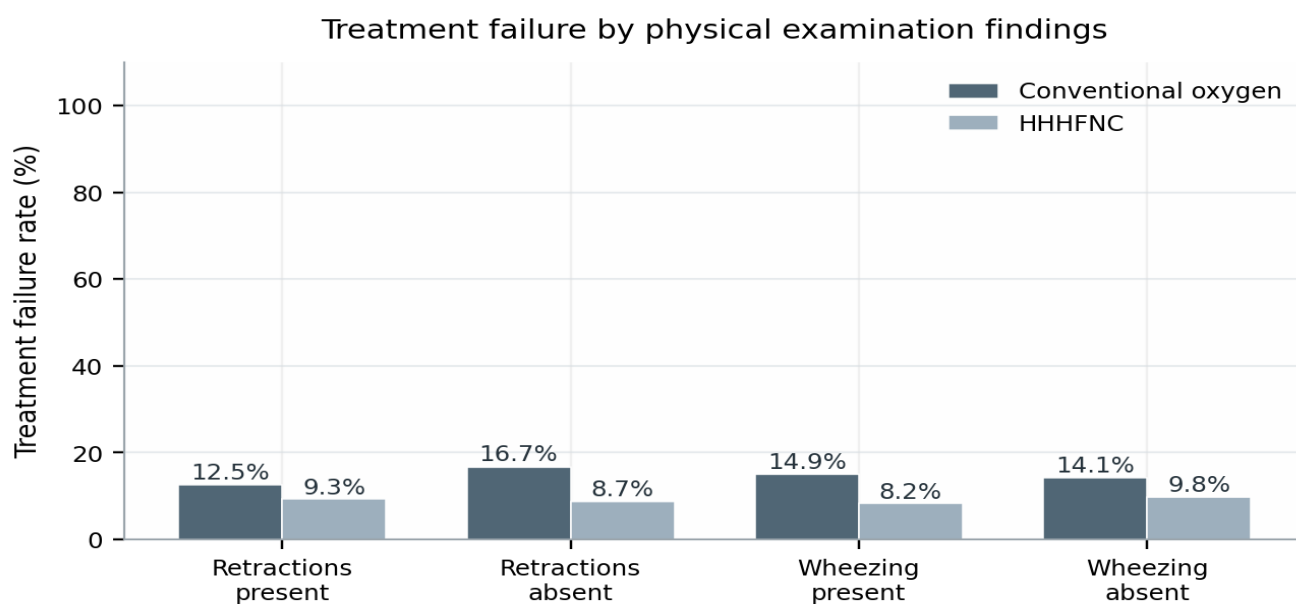


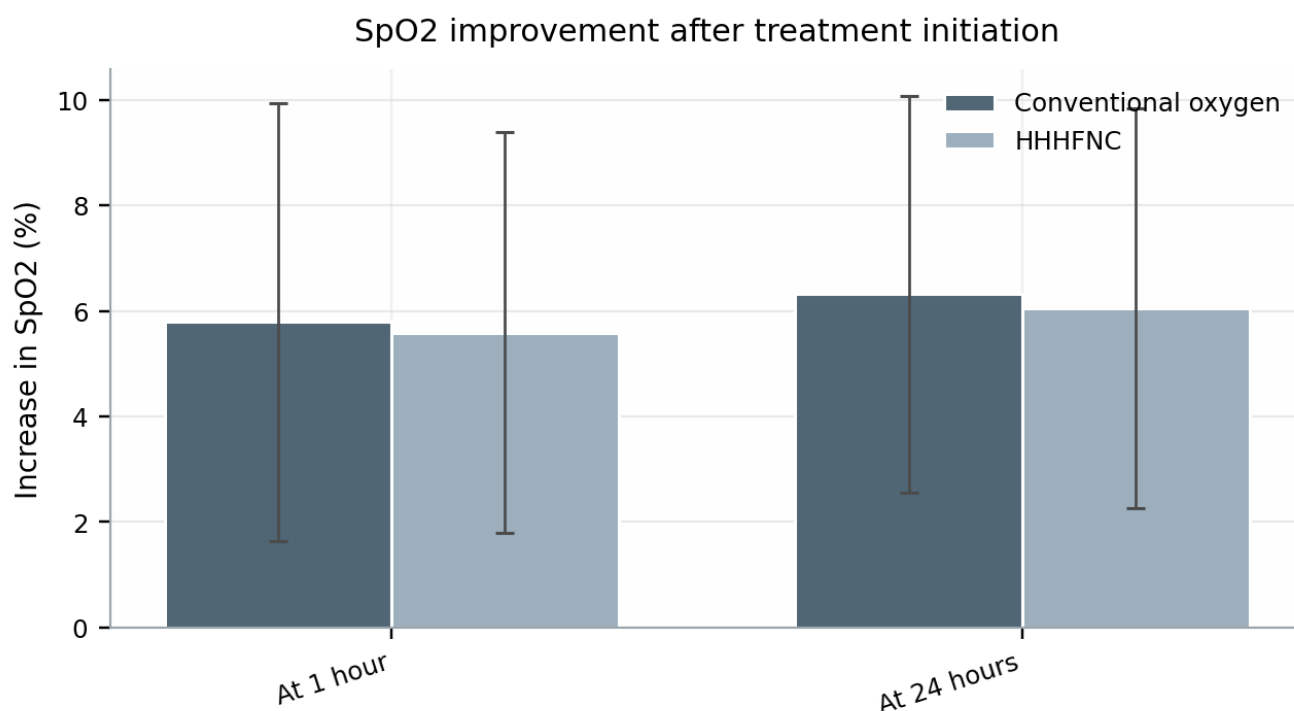
Figure 13. Treatment failure by physical examination findings.

Mean SpO₂ gain from admission was similar after 1 hour and after 24 hours in the two groups (Table 14; Figure 14).

Table 14. SpO2 improvement after treatment initiation.

Time point	Conventional oxygen, mean	HHHFNC, mean $\pm$ SD	Mean	P value
At 1 hour	5.79 $\pm$ 4.15%	5.59 $\pm$ 3.79%	0.20%	0.726
At 24 hours	6.32 $\pm$ 3.76%	6.05 $\pm$ 3.79%	0.27%	0.624

Note. Values represent percentage-point improvement from admission.

**Figure 14. SpO2 improvement after treatment initiation. Bars show mean values; error bars show SD.**

3.6 Overall outcome comparison

In the final outcome table, treatment failure remained lower with HHHFNC than with conventional oxygen. Oxygen duration and hospital stay were again longer with HHHFNC. The denominator for the conventional oxygen failure rate in this table is 96 rather than the 100 participants described elsewhere in the thesis; the values are therefore reproduced exactly and the discrepancy is not corrected retrospectively (Table 15; Figure 15).

Table 15. Overall treatment-outcome comparison.

Outcome parameter	Conventional oxygen	HHHFNC	P value
Treatment failure rate	21.9% (21/96)	9.0% (9/100)	0.021
Age (months), mean $\pm$ SD	13.17 $\pm$ 6.68	13.30 $\pm$ 6.26	0.886
Respiratory rate (/min), mean $\pm$ SD	57.28 $\pm$ 9.23	62.48 $\pm$ 6.91	<0.001
Pulse rate (/min), mean $\pm$ SD	139.34 $\pm$ 29.36	137.25 $\pm$ 26.55	0.601
SpO2 at admission (%), mean $\pm$ SD	89.07 $\pm$ 3.00	89.11 $\pm$ 3.06	0.932
O2 flow rate (L/min), mean $\pm$ SD	5.73 $\pm$ 2.33	5.78 $\pm$ 2.36	0.885
O2 duration (days), mean $\pm$ SD	2.53 $\pm$ 1.18	3.56 $\pm$ 0.54	<0.001
Hospital stay (days), mean $\pm$ SD	4.96 $\pm$ 1.31	5.90 $\pm$ 0.86	<0.001

Note. Values are transcribed as reported in the source table. The table uses 96 conventional-oxygen participants for the treatment-failure denominator.

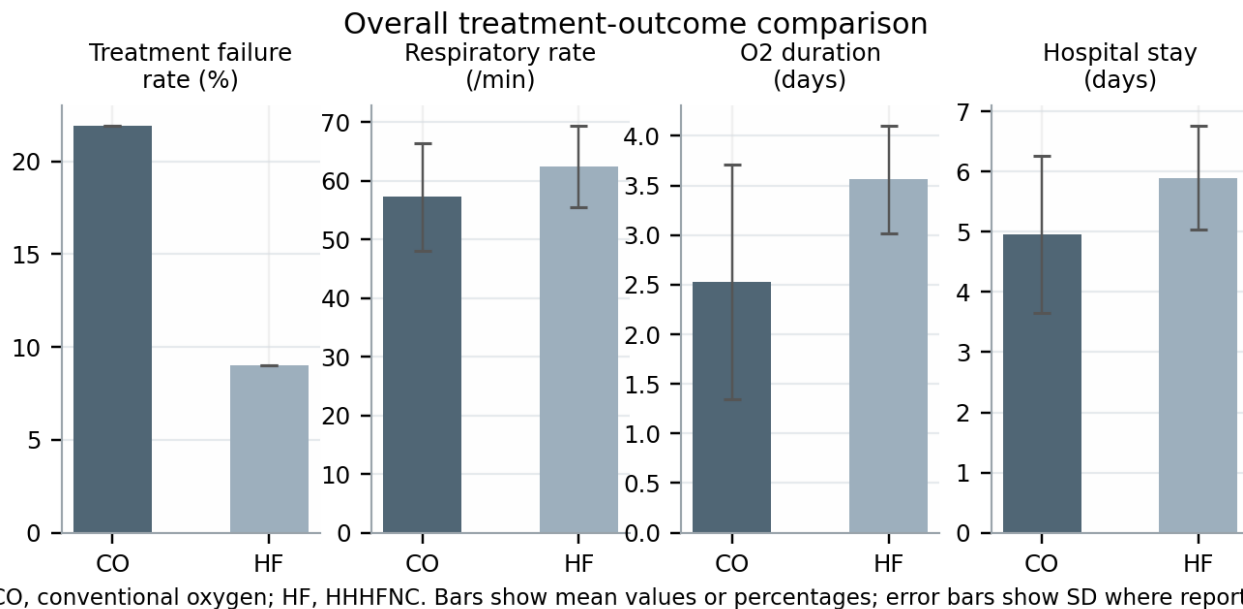


Figure 15. Overall treatment-outcome comparison. CO, conventional oxygen; HF, HHHFNC. Bars show mean values or percentages; error bars

4. DISCUSSION

This prospective observational study compared heated humidified high-flow nasal cannula (HHHFNC) with conventional oxygen therapy in 200 children hospitalized with bronchiolitis. The two cohorts were broadly similar at admission with respect to age, sex distribution, pulse rate, oxygen saturation, temperature, and duration of preceding illness. These similarities reduce the likelihood that demographic or baseline clinical differences alone explain the observed difference in treatment failure. However, because treatment allocation was not randomized, confounding by indication cannot be completely excluded.

Both groups achieved rapid improvement in oxygen saturation. By the first hour, mean SpO₂ increased from approximately 89% to more than 94% in each cohort, and this improvement was maintained at 24 hours. This finding indicates that conventional oxygen therapy remains effective for correcting hypoxemia in many children with ward-level bronchiolitis. It also suggests that the principal advantage of HHHFNC was not simply a greater immediate increase in SpO₂, but rather a broader physiological effect that may have reduced the likelihood of clinical deterioration or inadequate respiratory support.

The most clinically important finding was the lower treatment-failure rate in the HHHFNC group. Treatment failure occurred in 9% of children receiving HHHFNC compared with 22% receiving conventional oxygen therapy. Recovery was correspondingly higher in the HHHFNC group, while referral and mortality were numerically lower. These findings are broadly consistent with randomized and observational evidence suggesting

that high-flow therapy can reduce treatment escalation in children with bronchiolitis requiring respiratory support [6,7,35–42].

The treatment-failure rate observed with HHHFNC in the present study was lower than rates reported in some pediatric intensive-care populations. In multicenter studies of respiratory-support practices, treatment failure has generally been higher among children managed in critical-care settings, where baseline illness severity and thresholds for escalation differ [44]. The lower failure rate in the present ward-based cohort may therefore reflect the inclusion of children with predominantly moderate disease and the use of HHHFNC before progression to more severe respiratory compromise.

Several physiological mechanisms may explain the observed clinical benefit of HHHFNC. High-flow therapy can better match inspiratory flow demand, reduce entrainment of room air, wash out carbon dioxide from anatomical dead space, and generate a degree of positive expiratory pressure that may help maintain airway patency. Heating and humidification may also support mucociliary function and improve treatment tolerance [28–34]. These effects are particularly relevant in bronchiolitis, in which small-airway edema, mucus accumulation, and increased airway resistance contribute substantially to respiratory effort.

The similar improvement in oxygen saturation but different treatment-failure rates is noteworthy. Oxygen saturation primarily reflects oxygenation, whereas treatment failure is influenced by several additional factors, including respiratory workload, fatigue, feeding ability, comfort, and the capacity to maintain spontaneous breathing. HHHFNC may therefore provide

clinical stabilization even when the measured oxygen-saturation response is comparable with conventional oxygen therapy. This finding supports the use of broader clinical endpoints rather than oxygenation alone when evaluating non-invasive respiratory-support strategies.

The longer duration of oxygen therapy and hospital stay observed in the HHHFNC cohort requires careful interpretation. A longer duration could indicate greater underlying clinical severity, but it may also reflect conservative oxygen-weaning practices, prolonged observation after stabilization, or differences in local discharge criteria. The present observational study cannot distinguish among these explanations. Previous studies have similarly reported variable effects of HHHFNC on oxygen duration and hospital length of stay depending on disease severity, treatment protocols, and discharge criteria [7,29,39,40,45]. Standardized weaning procedures and clearly defined discharge criteria may therefore be important when implementing HHHFNC in general pediatric wards.

Age-stratified analysis showed lower treatment-failure rates with HHHFNC across all age categories. Younger infants have smaller airways, more compliant chest walls, and less developed respiratory musculature, which may increase physiological vulnerability to respiratory compromise. Although the subgroup comparisons were not statistically significant, the consistent direction of the findings across the 2–24-month age range suggests that the observed association was not confined to a single age category. However, these subgroup findings should be interpreted cautiously because the study was not powered to establish age-specific treatment effects.

The correlation findings reinforce the close relationship between respiratory recovery and hospital resource utilization. Oxygen duration was strongly correlated with hospital length of stay in both treatment groups, particularly in children who required prolonged respiratory support. This relationship is clinically expected because continued oxygen requirement is both a marker of unresolved respiratory illness and an important practical reason for continued hospitalization. The correlation between respiratory rate and oxygen flow in the conventional-oxygen group, but not in the HHHFNC group, may indicate that high-flow support partly reduces the dependence of oxygen requirements on respiratory effort.

Regression analysis identified respiratory rate as the principal significant predictor of treatment failure among children receiving conventional oxygen therapy. Tachypnea is an easily measurable marker of respiratory distress and is incorporated into several pediatric early-warning and bronchiolitis severity assessment systems. The absence of a statistically significant baseline predictor in the HHHFNC cohort may suggest that high-flow support provided relatively consistent clinical

support across the range of baseline severity represented in this study. However, the confidence intervals were relatively wide, and the study was not designed to establish the absence of predictors definitively.

Sex-specific analysis demonstrated some differences in physiological and resource-use measures among children receiving conventional oxygen therapy, whereas similar differences were not observed in the HHHFNC cohort. Previous epidemiological studies have reported differences in the severity of bronchiolitis according to sex [43]. Nevertheless, the subgroup sample sizes in the present study were modest, and these findings should therefore be considered exploratory and hypothesis-generating rather than conclusive.

The observed benefit of HHHFNC was not restricted to children with prominent chest retractions or wheezing. Treatment-failure rates were lower in the HHHFNC group across the clinical-sign subgroups examined. This pattern suggests that HHHFNC may be considered when hypoxemic bronchiolitis requires respiratory support rather than being reserved exclusively for children with the most pronounced clinical signs. However, children with apnea, exhaustion, altered consciousness, refractory hypoxemia, severe acidosis, or other signs of impending respiratory failure require prompt reassessment and escalation to an appropriate level of respiratory support.

Overall, the findings are broadly consistent with contemporary evidence regarding high-flow therapy in bronchiolitis. Systematic reviews have reported reductions in treatment failure and escalation compared with standard oxygen therapy, although comparisons with other non-invasive modalities such as CPAP remain dependent on patient severity, monitoring capacity, and clinical setting [7,8,29,36,42,47]. In a general pediatric ward, HHHFNC may therefore function as an intermediate respiratory-support strategy between conventional low-flow oxygen and more intensive non-invasive ventilation.

Strengths of the Study

- The study prospectively evaluated 200 children within the clinically relevant 2–24-month age range.
- Baseline demographic and physiological characteristics were broadly comparable between the two treatment cohorts.
- Oxygen saturation was assessed repeatedly, allowing evaluation of both early and sustained oxygenation responses.
- The analysis included correlation and multivariable regression analyses in addition to simple between-group comparisons.
- The ward-based setting provides clinically relevant information for hospitals where access to pediatric intensive-care facilities or CPAP may be limited.

Future Recommendations

- Multicenter randomized controlled trials should be conducted using concealed allocation and standardized bronchiolitis severity assessment.
- Standardized protocols for HHHFNC initiation, flow and FiO₂ adjustment, monitoring, escalation, and weaning should be developed and evaluated.
- Future studies should incorporate validated bronchiolitis severity scores and objective measures of work of breathing.
- Viral testing should be considered to determine whether specific viral etiologies modify treatment response.
- Post-discharge follow-up should assess recurrent wheezing, readmission, and longer-term respiratory outcomes.
- Cost-effectiveness, equipment maintenance, nursing workload, and feasibility should be evaluated, particularly in resource-limited hospitals.
- Future studies should examine whether early HHHFNC use can reduce intensive-care transfer without increasing overall hospital length of stay.

5. LIMITATIONS

- The observational design and non-random treatment allocation may have introduced confounding by indication.
- The study was conducted at a single tertiary-care center, which may limit generalizability to other hospitals and patient populations.
- Viral etiology was not confirmed by laboratory testing; therefore, the influence of specific respiratory viruses on treatment response could not be evaluated.
- The source thesis did not provide a sufficiently detailed operational definition of treatment failure or complete information regarding device settings and oxygen-weaning parameters.
- The final outcome table used 96 conventional-oxygen participants for the treatment-failure denominator, whereas other tables described 100 participants in the conventional-oxygen cohort. This inconsistency could not be resolved from the available source data and should be verified against the original study records before publication.
- Long-term post-discharge outcomes were not assessed.
- The subgroup and regression analyses were exploratory and may have been underpowered to detect small or uncommon effects.

6. CONCLUSION

Among children aged 2–24 months hospitalized with bronchiolitis, HHHFNC was associated with a lower

treatment-failure rate and a higher recovery rate than conventional oxygen therapy. Both treatment approaches produced substantial improvement in oxygen saturation during the first 24 hours; however, HHHFNC was associated with fewer treatment failures across the clinical subgroups examined.

The longer duration of oxygen therapy and hospital stay observed in the HHHFNC group should be interpreted in the context of the observational design and may reflect differences in clinical severity, monitoring practices, oxygen-weaning strategies, or discharge criteria rather than reduced treatment efficacy. HHHFNC may represent a useful non-invasive respiratory-support option for children with bronchiolitis in general pediatric wards, particularly where intensive-care resources are limited. Nevertheless, multicenter randomized studies using standardized definitions of treatment failure, severity assessment, treatment protocols, and weaning criteria are required to establish its comparative effectiveness and optimal clinical use.

7. DECLARATIONS

Ethics Approval and Consent to Participate

The study was conducted in accordance with the ethical requirements of Darbhanga Medical College and Hospital, Laheriasarai, Bihar, India. The study was approved by the Institutional Ethics Committee of Darbhanga Medical College and Hospital. Written informed consent was obtained from the parents or legal guardians of all participants before enrollment.

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Competing Interests

The authors declare that they have no competing interests.

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Authors' Contributions

All authors contributed to the conception and design of the study, data collection, analysis and interpretation of the results, and preparation of the manuscript. All authors critically reviewed the manuscript, approved the final version, and agreed to be accountable for all aspects of the work.

AI Use Disclosure

The authors declare that no generative artificial intelligence tools were used to generate or substantially modify the scientific content of this manuscript.

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