Comparison between the effect of heated and humidified high-flow nasal oxygen and conventional oxygen during acute hypoxemic respiratory failure

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Background Hypoxemia is the most serious threat to organ function. Therefore, the goal is to reverse tissue hypoxia. The aim of this study was to compare heated and humidified high-flow nasal cannula (HFNC) with conventional low-flow nasal cannula (LFNC) oxygen therapy in acute hypoxemic respiratory failure (RF).

Patients and methods This prospective study was conducted on 60 patients with acute hypoxemic RF. Patients were randomly classified into two groups. Group I received LFNC oxygen therapy. Group II received heated humidified HFNC oxygen therapy. Comparison between the two groups was made using dyspnea scales, heart rate, respiratory rate, and oxygenation status.

Results There were no statistically significant differences as regards age, sex, smoking status, causes of RF, and presence of comorbidities between the two groups. There was no statistically significant difference in the modified Borg scale and visual analog scale (VAS) score between the two groups at baseline ($P>0.05$). After 24 h, the HFNC group had a significant decrease in these scores ($P<0.05$). Respiratory rate and heart rate significantly decreased, whereas arterial oxygen saturation and tension increased significantly in the HFNC group compared with the conventional LFNC group ($P<0.05$).

Only one patient in the HFNC group versus three patients in the LFNC group required mechanical ventilation. Two patients experienced nasal discomfort in the HFNC group versus five patients in the LFNC group.

Conclusion Treatment of acute hypoxemic RF with HFNC was associated with better and rapid improvement in oxygenation when compared with LFNC, with fewer side effects, better convenience, and lesser need for mechanical ventilation.
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Introduction

Respiratory failure (RF) is the inability of the respiratory system to preserve adequate gas exchange to meet patients' requirements [1]. Oxygen therapy is essential to maintain proper tissue oxygenation [2].

Defects are associated with conventional oxygen therapy, such as limited and inaccurate FiO_2, and poor tolerance because of insufficient heating and humidification [3–7].

High-flow nasal cannula (HFNC) delivers heated humidified oxygen at high flow up to 60 l/min. It allows delivery of FiO_2 up to 100% independent of breathing pattern of patients [8,9]. It prevents epithelial damage and reduces patient discomfort [10,11]. Optimal humidity (100% relative humidity) mimics natural airways physiological conditioning [12,13]. These mechanisms are efficient for treating patients with hypoxemic RF [14,15].

HFNC devices require three components: a nasal interface, air–oxygen blender with high-flow meter, and an active heater and humidifier [16]. Evidence of HFNC use in adult patients remains uncertain [17].

Patients and methods

A prospective randomized study was conducted in the Emergency Department (ED) of our University Hospital. All patients underwent the standard procedures [2]. All members of the team, including nurses, were educated about this new system before starting the study.

The aim of this work was to compare the effect of heated and humidified HFNC oxygen therapy and conventional oxygen therapy in patients with acute hypoxemic RF presenting to the ED.

The local institutional Research Ethical Committee approved the design of the study. Informed written consent was obtained from all patients or from the relatives after full explanation of benefits and risks. Privacy of all patient data was granted and there was code number for every patient file that includes all investigations.

This study was carried out from April to October 2015 on 60 patients of both sexes. The records of all patients were reviewed and data were collected prospectively. Patients were randomly classified using closed envelops and computer-generated random numbers into two groups of 30 patients each: group I included patients who received conventional oxygen therapy through low-flow nasal cannula (LFNC), and group II included patients who received heated and humidified HFNC oxygen therapy.

Patients with acute hypoxemic RF ($P_aO_2 < 60$ mmHg in room air) were included in the study. Patients with hypercapnic RF 'type II respiratory failure' ($P_aCO_2 > 50$ mmHg), patients with chronic obstructive pulmonary disease, patients with impaired conscious level, disoriented patients, or inability to give informed consent, those in immediate need for invasive or noninvasive mechanical ventilation, and hemodynamically unstable patients were excluded from the study.

All patients were subjected to full history taking from the patient or his/her relatives (including age, sex, smoking history, history of chest disease, and medical history) and clinical examination (including general and local chest, cardiac, abdominal, and neurological examination). Routine laboratory investigations were carried out (random blood sugar, serum electrolytes, kidney and liver function tests, and complete blood picture). In addition, plain posteroanterior chest radiography and ECG were performed.

In group I, patients were connected to conventional oxygen therapy using LFNC. The nasal cannula (NC) rests just below the nostrils and delivers a flow of oxygen into the nasopharynx ranging from 4 to 6 l/min in the present study.

In group II, patients were connected to the Optiflow Device System (Fisher & Paykel 850 system, New Zealand) using a large-diameter NC (Optiflow nasal cannula). This system basically works with an air–oxygen blender (Max–Venturi), allowing delivery of consistent FiO_2 from 0.21 to 1.0, and generates up to 60 l/min flow rates. Figure 1 shows the Optiflow System used in this study.

All patients in group II were maintained on an initial flow rate of 6 l/min and increased to 40 l/min over a few minutes to allow patients to adjust to high flow. After 2 h, flow rate was decreased to 30–35 l/min according to the response and comfort of the patient.

Fraction of inspired oxygen (FiO_2) started at 0.6 and after 2 h decreased to 0.35 and 0.4. Because flows used are high,

Figure 1

Optiflow System used in this study

heated water humidification through an active heated humidifier (MR850 Humidifier, Fisher & Paykel, New Zealand) is necessary to avoid drying of respiratory secretions and to maintain nasal cilia function. Once the patient stabilized, flow rate was decreased to low flow (≤ 20 l/min) to allow weaning from HFNC.

Patients in both groups were assessed through monitoring of the vital signs [mainly SpO_2, respiratory rate (RR), and heart rate (HR)], frequent assessment of dyspnea using the Borg scale [18] and the VAS [19], and frequent arterial blood gas analysis. These variables were collected in both groups at baseline, 30 min, 2 h, and 24 h after use of conventional oxygen therapy and HFNC in groups I and II, respectively.

At the end of the study, patients were asked for their satisfaction about the technique using a simple questionnaire with either satisfied or unsatisfied as response. This questionnaire was administered at the time of discharge from the ED.

The collected data were organized, tabulated, and statistically analyzed using statistical package for the social studies, version 19 (SPSS; IBM, Illinois, Chicago, USA). For numerical values the range mean and SD were calculated. The differences between two mean values between the two studied groups were determined using Student's *t*-test. Differences in mean values at different periods of follow-up were tested using repeated measurement analysis of variance (*F*), and, when found significant, the least significant difference test was used to compare between two groups. For categorical variables the number and percentage were calculated and differences between subcategories were tested using the Monte Carlo exact test. The level of significance was adopted at *P* less than 0.05.

Results

A total of 60 patients presented to our ED with acute hypoxemic RF.

In group I, patients' ages ranged from 30 to 66 years with a mean value of 49.50 years. In group II, patients' ages ranged from 32 to 61 years with a mean value of 50.33 years. There was no statistically significant difference between the two studied groups ($P>0.05$) (Table 1).

Group I included 17 (56.7%) male and 13 (43.3%) female patients. Group II included 20 (66.7%) male and 10 (33.3%) female patients. There was no statistically significant difference between the two studied groups ($P>0.05$) (Table 1).

In group I, about 60% of patients were nonsmokers and 33.3% were smokers. In group II, about 53.35% of patients were nonsmokers and 43.3% were smokers. There was no statistically significant difference between the two studied groups ($P>0.05$) (Table 1).

In group I, about 20% of patients had hypertension and 13.3% of patients had diabetes. In group II, about 10% of patients had hypertension and 13.3% of patients had diabetes. There was no statistically significant difference between the two studied groups ($P>0.05$) (Table 1).

Causes of RF were pneumonia (53.3 and 60% in groups 1 and 2, respectively), interstitial lung disease (23.3 and 20% in groups 1 and 2, respectively), pleural effusion (10 and 10% in groups 1 and 2, respectively), pulmonary edema (6.7 and 6.7% in groups 1 and 2, respectively), and acute exacerbation of bronchial asthma (6.7 and 3.3% in groups 1 and 2, respectively), with no statistically significant difference between the two groups (Table 1).

The modified Borg scale, VAS, HR, RR, arterial oxygen saturation (SaO_2), and partial pressure of oxygen in arterial blood (PaO_2) recordings are presented in Tables 2–7.

The blood pH, HCO_3, and the $PaCO_2$ showed no significant change in the standard NC group and the HFNC group at different periods ($P>0.05$).

Complications of the study were few and are presented in Table 8. In the conventional NC group, five patients complained of nasal discomfort. In the HFNC group, two patients complained of nasal discomfort with high gas flow (40 l/min). Flow rate decreased for the last two patients to 31 l/min and both patients tolerated HFNC until the end of the study. As regards need for mechanical ventilation, three patients in group I needed mechanical ventilation (two patients needed noninvasive ventilation and one patient needed invasive mechanical ventilation) to maintain better oxygenation after 25, 27, and 30 h, respectively. Only one patient in group II needed invasive mechanical ventilation after 26 h.

Five (16.67%) patients and one (3.33%) patient in the conventional NC group and the HFNC group, respectively, were unsatisfied about the technique.

Table 1 Baseline characteristics in the two studied groups

Baseline characteristics	Conventional NC ($n=30$)	HFNC ($n=30$)	P value
Age (mean±SD) (years)	49.50±10.776	50.33±8.604	0.7
Sex [n (%)]			
Male	17 (56.7)	20 (66.7)	0.4
Female	13 (43.3)	10 (33.3)	
Smoking history [n (%)]			
Nonsmoker	18 (60)	16 (53.35)	
Smoker	10 (33.3)	13 (43.3)	0.7
Ex-smoker	2 (6.7)	1 (3.35)	
Medical history [n (%)]			
No comorbidities	20 (66.7)	23 (76.7)	
Hypertension	6 (20)	3 (10)	0.5
Diabetes	4 (13.3)	4 (13.3)	
Causes of respiratory failure [n (%)]			
Pneumonia	16 (53.3)	18 (60)	0.983
Interstitial lung disease	7 (23.3)	6 (20)	
Pleural effusion	3 (10)	3 (10)	
Pulmonary edema	2 (6.7)	2 (6.7)	
Acute exacerbation of bronchial asthma	2 (6.7)	1 (3.3)	

HFNC, high-flow nasal cannula; NC, nasal cannula.

Table 2 Comparison of the modified Borg scale between the two studied groups

Modified Borg scale	Conventional NC (n=30)	HFNC (n=30)	t-Test	P value
At baseline				
Range	4–7	4–8		
Mean±SD	5.33±0.92	5.33±1.12	0.000	1.000
After 30 min				
Range	4–7	2–6		
Mean±SD	5.33±0.92	3.90±1.13	5.379	0.001*
After 2 h				
Range	3–6	2–6		
Mean±SD	4.53±1.00	3.33±0.99	4.624	0.001*
% of change±SD	−15.54±8.59	−37.96±10.96	8.819	0.001*
After 24 h				
Range	3–6	1–5		
Mean±SD	4.10±0.84	2.63±1.07	5.905	0.001*
% of change±SD	−23.27±7.00	−51.96±12.94	10.684	0.001*
F	140.706	193.028		
P value	0.001*	0.001*		

HFNC, high-flow nasal cannula; NC, nasal cannula. *$P<0.05$, statistically significant.

Table 3 Comparison of visual analog scale between the two studied groups

VAS	Conventional NC (n=30)	HFNC (n=30)	t-Test	P value
At baseline				
Range	5–7	4–8		
Mean±SD	6.17±0.8	5.73±1.08	1.772	0.082
After 30 min				
Range	5–7	2–8		
Mean±SD	6.17±0.8	4.53±1.36	5.692	0.001*
After 2 h				
Range	4–6	1–7		
Mean±SD	5.33±0.76	4±1.41	4.551	0.001*
% of change±SD	−13.49±6.46	−31.94±15.85	5.904	0.001*
After 24 h				
Range	3–6	1–5		
Mean±SD	4.8±0.96	3.17±1.12	6.071	0.001*
% of change±SD	−22.65±9.17	−45.98±12.89	8.077	0.001*
F	158.941	158.335		
P value	0.001*	0.001*		

VAS, visual analog scale; HFNC, high-flow nasal cannula; NC, nasal cannula. *$P<0.05$, statistically significant.

Table 4 Comparison of respiratory rate between the two studied groups

RR (breaths/min)	Conventional NC (n=30)	HFNC (n=30)	t-Test	P value
At baseline				
Range	27–36	26–36		
Mean±SD	31±2.64	30.7±2.63	0.441	0.661
After 30 min				
Range	26–34	22–30		
Mean±SD	29.13±2.24	25.6±2.21	6.155	0.001*
After 2 h				
Range	25–30	20–28		
Mean±SD	27.07±1.74	23.57±2.28	6.647	0.001*
% of change±SD	−12.49±3.49	−23.06±6.36	7.974	0.001*
After 24 h				
Range	23–29	19–26		
Mean±SD	26.37±1.52	21.5±1.83	11.193	0.001*
% of change±SD	−14.69±4.15	−29.84±4.17	14.100	0.001*
F	82.899	386.942		
P value	0.001*	0.001*		

HFNC, high-flow nasal cannula; NC, nasal cannula; RR, respiratory rate. *$P<0.05$, statistically significant.

Table 5 Comparison of heart rate between the two studied groups

HR (beats/min)	Conventional NC (n=30)	HFNC (n=30)	t-Test	P value
At baseline				
Range	124–146	129–140		
Mean±SD	136.9±5.98	134.8±2.92	1.728	0.091
After 30 min				
Range	120–140	114–133		
Mean±SD	131.37±5.99	125.43±4.15	4.459	0.001*
After 2 h				
Range	116–136	98–122		
Mean±SD	125.8±5.67	109.8±5.63	10.973	0.001*
% of change±SD	−8.1±1.71	−18.58±2.95	16.821	0.001*
After 24 h				
Range	108–129	81–101		
Mean±SD	117.9±5.54	89.8±5.67	19.409	0.001*
% of change±SD	−13.86±2.24	−33.41±3.37	26.459	0.001*
F	316.878	1151.013		
P value	0.001*	0.001*		

HFNC, high-flow nasal cannula; HR, heart rate; NC, nasal cannula. *$P<0.05$, statistically significant.

Table 6 Comparison of SpO$_2$ between the two studied groups

SpO$_2$ (%)	Conventional NC (n=30)	HFNC (n=30)	t-Test	P value
At baseline				
Range	82–89	83–88		
Mean±SD	86.03±1.83	86.13±1.53	0.230	0.819
After 30 min				
Range	90–93	91–98		
Mean±SD	91.87±0.86	93.83±2.17	4.620	0.001*
After 2 h				
Range	92–98	93–99		
Mean±SD	94.53±1.8	96.03±1.69	3.331	0.002*
% of change±SD	9.9±2.33	11.51±1.99	2.861	0.006*
After 24 h				
Range	92–98	95–99		
Mean±SD	94.9±1.73	98.1±1.55	8.429	0.001*
% of change±SD	10.33±2.21	7.39±0.023	6.883	0.001*
F	237.073	1263.135		
P value	0.001*	0.001*		

HFNC, high-flow nasal cannula; NC, nasal cannula. *$P<0.05$, statistically significant.

Table 7 Comparison of PaO$_2$ between the two studied groups

PaO$_2$ (mmHg)	Conventional NC (n=30)	HFNC (n=30)	t-Test	P value
At baseline				
Range	45.4–58.8	41.7–59.8		
Mean±SD	52.55±4.04	52.18±4.76	0.325	0.747
After 30 min				
Range	57.4–81.8	90.8–129.7		
Mean±SD	69.01±7.25	106.12±9.48	17.025	0.001*
After 2 h				
Range	61.7–89.7	95.7–134.8		
Mean±SD	76.6±7.64	118.73±9.97	18.370	0.001*
Mean change±SD	46.36±16.42	130.22±34.86	11.919	0.001*
After 24 h				
Range	72.8–105.9	109.6–143.7		
Mean±SD	87.04±10.49	130.32±7.58	18.314	0.001*
Mean change±SD	66.39±22.54	152.32±31.76	12.085	0.001*
F	99.619	587.222		
P value	0.001*	0.001*		

HFNC, high-flow nasal cannula; NC, nasal cannula. *$P<0.05$, statistically significant.

Table 8 Complication of the study in both groups

Complications	Group I (LFNC) (n=30) [n (%)]	Group II (HFNC) (n=30) [n (%)]	P
Nasal bleeding	0 (0)	0 (0)	−
Nasal discomfort	5 (16.67)	2 (6.67)	0.008*
Mechanical ventilation	3 (10)	1 (3.33)	0.021*

HFNC, high-flow nasal cannula; LFNC, low-flow nasal cannula. *$P < 0.05$, statistically significant.

Discussion

HFNC is a relatively new therapeutic device for patients with hypoxemia. It has emerged as an alternative to conventional oxygen therapy in the last decade [20].

Multiple studies showed that the use of HFNC was associated with better or comparable oxygenation when compared with conventional oxygen therapy through NC or face masks [21]. This study aimed to compare the effect of heated and humidified HFNC oxygen therapy and conventional oxygen therapy with standard NC in patients with acute hypoxemic RF.

In the present study, the use of HFNC was associated with rapid improvement in dyspnea scales. Moreover, there was a statistically significant decrease in RR and in HR with the HFNC group as compared with the standard NC group. Moreover, there was a statistically significant increase in oxygen saturation and in partial pressure of oxygen in arterial blood with the HFNC group as compared with the standard NC group.

Several mechanisms can account for rapid improvement in patients in group II (the HFNC group) as compared with group I (the standard NC group). The use of high-flow oxygen leads to wash out of CO_2 in the anatomical dead space, and thus decreases the nasopharyngeal dead space. High-flow oxygen also minimizes the airway resistance by providing gas flows that match the patient's peak inspiratory flow, resulting in decreased work of breathing [4]. High-flow oxygen generates a positive airway pressure and leads to better oxygenation.

Active humidification of oxygen in HFNC can prevent drying of the airway, minimize airway constriction, reduce work of breathing, and result in better oxygenation [3,22].

The results of the present study are in line with Frat et al. [23], who showed that HR and RR were significantly decreased after application of HFNC ($P < 0.05$). There was a statistically significant increase in the PaO_2 after the use of HFNC ($P < 0.01$). There was no significant change in pH and $PaCO_2$ ($P > 0.05$).

Another study by Rittayamai et al. [24] found that the VAS, the RR, and the HR were decreased significantly in the HFNC group as compared with the nonrebreathing mask group ($P < 0.05$).

In addition, Lenglet et al. [25] revealed that the Borg scale, the VAS, and the RR were decreased significantly with the use of HFNC ($P < 0.05$). A significant increase in the SpO_2 and PaO_2 was documented after the use of HFNC ($P < 0.05$). There was no significant change in pH and $PaCO_2$ ($P > 0.05$).

There were several limitations in the present study; one of them was the smaller size of the sample, which was 60 patients. The short period of follow-up for the patients, which was 24 h, was another limitation. The explanation is that this study was conducted in the ED where the patient is kept for a maximum of 24 h; after that the patients were admitted to the ICU or ward.

Another limitation was partial pressure of oxygen in arterial blood (PaO_2) of patients, which was greater than or equal to 40 mmHg (represent mild and moderate degree of hypoxemia). This may be attributed to the inclusion criteria of this study, which included conscious patients, with no need for immediate mechanical ventilation. There are no recommendations to use HFNC in patients with severe hypoxemic RF ($PaO_2 < 40$ mmHg). Thus, more studies are needed to support the use of HFNC in severe RF.

Conclusion

Treatment with HFNC and conventional oxygen therapy through LFNC improved oxygenation, and reduced RR. Treatment of acute hypoxemic RF with HFNC was associated with better and rapid improvement of oxygenation when compared with LFNC, with fewer side effects, better convenience, and lesser need for mechanical ventilation.

Conflicts of interest
There are no conflicts of interest.

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