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High-Flow Nasal Cannula Therapy Versus Intermittent Noninvasive Ventilation in Obese Subjects After Cardiothoracic Surgery

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BACKGROUND: Obese patients are considered at risk of respiratory failure after cardiothoracic surgery. High-flow nasal cannula has demonstrated its non-inferiority after cardiothoracic surgery compared to noninvasive ventilation (NIV), which is the recommended treatment in obese patients. We hypothesized that NIV was superior to high-flow nasal cannula for preventing or resolving acute respiratory failure after cardiothoracic surgery in this population. METHODS: We performed a post hoc analysis of a randomized, controlled trial. Obese subjects were randomly assigned to receive NIV for at least 4 h/d (inspiratory pressure, 8 cm H_2O; expiratory pressure, 4 cm H_2O; F_{IO_2}, 0.5) or high-flow nasal cannula delivered continuously (flow, 50 L/min, F_{IO_2} 0.5). RESULTS: Treatment failure (defined as re-intubation, switch to the other treatment, or premature discontinuation) occurred in 21 of 136 (15.4%, 95% CI 9.8–22.6%) subjects with NIV compared to 18 of 135 (13.3%, 95% CI 8.1–20.3%) subjects with high-flow nasal cannula ($P = .62$). No significant differences were found for dyspnea and comfort scores. Skin breakdown was significantly more common with NIV after 24 h (9.2%, 95% CI 5.0–16.0 vs 1.6%, 95% CI 1.0–6.0; $P = .01$). No significant differences were found for ICU mortality (5.9% for subjects with NIV vs 2.2% for subjects with high-flow nasal cannula, $P = .22$) or for any of the other secondary outcomes. CONCLUSIONS: Among obese cardiothoracic surgery subjects with or without respiratory failure, the use of continuous high-flow nasal cannula compared to intermittent NIV (8/4 cm H_2O) did not result in a worse rate of treatment failure. Because high-flow nasal cannula presents some advantages, it may be used instead of NIV in obese patients after cardiothoracic surgery. *Key words: cardiothoracic surgery; bi-level positive airway pressure; high-flow nasal oxygen; noninvasive ventilation; obesity; respiratory failure.* [Respir Care 2017;62(9):1193–1202. © 2017 Daedalus Enterprises]

Introduction

Obesity (defined by a body mass index (BMI) ≥ 30 kg/m^2) affects many respiratory functions, including, among others, a reduction in functional residual capacity, an increase in airway resistance, and a high level of ventilation-perfusion mismatch.[1] The combination of obesity and postoperative respiratory muscle dysfunction could promote respiratory failure.[2] Hence, obesity is a risk factor for postoperative hypoxemia after cardiac[3] or thoracic[4] surgery. Prophylactic use of noninvasive ventilation (NIV) is recommended in this specific population in the postoperative period[5-8] or after extubation.[9] However, the success rate of NIV to treat acute respiratory failure in obese patients is currently unknown. In addition, this technique is

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difficult to implement, requires substantial resources, and may cause patient discomfort.[10,11] High-flow nasal cannula (HFNC) involves the continuous delivery of up to 60 L/min with optimal heat and humidity through a nasal cannula.[12,13] We have recently shown that the use of HFNC compared with NIV among cardiothoracic surgery subjects with or at risk for respiratory failure did not result in a worse rate of treatment failure.[14] Interestingly, HFNC improves oxygenation by increasing both end-expiratory lung volume and tidal volume and is most beneficial in patients with higher BMI.[15] Unfortunately, in a randomized, controlled trial, prophylactic extubation onto HFNC after cardiac surgery in obese subjects did not improve atelectasis and oxygenation when compared to standard oxygen therapy.[16] In our randomized, controlled trial, nearly one third of the subjects were obese,[14] so we hypothesized that NIV was superior to HFNC for preventing or resolving acute respiratory failure after cardiothoracic surgery in this specific population. We conducted a post hoc analysis in which the primary outcome was the frequency of treatment failure and secondary outcomes included early changes in respiratory variables, comfort, respiratory, and extrapulmonary complications.

QUICK LOOK

Current knowledge

Obese patients are considered at risk of respiratory failure after cardiothoracic surgery. The prophylactic or therapeutic use of noninvasive ventilation is recommended in this specific population in the postoperative period. High-flow nasal cannula has demonstrated its non-inferiority after cardiothoracic surgery compared to noninvasive ventilation. However, clinical studies have not confirmed these findings in obese patients.

What this paper contributes to our knowledge

Among obese cardiothoracic surgery subjects with or without respiratory failure, the use of continuous high-flow nasal oxygen compared with noninvasive ventilation did not result in a worse rate of treatment failure. Because high-flow nasal cannula presents some advantages, it may be used instead of noninvasive ventilation in obese patients after cardiothoracic surgery.

Methods

Study Design and Patients

We performed a post hoc analysis in the subset of obese subjects from a multi-center, randomized, controlled trial.[14] In the original trial, 830 subjects were randomly assigned in a 1:1 ratio to receive either NIV or HFNC. The trial was approved for all centers by the Comité de Protection des Personnes Ile-de-France VII (IRCB 2011-A00125-36) and funded by the participating centers, with no support from commercial sources. Because both study treatments were components of standard care, informed consent was not required. Written and oral information was provided to the subject or relatives.

In the original trial,[14] all subjects with a BMI > 30 kg/m^2 were eligible because obesity was considered as a risk factor for postextubation acute respiratory failure. However, some subjects also met any of the two following conditions:

1) Failed spontaneous breathing trial, defined as P_{aO_2} saturation (S_{aO_2}) below 90% with 12 L of O_2 during a T-tube trial or P_{aO_2} below 75 mm Hg with an F_{IO_2} of at least 0.5 during low-level pressure support;
2) Successful spontaneous breathing trial followed by failed extubation, defined as at least one of: P_{aO_2}/F_{IO_2} ratio less than 300, breathing frequency >25 breaths/min for at least 2 h, and use of accessory respiratory muscles or paradoxical respiration.

Exclusion criteria were obstructive sleep apnea, tracheostomy, do-not-intubate status, delirium, nausea and vomiting, bradypnea, impaired consciousness, and hemodynamic instability.

Study Intervention and Outcomes

High-flow humidified O_2 (37°C and 44 mg H_2O/L) was delivered continuously through a nasal cannula using Optiflow (Fisher and Paykel Healthcare, Auckland, New Zealand). The initial flow was 50 L/min, and the initial F_{IO_2} was 0.5, with subsequent adjustments at the physician's discretion to keep S_{aO_2} at 92–98%.

NIV was delivered using a face mask and either a ventilator specifically designed for NIV (BiPap Vision, Respironics, Carquefou, France) or an ICU ventilator in pressure-support mode with added PEEP (Dräger Evita XL or 4; Dräger Medical SAS, Antony, France; or Monnal T75, Air Liquide, Antony, France). Heat-and-moisture exchange filters were used. Inspiratory pressure was increased, starting at 8 cm H_2O, to achieve an exhaled tidal volume of 8 mL/kg and a breathing frequency < 25 breaths/min. PEEP was initially set at 4 cm H_2O. F_{IO_2} was 0.5 initially, then it was adjusted to keep S_{aO_2} at 92–98%. NIV was used initially for 2 h, then for about 1 h every 4 h, or more if needed to achieve clinical respiratory stability. Between NIV sessions, subjects received O_2 via a standard nasal cannula, simple face mask, or nonrebreathing mask to maintain S_{aO_2} at 92% or higher. F_{IO_2} was calculated by assuming that it increased by 0.03 per L of O_2;[14] for the

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nonrebreathing mask with a reservoir, F_{IO_2} was assumed to be 80%.

During the bedside morning round, when F_{IO_2} was no higher than 0.5 with high-flow nasal O_2 therapy, O_2 was administered via a nasal cannula instead. High-flow nasal O_2 therapy was stopped if S_{aO_2} was at least 95% with 6 L/min or P_{aO_2}/F_{IO_2} was at least 300. NIV was stopped when <4 h/d were needed. The same O_2 therapy method could be resumed within 24 h after stopping if required by the subject's clinical condition. After stopping, success was defined as absence of ventilatory support for the next 72 h.[14]

Arterial blood gas values and breathing frequency were collected at baseline (prior to any study intervention), after 1 h, and between 6 and 12 h; thereafter, the worst value for each respiratory variable was recorded once a day during the following days. Physiological variables were recorded after 1 h of NIV or HFNC, then at 6–12 h after study-treatment initiation, during NIV or standard O_2 therapy (as NIV was used intermittently) or during HFNC (which was used continuously).

Subjects were asked to grade treatment effects on their dyspnea[14] (+2, marked improvement; +1, slight improvement; 0, no change; −1 slight deterioration; −2, marked deterioration) and comfort[14] (1, very poor; 2, poor; 3, sufficient; 4, good; 5, very good). The degree of skin breakdown was assessed by the nurse or physician[14] (0, none; 1, local erythema; 2, moderate skin breakdown; 3, skin ulcer; and 4, skin necrosis). These three scales were assessed once daily, in the afternoon.

The primary outcome was treatment failure defined as re-intubation, switch to the other study treatment, or premature study-treatment discontinuation (at the request of the patient or for medical reasons, eg, gastric distention). Treatment failure also included death occurring during intervention. We used predefined criteria for re-intubation.[14] Re-intubation decisions were made by the attending physicians. An alternative to re-intubation was switching to the treatment used in the other study group, although physicians were encouraged to avoid this measure unless the subject had persistent dyspnea, hypoxemia, or hypercapnia >50 mm Hg.

Secondary outcomes included changes in respiratory variables after 1 h and between 6 and 12 h, changes in the worst daily values of respiratory variables under treatment, dyspnea score, comfort score, skin breakdown score, respiratory and extrapulmonary complications, and number of bronchoscopies. Fiberoptic bronchoscopy was performed at the discretion of the attending physician and was available 24 h/d. The time frame within which all events occurred was the ICU stay.

We recorded cases of pneumothorax and acute colonic pseudo obstruction (cecal diameter at least 10 cm on plain radiographs and/or neostigmine administration) during spontaneous ventilation. Nosocomial pneumonia was defined by a clinical suspicion with positive bacteriological cultures from deep lung specimens and was recorded throughout the ICU stay.

Statistical Analysis

An a posteriori power calculation based on our previous results[14] indicates that the number of obese subjects included permits us to show a difference of 13% for respiratory failure, with alpha set at 5% and beta at 20%. Baseline categorical characteristics were described as number (%) and quantitative variables as means (95% CI) or median (interquartile range).

The main outcome was compared using the chi-square test. For the analysis of secondary outcomes, dichotomous variables were compared using the chi-square test or Fisher exact test, as appropriate. We used 3 categories for the dyspnea scale results (improvement, +2 or +1; no improvement, 0; and deterioration, −1 or −2) and comfort scale results (poor, 1 or 2; acceptable, 3; and good, 4 or 5), and then we analyzed these categories as dichotomous repeated variables using the McNemar test. Continuous variables were compared using the *t* test or Wilcoxon rank-sum test. For quantitative repeated variables (physiologic variables at baseline, after 1 h and after 6–12 h), a linear mixed-effects model was built to compare the 2 study interventions, with subject as a random effect and graphical verification of model validity. For multiple between-group comparisons at baseline, after 1 h and after 6–12 h, we applied the Bonferroni correction. Statistical significance was defined as a $P \leq .05$.

A descriptive analysis of data with repeated measures was done in all subjects over the first 3 d. As the treatment failed or was successful in some subjects within the first 3 d, the number of subjects analyzed decreased between days 1 and 3; we therefore performed exploratory analyses of repeated measurements of clinically relevant quantitative data over the first 3 d using a linear mixed-effects model to compare the 2 study interventions, with subject as a random effect and graphical verification of model validity. For multiple between-group comparisons, we applied the Bonferroni correction.

Kaplan-Meier curves were plotted to assess time from enrollment to occurrence of treatment failure, and curves were compared with the log-rank test.

All analyses were performed using R software. Linear mixed-effects models were built using the RVAideMemoire package.

Results

Of the 830 subjects included in the original study, 231 (32.5%) were obese, all 231 of whom completed the

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Table 1. Subject Characteristics

Characteristics	NIV (n = 136)	HFNC (n = 135)	P
Age, years, mean ± SD	63.4 ± 11.8	64.5 ± 11.3	.40
Men, n (%)	87 (63.9)	81 (60.0)	.50
Body mass index, kg/m^2, mean ± SD	34.4 ± 3.8	34.2 ± 3.4	.60
Body mass index > 40 kg/m^2, n (%)	9 (6.6)	6 (4.4)	.40
Smoking, n (%)			.66
Former	69 (50.7)	70 (51.8)	
Current	27 (19.8)	22 (16.3)	
SAPS II score at admission, mean ± SD	25.4 ± 12.9	25.9 ± 11.1	.80
Acute respiratory failure at inclusion, n (%)	51 (37.5)	45 (33.3)	.47
P_{aO_2}/F_{IO_2} ratio < 200 at inclusion, n (%)	50 (36.8)	45 (33.3)	.55
Surgical procedures, n (%)			.59
Coronary arterial bypass grafting	40 (29.4)	54 (40.0)	
Valvular surgery	41 (30.2)	31 (23.0)	
Combined cardiac surgery with coronary arterial bypass grafting	9 (6.6)	8 (5.9)	
Thoracic aorta	9 (6.6)	6 (4.4)	
Pulmonary thromboendarterectomy	19 (14.0)	15 (11.1)	
Lung resection	6 (4.4)	9 (6.7)	
Heart, lung, heart-lung transplantations	0	2 (1.5)	
Others	12 (8.8)	10 (7.4)	
Cardiopulmonary bypass, n (%)	118 (86.8)	108 (80.0)	.14
Time on cardiopulmonary bypass, min, mean ± SD	120 ± 66	110 ± 60	.20
Time from surgery to randomization, days, median (IQR)	1.0 (0.0–1.0)	1.0 (0.0–1.0)	.58
Duration of mechanical ventilation at randomization, h, median (IQR)	9.0 (5.0–20.0)	8.0 (5.0–16.5)	.92

Spirometry results were available for 181 subjects: 94 (69.1%) in the NIV group and 87 (64.4%) in the high-flow nasal O_2 group. According to the spirometry classification, COPD was mild-to-moderate in 19 (13.9%) subjects in the NIV group and in 13 (14.9%) subjects in the high-flow nasal O_2 group (P = .41).
NIV = noninvasive ventilation
HFNC = high-flow nasal cannula
SAPS II = Simplified Acute Physiology Score version II
IQR = interquartile range

study. These subjects differed from non-obese patients by a lower simplified acute physiology score II, a lower acute respiratory status, and lower treatment failure and mortality rates (see the supplementary Table 1 at http://www.rcjournal.com). Acute respiratory failure was present at inclusion in 51 (37.5%) subjects allocated to NIV and 45 (33.3%) subjects allocated to HFNC (P = .40). Baseline characteristics were similar in the 2 groups (see the supplementary Table 1 at http://www.rcjournal.com).

Primary Outcome

Treatment failure occurred in 21 of 136 (15.4%, 95% CI 9.8–22.6%) subjects treated by NIV compared to 18 of 135 (13.3%, 95% CI 8.1–20.3%) subjects with HFNC (P = .62). Median time from treatment initiation to treatment failure was 1.0 d (interquartile range 0.0–2.0 d) with NIV versus 2.0 d (interquartile range 0.25–2.75 d) with HFNC (P = .26) for subjects who experienced treatment failure (Figure 1). Re-intubation was performed in 8 (5.9%, 95% CI 2.8–11.6%) subjects with NIV and 5 (3.7%, 95% CI 1.4–8.9%) subjects with HFNC (P = .40). Switching to the other study treatment occurred in 8 (5.9%, 95% CI 2.7–11.6%) subjects with NIV and 12 (8.9%, 95% CI 4.9–15.3) subjects with HFNC (P = .34). Premature discontinuation was noted in 5 (3.7%, 95% CI 1.4–8.8%) subjects with NIV and 1 (0.7%, 95% CI 0.04–4.7%) subject with HFNC (P = .12). Dichotomizing the subjects based on a P_{aO_2}/F_{IO_2} ratio <200 showed that NIV failed in 10 of 50 (20.0%, 95% CI 10.5–34.1%) subjects and HFNC failed in 13 of 45 (28.9%, 95% CI 16.8–44.5%) subjects (P = .35). For subjects included only for their obesity, treatment failure occurred in 11 of 85 (12.9%, 95% CI 7.0–22.0%) subjects with NIV compared to 5 of 90 (5.6%, 95% CI 2.0–13.0%) subjects with HFNC (P = .09).

Respiratory Variables

Courses of respiratory variables and subjective effects on dyspnea and comfort during the first 12 h were reported in Table 2. At 6–12 h after NIV initiation, mean tidal

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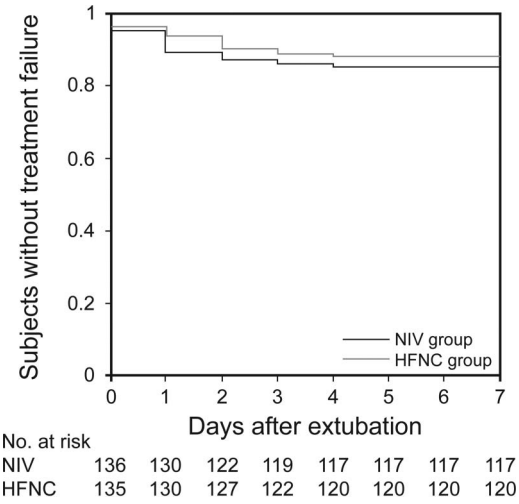

Fig. 1. Kaplan-Meier plot of postoperative obese subjects without treatment failure after extubation showing the percentages of obese patients in whom treatment with either NIV or high-flow nasal O_2 therapy did not fail after postoperative extubation. Treatment failure occurred in 21 of 136 (15.4%) patients with NIV and in 18 of 135 (13.3%) subjects with high-flow nasal O_2. Log-rank test = 0.49. Treatment failure was defined as re-intubation for mechanical ventilation, switch to the other study treatment, or premature study-treatment discontinuation (at the request of the patient or for medical reasons such as gastric distention), or death during intervention.

volume was 6.4 ± 4.9 mL/kg, mean inspiratory pressure was 9.5 ± 2.2 cm H_2O, and mean expiratory pressure was 4.2 ± 1.3 cm H_2O. In the HFNC group, mean pre-set flow was 50.4 ± 4.0 L/min.

Respiratory support was required throughout the first 3 d in 74 subjects (Table 3). P_{aO_2}/F_{IO_2} increased from day 1 to day 3 in both groups ($P < .001$) but was no different between groups ($P = .065$). Although P_{aCO_2}, breathing frequency, and pH varied significantly throughout the first 3 d, there were no differences between groups.

Clinical Outcomes and Adverse Events

The dyspnea and comfort scores and the proportion of subjects with skin breakdown are reported in Table 3. No significant differences were found for ICU mortality (8 subjects with NIV [5.9%, 95% CI 2.8–11.6%] and 3 subjects with HFNC [2.2%, 95% CI 0.6–6.8%], $P = .22$) or for any of the other secondary outcomes (Table 4). No death occurred during study intervention.

Discussion

In this post hoc study including only obese subjects with or without respiratory failure after cardiothoracic surgery, the rate of treatment failure was not different in subjects treated with HFNC versus NIV (8/4 cm H_2O). However, improvement in oxygenation was better with NIV.

Severe hypoxemia is common after cardiothoracic surgery,[19] and obesity is itself a risk factor for postoperative hypoxemia after cardiac[3] or thoracic[4] surgery. In this setting, perioperative atelectasis contributes to increasing the intrapulmonary shunt, which leads to hypoxemia[20] and promotes bacterial growth.[21]

Few studies have demonstrated that NIV could improve the outcome of cardiothoracic subjects with respiratory failure.[22,23] As a preventive tool, one randomized, controlled study comparing NIV with standard treatment was negative in subjects with COPD after lung resection,[24] but oxygenation improved and pulmonary complications after cardiac surgery were reduced when delivered in the continuous positive airway pressure mode.[25] A recent meta-analysis confirmed that the use of NIV after cardiothoracic surgery improved subjects's oxygenation and decreased the need for endotracheal intubation.[26]

NIV is one of the recommended treatments to improve pulmonary function and gas exchange in obese patients[5-9,11,27] and has been studied extensively in the postoperative period of abdominal surgery.[28,29] Interestingly, NIV can unload the inspiratory muscles of obese patients[27] and was superior to continuous positive airway pressure regarding the improvement of atelectasis[30] after cardiac surgery. However, it is recommended to set the PEEP at ≥10 cm H_2O.[8]

Recently it has been demonstrated that HFNC was not inferior to NIV to treat or prevent respiratory failure after cardiothoracic surgery[14] and in high-risk subjects (of whom 20% were obese) for respiratory failure after extubation.[31] Interestingly, HFNC was superior to conventional treatment even in low-risk patients.[32] This treatment has some advantages compared to NIV, such as ease of application,[12-14,33] comfort,[12-14,33,34] less skin breakdown,[14] and a lower nurse work load.[14,33] However, the device generated a maximal PEEP of around 5 cm H_2O when the flow was > 50 L/min and the subject breathed with a closed mouth[12,13,15]. A recent meta-analysis suggested that HFNC reduced the need for escalation of respiratory support compared with conventional oxygen therapy.[35]

Two randomized, controlled studies have reported the respiratory effects of HFNC after cardiac surgery. As a preventive strategy in subjects with a mean BMI of 28.4, application of HFNC for < 24 h did not lead to improvement of oxygenation or atelectasis occurrence, but it did reduce the requirement for escalation of respiratory support when compared to standard treatment.[34] In another trial, obese subjects were placed on HFNC after cardiac surgery for a mean of 10.9 h, and outcomes were compared to standard oxygen therapy after extubation.[16] There was no significant difference in the P_{aO_2}/F_{IO_2} ratio between groups in the first 24 h postextubation and in the atelectasis score.[16] In both studies, limiting the HFNC exposure

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Table 2. Physiological Variables and Subjective Effect on Dyspnea

Parameters	Baseline (prior to any study intervention)		After 1 h		*P*	After 6–12 h		*P*
	NIV ($n = 135$)	HFNC ($n = 135$)	NIV ($n = 134$)	HFNC ($n = 132$)		NIV ($n = 127$)	HFNC ($n = 121$)	
P_{aO_2}/F_{IO_2}, mean ± SD	244 ± 99	238 ± 92	255 ± 95	211 ± 73*	<.001	295 ± 132†	227 ± 101‡	<.001
P_{aCO_2}, mean ± SD	40.2 ± 7.3	39.6 ± 5.5	40.2 ± 6.3	39.2 ± 5.9	>.99	40.3 ± 5.7	39.3 ± 5.3	.85
pH, mean ± SD	7.37 ± 0.06	7.37 ± 0.06	7.37 ± 0.07	7.37 ± 0.06	>.99	7.38 ± 0.06§	7.39 ± 0.05‖	>.99
Breathing frequency, mean ± SD	21.0 ± 6.4	20.5 ± 5.9	21.3 ± 6.1	19.8 ± 5.6	.18	20.8 ± 5.2	20.9 ± 4.9	>.99
Dyspnea score, *n* (%) [95% CI]					>.99			.57
Improvement	ND	ND	81/133 (60.9) [52.1–69.2]	71/132 (53.8) [44.9–62.5]		68/127 (53.6) [44.5–62.4]	76/131 (58.0) [49.1–66.6]	
No improvement	ND	ND	47/133 (35.3) [27.3–44.1]	58/132 (43.9) [35.3–52.9]		53/127 (41.4) [33.0–50.8]	44/131 (33.6) [25.6–42.4]	
Deterioration	ND	ND	5/133 (3.8) [1.2–8.6]	3/132 (2.3) [0.5–6.5]		6/127 (4.7) [1.8–10.0]	1/131 (8.4) [0.02–4.2]	
Comfort score, *n* (%) [95% CI]					>.99			>.99
Poor	ND	ND	15/133 (11.3) [6.5–17.9]	20/131 (15.3) [9.6–22.6]		26/127 (20.5) [13.8–28.5]	16/121 (13.2) [7.8–20.6]	
Acceptable	ND	ND	42/133 (31.6) [23.8–40.2]	29/131 (22.1) [15.4–30.2]		35/127 (27.6) [20.0–36.2]	38/121 (31.4) [42.9–60.9]	
Good	ND	ND	76/133 (57.1) [48.3–65.7]	82/131 (62.6) [53.7–70.9]		66/127 (48.9) [23.3–40.5]	67/121 (55.4) [46.0–64.4]	

* Within-group comparison with Bonferroni's correction, 1 h vs baseline: $P < .001$.
† Within-group comparison with Bonferroni's correction, 6–12 h vs 1 h: $P < .001$.
‡ Within-group comparison with Bonferroni's correction, 6–12 h vs 1 h: $P = .001$.
§ Within-group comparison with Bonferroni's correction, 6–12 h vs 1 h: $P = .008$.
‖ Within-group comparison with Bonferroni's correction, 6–12 h vs 1 h: $P = <.001$.
NIV = noninvasive ventilation
HFNC = high-flow nasal cannula

Table 3. Subjective Effect on Dyspnea, Comfort Score, Nurse Interventions, and Markers of Illness Severity

Parameters	Study Treatment Day 1		*P*	Study Treatment Day 2		*P*	Study Treatment Day 3		*P*
	NIV (*n* = 133)	HFNC (*n* = 129)		NIV (*n* = 72)	HFNC (*n* = 69)		NIV (*n* = 38)	HFNC (*n* = 36)	
Duration of respiratory assistance per d (h)	5.9 ± 2.7	18.4 ± 5.9		6.0 ± 3.7	19.5 ± 7.0		5.7 ± 3.9	20.2 ± 6.2	
P_{aO_2}/F_{IO_2}, mean ± SD	157 ± 66	143 ± 45	.88	168 ± 70	146 ± 60	.44	208 ± 99	166 ± 66	.11
P_{aCO_2}, mean ± SD	40.7 ± 6.6	41.4 ± 6.0	>.99	40.1 ± 5.9	38.9 ± 5.6	>.99	39.9 ± 6.2	38.3 ± 6.1	.76
pH, mean ± SD	7.38 ± 0.06	7.38 ± 0.05	>.99	7.41 ± 0.05	7.41 ± 0.04	>.99	7.43 ± 0.05	7.41 ± 0.05	.61
Breathing frequency, mean ± SD	27.1 ± 6.1	25.7 ± 4.6	.79	29.7 ± 7.2	27.8 ± 6.3	.65	27.7 ± 6.1	26.8 ± 7.1	>.99
Dyspnea score, *n* (%) [95%CI]			.26			>.99			>.99
Improvement	63 (47.4) [38.7–56.2]	72 (56.7) [47.6–66.5]		43 (60.5) [48.3–72.0]	44 (63.8) [51.3–75.0]		22 (59.4) [42.1–75.3]	21 (58.3) [48.4–74.5]	
No improvement	58 (43.6) [35.0–49.2]	51 (40.1) [31.6–49.2]		24 (33.8) [23.0–46.0]	23 (33.3) [22.4–45.7]		10 (27.0) [13.8–44.1]	13 (36.1) [20.8–53.7]	
Deterioration	12 (9.0) [4.7–15.2]	4 (3.0) [0.9–7.9]		4 (5.6) [1.6–13.8]	2 (2.9) [0.4–10.1]		5 (13.5) [4.5–28.7]	2 (5.5) [0.7–18.7]	
Comfort score, *n* (%) [95%CI]			>.99			>.99			>.99
Poor	23 (17.3) [11.3–24.8]	16 (12.6) [7.4–19.7]		14 (19.7) [11.2–30.9]	10 (14.5) [7.2–25.0]		9 (24.3) [11.8–39.2]	8 (22.2) [10.1–39.2]	
Acceptable	39 (29.3) [21.7–37.8]	38 (29.9) [22.1–38.7]		19 (26.8) [16.9–38.6]	22 (31.9) [21.2–44.2]		9 (31.0)	9 (25.0) [12.1–42.2]	
Good	71 (53.4) [44.5–62.1]	73 (57.5) [48.4–66.2]		38 (53.5) [41.3–65.4]	37 (53.6) [41.2–65.7]		19 (51.3) [34.4–68.1]	19 (52.8) [25.5–69.6]	
Skin breakdown, *n* (%) [95%CI]			.01			.82			>.99
None	119 (90.8) [84.0–95.0]	127 (98.4) [94.0–99.0]		65 (91.5) [82.0–96.0]	67 (97.1) [89.0–99.0]		33 (91.7) [76.0–98]	32 (89.0) [73–96]	
Focal erythema	11 (8.4) [4.5–14.9]	1 (0.8) [0.04–4.8]		6 (8.5) [3.5–18.1]	2/69 (2.9) [0.50–11.0]		3 (8.3) [2.2–23.6]	4 (11.1) [3.6–27.0]	
Moderate skin breakdown	0	1 (0.8) [0.04–0.48]		0	0		0	0	
Skin ulcer	0	0		0	0		0	0	
Skin necrosis	1 (0.8) [0.04–4.8]	0		0	0		0	0	
Number of patients with at least 1 fiberoptic bronchoscopy, *n* (%)	2 (1.5) [0.3–5.9]	6 (4.6) [1.9–10.3]	.5	3 (4.2) [0.1–12.5]	4 (5.8) [0.2–14.9]	>.99	2 (5.3) [0.9–19.0]	5 (13.9) [5.2–3.3]	.79
Radiologic score, points*	3.6 ± 1.8	4.1 ± 1.8	.03	4.1 ± 1.7	4.0 ± 1.8	>.99	4.5 ± 1.7	4.4 ± 2.1	>.99
SOFA score, points	4.1 ± 2.2	4.3 ± 1.9	.87	4.0 ± 2.0	4.1 ± 1.9	>.99	4.1 ± 2.0	4.3 ± 1.9	>.99

* The radiologic score was determined using a modification of the technique described by Weinberg and co-workers.[17] Briefly, anterior-posterior chest roentgenograms were divided into 4 zones using a horizontal line originating from the hilus. Each zone was then graded as follows: 0, normal; 1, interstitial pulmonary infiltrates; 2, fluffy alveolar infiltrates; 3, dense alveolar infiltrates. Thus, the score could range from 0 to 12, with higher scores indicating greater severity of infiltration.

NIV = noninvasive ventilation

HFNC = high-flow nasal cannula

SOFA = Sequential Organ Failure Assessment score (range, 0–24; higher scores indicate more severe illness)[18]

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Table 4. Clinical Outcomes and Adverse Events During ICU Stay

Events	NIV Group (n = 136)	HFNC Group (n = 135)	P
Nosocomial pneumonia, n (%) [95%CI]	17 (12.5) [7.7–19.5]	17 (12.6) [7.7–19.7]	.98
Pneumothorax, n (%) [95%CI]	2 (1.5) [0.2–5.7]	0	.49
Acute colonic pseudoobstruction, n (%) [95%CI]	1 (0.7) [0.4–4.6]	1 (0.7) [0.04–4.7]	.75
Number of days with respiratory support, median (IQR)	2 (1–3)	1 (1–3)	.79
ICU length of stay, d, median (IQR)	4.0 (2.7–7.2)	5.0 (3.0–7.0)	.63
Hospital length of stay, d, median (IQR)	11.0 (8–17)	10.0 (8.0–14.0)	.71

NIV = noninvasive ventilation
HFNC = high-flow nasal cannula
IQR = interquartile range

time and the population studied may have had an impact on outcome.

Our study suggested that NIV was not superior to HFNC. HFNC and NIV have fundamental differences. First, HFNC is applied in a continuous fashion, whereas NIV, in our study, was applied intermittently. Second, HFNC provided a continuous flow, but pressure is not continuous, and pressure fluctuations are also different as pressure dips during inspiration and peaks during expiration; the opposite is found during NIV at possibly higher levels.[36] There are data to suggest that fully saturated inspired gas with higher absolute humidity at near-body temperature preserves mucociliary clearance and pulmonary function.[37,38] Therefore, HFNC may improve small airway function and reduce air trapping by improving mucociliary clearance,[38] and could decrease airway resistance[13] in obese patients. Moreover, it has been recently demonstrated that HFNC reduced inspiratory muscle effort.[39] This last effect combined with a humidified and heated gas can be compared with the pressure support generated by NIV but to a lesser degree. HFNC was also associated with an increase in end-expiratory volume, which was significantly greater in obese subjects.[15] However, oxygenation improved more with NIV, as previously reported,[14] perhaps due to the higher PEEP compared to HFNC.[12,13,15] Interestingly, the course of radiologic scores, which can be considered among other things as a surrogate of atelectasis, was similar between the 2 groups, and the number of nosocomial pneumonia was similar. Effects on dyspnea and comfort were similar for both treatments as discussed in the original report[14] underlying the absence of the impact of obesity on these outcomes. Skin breakdown was significantly more common in the NIV group but with the same range as in the original study.[14]

Our study has several limitations. First, this is a post hoc analysis and some concern regarding the power could be raised. However, the number of subjects gave a reasonable power to validate the results. Second, the PEEP was only around 4 cm H_2O, which was lower than the 10 cm H_2O recommended by experts.[8] However, this threshold is rarely reported.[9,28] Third, NIV or HFNC was used for preventive or curative treatment. These two situations may be difficult to differentiate when using NIV[40] or HFNC, because in some cases the therapy may mask an underlying deterioration in physiology. Fourth, the F_{IO_2} delivered was not measured and we may therefore have underestimated the P_{aO_2}/F_{IO_2} ratio in the two groups. Finally, we cannot exclude that some subjects suffered from obstructive sleep apnea syndrome, for which continuous positive airway pressure is the treatment of choice.

Conclusions

Among obese cardiothoracic surgery subjects with or without respiratory failure, the use of continuous HFNC compared with intermittent NIV (4/8 cm H_2O) did not result in a worse rate of treatment failure. Because HFNC presents some advantages, it may be used instead of NIV in obese patients after cardiothoracic surgery.

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