The Double-Trunk Mask Improves Oxygenation During High-Flow Nasal Cannula Therapy for Acute Hypoxemic Respiratory Failure

Frédéric Duprez, Arnaud Bruyneel, Shahram Machayekhi, Marie Droguet, Yves Bouckaert, Serge Brimioulle, Gregory Cuvelier, and Gregory Reychler

BACKGROUND: High-flow nasal cannula (HFNC) oxygen therapy is used to deliver an FIO2 from 0.21 to 1.0. The double-trunk mask (DTM) is a device designed to increase the FIO2 in patients with a high inspiratory flow demand. The aim of our study was to evaluate the effect of DTM in hypoxemic subjects already receiving HFNC. METHODS: We report a prospective multi-center crossover pilot study including 15 subjects treated with HFNC for acute hypoxemic respiratory failure. Measurements were performed at the end of 30-min periods with HFNC only, with HFNC/DTM, and again with HFNC only. RESULTS: Compared with HFNC alone, HFNC/DTM increased PaO2 from 68 ± 14 mm Hg to 85 ± 22 mm Hg (P < .001) and did not affect PaCO2 (P = .18). In the 11 responders, the PaO2 increased from 63 ± 12 mm Hg to 88 ± 23 mm Hg (P < .001). No complications were reported during DTM use. CONCLUSION: In subjects receiving oxygen via HFNC, the addition of the DTM over the HFNC increased PaO2 without changing the PaCO2. Key words: high-flow nasal cannula; high-flow oxygen therapy; acute respiratory failure; oxygen delivery; double-trunk mask. [Respir Care 0;0(0):1–. © 0 Daedalus Enterprises]

Introduction

High-flow nasal cannula (HFNC) oxygen therapy is a technique used to deliver a high flow of heated and humidified gas to hypoxemic subjects. HFNC allows a FIO2 from 0.21 to 1.0 using an air-oxygen blender and can generate gas flows of 10–60 L/min.1,2 Compared to low-flow oxygen therapy, HFNC allows better control of FIO2.3,4 However, the FIO2 delivered via HFNC remains dependent on the amount of flow, nasal cannula size, and mouth position.5–8 In the case of respiratory distress, the inspiratory flow can exceed 100 L/min, causing dilution of the administered oxygen by room air.7,9–11

The double-trunk mask (DTM) is a device designed to increase the FIO2 in adult patients who receive oxygen by a nasal cannula. The mask was developed by Hnatiuk et al12 and modified by Bodur et al.13 The DTM is composed of a regular aerosol mask with corrugated tubing (15 cm length) inserted into two lateral holes. The dead space of the mask is 210 mL, and volume of the trunks is 120 mL. The DTM was used with subjects who were already receiving oxygen via nasal cannula (Fig. 1). The tubing collects oxygen coming from the nasal cannula during expiration. During the next inspiration, the subject inhales the oxygenated gas mixture from the tubing in-
stead of room air. The mask has been shown to increase PaO₂ without increasing PaCO₂. Our hypothesis was that the addition of the DTM to a HFNC would prevent the dilution of inspired gas by room air due to high inspiratory flow or to mouth position, thereby increasing FIO₂ and thus PaO₂. The primary outcome of our study was to evaluate the effect of the DTM on PaO₂ in hypoxic subjects treated with HFNC. The secondary outcomes were changes in PaCO₂ and subject comfort.

Methods

This was a prospective multi-center crossover pilot study with assessment by an independent evaluator. The ethics review boards for the Erasmes Hospital and Epicura-Tivoli Hospital approved the study protocol. Written informed consent was obtained from all participants before inclusion (NERB034008). The study was registered with ClinicalTrials.gov (NCT03319602).

We included 15 non-intubated adult subjects with acute hypoxic respiratory failure admitted to the ICUs at Epicura Hospital in Hornu, Belgium, and at Tivoli University Hospital in La Louvière, Belgium, from October 2017 to March 2018.

Criteria for inclusion were hypoxemia (PaO₂/FIO₂/H₁/₁₀₂₁ 300 mm Hg), new or worsening respiratory symptoms (eg, dyspnea, shortness of breath), use of accessory muscle, breathing frequency ≥ 30 breaths/min, and an inline arterial catheter without anticipated changes to respiratory clinical management over the next 2 h (eg, use of noninvasive or invasive mechanical ventilation). Subjects were included only when the investigators were present in the ICU. The level of severity of hypoxemia was assessed as follows: mild (PaO₂/FIO₂/H₁/₁₀₂₁ 200–300 mm Hg), moderate (PaO₂/FIO₂/H₁/₁₀₂₁ 100–200 mm Hg), and severe (PaO₂/FIO₂/H₁/₁₀₂₁ < 100 mm Hg). Exclusion criteria included COPD, pulmonary fibrosis, hypoventilation obesity syndrome, respiratory acidosis, cardiogenic pulmonary edema, systolic arterial pressure < 60 mm Hg or treatment with epinephrine > 0.1 μg/kg/min, altered consciousness (≤ 12 on the Glasgow Coma scale), and confusion. The flow chart for participant enrollment, allocation, and analysis is presented in Figure 2.

Data Collection

At enrollment, the following variables were collected: age, weight, height, arterial pressure (systolic, diastolic, mean), heart rate, breathing frequency, arterial blood gases, Sequential Organ Failure Assessment (SOFA) score on the day of the study, Medical Research Council dyspnea 5-point Likert scale, subject comfort using a numeric scale, and Glasgow Coma scale. Etiology of acute hypoxic respiratory failure and presence of bilateral pulmonary infiltrates on a chest radiograph were reported by a physician.

QUICK LOOK

Current knowledge

High-flow nasal cannula (HFNC) oxygen therapy might benefit patients with hypoxemia. This technique decreases oxygen dilution and anatomical dead space, increases patient comfort, and can generate positive airway pressure.

What this paper contributes to our knowledge

The double-trunk mask (DTM) boosts FIO₂ during low-flow oxygen via nasal cannula. In subjects receiving HFNC therapy, placing a DTM over the nasal prongs increased PaO₂ without significantly increasing PaCO₂. These results mean the DTM can potentially improve the oxygenation status of patients during HFNC therapy.
Materials

The HFNC flow was generated with an AIRVO 2 (Fisher and Paykel Healthcare, Auckland, New Zealand) connected to a standard nasal prong (Optiflow nasal cannula for MR850 AIRVO, Auckland, New Zealand). The AIRVO 2 can deliver flows of 10–60 L/min. A calibrated ultrasonic oxygen analyzer measured the gas output of the system. AIRVO 2 was connected to a RTM3 oxygen Thorpe Tube (Air Liquide, Paris, France) with O2 flow of 0–60 L/min connected to a wall oxygen supply. The DTM consisted of an aerosol mask (Dahlhausen, Köln, Germany) and 2 corrugated tubes (Dahlhausen) of 22 mm diameter, shortened to 15 cm (Fig. 1).

Study Protocol

Subjects were placed in a semi-recumbent position, in a quiet environment with the Optiflow nasal cannula in place. The FIO2 and flow were adjusted to obtain a peripheral S\textsubscript{pO2} ≥ 90%. In some cases, the flow was adjusted for subject comfort. During high inspiratory flow demand, the flow was initially adjusted to 60 L/min. No further modifications to HFNC settings were made during the investigation (Fig. 2).

Each subject went through 3 treatment phases (Figure 3). In phase 1 (HFNC), oxygen was administered using only HFNC for a period of 30 min. After that, if the subject remained stable, arterial blood gases were measured using the arterial catheter. In phase 2 (HFNC + DTM), the clinician placed the DTM over the nasal prongs without changing HFNC settings (Fig. 1). Arterial blood gases were measured after 30 min. Subjects in whom the PaO2 increased by at least 10% were considered responders. In phase 3 (HFNC), the DTM was withdrawn while HFNC...
was continued with the same settings. Arterial blood gases were measured after 30 min.

Respiratory and hemodynamic status were also reassessed at the end of each study phase. The subjects did not receive any instruction regarding opening or closing their mouth during any of the study phases.

**Statistical Analysis**

In the absence of data allowing for the estimation of a sample size, we decided to enroll 15 subjects in this exploratory study, with the hypothesis that this number would be sufficient to detect a significant variation in PaO2. Data were analyzed with SigmaPlot version 12.0 (Systat Software, San Jose, California). Data are presented as mean ± SD for normally distributed variables, and as median and interquartile range for non-normally distributed variables. Distribution of data were evaluated with a Kolmogorov-Smirnov test. Differences between variables across the study phases were tested with 1-way analysis of variance (ANOVA) for repeated measures for parametric data, and with 1-way repeated measure ANOVA on ranks for non-parametric data. Pairwise multiple comparison procedures (Tukey test) were performed when statistically significant differences were found between groups.

**Results**

The subjects are described in Table 1. Fifteen subjects were included: 13 men (86%) and 2 women (13%). Mean age was 67 ± 16 y, and body mass index was 26 ± 6 kg/m². At enrollment, all subjects had a PaO2/FIO2 < 200 mm Hg, with 13 (87%) having a ratio < 100 mm Hg. ROX index was defined as the ratio of pulse oximetry/fraction of inspired oxygen to respiratory rate. The flow during HFNC was 51 ± 6 L/min (range, 40–60 L/min). No adverse events were observed during the study.

Compared with HFNC alone, HFNC + DTM increased PaO2 from 68 ± 14 mm Hg to 85 ± 22 mm Hg (P < .001) and did not affect PaCO2 (P = .18) (Table 2, Fig. 4 and Fig. 5). In the 11 responders, PaO2 increased from 63 ± 12 mm Hg to 88 ± 23 mm Hg (P < .001). After removal of the DTM, all variables returned to baseline values.

**Discussion**

The present study shows that in subjects with moderate (n = 4) and severe (n = 11) acute hypoxemic respiratory failure who were already receiving HFNC therapy, the addition of the DTM increased the PaO2 from 68 ± 14 mm Hg to 85 ± 22 mm Hg (P < .001) and did not affect PaCO2 (P = .18). In the 11 responders, PaO2 increased from

<table>
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<tr>
<th>Subject</th>
<th>Age, y</th>
<th>Sex</th>
<th>Body Mass Index, kg/m²</th>
<th>Set FIO2</th>
<th>Flow, L/min</th>
<th>SOFA Score on Admission</th>
<th>Etiology of AHRF</th>
<th>Bilateral Infiltrates</th>
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Total or mean ± SD: 16 ± 2 male, 16 ± 2 female

ROX Index is defined as the ratio of pulse oximetry/FIO2 to breathing frequency.

SOFA = Sequential Organ Failure Assessment

AHRF = acute hypoxemic respiratory failure

CAP = community-acquired pneumonia

HAP = hospital-acquired pneumonia

ES = extrapulmonary sepsis
Median $P_{aO_2}$ increased between phase HFNC and HFNC + DTM and returned to the baseline values during the washout periods. Column variation (%) corresponded to the relative $P_{aO_2}$ variation (%) between phase HFNC and phase HFNC + DTM. Subjects 2, 4, 5, and 6 were considered nonresponsive.

HFNC = high-flow nasal cannula

DTM = double-trunk mask

Table 2. Median $P_{aO_2}$ (and $P_{aO_2}/FIO_2$) Variation Between Phases

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<tr>
<th>Subject</th>
<th>$P_{aO_2}$, mm Hg</th>
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<th>Variation Between Phase 1 and 2, %</th>
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Fig. 4. $P_{aO_2}$ comparisons by Friedman test between HFNC alone during phase 1, HFNC + DTM during phase 2, and HFNC alone during phase 3. The boxes illustrate interquartile range and 25th, 50th, and 75th percentiles; the whiskers correspond to the 5th and 95th percentiles, and dots are outliers. $P_{aO_2}$ levels show a statistically significant increase at phase 2 compared to phase 1 (+26%). When the mask was removed, the $P_{aO_2}$ returned to the baseline values during the washout periods and subsequently during the recovery period.

$63 \pm 12$ mm Hg to $88 \pm 23$ mm Hg ($P < .001$). The $P_{aO_2}$ increase can be explained by eliminating entrainment of room air when inspiratory flows are above the flow delivered with HFNC or when the nasals prongs are not correctly positioned in the nares. Entrainment of room air is known to dilute the gas mixture and decrease delivered $FIO_2$. When the DTM was added, room air was no longer entrained and the subject inspired the oxygen-enriched mixture collected in the additional tubes. Actual $FIO_2$ increased or was closer to the set $FIO_2$, thereby increasing oxygenation. However, we had 4 non-responders, which we believe was due to the differences in inspiratory
flow demand and the amount of air entrainment through leaks around the mask. Few studies have examined the inspiratory flow values during acute respiratory failure. Two studies have examined the role of inspiratory flow in healthy subjects receiving HFNC at rest and during exercise.5,28 The authors concluded that HFNC cannot be considered a constant oxygen delivery system because the accuracy of the system depends on the patient’s breathing pattern, especially if the inspiratory flow demand is above the HFNC gas flow value.

In our study, the PaCO₂ remained unchanged despite an increase in dead space. This observation can be explained by the tube washout caused by gas coming from the HFNC.14 Indeed, with a 60 L/min (ie, 1,000 mL/s) flow from the HFNC, the total trunk volume of 120 mL was entirely washed out in ~0.12 s. Even with the high breathing frequency and short expiratory time of subjects with acute hypoxemic respiratory failure, this limited duration was appropriate to wash out the expired CO₂ from the tubes. According to our calculations, a frequency > 60 breaths/min would be required to result in CO₂ re-breathing.

Another issue relates to our classification of subjects with acute hypoxemic respiratory failure. The main determinant of our subject’s classification into subgroups with mild, moderate, or severe acute hypoxemic respiratory failure is the PaO₂/FIO₂ ratio. Our data show that actual FIO₂ is overestimated in many subjects with acute hypoxemic respiratory failure, resulting in erroneously low PaO₂/FIO₂ values. The use of the DTM may reverse this confusing effect, by minimizing the difference between set FIO₂ and actual FIO₂ and restoring an accurate PaO₂/FIO₂ ratio.

Severe hypoxemia is deleterious to patients and should be considered an indication for positive airway pressure and mechanical ventilation.29 Thus, caution should be used when applying the DTM to prevent delayed intubation and prolonged duration of critical hypoxemia. Suggested indications include transient hypoxemia (eg, related to cardiogenic pulmonary edema expected to respond rapidly to medical therapy), pre-oxygenation before intubation, hematological patients (in whom invasive mechanical ventilation carries specific risks), and patients with a do-not-intubate order. Although few subjects complained, the DTM has a bulky design that could potentially cause discomfort.

This study has several limitations. The number of included subjects was small, and the male/female ratio is high, which may not be representative of general ICU populations. The sequence of treatments was not randomized, but time effects can be reasonably excluded secondary to the double-crossover design. In addition, subjects were included in the study only when investigators were present in the ICU. The results thus deserve to be confirmed in a larger set of ICU subjects with hypoxemic acute respiratory failure.

Conclusion

Our data show that, in subjects with acute hypoxemic respiratory failure who are already receiving HFNC oxygenation, the addition of DTM to HFNC increased PaO₂ without significantly changing the PaCO₂. The DTM can thus be useful in in select patients with increased inspiratory flow demands.
REFERENCES

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