ORIGINAL RESEARCH

Effect of Different Oxygen Delivery Methods on Transcutaneous Oxygen Pressure and Fraction of Inspired Oxygen During Noninvasive Positive Pressure Ventilation

Song Mi, MD; Chunguo Jiang, MD, PhD; Xiaokai Feng, MD, PhD; Liming Zhang, MD, PhD

ABSTRACT

Objective • The aim of this study was to investigate the effects of different oxygen delivery methods during noninvasive positive-pressure ventilation (NPPV) on transcutaneous oxygen pressure ($PtcO_2$), transcutaneous carbon dioxide pressure ($PtcCO_2$) and fraction of inspired oxygen (FiO_2) in order to find more effective oxygen delivery methods.

Methods • A total of 20 healthy volunteers participated in this study, all of whom received NPPV. All volunteers received oxygen through a nasal cannula (NC) located in a mask or through a mask alone (OSTM) (oxygen flow rate was 3L/min and 5L/min), $PtcO_2$ and $PtcCO_2$ were measured, and the effects of the 2 methods of oxygen concentration on $PtcO_2$ and $PtcCO_2$ levels were evaluated during noninvasive ventilation. Then, the additional oxygen concentration was stopped, oxygen was delivered through the ventilator, and the oxygen concentration was adjusted so that the $PtcO_2$ reached the same oxygen concentration level as noted through the NC or OSTM. This concentration of oxygen indirectly reflects FiO_2 in different oxygen delivery methods.

Results • When NPPV was used under the same pressure, FiO_2 increased from 44.4% to 65.3% when oxygen was delivered through an NC compared with oxygen supplied by OSTM alone. $PtcO_2$ was also significantly increased from 18.9% to 24.9%; the difference was significant ($P < .05$), while there was no significant change in $PtcCO_2$ ($P > .05$).

Conclusion • When NPPV is used, an NC can obviously improve FiO_2 and $PtcO_2$ without increasing $PtcCO_2$. It can save oxygen and is more suitable for NPPV during an emergency and for home use. (*Altern Ther Health Med.* 2022;28(3):24-29).

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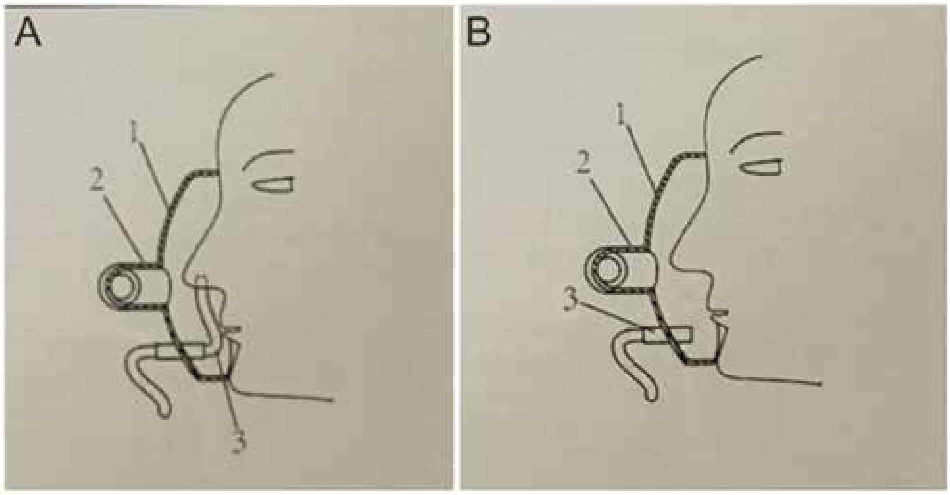
INTRODUCTION

In recent years, noninvasive positive-pressure ventilation (NPPV) has been widely used in the treatment of chronic obstructive pulmonary disease (COPD), cardiogenic pulmonary edema, acute respiratory distress syndrome and other diseases, and has shown a remarkable curative clinical effect. Sites for NPPV implementation have expanded from intensive care units to general wards, emergency departments and even communities and families.[1,2,3] At the same time, a portable noninvasive ventilator has been widely used with NPPV. Most portable ventilators have no air oxygen blender. The existing oxygen delivery method—through the mask—can cause serious oxygen dilution and reduce the concentration of inhaled oxygen, which does not meet clinical needs,[4] especially when NPPV is used at home. Most oxygen delivery methods operate via a molecular sieve oxygen generator connected to a mask. The oxygen flow rate of most oxygen generators is 3L/min to 5L/min, which does not particularly meet clinical needs.

In order to find an oxygen delivery method that increases the partial pressure of oxygen by increasing the concentration of inhaled oxygen during NPPV, we established an NPPV model.[5] We found that under different pressures (constant tidal volume) or different tidal volumes (constant pressure) at the same oxygen flow rate (5L/min), the fraction of inspired O_2 (FiO_2) was significantly higher when oxygen was delivered through a nasal cannula (NC) in the mask compared with

Figure 1. Schematic diagram of oxygen delivery mode. A. Schematic diagram of oxygen delivery through a nasal cannula (NC) (1: mask; 2: the tube connecting ventilator; 3: NC). **B.** Schematic diagram of the oxygen supply through the mask (OSTM) (1: mask; 2: the tube connecting ventilator; 3: oxygen tube on the mask.).



through the mask itself (OSTM), suggesting that the use of an NC in NPPV can improve the FiO_2, save oxygen and is also more suitable for portable noninvasive ventilators. However, these results have not been validated in clinical practice.

To further understand the effect of different oxygen supply methods on FiO_2, we performed NPPV on healthy volunteers and measured transcutaneous oxygen pressure ($PtcO_2$) and transcutaneous carbon dioxide pressure ($PtcCO_2$) of different oxygen delivery methods at the same oxygen flow rate.

After stopping the oxygen provided by OSTM or an NC, the oxygen concentration supplied by a noninvasive ventilator was adjusted via the air oxygen blender to achieve the $PtcO_2$. At that time, the concentration of ventilator oxygen delivered indirectly reflects the FiO_2 that can be achieved with different oxygen delivery methods.

This study further verified the conclusion that FiO_2 can be increased by using an NC during NPPV by both direct and indirect methods.

MATERIALS AND METHODS

Study Participants

A total of 20 medical staff members in our department with no history of chronic cardiopulmonary disease were included in this study as healthy volunteers; all gave written informed consent to participate in the study.

Of the volunteers, 10 were men, age 23 to 42 years (mean age 29.9 ± 5.9 years), with an average height of 174.8 ± 7.6 cm and an average weight of 69.6 ± 10.8 kg; 10 were women, age 23 to 36 years (mean age 29.1 ± 5.2 years), with an average height of 162.9 ± 7.4 cm and an average weight of 52.1 ± 10.7 kg. This study was reviewed by the Ethics Committee of our hospital.

Noninvasive Ventilator

A Philips Respironics V60 ventilator (Philips Respironix, Murrysville, Pennsylvania, USA) with an air-oxygen blender that can precisely regulate the concentration of inhaled oxygen was used with the Philips Respironics ComfortFull 2 oronasal mask.

Mask and Oxygen Supply

A new type of noninvasive ventilation mask suitable for oxygen delivery through an NC has been successfully developed and patented (patent number: ZL 2016 2 03366274.2) (Figure 1A).

Determination of $PtcO_2$ and $PtcCO_2$

$PtcO_2$ and $PtcCO_2$ were measured by a Radiometer, Inc. (Cleveland, Ohio, USA) TCM4 monitor.

Study Procedures

The volunteers were seated and told to breathe calmly. First, $PtcO_2$ and $PtcCO_2$ were measured while the participants breathed air, and heart rate (HR), respiratory rate (RR), and mean arterial pressure (MAP) were recorded.

Volunteers wore masks either with an NC or OSTM. Air leakage from the mask was set at <30L/min by adjusting the fixing band. The ventilator was set to the BiPAP S/T mode. Fixed parameters were expiratory pressure (EPAP), 4 cm H_2O; inspiratory time, 1.0 sec; background respiratory rate, 10 BPM; and pressure rise time, grade 1. The adjustment parameters were inspiratory pressure (IPAP), catheter oxygen flow rate, and ventilator oxygen concentration.

IPAP was adjusted to 12 cmH_2O, catheter oxygen supply flow was adjusted to 3 L/min and ventilator oxygen supply was stopped (21% of ventilator oxygen concentration was adjusted). $PtcO_2$ and $PtcCO_2$ were recorded during NC or OSTM, respectively. NC or OSTM was stopped, and the ventilator was used to deliver oxygen. The concentration of oxygen delivered by the ventilator was adjusted so that $PtcO_2$ reached the same level as the NC or OSTM, which indirectly reflected the FiO_2 when different oxygen delivery methods were used. The principle is that under the same ventilator pressure support, tidal volume (Vt) and minute ventilation (MV) volume, the only factor determining the $PtcO_2$ is FiO_2. Therefore, the FiO_2 can be indirectly measured under the same support conditions, specific oxygen delivery modes, and flow rates by precisely adjusting the oxygen supply concentration of the ventilator to reach the predetermined $PtcO_2$ under the same support conditions.

IPAP and flow rates were adjusted to 12 cmH_2O and 5 L/min, 15 cm H_2O and 3 L/min, 15 cm H_2O and 5 L/min, respectively. The experimental procedures were repeated. $PtcO_2$, $PtcCO_2$, and FiO_2 were recorded when oxygen was delivered OSTM and NC with different IPAP and catheter oxygen flow combinations.

Vital signs (HR, blood pressure [BP], respiration rate [RR]) of the participants were recorded during the test, and the Vt, MV, and air leakage (LEAK) monitored by the ventilator were recorded.

The differences in FiO_2, $PtcO_2$, and $PtcCO_2$ when NC or OSTM under the same IPAP, EPAP and oxygen flow rate were compared.

Each test condition lasted for 15 minutes. After the test value was stable, it was recorded once every minute for a total of 10 times, and the mean and standard deviation (SD) were calculated.

Table 1. Study Participants' $PtcO_2$, $PtcCO_2$, FiO_2, Vital Signs and Ventilator Monitoring Indicators (IPAP 12 cm H_2O, Oxygen Flow 3 L/min)

Monitoring Indicators	No Oxygen Supply	OSTM	NC
$PtcO_2$ (mmHg)	96.2 ± 11.3	104.2 ± 21.0[a]	123.7 ± 26.8[a]
FiO_2(%)	—	27.2 ± 1.3[a]	39.2 ± 0.2[a]
$PtcCO_2$ (mmHg)	36.6 ± 3.5	36.4 ± 4.3	35.1 ± 3.2
HR (bpm)	73.7 ± 16.6	73.2 ± 19.3	73.8 ± 16.8
RR (BPM)	16.8 ± 2.3	17.5 ± 3.6	17.8 ± 4.7
MBP (mmHg)	81.5 ± 9.7	78.8 ± 8.9	79.7 ± 12.5
Vt (ml/kg)	14.3 ± 2.1	14.1 ± 2.8	15.7 ± 2.6
MV (L/min)	14.1 ± 4.7	14.4 ± 2.5	14.5 ± 7.9
LEAK (L/min)	26.7 ± 4.3	25.7 ± 3.7	27.8 ± 5.1

[a]$P < .05$ for comparison of $FiO_2$and $PtcO_2$ between the NC and the OSTM groups.

Abbreviations: bpm, beats per minute; BPM, breaths per minute; FiO_2, fraction of inspired oxygen; HR, heart rate; IPAP, inspiratory positive airway pressure; MBP, mean blood pressure; MV, minute ventilation; NS, nasal cannula; OSTM, oxygen supply through the mask; $PtcCO_2$, transcutaneous carbon dioxide partial pressure; $PtcO_2$, transcutaneous oxygen partial pressure; RR, respiratory rate; Vt, tidal volume.

Statistics

IBM® SPSS17.0 software was used for data analysis. The test data were expressed as mean ± SD. A paired *t* test was used to compare the differences in all indicators, and the test standard was fixed at $P = .05$.

RESULTS

A total of 20 subjects underwent NPPV in BiPAP S/T mode, EPAP fixed at 4 cm H_2O, given NC or OSTM and with adjusted IPAP and oxygen flow, respectively. $PtcO_2$, $PtcCO_2$ ventilator parameters and vital signs were recorded with different combinations of IPAP and oxygen flow rate.

After stopping the NC or OSTM and using the air oxygen blender provided by the ventilator to deliver oxygen, the FiO_2 was indirectly determined and recorded with different combinations of IPAP and oxygen flow rate.

When IPAP was 12 cm H_2O and the oxygen flow rate was 3 L/min, oxygen delivery by NC was better than by OSTM.

When the mask was used for oxygen delivery, the $PtcO_2$ was 104.2 ± 21.0 mmHg. When the $PtcO_2$ reached 104 mmHg via the ventilator, the concentration of inspired oxygen required was 27.2 ± 1.3%. This indicated that under these conditions, the FiO_2 reached by OSTM was 27.2 ± 1.3%, and the $PtcO_2$ was 104.2 ± 21.0 mmHg.

When the NC was used for oxygen delivery, the $PtcO_2$ was 123.7 ± 26.8 mmHg and the FiO_2 was 39.2 ± 0.2%, verified by ventilator oxygen supply. There were no significant changes in HR, RR, BP, Vt, MV or LEAK.

This indicated that compared with the OSTM, the FiO_2 achieved with an NC increased by 44.1%, and $PtcO_2$ increased by 18.7%; the difference was significant ($P < .05$), while there was no difference in $PtcCO_2$. The results are shown in Table 1.

When IPAP was 15 cmH_2O and the oxygen flow rate was 3 L/min, oxygen delivery by NC was better than by OSTM.

When OSTM was used for oxygen delivery, the $PtcO_2$ was 103.2 ± 21.2 mmHg and the FiO_2 was 26.5 ± 1.1%, verified by ventilator oxygen supply. When an NC was used for oxygen delivery, the $PtcO_2$ was 122.7 ± 28.3mmHg and the FiO_2 was 40.4 ± 0.2%, verified by ventilator oxygen supply. There were no significant changes in HR, RR, MBP, Vt, MV, or LEAK.

This indicated that compared with OSTM, the FiO_2 achieved by NC increased by 52.5% (40.4 ± 0.2% vs 26.5 ± 1.1%), and the $PtcO_2$ increased by 18.9% (122.7 vs 103.2); the difference was significant ($P < .05$), while there was no difference in $PtcCO_2$. The results are shown in Table 2.

When IPAP was 12 cm H_2O and the oxygen flow rate was 5 L/min, the oxygen delivery by NC was better than by OSTM.

When an NC was used for oxygen delivery, the $PtcO_2$ was 123.2 ± 21.0 mmHg and the FiO_2 was 31.4±1.8%, verified by ventilator oxygen supply. When an NC was used for oxygen delivery, the $PtcO_2$ was 153.9±27.8 mmHg and the FiO_2 was 51.9±0.2%, verified by ventilator oxygen supply. There were no significant changes in HR, RR, MBP, Vt, MV, or LEAK.

Table 2. Study Participants' $PtcO_2$, $PtcCO_2$, FiO_2, Vital Signs and Ventilator Monitoring Indicators (IPAP 15 cm H_2O; Oxygen Flow 3 L/min)

Monitoring Indicators	No Oxygen Supply	OSTM	NC
$PtcO_2$ (mmHg)	97.5 ± 10.7	103.2 ± 21.2[a]	122.7 ± 28.3[a]
FiO_2(%)	—	26.5 ± 1.1[a]	40.4 ± 0.2[a]
$PtcCO_2$ (mmHg)	41.7 ± 3.8	35.7 ± 4.2	34.6 ± 4.7
HR (bpm)	72.4 ± 11.3	72.6 ± 18.7	77.3 ± 18.2
RR (BPM)	15.2 ± 3.6	17.9 ± 4.3	17.8 ± 5.5
MBP (mmHg)	84.5 ± 11.5	78.6 ± 8.7	77.9 ± 12.6
Vt (ml/kg)	15.1 ± 2.7	15.8 ± 1.7	15.7 ± 1.3
MV (L/min)	16.8 ± 5.2	16.2 ± 4.7	17.5 ± 4.9
LEAK (L/min)	28.3 ± 5.1	27.3 ± 7.2	28.5 ± 4.7

[a]$P < .05$ for comparison of FiO_2 and $PtcO_2$ between the NC and OSTM groups.

Abbreviations: bpm, beats per minute; BPM, breaths per minute; FiO_2, fraction of inspired oxygen; HR, heart rate; IPAP, inspiratory positive airway pressure; LEAK, air leakage; MBP, mean blood pressure; MV, minute ventilation; NS, nasal cannula (oxygen supplied via nasal cannula in mask); OSTM, oxygen supply through the mask; $PtcCO_2$, transcutaneous carbon dioxide partial pressure; $PtcO_2$, transcutaneous oxygen partial pressure; RR, respiratory rate; Vt, tidal volume.

Table 3. Study Participants' $PtcO_2$, $PtcCO_2$, FiO_2, Vital Signs and Ventilator Monitoring Indicators (IPAP 12 cmH_2O, Oxygen Flow 5L/min)

Monitoring Indicators	No Oxygen Supply	OSTM	NC
$PtcO_2$ (mmHg)	98.2 ± 12.8	123.2 ± 21.0[a]	153.9 ± 27.8[a]
FiO_2 (%)	—	31.4 ± 1.8[a]	51.9 ± 0.2[a]
$PtcCO_2$ (mmHg)	43.2 ± 3.5	35.4 ± 5.2	34.3 ± 4.7
HR (bpm)	73.7 ± 16.6	73.4 ± 17.8	75.1 ± 17.5
RR (BPM)	14.8 ± 2.3	16.5 ± 4.7	16.7 ± 4.9
MBP (mmHg)	82.5 ± 10.3	78.8 ± 6.9	77.8 ± 11.4
Vt (ml/kg)	15.7 ± 2.7	16.5 ± 3.4	15.3 ± 2.6
MV (L/min)	16.5 ± 5.4	17.3 ± 4.1	17.9 ± 6.3
LEAK (L/min)	28.3 ± 5.1	29.4 ± 4.2	27.9 ± 5.6

[a]$P <.05$ for comparison of FiO_2 and $PtcO_2$ between the NC and OSTM groups.

Abbreviations: bpm, beats per minute; BPM, breaths per minute; FiO_2, fraction of inspired oxygen; HR, heart rate; IPAP, inspiratory positive airway pressure; LEAK, air leakage; MBP, mean blood pressure; MV, minute ventilation; NS, Nasal cannula (oxygen supplied via nasal cannula in mask); OSTM, oxygen supply through the mask; $PtcCO_2$, transcutaneous carbon dioxide partial pressure; $PtcO_2$, transcutaneous oxygen partial pressure; RR, respiratory rate; Vt, tidal volume.

Table 4. Study Participants' $PtcO_2$, $PtcCO_2$, FiO_2, Vital Signs and Ventilator Monitoring Indicators (IPAP 15 cmH_2O, Oxygen Flow 5L/min)

Monitoring Indicators	No Oxygen Supply	OSTM	NC
$PtcO_2$ (mmHg)	97.5 ± 10.7	124.2 ± 21.0[a]	151.7 ± 24.2[a]
FiO_2 (%)	—	31.8 ± 1.5[a]	50.4 ± 0.1[a]
$PtcCO_2$ (mmHg)	41.7 ± 3.8	36.4 ± 5.9	35.1 ± 6.2
HR (bpm)	72.4 ± 11.3	73.9 ± 19.3	75.8 ± 17.2
RR (BPM)	15.2 ± 3.6	17.5 ± 4.7	17.8 ± 6.9
MBp (mmHg)	84.5 ± 11.5	81.8 ± 8.9	79.7 ± 12.8
Vt (ml/kg)	17.6 ± 3.1	17.5 ± 2.9	19.1 ± 2.6
MV (L/min)	18.7 ± 6.2	18.7 ± 6.3	19.5 ± 8.3
LEAK (L/min)	27.7 ± 9.1	28.9 ± 8.2	28.5 ± 8.3

[a]$P < .05$ for comparison of FiO_2 and $PtcO_2$ between the NC and OSTM groups.

Abbreviations: bpm, beats per minute; BPM, breaths per minute; FiO_2, fraction of inspired oxygen; HR, heart rate; IPAP, inspiratory positive airway pressure; LEAK, air leakage; MBP, mean blood pressure; MV, minute ventilation; NS, nasal cannula (oxygen supplied via nasal cannula in mask); OSTM, oxygen supply through the mask; $PtcCO_2$, transcutaneous carbon dioxide partial pressure; $PtcO_2$, transcutaneous oxygen partial pressure; RR, respiratory rate; Vt, tidal volume.

This indicated that compared with OSTM, the FiO_2 achieved by an NC increased by 65.3% (51.9 ± 0.2% vs 31.4 ± 1.8%), and $PtcO_2$ increased by 4.9% (153.9 vs 123.2); the difference was significant ($P < .05$), while there was no difference in $PtcCO_2$. The results are shown in Table 3.

When IPAP was 15 cm H_2O and the oxygen flow rate was 5 L/min, oxygen delivery by NC was better than by OSTM.

When OSTM was used for oxygen delivery, the $PtcO_2$ was 124.2 ± 21.0 mmHg and the FiO_2 was 31.8 ± 1.5%, verified by ventilator oxygen supply. When an NC was used for oxygen delivery, the $PtcO_2$ was 151.7 ± 24.2 mmHg, and the FiO_2 was 50.4 ± 0.1%, verified by ventilator oxygen supply. There were no significant changes in HR, RR, MBP, VT, MV or LEAK.

This indicated that compared with OSTM, the FiO_2 achieved by an NC increased by 58.5% (50.4±0.1% vs 31.8±1.5%), and the $PtcO_2$ increased by 22.2% (151.7 vs 124.2) ($P <.05$), while there was no difference in $PtcCO_2$. The results are shown in Table 4.

The results also showed that the change in IPAP had no significant effect on FiO_2 and $PtcO_2$ with the same oxygen delivery mode and flow rate ($P >.05$) (Table 5).

These results showed that the FiO_2 and $PtcO_2$ were higher when oxygen was delivered via NC mask than via OSTM with different IPAP and oxygen flow rates. Compared with conventional OSTM, the FiO_2 was increased by 44.1% to

Table 5. The FiO_2 and $PtcO_2$ under the same oxygen supply mode, flow rate and different IPAPs

	NC (3 L/min)		NC (5 L/min)		OSTM (3 L/min)		OSTM (5L/min)	
IPAP (cmH_2O)	12	15	12	15	12	15	12	15
FiO_2 (%)	39.2 ± 0.2	40.4 ± 0.2[a]	51.9 ± 0.2	50.4 ± 0.1[a]	27.2 ± 1.3	26.5 ± 1.1[a]	31.4 ± 1.8	31.8 ± 1.5[a]
$PtcO_2$ (mmHg)	123.7 ± 26.8	122.7 ± 28.3[a]	153.9 ± 27.8	151.7 ± 24.2[a]	104.2 ± 21.0	103.2 ± 21.2[a]	123 ± 21.0	124.2 ± 21.0[a]

[a]$P > .05$ for comparison of FiO_2 and $PtcO_2$ between different IPAPs with the same oxygen supply mode and flow rate.

Abbreviations: FiO_2, fraction of inspired oxygen; IPAP, inspiratory positive airway pressure; NS, nasal cannula (oxygen supplied via nasal cannula in mask); OSTM, oxygen supply through the mask; $PtcO_2$, transcutaneous oxygen partial pressure.

65.3% when oxygen was delivered via NC. With the same oxygen supply mode and flow rate, IPAP change had no significant effect on FiO_2 or $PtcO_2$. There were no significant differences in ventilator monitoring indexes (Vt, MV, LEAK), vital signs (HR, RR, MBP), and $PtcCO_2$ between OSTM oxygen delivery and NC oxygen delivery with different IPAP and oxygen flow rates. This indicates that when oxygen is supplied via an NC, the dilution of oxygen is significantly reduced due to the direct entry of oxygen into the upper respiratory tract, and the FiO_2 and $PtcO_2$ were higher than when oxygen was delivered OSTM. At the same time, because there was no change in ventilation, there was no significant change in $PtcCO_2$ and no adverse effect on the participants' vital signs (HR, RR, MBP). It was suggested that compared with conventional OSTM, oxygen delivery by NC is a safe and effective method to increase FiO_2.

DISCUSSION

NPPV is an important way to treat respiratory failure, which can not only significantly reduce mortality in patients with acute respiratory failure,[6,7] but also improve their quality of life. In recent years, the implementation sites of NPPV have been expanded from the intensive care unit to the general ward, emergency department, even community and family. A portable NPPV ventilator has been widely used with the continuous extension of its implementation sites.[2,8] Compared with invasive ventilation, NPPV mostly uses a single-circuit without an air-oxygen blender, which requires additional oxygen access, and oxygen is usually connected to the mask or the pipeline.[9] However, the flow rate of single loop NPPV is as high as 40 L/min to 80 L/min, while the oxygen flow rate of ordinary central oxygen supply and oxygen cylinders is usually only 1L /min to 10L/ min, and the oxygen flow rate of a molecular sieve oxygen generator is primarily 3 L/ min to 5L/min. Routine oxygen supply causes severe dilution of the oxygen, resulting in a significant decrease in FiO_2, even lower than that with an NC oxygen supply.[10] Patients requiring higher oxygen concentration and patients who use a molecular sieve oxygen generator at home NPPV cannot achieve a therapeutic effect.

In patients with respiratory failure, oxygen saturation (SpO_2) is usually maintained at 88% to 92% by adjusting the oxygen flow rate in clinical applications.[11] Laboratory studies and clinical observations have found that when external oxygen sources were used for NPPV, especially when oxygen was supplied through a mask, the actual SpO_2 was often low and varied greatly; it was difficult to maintain the target SpO_2 and required frequent adjustment of the oxygen flow. This was very unfavorable for the treatment of patients with hypoxic respiratory failure.

In order to prevent the dilution of inhaled oxygen during OSTM, we designed an oxygen delivery method via an NC cannula inside the mask. In the study of a simulated lung noninvasive ventilation model,[5] we demonstrated that the FiO_2 of oxygen concentration was significantly higher when oxygen was supplied via NC than via OSTM. In this study in healthy volunteers, it was also confirmed that the $PtcO_2$ was significantly higher when oxygen was supplied via NC and also indirectly proved that FiO_2 could be increased by an NC. In this study, FiO_2 and $PtcO_2$ were also significantly elevated in the healthy volunteers. It is especially suitable for patients who use a molecular sieve oxygen generator in home NPPV to deliver oxygen in the treatment of chronic respiratory failure.

Up to now, there are few definitive methods to estimate the FiO_2 by routine OSTM or connecting an oxygen line to the ventilator line, which makes treatment difficult to control.[4,12] Different connection methods of oxygen delivery and different inspiratory flow (including air leakage, etc.) all affect the actual FiO_2. It has also been shown that the use of portable noninvasive ventilators to implement NPPV has a maximum oxygen concentration of only approximately 60%, and is affected by many factors such as the location of the oxygen injection point.[9-12] Schwartz, et al.[10] analyzed many factors that may affect oxygen concentration and showed that the position of the exhalation hole, the connection position of the oxygen, and the preset pressure of the ventilator all affect oxygen concentration. Our results showed that the oxygen concentration was higher when oxygen was connected to the mask and the exhalation holes were located on the pipeline, while when both the oxygen and the exhalation holes were located on the mask, the oxygen concentration was significantly lower. The reason may be that when the expiratory hole is located on the mask, most of the oxygen delivered through the mask leaks through this hole, thus reducing the concentration of inhaled oxygen.

Prior to this, Waugh, et al[13] connected oxygen to the near end of the ventilator line and then the mask and compared the measured oxygen concentration in both cases. Expiratory holes were positioned on the mask during the test. Similar to Schwartz's conclusion, the oxygen concentration was higher when the supply is connected to the ventilator line. Thys, et al[14] placed the exhalation holes on the ventilator pipeline and connected oxygen to 3 different locations: the near end of the ventilator line, the mask and the middle of the ventilator line. It was concluded that the oxygen concentration when oxygen was connected to the near end of the ventilator line was higher than when connected to the mask, and the highest oxygen concentration was measured when oxygen was connected to the middle of the ventilator line. However, in the clinical setting, it is difficult to connect the oxygen to the middle of the ventilator line, which needs to be cut off.

In the these tests, it is difficult to avoid serious dilution of inhaled oxygen by high airflow of the ventilator in the process of noninvasive ventilation, which lowers the actual concentration of inhaled oxygen.

In this study, a new shortcut was created by placing the NC in the mask, so that oxygen was directly delivered into the upper respiratory tract through the NC while mechanical ventilation was performed. The study results from mechanical ventilation in healthy volunteers confirmed that the $PtcO_2$ achieved by an NC in the mask was higher than that by OSTM, and the $PtcCO_2$ of the subjects did not increase with the increase of $PtcO_2$. The main reason was that the Vt and MV did not decrease during noninvasive ventilation. Our study shows that the NC method can improve the concentration of inhaled oxygen and save oxygen, which is more suitable for patients who use portable noninvasive ventilators.

In order to further evaluate the FiO_2 achieved by different oxygen delivery methods in NPPV accurately, the FiO_2 achieved by different oxygen connection modes was evaluated in this study using a noninvasive ventilator with an air-oxygen blender that accurately adjusts oxygen concentration. The results showed that the FiO_2 achieved by the NC oxygen delivery was increased by 44.4% to 65.3% compared with conventional OSTM. This is higher than that reported in the past when oxygen is connected to the near end of the ventilator pipeline, the middle of the pipeline or the mask.

Study Limitations

In this study, only the commonly used NPPV support conditions (EPAP, 4 cm H_2O; IPAP 12,15 cm H_2O) were studied. The oxygen flow rate was also selected as the flow rate（3 L/min, 5L/min) that was easily tolerated by the nasal cavity and easily reached by home and community oxygen generators. It is not suitable in patients with severe respiratory failure who were highly dependent on oxygen.

CONCLUSION

The results of this study showed that the use of an NC during NPPV could improve FiO_2 and $PtcO_2$ without increasing $PtcCO_2$. It can save oxygen, adapt to emergency and portable home noninvasive ventilators, and provide a theoretical basis for better patient rescue. According our research, a new type of noninvasive ventilation mask suitable for an NC has been successfully developed and patented. The NC is connected to a special interface on the inner surface of the mask and connected to the oxygen catheter outside the mask, which can be used conveniently and reduce mask air leakage.

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