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High-Velocity Nasal Insufflation Increases Nasopharyngeal Pressure with Flow-Dependent Manner Compared with High Flow Nasal Cannula in Adult Volunteers – A Single-Center Prospective Observational Study

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BACKGROUND: High flow nasal cannula (HFNC) can produce positive airway pressure, and the pressure increases in proportion to the gas flow. Recently, high-velocity nasal insufflation (HiVNI) was developed as a new system of HFNC. However, it is still unclear whether HiVNI can increase the airway pressure. The purpose of our study was to evaluate whether the HiVNI can increase the airway pressure compared to HFNC, under various gas flows. METHODS: This single-center prospective observational study recorded nasopharyngeal pressures in fifteen healthy volunteers who received both normal HFNC and HiVNI. After a 10 Fr catheter was inserted via the nose, the catheter was connected to the manometer and high flow oxygen therapy was performed using both systems. The measurements were carried out at flows of 20, 30, and 40 L/min, and the pressures were recorded at 50 Hz. The measurements were repeated with the mouth in the open and closed positions for each high-flow system. RESULTS: With the mouth open, the mean nasopharyngeal pressure was low in both systems, and the difference between the two systems was not significant. However, with the mouth closed, a significantly higher nasopharyngeal pressure was recorded with the HiVNI system compared to the HFNC system at all flows (P < .01). Furthermore, the difference between HiVNI and HFNC at each flow became significantly greater with the increase of flow (P < .01). CONCLUSION: In healthy volunteers, HiVNI can produce higher nasopharyngeal pressure than normal HFNC in a flow-dependent manner.

INTRODUCTION

Respiratory failure poses a severe problem in ICU and the number of patients suffering from respiratory failure is also increasing and mortality is high [1,2]. Respiratory failure is caused by pneumonia and sepsis et al and respiratory failure with hypoxia and hypercapnia leads to multiorgan disfunction. Oxygenation is a key strategy for patients with respiratory failure to improve their survival, and ventilators provide conventional therapy for respiratory care, to maintain and improve oxygenation. However, respiratory care with ventilators often requires sedation, resulting in prolonged ICU stays and increasing the likelihood of ventilator-associated pneumonia [3].

High flow nasal cannula (HFNC) is frequently used as oxygen therapy for respiratory failure and can provide high gas flows, which are heated and fully humidified, via nasal cannula. It can deliver high and relatively accurate F_IO_2. It is also thought that high gas flows can wash out the anatomical airway dead space and can generate mild positive end expiratory pressure [4,5]. Development of positive airway pressure is said to be one of the beneficial mechanisms of HFNC [4,6]. Previous studies have reported that HFNC can produce positive airway pressure and the pressure increases in proportion to the gas flow [6-9].

Recently, high-velocity nasal insufflation (HiVNI) was developed as a new system of HFNC. It uses a small-bore nasal cannula (for adults: 4.8 mm external diameter and 2.7mm internal diameter), which can produce higher gas velocities than normal bore nasal cannulas[10]. Recent studies have indicated that HiVNI was not inferior to noninvasive positive pressure ventilation (NPPV) for the treatment of adult patients with respiratory failure from various causes including hypercapnia[10,11]. However, it is still unclear whether HiVNI can increase the airway pressure compared to HFNC with the mouth closed or open.

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The purpose of our study is to evaluate the effect of HiVNI on increase the airway pressure compared to HFNC under various gas flow rates.

MATERIALS AND METHODS

This is a single-center prospective observational study, which was conducted at Otsu City Hospital in Japan. The study was approved by the regional Ethics Committee of Otsu municipal Hospital (No. 344). The participants in the study cohort were healthy volunteers who did not smoke and had no past medical history of respiratory disease. Informed consent was obtained from all participants.

Participants were seated in an upright position at rest. After local anesthesia to the nose with 2% lidocaine gel (Aspen, Japan), a 10 Fr catheter (TERUMO, Japan) was inserted into the nasopharynx via the nose. After placement of the catheter was confirmed visually to ensure that the tip of catheter was placed just behind the uvula, the catheter was connected to the manometer (Handy manometer DMH-01, Kobata Gauge MFG.Co. Ltd, Osaka, Japan).

Evita infinity® V500 (Dräger, USA) with oxygen therapy mode with Nasal cannula No.3 (Pacific medico, Tokyo, Japan) was used for the HFNC system (HFNC group). Precision Flow® (Vapotherm, USA) with small-bore nasal cannula (PF prong for adults) (Vapotherm, USA) was used for the HiVNI system (HiVNI group). After the temperature of the system was stabilized at the target temperature (37°C), a nasal prong was connected to the HFNC system and high flow oxygen therapy was started. We also confirmed the alignment of the nasal cannula visually. We measured nasopharyngeal pressure as airway pressure in this study because of the acceptability in conscious patients. This technique had been used in previous reports [6-9]. Nasopharyngeal airway pressures were recorded over 1 minute at various flows with the mouth open and closed. The measurements were performed at flows of 20, 30, and 40 L/min. Fraction of inspiratory oxygen was set at 0.21 in all cases. The nasopharyngeal pressures were recorded at 50 Hz and waveforms were generated in a spreadsheet (Microsoft Excel, USA).

All statistical analyses were performed with EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), a graphical user interface for R 2.13.0 (R Foundation for Statistical Computing, Vienna, Austria). EZR is a modified version of R commander (version 1.6-3) designed to add statistical functions frequently used in biostatistics.

Data was presented as mean ± SD. Group differences in the nasopharyngeal pressures with each flow were assessed by repeated-measures ANOVA. P values < .05 were considered to be statistically significant.

The planned sample size of fifteen was calculated based on 90% power, 0.05 α-error, difference in means and standard deviation with reference to previous report [7,8].

RESULTS

Data from fifteen participants were analyzed, of which 8 were males and 7 females. One volunteer was excluded because of difficulty inserting the catheter via the nose. The continuous variables were tested for normality using the Kolmogorov-Smirnov test and were found to have a normal distribution. The characteristics of the cohort are shown in Table I. The participants had a mean age of 28.7 ± 5.4 years, height of 165.3 ± 10.0 cm, body weight of 58 ± 9.5 kg, and BMI of 21.2 ± 1.6 kg/m^2.

Typical waveforms of the nasopharyngeal pressures obtained from both the HiVNI and the HFNC with the mouth closed are presented in Figure 1. The nasopharyngeal pressure decreased in the inspiratory phase and increased in the expiratory phase.

Table I. Cohort characteristics: mean±SD

Age (years)	28.7±5.4
Male, n	8
Female, n.	7
Height (cm)	165.3±10.0
Body Weight (kg)	58±9.5
Body Mass Index (kg/m^2)	21.1±1.6

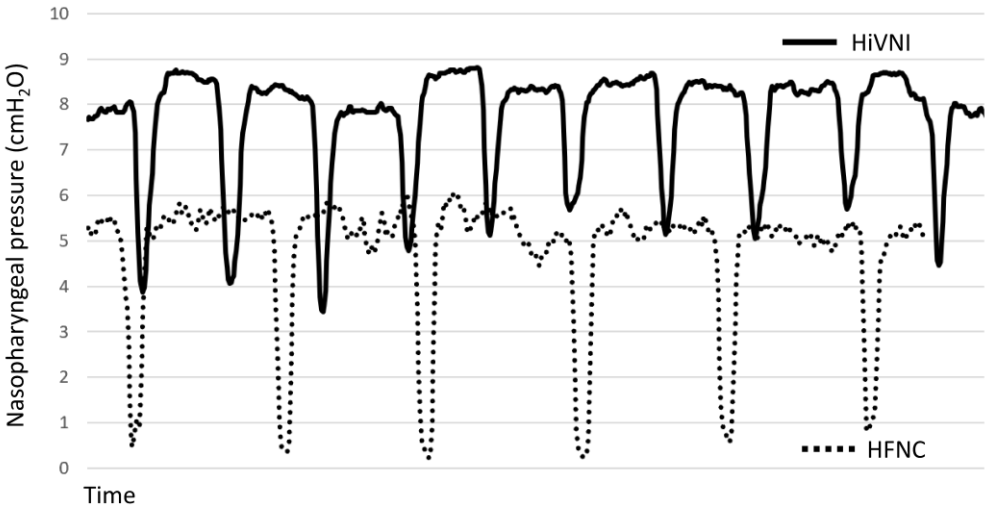

Figure 1. Typical waveforms of nasopharyngeal pressure with HiVNI and HFNC.

HiVNI increases nasopharyngeal pressure in a flow-dependent manner compared to normal HFNC.

Table II and Figure 2 show the mean nasopharyngeal pressure of each high flow therapy system with the mouth open and closed. With the mouth open, the mean nasopharyngeal pressure was low in both systems and the difference between both systems was not significant. However, with the mouth closed, significantly higher nasopharyngeal pressures were recorded with the HiVNI system compared to the HFNC system ($P < .01$). Furthermore, the difference between the HiVNI and HFNC systems at each flow became significantly greater with increasing flow ($P < .01$).

Table II. Mean nasopharyngeal pressure of HiVNI and HFT, with mouth open or closed.

Flow (L/min)	Mouth Open		Mouth Closed	
	HFNC	HiVNI	HFNC	HiVNI
20	0.31±0.56	0.61±0.62	1.09±0.60	1.69±1.02*
30	0.58±0.65	1.09±0.91	2.27±1.10	3.55±1.94*
40	1.22±0.83	1.37±0.98	3.51±1.43	5.65±2.87*

* : $P < .05$, Pairwise comparisons using Paired t-test.

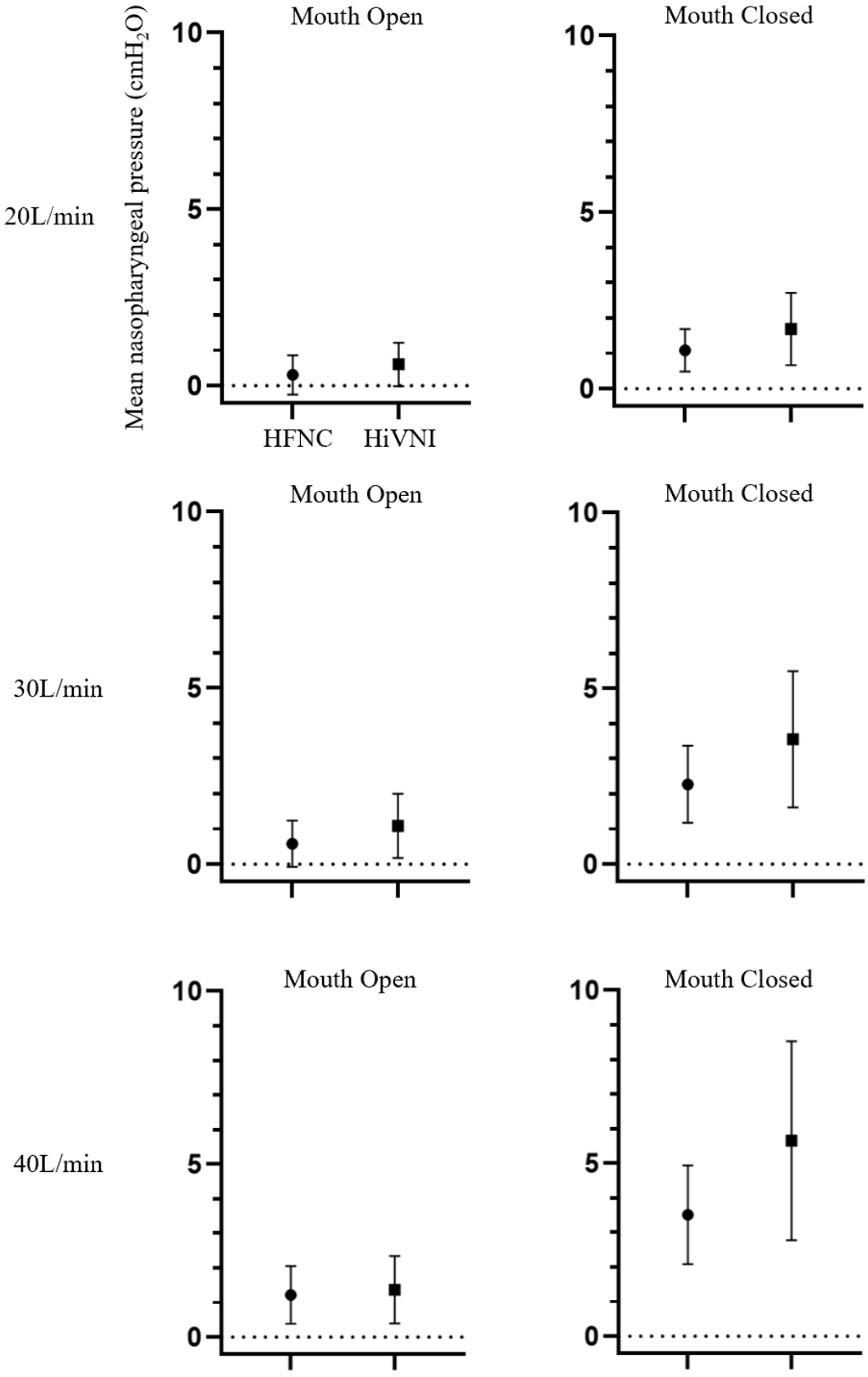

Figure 2. Mean nasopharyngeal pressure of HiVNI and HFNC, with the mouth open or closed.

DISCUSSIONS

To our knowledge, this is the first study to demonstrate the effect of HiVNI on nasopharyngeal pressure. Our study showed that HiVNI produces higher nasopharyngeal pressures than normal HFNC at the same gas flow.

HFNC has several possible mechanisms of oxygenation, which include accurate oxygen delivery (up to 100%), high humidification performance, washout effect of anatomical nasopharynx dead space, and positive airway pressure [12]. A recent study has shown that HFNC is as effective as NPPV in the treatment of hypoxemia respiratory failure without hypercapnia [13]. Another study has indicated that HiVNI was not inferior to NPPV for the treatment of adult patients with respiratory failure from various causes including hypercapnia [10]. In this study, we found that high nasopharyngeal pressure in HiVNI with the mouth closed may have more beneficial effects for respiratory failure patients than normal HFNC, even though pressures are low with the mouth open. Furthermore, our data also demonstrates the positive linear relationship between the gas flow and the mean nasopharyngeal pressure. It indicates that the effect of HiVNI may be greater with higher gas flows. And positive airway pressure produced by HFNC is said to have beneficial effects such as improved oxygenation, improved ventilator-perfusion mismatch due to lung recruitment, reduced airway resistance and reduced work of breathing [4,6,9]. Therefore, HiVNI can produce a higher nasopharyngeal pressure than normal HFNC, especially with high gas flows, which may lead to these beneficial effects stronger.

HFNC can wash out the anatomical dead space [14,15] and might reduce rebreathing, resulting in reduced work of breathing [16]. A previous study has shown that increasing the gas flow of HFNC resulted in increased end expiratory lung impedance, end expiratory lung volume, and decreased respiratory rate [17]. It might also cause an increase in the functional residual capacity and tidal volume. In this study, we found a flow-dependent difference in the nasopharyngeal pressure between HiVNI and HFNC (0.60, 1.28, and 2.14 cmH_2O at 20, 30, and 40 L/min, respectively). We speculate that this difference of nasopharyngeal pressure may be caused by the bore size difference of the nasal cannula utilized in the HiVNI and HFNC. The bore of nasal cannula used for the HiVNI is smaller than the cannula for the HFNC (HiVNI for adults: 2.7 mm internal diameter, HFNC: 4.3 mm internal diameter). Hence, the smaller bore size of the HiVNI may produce a higher flow velocity compared to the normal bore cannula, resulting in the washout of anatomical dead space and reduction in the work of breathing. Finally, the higher velocity and higher airway pressure of HiVNI may improve oxygenation and also ventilation compared to the HFNC.

This study has several limitations. First, it was conducted in healthy volunteers, so this result may not be applicable to all patients with acute respiratory failure. Secondary, this study was technically unable to blind regarding the system. However, the insufficiency of blinding is limited because participants were not familiar with the HiVNI system, leading to the difficulty to fluctuate their breathing patterns consciously. Finally, the nasopharyngeal pressure was higher in HiVNI than in normal HFNC with the mouth closed, but that does not necessarily mean that HiVNI is superior to normal HFNC in the management of acute respiratory failure including hypercapnia. Therefore, further studies are recommended to compare HiVNI to HFNC in patients with acute respiratory failure including hypercapnia in a randomized controlled trial.

CONCLUSIONS

In healthy volunteers, HiVNI produces higher nasopharyngeal pressure than normal HFNC at the same gas flow. In addition, there was a positive linear relationship between the gas flow and the mean nasopharyngeal pressure, and the difference in the nasopharyngeal pressure between the HiVNI and normal HFNC was flow dependent.

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