A Nasal High-Flow System Prevents Hypoxia in Dental Patients Under Intravenous Sedation

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Purpose: Hypoxia is a major complication in dental patients under intravenous sedation (IVS). A nasal high-flow (NHF) system has been reported to achieve effective oxygenation in patients with sleep apnea syndrome. This study investigated the ability of the NHF system to prevent hypoxia in dental patients under IVS.

Materials and Methods: Thirty patients scheduled for dental treatment under IVS were enrolled. Patients were randomly divided into 3 groups: patients spontaneously breathing oxygen at 5 L/minute through a nasal cannula (NC5 group), patients administered oxygen at 30 L/minute through the NHF system, and patients administered oxygen at 50 L/minute through the NHF system. Hypnosis was induced by bolus administration of midazolam (0.05 mg/kg) followed by continuous administration of propofol (target blood concentration, 1.2 to 2 μg/mL). Noninvasive blood pressure, peripheral capillary oxygen saturation (SpO_2), heart rate, and bispectral index values were recorded every 2.5 minutes before the induction of anesthesia. Interventions, such as jaw lifting, were recorded during IVS and arterial blood gas analysis was performed at the end of sedation. Patient and surgeon satisfaction with IVS was evaluated by interview.

Results: Minimum SpO_2 was lowest in and surgeons were least satisfied with the NC5 group. In addition, interventions were required most frequently in the NC5 group ($P < .05$). Compared with the NC5 group, use of the NHF system improved partial pressures of oxygen and carbon dioxide in dental patients under IVS ($P < .05$).

Conclusions: These results suggest that use of the NHF system can prevent hypoxia in dental patients under IVS. Further studies are necessary to determine the appropriate flow rate and indications for NHF in obese patients.

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Intravenous sedation (IVS) is widely used to relieve patient anxiety during dental treatment. In addition, IVS is applied in patients with circulatory complications to stabilize their hemodynamic condition during treatment. Propofol and midazolam are commonly used sedative agents; their attenuation of autonomic activation creates hemodynamic stability, thus countering the surgical stress involved in dental treatment.[1,2] Although the application of IVS during dental treatment has many advantages, the procedure carries some risks, including hypoxia induced by upper airway obstruction (UAO) and pulmonary aspiration caused by inhibition of the oropharyngeal reflex.

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Induction of IVS with excessive doses of sedative agents commonly results in decreased muscle tone, which can cause UAO at the levels of the soft palate, epiglottis, and tongue.[3] Hypoxia triggers sympathetic activation, which can induce tachycardia and systemic hypertension, with adverse effects. Therefore, maintenance of the patency of the upper airway is of clinical importance for patient safety during IVS.

Several maneuvers, including jaw lifting and anterior mandibular shifting, can be applied to maintain upper airway patency.[4,5] A previous study reported that elevation of the head also is useful in the maintenance of airway patency under the continuous administration of propofol.[6] However, the head position of patients is usually adjusted by surgeons during treatment; thus, repositioning the head is difficult during dental treatment.

Recently, a nasal high-flow (NHF) system was reported to have beneficial effects in patients with obstructive sleep apnea syndrome (SAS),[7] chronic obstructive pulmonary disease (COPD) as well as and idiopathic pulmonary fibrosis,[8] acute respiratory failure,[9] among others.

The actual NHF system is described in detail. This system can deliver continuous positive airway pressure (CPAP) in the upper airway without the use of an uncomfortable face or nasal mask as for the conventional CPAP machine. The flow rate is much higher than with a conventional CPAP machine. Patients can comfortably breathe warmed and fully humidified air, even when the flow rate is increased to the maximum of 50 L/minute. Flow rate and fraction of oxygen in mixed gas are independently controlled by turning knobs on the machine (Fig 1A). The fraction of oxygen in expiratory flow to the patient is monitored by the oxygen sensor on the mixed gas outlet. The device pressurizes room air with the addition of oxygen dialed to the desired percentage of fraction of inspiratory oxygen (F_{IO_2}). The machine adjusts fresh gas flow ratios accordingly, thus ensuring delivery at the desired total gas flow (liters per minute) at the desired F_{IO_2}. The gas is humidified with a heated water chamber immediately before delivery to the patient. The nasal cannula also consists of a unique wide-bore probe designed to deliver a wide-ranging gas flow directly into the nares without a gas jet (Fig 1B). The nasal cannula of the NHF system and a traditional nasal cannula are shown in Figure 1C.

These beneficial effects of the NHF system have been assessed based on 3 physiologic conditions: decreased dead space, a high concentration of inspiratory oxygen, and positive pressure in the oro-laryngeal cavity.[10] A positive relation between nasal flow rate and airway pressure in healthy adult volunteers has been reported.[11,12]

The authors speculated that use of the NHF system could prevent hypoxia caused by UAO during dental treatment under IVS. This study investigated clinical effects on the respiratory system with the application of the NHF system in dental patients under IVS.

Materials and Methods

This study was approved by the clinical research ethics committee of Kyushu Dental University, Kitakyushu, Fukuoka, Japan (number 13-29), and written informed consent was obtained from all participants. Patients with a body mass index greater than 35 kg/m^2 or with COPD and those undergoing medical treatment for SAS were excluded. Thus, 30 adult patients scheduled for dental treatment under IVS were enrolled. Participants were randomly divided into 3 groups: those receiving oxygen at 5 L/minute through a conventional nasal cannula (OX-20; Atom Medical Corporation, Saitama, Japan; NC5 group), those receiving oxygen at 30 L/minute through the NHF system (Optiflow; Fisher & Paykel Healthcare, Auckland, New Zealand; NHF30 group), and those receiving oxygen at 50 L/minute through the NHF system (NHF50 group). The NHF30 and NHF50 groups received oxygen through the same NHF interface (OPT544; Fisher & Paykel Healthcare). The F_{IO_2} was set at 40% with the OPT544 because F_{IO_2} was estimated to be approximately 40% with an oxygen flow of 5 L/minute through the nasal cannula. All gases for patients using NHF were administered through the humidifier and breathing circuits (850 System; Fisher & Paykel Healthcare).

ANESTHESIA AND MEASUREMENTS

No patient received premedication. On arrival at the operating room, infusion of Ringer lactate solution was started at 5 mL/kg per hour through a 22-guage intravenous catheter positioned in the forearm. Routine monitoring included noninvasive blood pressure, pulse rate, and pulse oximetry (peripheral capillary oxygen saturation [SpO_2]), and electrocardiography (lead II) was performed before the induction of anesthesia. Electroencephalography was performed using the Bispectral Index Monitor (Aspect Medical Systems, Inc, Natick, MA) to evaluate the depth of anesthesia. The head position of each participant was adjusted by the surgeon depending on the procedure. Anesthesiologists carefully monitored for UAO by listening to breathing sounds and observing movement of the chest wall and confirmed any possible UAO by pretracheal stereoscopy. Sedation was induced with a bolus injection of midazolam 0.05 mg/kg followed by the continuous infusion of propofol using a target-controlled infusion system (TCI pump TE371; Terumo Corporation, Tokyo Japan). The target blood concentration of propofol was maintained at 1.2 to 2 μg/mL to obtain an adequate depth of anesthesia, which was indicated

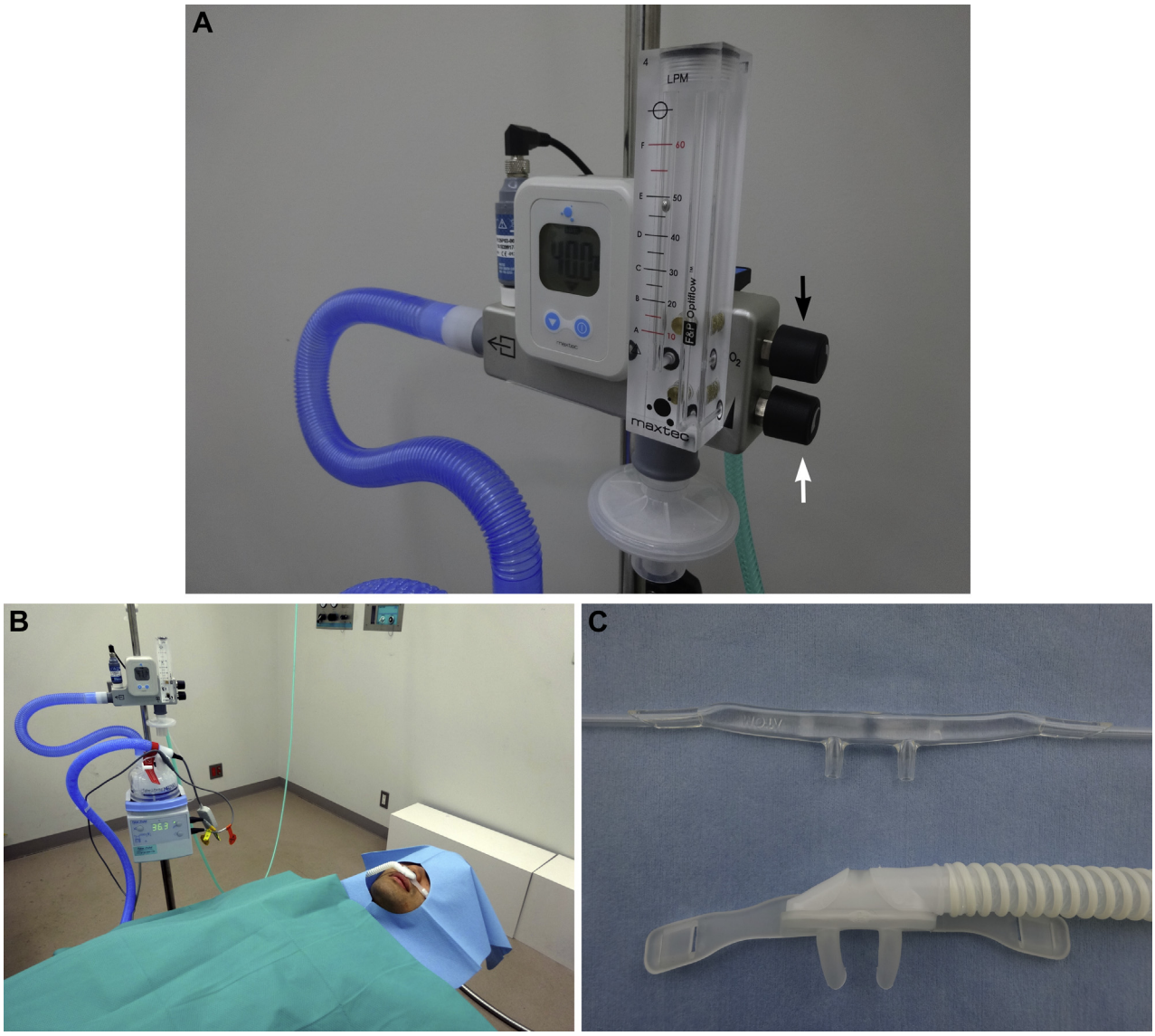

FIGURE 1. *A*, Controller of oxygen flow and fraction of inspiratory oxygen. The upper dial (*black arrow*) adjusts the fraction of inspiratory oxygen. The lower dial (*white arrow*) adjusts oxygen flow rate. *B*, Clinical setting of the nasal high-flow system. *C*, The wide-bore nasal probe of nasal high-flow system compared with the traditional nasal probe.

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by a bispectral index (BIS) value of approximately 70. Administration of oxygen was initiated in each group once an adequate depth of sedation was achieved. A 2% lidocaine solution containing 1:80,000 epinephrine was injected for regional anesthesia after disinfection of the surgical field. Systolic and diastolic blood pressures, heart rate, SpO_2, and BIS were measured and recorded every 5 minutes throughout the study. When SpO_2 decreased below 95% for longer than 1 minute, an intervention, such as jaw lifting or placing the head in the "sniffing position," was performed by the anesthesiologist. At termination of the surgical procedure, an arterial blood sample was taken through the radial artery and blood gas analysis was performed to evaluate the respiratory condition. In this study, the target concentration did not change until the surgical procedure was terminated.

Before leaving the operating room, participants evaluated their satisfaction with IVS by scoring their experience on a scale of 1 to 5 (1, unacceptable; 2, poor; 3, satisfactory; 4, good; 5, excellent). In addition, at the end of the procedure, surgeons evaluated their satisfaction with the surgical conditions during IVS by scoring their experience on a scale of 1 to 5 (1, unacceptable; 2, poor; 3, satisfactory; 4, good; 5, excellent).

STATISTICAL ANALYSIS

All data are presented as mean ± standard deviation. Statistical analysis was performed using the Tukey

honestly significant difference test (SPSS 20.0; IBM Corp., Armonk, NY). A P value less than .05 was considered statistically significant for all tests.

Results

There were no statistical differences in demographic data among the 3 groups (Table 1). No patient dropped out from this study. Therefore, all 30 patients were included in the statistical analysis. They received surgical treatment for pericoronitis of the wisdom tooth (16 patients; NC5, 5 patients; NHF30, 5 patients; NHF50, 6 patients), dental caries (7 patients; NC5, 2 patients; NHF30, 3 patients; NHF50, 2 patients), cysts (4 patients; NC5, 2 patients; NHF30, 1 patient; NHF50, 1 patient), or other conditions (3 patients; 1 patient in each group). No case became critical during dental treatment under IVS using the conventional nasal cannula or the NHF system. Although there was no difference in patient satisfaction among the 3 groups, surgeon satisfaction with the surgical conditions during IVS was lowest for the NC5 group ($P < .05$; Table 2). There was a statistical difference in surgeon satisfaction between the NC5 and NHF50 groups. There was no statistical difference in surgeon satisfaction between the NC5 and NHF30 groups and between the NHF30 and NHF50 groups.

Among the 3 groups, minimum SpO_2 during treatment was significantly lowest in the NC5 group ($P < .05$; Fig 2), although there was no statistical difference between the NHF30 and NHF50 groups.

Interventions decreased when the flow rate of oxygen increased. In 4 cases in the NC5 group and 2 in the NHF30 group, jaw lifting was applied to release UAO and facilitate spontaneous breathing. Conversely, no patients in the NHF50 group required intervention during treatment (Fig 3).

There was a significant difference between the partial pressure of carbon dioxide ($PaCO_2$) between the NC5 and NHF50 groups ($P < .05$), although there was no statistical difference in $PaCO_2$ between the NC5 and NHF30 groups and between the NHF30 and NHF50 groups (Fig 4).

Figure 5 shows the partial pressure of oxygen (PaO_2) at the target concentration of propofol during

Table 1. DEMOGRAPHIC AND ANTHROPOMETRIC CHARACTERISTICS OF PATIENTS

	NC5	NHF30	NHF50
Age (yr)	40.1 ± 15.4	36.8 ± 11.8	38.9 ± 10.9
Weight (kg)	60.2 ± 9.3	60.2 ± 12.8	59.5 ± 11.2
Height (cm)	1.63 ± 0.09	1.66 ± 0.12	1.64 ± 0.08
BMI (kg/m^2)	22.7 ± 3.0	21.6 ± 2.6	21.8 ± 2.5
BIS	73.0 ± 6.6	70.3 ± 6.2	72.5 ± 4.5
Ope time (minutes)	41.9 ± 16.9	50.1 ± 23.9	39.5 ± 20.3

Note: Data are expressed as mean ± standard deviation.

Abbreviations: BIS, bispectral index; BMI, body mass index; NC5, patients receiving oxygen at 5 L/minute through a conventional nasal cannula; NHF30, patients receiving oxygen at 30 L/minute through the nasal high-flow system; NHF50, patients receiving oxygen at 50 L/minute through the nasal high-flow system.

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Table 2. EVALUATION OF INTRAVENOUS SEDATION BY PATIENTS AND SURGEONS

	NC5	NHF30	NHF50
Patients	4.3 ± 0.6	4.3 ± 0.7	4.4 ± 0.5
Surgeons	3.7 ± 0.9*	4.1 ± 0.7	4.6 ± 0.5

Note: Data are expressed as mean ± standard deviation.

Abbreviations: NC5, patients receiving oxygen at 5 L/minute through a conventional nasal cannula; NHF30, patients receiving oxygen at 30 L/minute through the nasal high-flow system; NHF50, patients receiving oxygen at 50 L/minute through the nasal high-flow system.

* $P < .05$ versus NHF50.

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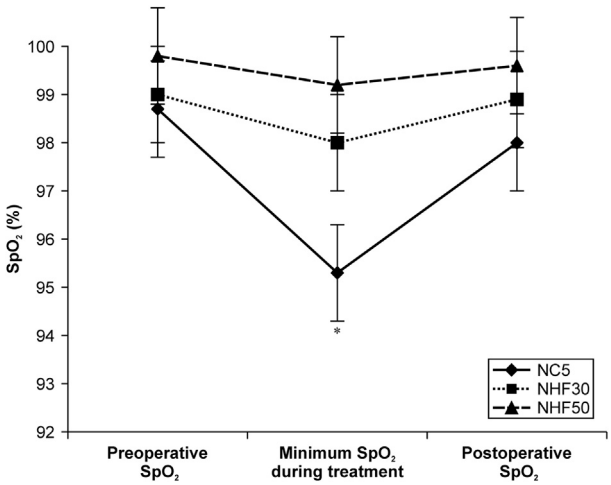

FIGURE 2. Sequence of SpO_2 values in each group throughout this study. Presurgical SpO_2 was determined just before the initiation of intravenous sedation. The minimum SpO_2 during treatment was selected from the anesthesia electrical record in which the data were stored every minute. Postsurgical SpO_2 was measured at the end of surgery. SpO_2 data are presented as mean ± standard deviation. The average of the minimum value of SpO_2 during treatment was significantly lowest in the NC5 group (*$P < .05$ vs NHF30 and NHF50 groups, respectively). NC5, patients receiving oxygen at 5 L/minute through a conventional nasal cannula; NHF30, patients receiving oxygen at 30 L/minute through the nasal high-flow system; NHF50, patients receiving oxygen at 50 L/minute through the nasal high-flow system; SpO_2, peripheral capillary oxygen saturation.

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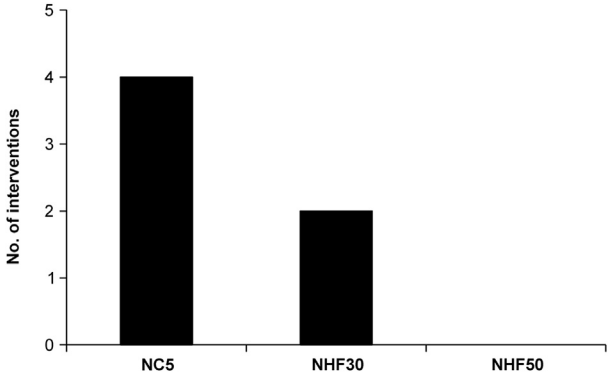

FIGURE 3. Frequency of intervention during dental treatment under intravenous sedation. No intervention occurred in the NHF50 group during treatment versus 4 patients in the NC5 group and 2 patients in the NHF30 group. NC5, patients receiving oxygen at 5 L/minute through a conventional nasal cannula; NHF30, patients receiving oxygen at 30 L/minute through the nasal high-flow system; NHF50, patients receiving oxygen at 50 L/minute through the nasal high-flow system.

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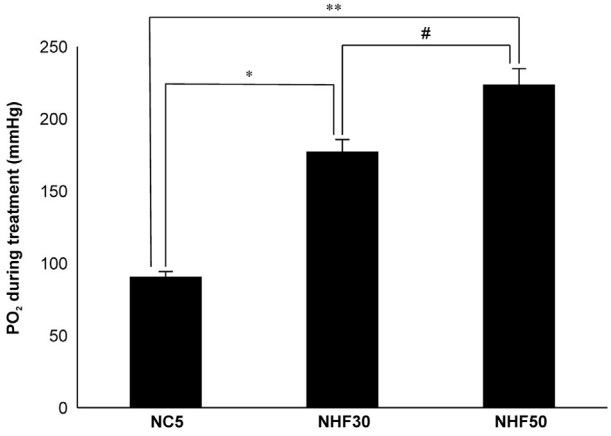

FIGURE 5. PO_2 at the end of the maximum rate of intravenous propofol infusion. PO_2 increased with increasing nasal flow rate. There were significant statistical differences in PO_2 between 2 of the 3 groups ($P < .05$, *NC5 vs NHF30, **NC5 vs NHF50, #NHF30 vs NHF50). NC5, patients receiving oxygen at 5 L/minute through a conventional nasal cannula; NHF30, patients receiving oxygen at 30 L/minute through the nasal high-flow system; NHF50, patients receiving oxygen at 50 L/minute through the nasal high-flow system; PO_2, partial pressure of oxygen.

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treatment. PaO_2 increased as oxygen flow rate increased ($P < .05$ in each group).

Discussion

This study showed that the NHF system achieves effective oxygenation of dental patients under IVS. Interruptions were necessary less frequently during dental treatment with the NHF system than with the conventional nasal cannula. However, a flow rate faster than 30 L/minute might be necessary to maintain upper airway patency under IVS.

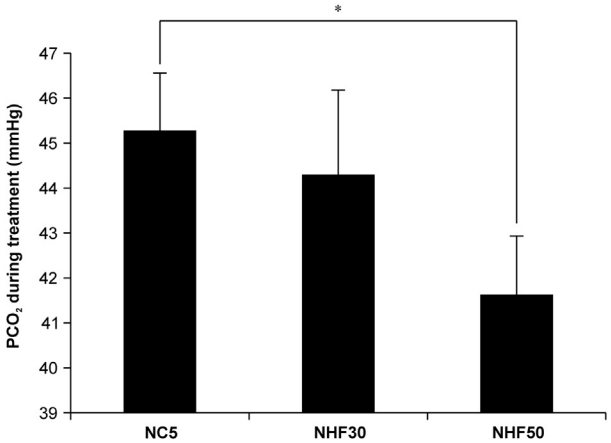

FIGURE 4. PCO_2 at the end of the maximum rate of intravenous propofol infusion. Arterial blood was taken through the radial artery and analyzed immediately for the efficiency of oxygenation and ventilation. PCO_2 of the NHF50 group was significantly lower than that of the NC5 group (*$P < .05$). NC5, patients receiving oxygen at 5 L/minute through a conventional nasal cannula; NHF30, patients receiving oxygen at 30 L/minute through the nasal high-flow system; NHF50, patients receiving oxygen at 50 L/minute through the nasal high-flow system; PCO_2, partial pressure of carbon dioxide.

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Among the 3 groups, minimum SpO_2 was statistically lowest in the NC5 group during dental treatment. Conversely, PaO_2 at the end of treatment was statistically increased by the increased flow rate of oxygen offered by the NHF system. The high-efficiency oxygenation effected by the NHF system can be explained by a higher FIO_2 or less frequent UAO during dental treatment. FIO_2 was set at 40% in groups using the NHF system, because FIO_2 was estimated to be approximately 40% with an oxygen flow of 5 L/minute using a conventional nasal cannula. Moreover, PaO_2 was higher in the NHF50 group than in the NHF30 group, although FIO_2 was identical. Although FIO_2 was not measured in these patients, it could be higher in patients receiving increased nasal oxygen flow using the NHF system. In this study, oxygen was supplied from the central piping system for oxygen requirements. The NC5 group consumed approximately 150 L of oxygen, and the NHF50 group required approximately 285 L of oxygen for 30 minutes (50 L $\times$ 30 minutes $\times$ 0.4 to 0.21%). The NHF system might not be suitable when using a standard oxygen cylinder because of the high oxygen consumption of the NHF system. Moreover, attention should focus on the quick exhaustion of oxygen volume when using a standard cylinder.

Decreased rebreathing of expired air with the NHF system, that is, "washing out" the dead space, might underlie the higher FIO_2,[13] because $PaCO_2$ decreased

with an increased nasal oxygen flow rate. Moreover, inspiratory effort could be increased by positive pressure in the pharyngeal space caused by the use of the NHF system.[11,12] These improvements in respiratory parameters occur even in patients with COPD.[8] Although the NHF system was developed to treat patients with SAS,[7,10] it might facilitate effective oxygenation during dental treatment in patients with COPD.

Deterioration of SpO_2 was evident even with 5 L/minute of oxygen though the nasal cannula, because UAO caused hypoventilation of the alveoli. Moreover, propofol was infused continuously to maintain a hypnotic state during IVS. A previous study showed that the infusion of propofol was associated with the collapsibility of the upper airway and weakened the central respiratory drive.[14] Patency of the upper airway is considered a major contributor to the maintenance of oxygenation under IVS.

The NHF system has been reported to generate little or no pressure in the oral cavity in patients with an open mouth.[12] Although the mouths of the present patients were usually open during dental treatment, the sound of sneezing caused by transient UAO was generated by the tongue plugging the pharyngeal ring or attachment of the uvula to the posterior wall of the pharynx during dental treatment under IVS. The NHF system has been found to generate positive pressure in the nasal cavity, depending on the size of the nasal prong of the cannula and the flow rate.[15] Positive pressure in the nasal cavity generated with the NHF system might hold the uvula away from the posterior wall of the pharynx. If the nasal flow rate exceeds the inspiratory flow rate, the patient could breathe spontaneously through the nasal cavity during inspiration. Because some patients in the NHF30 group required jaw lifting to open the upper airway, the positive pressure generated at this oxygen flow rate could be insufficient to release an obstruction caused by the heavy tongue or the inspiratory flow could be insufficient to allow spontaneous breathing because the inspiratory nasal flow must combat the resistance of the upper airway. A previous study confirmed the occurrence of positive inspiratory pressure with an open mouth at a flow rate faster than 40 L/minute.[11] Those data support the authors' speculation that UAO and soft tissue obstruction were prevented by increasing the inspiratory pressure of the NHF system to 50 L/minute under IVS. Further investigation, including magnetic resonance imaging and fiberoptic scope observation, is necessary to elucidate the mechanism by which the NHF system releases UAO. The CPAP machine has been commonly used to release UAO; it is believed that CPAP could have the same effects as the NHF system. However, the CPAP mask is very large for use in dental patients and interferes with their treatment.

In general, it is believed that conventional nasal cannulae should be used only with an oxygen flow rate of 10 L/minute, because exceeding 10 L/minute causes dryness of the nasal mucosa. A previous study reported that an oxygen flow rate of up to 50 L/minute could be delivered by a conventional nasal cannula, but only when the gas is optimally warmed and humidified.[9] Although the heated humidification of inspiratory gas flow through the nasal cavity can attenuate nasal resistance,[16] increases in nasal secretions and bleeding have been reported[17] as complications of using the NHF system in infants.

The satisfaction of surgeons with IVS was statistically lower for the NC5 group than for the NHF50 group. One plausible reason for the high satisfaction of surgeons with use of the NHF system is that fewer interruptions occurred because of hypoxia during IVS. One study found that the cough reflex is triggered more frequently under IVS.[18] Frequent coughing would lower the satisfaction of surgeons during treatment. Deep sedation can overcome this, but also might increase the incidence of aspiration pneumonia after dental treatment with IVS. Additional studies are required to investigate the effect of the use of the NHF system on the cough reflex and postoperative complications.

In conclusion, the present results showed that the NHF system provides excellent oxygenation in dental patients under IVS. Further studies are necessary to determine the appropriate flow rate to avoid nasal complications.

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