Effects of Nasal Prongs on Nasal Airflow Resistance*

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Study objectives: The aim of this study was to investigate whether nasal prongs, which have been proposed to assess nasal flow during sleep, affect nasal airflow resistance (NR).

Design: NR was estimated by posterior rhinomanometry at a 0.5 L/s flow, under eight conditions: in the basal state, and with seven different nasal prongs.

Participants: The study was performed in 17 healthy supine subjects, 8 of whom had basal NR values within the normal range (≤ 2 cm H₂O·L⁻¹·s, group 1), and 9 had increased basal NR values (> 2.5 cm H₂O·L⁻¹·s, group 2), because of nare narrowness and/or deviated nasal septum.

Measurements and results: NR increased significantly while breathing with nasal prongs (p < 0.0001 in both groups). The changes in NR (ΔNR) induced by the different nasal prongs were characterized by large intersubject and intrasubject variability, with a maximum ΔNR of 24.2 cm H₂O·L⁻¹·s.

Significant differences were found between the ΔNR induced by the different nasal prongs (p < 0.001 in group 1, and p < 0.0003 in group 2), and for six of them, ΔNR was significantly higher in group 1 than in group 2 (p < 0.02).

Conclusions: This study demonstrates that nasal prongs can markedly increase NR in subjects presenting with nare narrowness and/or deviated nasal septum. Further investigations that would include nocturnal polysomnography are still required to evaluate the possible influence of nasal prongs on the diagnosis of obstructive sleep apnea syndrome and its severity.

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Key words: posterior rhinomanometry; nasal airflow resistance; nasal prongs

Abbreviations: NR = nasal airflow resistance; OSAS = obstructive sleep apnea syndrome; Ptn = transnasal pressure; UAR = upper airway resistance; V = nasal flow

Thermistors have been routinely used for the diagnosis of obstructive sleep apnea syndrome (OSAS). However, they have poor accuracy and do not allow the detection of inspiratory flow limitation, which is a predictive index for upper airway narrowing.1,2 Presently, the reference method recommended for nasal airflow measurement is a pneumotachograph attached to a tight-fitting face mask.3 An alternative to nasal airflow is nasal pressure, which is measured by nasal prongs—originally designed for O₂ therapy (O₂ nasal prongs) or for measurements of expired CO₂ concentration (CO₂ nasal prongs)—connected to a pressure transducer.3 Nasal pressure is used for the visual detection of respiratory events during sleep,4,5 as well as in computer-controlled devices designed for automatic diagnosis of OSAS and nasal continuous positive airway pressure titration.6,7 Lastly, it has been demonstrated that, when appropriately corrected, nasal pressure was comparable to the signal of a conventional pneumotachograph.8 However, although it has been suggested that nasal prongs might increase nasal airflow resistance (NR) in individuals with small nares,4 the effect of occluded nasal prongs on NR has never been quantified. Therefore, the aim of the present study was to evaluate the potential effects of nasal prongs on NR assessed by posterior rhinomanometry.

Materials and Methods

Subjects

The study was performed in a group of 17 asymptomatic healthy volunteers (5 men and 12 women), aged 22 to 54 years, with no upper or lower respiratory complaints. Eight subjects had
normal nasal morphology and basal NR values within the normal range, ie, ≤2 cm H₂O L⁻¹ s⁻¹ (group 1); nine subjects had nasal anatomic abnormalities, such as nares narrowness and/or deviated nasal septum, and NR basal values ≥2.5 cm H₂O L⁻¹ s⁻¹ (group 2).

**NR Measurement**

NR was measured by posterior rhinomanometry. The subjects breathed quietly through a nasal mask, with the mouth occluded by a closed mouth piece in which a 3-mm inner-diameter catheter was inserted to measure pharyngeal pressure. Transnasal pressure (Ptn) was measured by a differential pressure transducer (Validyne DP45, ± 14 cm H₂O; Validyne; Northridge, CA), with one port connected to the nasal mask and the other to the catheter. Nasal flow (V) was sensed by a screen pneumotachograph (Fleisch n°1; Fleisch; Lausanne, Switzerland) connected to a differential pressure transducer (Validyne DP45, ± 2.25 cm H₂O; Validyne). Pressure and flow signals were sampled at 32 Hz by an analog-to-digital converter. To determine nasal inspiratory airflow resistance, Ptn and V inspiratory data were analyzed by linear regression analysis of Ptn over V, according to the following equation:

\[ Ptn = K \cdot V \]

NR was then calculated at the 0.5 L/s airflow, as NR = 0.5 K, where K is the slope of the regression line. Three to four consecutive measurements were performed within a 1-min period, and NR was taken as the average of the NR estimates corresponding to an \( r² \) value > 99%.

**Experimental Protocol**

Six O₂ nasal prong devices (Allegiance Healthcare, McGaw Park, IL; Invacare, Elyria, OH; Kendal, Neustadt, Germany; Sims, Pro-Tech, Uno, Taema) were used. Scanned pictures of the different nasal prongs are shown in Figure 1. All nasal prongs were made of nonrigid material, except the Taema device.

![Figure 1: Scanned pictures of the different nasal prongs. All nasal prongs were made of nonrigid material, except the Taema device.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21950/ on 06/04/2017)
Sims, Ft. Myers, FL; Taema, Antony, France; and Uno, Maersk Medical, Lynge, Denmark), and one CO₂ device (Pro-Tech, Woodinville, WA) were successively tested in a randomly selected order in each subject (Fig 1). For each of the devices, NR was measured in the basal state, while breathing with nasal prongs, and in the basal state once again. Great care was taken to avoid air leaks at the mask and to position the nasal prongs correctly. For this purpose, the lateral prong tubing was shortened to allow its subsequent nasal positioning inside the nasal mask, a thin strip was introduced into the tubing, and the tubing ends were occluded and made airtight by silicone gel. The tips of the nasal prongs were then inserted into the nostrils, and the two extremities of the strip were passed over both ears and tied together under the chin to simulate the usual placement of the nasal prongs. Finally, the nasal mask was positioned, and its airtightness was checked.

All NR measurements were performed in the supine position. In order to avoid nasal congestion that may progressively occur in this position, the subjects were asked to sit up for 5 min before each set of NR measurements. The absence of nasal congestion was checked by comparing the NR basal values obtained before and after each measurement with nasal prongs.

The effect of each type of nasal prongs on NR was assessed by the corresponding change in ΔNR.

### Statistical Analysis

Statistical analysis was performed using parametric and non-parametric tests, depending on whether the data distribution could be assumed to be gaussian or not. Basal NR values were compared by one-way analysis of variance for repeated measures. NR values with nasal prongs and ΔNR values were compared by the Friedman test (nonparametric analysis of variance), and the Wilcoxon and the Mann-Whitney rank sum tests. A p value < 0.05 was considered significant. Values are means ± SEM, except when otherwise indicated.

### Results

In the initial basal state, NR ranged from 1.2 to 1.8 cm H₂O·L⁻¹·s in group 1, with a mean value of 2.4 ± 0.1 cm H₂O·L⁻¹·s, and from 2.5 to 4.5 cm H₂O·L⁻¹·s in group 2, with a mean value of 3.0 ± 0.2 cm H₂O·L⁻¹·s. No significant difference was observed between the NR basal values obtained before and after each measurement with nasal prongs (p > 0.6).

When breathing with nasal prongs, the Ptn-V relationship became more curved (Fig 2), and NR significantly increased in both groups (p < 0.0001 in both groups) for all the nasal prongs (group 1, n = 8) and with nasal anatomic abnormalities (group 2, n = 9). Bars indicate SE. +, *, and **: significantly higher than NR basal values (p < 0.03, 0.02, and 0.008, respectively). Note the different scales for NR in both groups. cmH₂O·L⁻¹·s = cm H₂O·L⁻¹·s.
induced by the different types (p = 0.001 in group 1, and p = 0.0003 in group 2), and the Taema and Pro-Tech devices were found to result in the lowest ΔNRs (Fig 5 and Table 1).

**Discussion**

Nasal prongs were demonstrated to be convenient for ventilation monitoring during sleep, even if their sensitivity and specificity for assessing the severity of flow limitation are lower than those found using a pneumotachograph.9 As easily usable as thermistors, they provide a semiquantitative evaluation of airflow, and thereby are more sensitive for the detection of sleep respiratory events, including inspiratory flow limitation.4,5 However, the main requirement for nasal prongs to be routinely used during sleep is that they do not partly occlude the nasal passage, which might cause sleep breathing disorders associated with brief arousals.10 The present study was therefore initiated to evaluate the potential effects of nasal prongs on nasal resistance.

As NR is flow dependent, a choice has to be made with regard to the flow or pressure level at which it is calculated. The NR index retained in the present study has proved suitable for assessing the effects of

**Figure 4.** Intraindividual changes in NR (ΔNR) observed in both groups with the different nasal prongs. Note that the scales for ΔNR are different in both groups, and that subjects with normal nasal morphology (group 1) exhibited relatively small changes in NR, whereas those with nasal anatomic abnormalities (group 2) exhibited large increases. The largest increases in the subjects of group 2 were observed with different nasal prongs, indicating an interaction between the nose morphology and the nasal prong design. See Figure 3 legend for abbreviations.

**Figure 5.** Mean increases in NR (ΔNR) observed in subjects with normal nasal morphology (group 1, n = 8) and nasal anatomic abnormalities (group 2, n = 9) with the different nasal prongs (Allegiance, Invacare, Kendal, Sims, Taema, Uno, and Pro-Tech). Bars indicate SE. +, *, ++, and **: significantly higher than in group 1 (p < 0.02, 0.005, 0.002, and 0.001, respectively). See Figure 3 legend for abbreviations.

| Table 1—Significance Observed Between the Increases in NR Induced by the Different Nasal Prongs in Subjects With Normal Nasal Morphology (Group 1) and With Nasal Anatomic Abnormalities (Group 2)* |
|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Devices         | Allegiance     | Invacare       | Kendal         | Sims           | Taema          | Uno            |
| Group 1 (n = 8) | NS             | NS             | NS             | NS             | NS             | NS             |
| Invacare        | NS             |                |                |                |                |                |
| Kendal          | NS             |                |                |                |                |                |
| Sims            | NS             | NS             | NS             | NS             | NS             | NS             |
| Taema           | p < 0.04       | NS             | p < 0.02       | NS             |                |                |
| Uno             | p < 0.05       | p < 0.05       | p < 0.04       | NS             | NS             | NS             |
| Pro-Tech        | p < 0.02       | p < 0.05       | NS             | NS             | NS             | NS             |
| Group 2 (n = 9) | p < 0.03       | p < 0.02       |                |                |                |                |
| Invacare        | p < 0.03       |                |                |                |                |                |
| Kendal          | p < 0.02       |                |                |                |                |                |
| Sims            | p < 0.05       | p < 0.05       | NS             |                |                |                |
| Taema           | p < 0.03       | p < 0.03       | p < 0.04       | p < 0.01       |                |                |
| Uno             | NS             | NS             | NS             | p < 0.01       | NS             |                |
| Pro-Tech        | p < 0.02       | NS             | NS             | p < 0.01       | NS             | p < 0.01       |

*The p values are derived from the Wilcoxon rank sum test; NS = not significant.
topical decongestants and nasal mechanical dilators on NR. To avoid any influence of diurnal variation on NR, all of our subjects were studied at the same time of day. The nasal prongs were occluded to reproduce the conditions in which they are used to measure nasal pressure, ie, with their tubing connected to a pressure transducer. The effect of nasal prongs on NR was evaluated in the supine position, the one used for subjects undergoing polysomnographic studies, because increases in NR have been reported when shifting from the sitting to the supine position. This postural influence on NR is partly attributable to an increase in mucosal thickness due to vascular dilation, which makes NR values unstable (unpublished results). It therefore appeared important to prevent the development of nasal congestion by shortening the period spent in the supine position. In that way, the changes we observed in NR were exclusively attributable to the nasal prongs.

Nasal prongs resulted in a significant increase in NR in both groups (Fig 3), which can be attributed to the fact that they reduce the nasal cross-sectional area available for airflow. Moreover, in certain subjects, some nasal prongs increased NR to a resistance level comparable to the normal uninasal resistance level, ie, NR became roughly equivalent to NR during complete obstruction of one nostril, a situation known to induce a significant increase in the apnea and arousal indexes.

One of the most interesting results of this study concerns the wide intersubject and intrasubject variability of ΔNR (Fig 4), which proves that the different types of nasal prongs cannot be used indiscriminately. For example, the same devices could result in the lowest or the highest ΔNR, depending on the subject (Fig 4). Both intersubject and intrasubject variabilities are explained by the combination of the following: (1) the great diversity of the nasal prong tips used in the present study as regards their section profile, their maximal external diameter, their length, their curvature, and their stiffness (Fig 1); and (2) the great diversity of nose morphology, especially of the nare geometry in the region located downstream of the nasal valve, which determines the depth of nasal prong penetration and the nasal cross-sectional area remaining available for airflow. For example, nasal prongs made of nonrigid material and with a large maximal diameter result in a ΔNR all the more high, as their tips occlude the nasal passage, ie, as the nares are narrow and/or the nasal septum is deviated. Similarly, the increase in NR will be all the more marked, as the nonrigid tips are long and the nares short, because the tips will then reach the valve region. The highest ΔNR was indeed observed with the Uno device, which had the longest nonrigid tips (Fig 1), in a group 2 subject who had both deviated nasal septum and short narrow nares (Fig 4). Such a high ΔNR value was probably due to the fact that the Uno device resulted at the same time in the total occlusion of one nare, and a marked reduction of the cross-sectional area of the other. By contrast, the Taema nasal prongs, which are the only ones made of rigid material that were tested in this study, tend to dilate the nares and thereby limit their occlusive effect.

Another interesting result is that, when compared to the other devices, the Taema and Pro-Tech nasal prongs resulted in the lowest ΔNRs in both groups (Fig 4, 5 and Table 1). This finding may be easily explained by the respective designs of these two devices (Fig 1). Due to the length and stiffness of their tips, the Taema nasal prongs have an expanding effect on nasal valves, comparable to the one of a mechanical internal nasal dilator. Indeed when breathing with this device, most subjects reported the sensation of nasal dilation, sometimes associated with the feeling of discomfort resulting from the hardness of the tip material. This expanding effect may have partly, and sometimes even completely counterbalanced the increase in NR induced by the reduction of the nasal cross-sectional area available for airflow (Fig 4). Conversely, the Pro-Tech nasal prongs, which were originally designed to measure the CO₂ concentration in the expired gas, are characterized by very short and narrow soft tips, which considerably limit the reduction of the nasal cross-sectional area available for airflow and induces no sensation of discomfort. Besides, although their tips are a little longer, they are narrower than those of the conventional pediatric O₂ nasal prongs, and their inter-tips space allows them to better fit an adult nose.

Our results also demonstrate that whereas nasal prongs have relatively little effect on NR in subjects with normal nasal anatomy, they can dramatically increase NR in subjects with nasal anatomic abnormalities (Figs 3–5). In patients presenting with a deviated nasal septum, certain types of nasal prongs might even result in the total occlusion of one nare. Consequently, the choice of a type of nasal prongs for a polysomnographic study in a patient consulting for suspected OSAS is all the more tricky, as the patient has a high NR basal value.

Moreover, the ΔNR values observed in the present study do not allow prediction of the total increase in upper airway resistance (UAR) resulting from the use of nasal prongs. It has indeed been shown that external resistive loads result in significant increases in UAR during nonrapid eye movement sleep in healthy men, which closely correlated with the basal UAR values. Consequently, in certain patients presenting with highly resistive nares,
the use of nasal prongs for airflow monitoring during sleep might induce dramatic increases in total UAR and thereby promote the occurrence of sleep respiratory events.

In conclusion, our results demonstrate that nasal prongs may dramatically increase NR in subjects presenting with nare narrowness and/or deviated nasal septum. Further studies that would include nocturnal polysomnography are still required to accurately evaluate the possible influence of nasal prongs on the diagnosis of OSAS and its severity.

REFERENCES


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