

Relationship between Oral Flow Patterns, Nasal Obstruction, and Respiratory Events during Sleep

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Study Objectives: Sleep breathing patterns are altered by nasal obstruction and respiratory events. This study aimed to describe the relationships between specific sleep oral flow (OF) patterns, nasal airway obstruction, and respiratory events.

Methods: Nasal flow and OF were measured simultaneously by polysomnography in 85 adults during sleep. OF was measured 2 cm in front of the lips using a pressure sensor.

Results: OF could be classified into three patterns: postrespiratory event OF (postevent OF), during-respiratory event OF (during-event OF), and spontaneous arousal-related OF (SpAr-related OF). Postevent OFs begin at the end of airflow reduction, are preceded by respiratory arousal, and are accompanied by postapneic hyperventilation; during-event OFs occur during nasal flow reduction; and SpAr-related OFs to OF begin during stable breathing, and are preceded by spontaneous arousal but are rarely accompanied by apnea/hypopnea. Multivariate regression showed that nasal

obstruction was predictive of SpAr-related OF. The relative frequency of SpAr-related OF events was negatively correlated with the apnea-hypopnea index. The fraction of SpAr-related OF duration relative to total OF duration was significantly greater in patients with nasal obstruction than in those without.

Conclusions: SpAr-related OF was associated with nasal obstruction, but not respiratory events. This pattern thus functions as a “nasal obstruction bypass”, mainly in normal subjects and patients with mild sleep disordered breathing (SDB). By contrast, the other two types were related to respiratory events and were typical patterns seen in patients with moderate and severe SDB.

Keywords: nasal obstruction, oral breathing, sleep disordered breathing, spontaneous arousal

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Nasal breathing is physiologic during sleep. Respiratory physiology and the nature of the upper and lower airways encourage nasal breathing during sleep. However, in nasal diseases such as nasal deviation or inferior turbinate hypertrophy, nasal obstruction can be bypassed by opening the mouth and allowing a greater volume of air to be inspired and expired. McLean et al.¹ showed that oral breathing during sleep is induced by increased nasal resistance. Mouth opening increased upper airway collapsibility during sleep, which is different from that seen when awake.² Fitzpatrick et al.³ confirmed that during sleep, upper airway resistance during oral breathing was 2.5 times higher than that during nasal breathing. Mouth opening may be associated with narrowing of the pharyngeal lumen and decreases in the retroglottal diameter. Mouth opening and oral breathing may, but not necessarily, lead to hypopnea or apnea. However, Lavie et al.⁴ showed that nasal obstruction caused a significant increase in the number of arousals during sleep in patients with nonapneic breathing disorders. In another recent study, Hsia et al.⁵ described a snoring pattern during nasal breathing in patients with nasal obstruction that was alleviated with oral breathing.

Against this background, we hypothesized that different kinds of oral flow (OF) patterns exist during sleep and are associated with distinct sleep related respiratory events. The

BRIEF SUMMARY

Current Knowledge/Study Rationale: The relationship between oral flow (OF) patterns, nasal obstruction, and obstructive respiratory events is unclear. We hypothesized that specific OF patterns are associated with different obstructive events during sleep.

Study Impact: Three distinct OF patterns were identified during sleep, termed postrespiratory event OF, during-respiratory event OF, and spontaneous arousal-related OF. The first two were related to apnea/hypopnea and were the typical patterns observed in patients with moderate to severe sleep disordered breathing (SDB);, by contrast, spontaneous arousal-related OF was associated with nasal obstruction, observed mainly in normal subjects and patients with mild SDB, and prevented apnea/hypopnea by bypassing nasal obstruction.

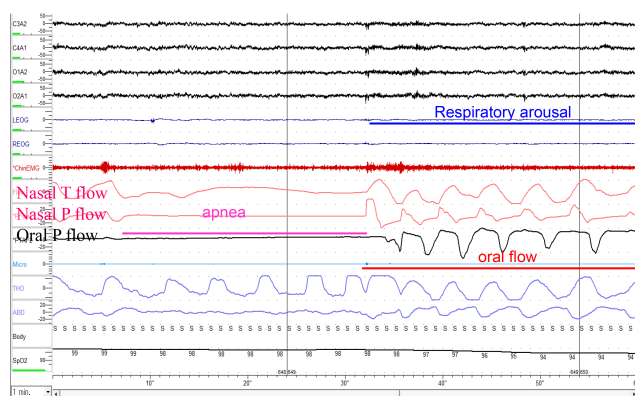
aim of this study was to clarify the relationship between OF patterns, nasal airway obstruction, and obstructive respiratory events such as flow limitation, respiratory effort-related arousal (RERA), hypopnea, and apnea.

PATIENTS AND METHODS

Patients

We conducted an observational cross-sectional study of 85 Japanese adult patients examined by our sleep laboratory for

Figure 1—A polysomnographic trace showing typical oral flow (OF) postrespiratory event: postevent OF pattern.



Bursts of oral breathing preceded by apnea and respiratory arousal. Polysomnographic trace: 60 sec. P, pressure; T, thermistor.

suspected sleep disorders. Exclusion criteria were evidence of adenoid or tonsil hypertrophy, pulmonary disease such as asthma or chronic obstructive pulmonary disease, and five or more central sleep apnea events per hour. The Ethics Committee of Teikyo University approved the study (Approval Number 13-103), and informed consent was obtained from all subjects.

Nasal resistance was measured with an anterior rhinomanometer (HI-801™, CHEST, Tokyo, Japan) in the supine position 1 h before sleep studies. Total inspiratory nasal resistance at negative 100 Pa was calculated from the unilateral rhinomanometry recordings.⁶ On the basis of nasal endoscopy and x-ray findings, subjects were classified as those with or without nasal obstruction: those with nasal obstruction had nasal resistance ≥ 0.41 Pa/cm³/sec and nasal disease such as nasal deviation, nasal allergy, or nasal polyp [nasal resistance, 0.82 ± 0.70 Pa/cm³/sec (range, 0.41–2.07 Pa/cm³/sec); age, 37.6 ± 10.6 y (range, 16–68 y); body mass index (BMI), 23.9 ± 3.7 kg/m² (range, 18.4–37.5 kg/m²); apnea-hypopnea index (AHI), 18.5 ± 15.6 /h (range, 1–79.2/h); n = 44]; those without nasal obstruction were those with nasal resistance ≤ 0.18 Pa/cm³/sec and no nasal disease or complaints of nasal obstruction [nasal resistance, 0.16 ± 0.07 Pa/cm³/sec (range, 0.04–0.18 Pa/cm³/sec); age, 34.6 ± 10.6 y (range, 17–61 y); BMI, 23.8 ± 3.6 kg/m² (range, 19.6–32.3 kg/m²); AHI, 19.4 ± 21.1 /h (range, 0–60.3/h); n = 41]. Nasal resistance values (0.41, and 0.18 Pa/cm³/sec) were derived from Japanese mean ± 2 standard deviation.⁷

Polysomnography and OF Measurement

All subjects underwent overnight polysomnography (PSG) carried out using a computerized polysomnograph (Alice 5, Philips Respironics, Pittsburgh, PA, USA). Nasal flow and OF were measured separately by PSG. Nasal air flow was measured with pressure and thermistor sensors at the nostrils. For the OF measurement, another pressure sensor cannula with its tip cut off was positioned 2 cm in front of the lips. The pressure sensor for measuring OF was connected to PTA2 (Pro-Tech Services Inc., Mukilteo, WA, USA), and the output cables were connected to the PSG input. The following tests were also

conducted simultaneously: electroencephalography (EEG; C4/A1, C3/A2), electrooculography (EOG), submental surface electromyography (EMG), electrocardiography (ECG) using surface electrodes, measurement of respiratory movements of the rib cage and abdomen by inductive plethysmography, and measurement of percutaneous arterial oxygen saturation (SpO₂) using finger pulse oximetry.

Obstructive respiratory events included apnea, hypopnea, RERA, snoring, and flow limitation. Apnea was identified as almost flat airflow ($< 10\%$ of baseline; the baseline amplitude was identified in the preceding period of regular breathing with a stable oxygen saturation) for at least 10 sec.^{8,9} Hypopnea was identified as an airflow or a thoracoabdominal excursion $< 30\%$ of baseline for at least 10 sec associated with either oxygen desaturation $> 3\%$ or an arousal.^{8,9} Flow limitation was defined as an abnormal contour that was present for at least four consecutive breaths, with inspiratory flattening of the waveform on the top of the nasal airflow curve that did not meet the criteria for apnea or hypopnea.^{10,11} Flow reduction was defined as reduced airflow including not only an obstructive respiratory event, but also reduced airflow that did not meet the criteria for an obstructive respiratory event. An arousal was defined as an abrupt shift in EEG frequency for 3–15 sec, which had particular patterns in the EEG tracing.^{8,9} Patients were considered to have obstructive sleep apnea (OSA) if the obstructive AHI score, as measured by overnight PSG, was ≥ 5 .

Statistical Analysis

All descriptive statistics calculated for each variable are presented as mean \pm standard deviation. Differences between unpaired subjects were evaluated by the Mann–Whitney *U* test. A *p* value < 0.05 was considered significant. Correlations between parameters were analyzed using Spearman correlation coefficients. All statistical analysis was performed using the Statistical Package for Social Sciences, version 11.01 (SPSS Inc., Chicago, IL, USA).

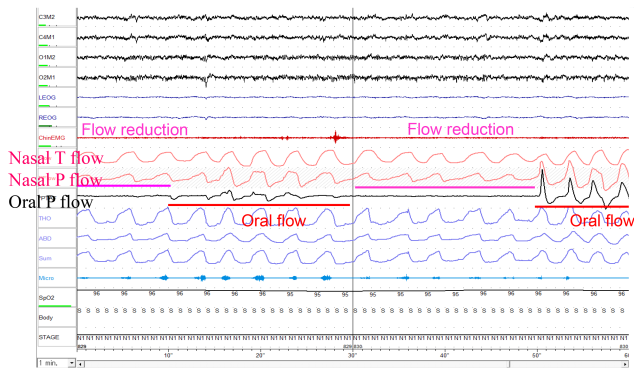
RESULTS

Oral flow could be divided into three main patterns: OF after a respiratory event (postevent OF), OF during a respiratory event (during-event OF), and spontaneous arousal-related OF (SpAr-related OF). Respiratory patterns not conforming to the definitions of these three patterns were collectively categorized as “Other.”

The postevent OF pattern refers to OF events starting at the end of obstructive respiratory events, often preceded by respiratory arousal, and accompanied by hyperventilation. This type of OF event is well known to clinicians. **Figure 1** shows a PSG trace of the typical postevent OF pattern. OF events beginning at the end of flow reduction that did not meet the criteria for obstructive respiratory events were also considered postevent OFs (**Figure 2**).

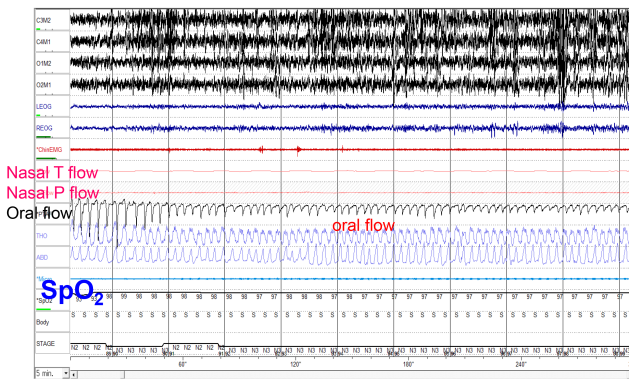
The during-event OF pattern refers to any OF event occurring during nasal flow reduction. **Figures 3, 4, and 5** show PSG traces of this pattern. Events of this type also included flow reductions that did not meet the criteria for obstructive respiratory events. Some of the OFs of this type may not be associated with increased respiratory effort, presumably in cases

Figure 2—The postevent oral flow pattern that does not meet the criteria for obstructive respiratory events.



During flow reduction, the oral channel shows little to no oral breathing. At the end of flow reduction, the subject switches between oral and nasal breathing. Polysomnographic trace: 60 sec. P, pressure; T, thermistor.

Figure 4—A prolonged stretch of oral breathing.

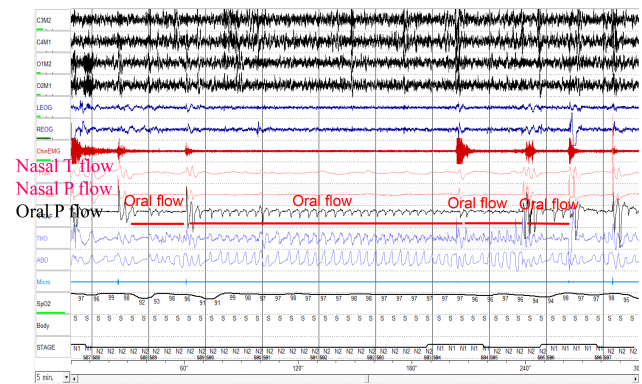


The patient continues to show oral breathing. Both nasal channels show flat lines, indicating no nasal breathing. The signal excursions of the oral pressure sensor before and after this oral flow event were 100% of baseline, which indicates that the absence of nasal signals was not due to sensor displacement. Polysomnographic trace: 300 sec. P, pressure; SpO₂, percutaneous arterial oxygen saturation; T, thermistor.

where the decreased volume of air through the nose may be replaced by an equivalent volume of air that passes through the mouth during inspiration and expiration (**Figures 3 and 4**). In addition, OF events occasionally exhibited long (> 10 min) stretches of oral breathing (**Figure 4**). However, oral and nasal breathing sometimes occurred simultaneously and could be accompanied by desaturation and arousal (**Figures 3 and 5**).

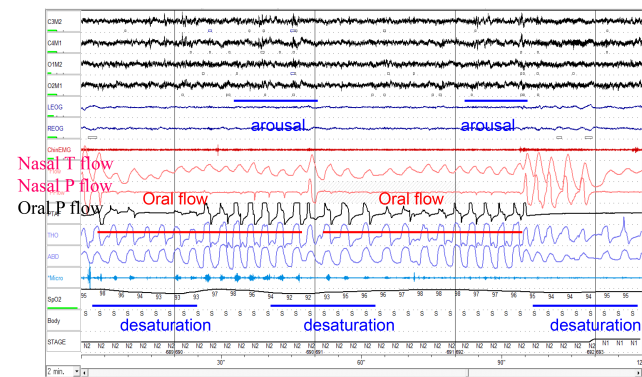
The SpAr-related OF pattern refers to OF events beginning during stable breathing, preceded by spontaneous arousal, and accompanied by EMG activation. This OF pattern was not associated with respiratory events such as hypopnea or apnea. **Figure 6** shows a PSG trace of a typical SpAr-related OF event. If no flow reduction or snoring preceded arousal and if arousal was followed by oral breathing, the flow was regarded as SpAr-related OF. If flow reduction or snoring preceded arousal, the flow pattern was classified as either postevent OF or during-event OF.

Figure 3—A polysomnographic trace showing typical oral flow during a respiratory event: during-event oral flow (OF) pattern.



Oral breathing episodes occur during reduction of nasal flow. The OF events in this pattern are associated with arousals. Some are not associated with oxygen desaturation, such as the second and fourth OF events, while others are accompanied by desaturation like the first and third OF events. Polysomnographic trace: 300 sec. P, pressure; T, thermistor.

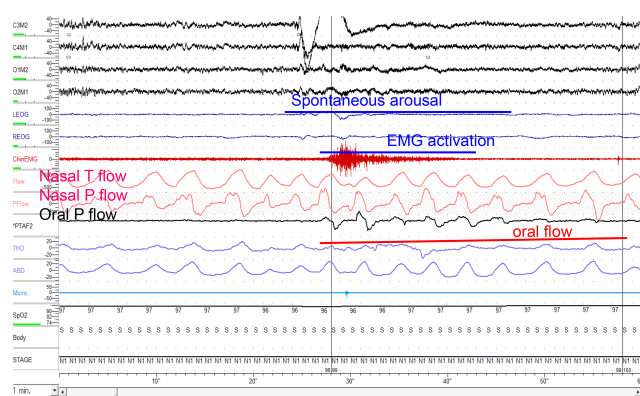
Figure 5—The during-event oral flow (OF) pattern that meets the criteria for hypopnea.



Oral and nasal breathing episodes occur simultaneously and were associated with arousal and desaturation. These OF events can be scored as obstructive hypopnea events. Polysomnographic trace: 120 sec. P, pressure; T, thermistor.

We included nasal obstruction, fraction of time spent in different sleep stages, AHI, lowest SpO₂, age, and BMI as independent variables in multivariate stepwise regression analysis of the relative incidence of each OF pattern (number of each OF event type over the total number of OF events). Regression analysis showed that the incidence of each OF type had one significant determinant. AHI ($t = 5.56$, $b = 0.62$, $p < 0.001$) significantly predicted relative incidence of postevent OF, whereas the percent duration of nonrapid eye movement sleep (%NREM) ($t = 4.55$, $b = 0.56$, $p < 0.001$) significantly predicted relative incidence of during-event OF. For SpAr-related OF, nasal obstruction was the strongest predictor of incidence ($t = 2.01$, $b = 0.31$, $p < 0.001$), whereas lowest SpO₂, %REM, age, BMI, and AHI were not significant predictors.

Figure 6—Spontaneous arousal-induced (SpAr) oral flow (OF) SpAr-related OF pattern.



Oral breathing begins during stable breathing. A brief arousal occurs and is followed by transition from nasal to oral breathing, accompanied by electromyographic activation. No snoring or flow reduction precedes this arousal. Polysomnographic trace: 60 sec. EMG, electromyography; P, pressure; T, thermistor.

Figure 7 shows that the relative incidence of SpAr-related OF events (% of total) was negatively correlated with AHI (Spearman $\rho = -0.85$, $p < 0.001$), indicating that this OF pattern occurred mainly in normal subjects and patients with mild sleep disordered breathing (SDB) but rarely in those with moderate to severe SDB. By contrast, most postevent OFs and during-event OFs were associated with subsequent obstructive respiratory events. Furthermore, the relative incidence of these two patterns was positively correlated with AHI ($\rho = 0.87$, $p < 0.001$; $\rho = 0.91$, $p < 0.001$, respectively), indicating that postevent OFs and during-event OFs were more often observed in patients with moderate to severe SDB.

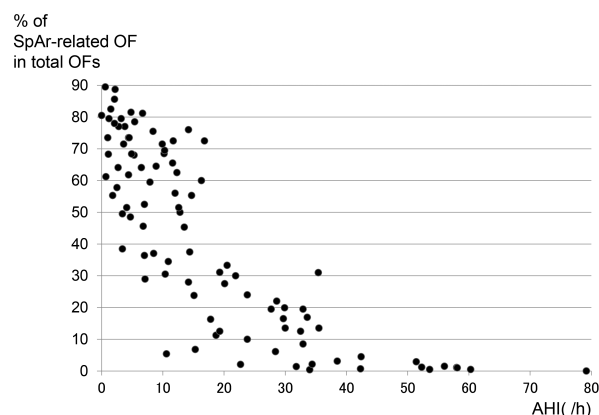
Comparative studies between patients with nasal obstruction and patients without nasal obstruction revealed that the fraction of SpAr-related OF duration relative to total OF duration was significantly higher in patients with nasal obstruction than in those without nasal obstruction ($30.4\% \pm 24.3$ versus $24.4\% \pm 18.8$; $p = 0.041$). Furthermore, the fraction of SpAr-related OF duration relative to total OF duration was significantly greater in non-OSA patients with or without nasal obstruction than in OSA patients, at $52.0\% \pm 33.4$ ($n = 13$) and $38.0\% \pm 21.2$ ($n = 11$), respectively ($p = 0.038$). By contrast, there was no significant difference between patients with and without nasal obstruction in the fraction of postevent OF duration ($33.1\% \pm 28.5$ versus $37.7\% \pm 23.8$, respectively; $p = 0.079$) or during-event OF duration ($32.9\% \pm 19.1$ versus $29.6\% \pm 24.8$, respectively; $p = 0.262$).

DISCUSSION

The Three Patterns of OF

This is the first study to describe the relationships among specific patterns of oral flow (postevent OF, during-event OF, and SpAr-related OF), nasal airway obstruction, and

Figure 7—Correlation between relative spontaneous arousal (SpAr)-related oral flow (OF) event incidence and apnea-hypopnea index (AHI).



The relative incidence of SpA-induced OF is negatively correlated with AHI (Spearman $\rho = -0.85$, $p < 0.001$).

respiratory events during sleep. Both the postevent and during-event OF patterns were associated with respiratory events, possibly because mouth opening during sleep can increase the collapsibility of the pharyngeal airway, increasing the risk of airway obstruction. Indeed, both patterns were typically seen in patients with moderate or severe SDB. They are “apnea or hypopnea inductors” and are closely related. These two OF patterns periodically repeat in the presence of many obstructive respiratory events (**Figures 2, 3, and 5**). SpAr-related OF, however, is a “nasal obstruction bypasser” rather than an “apnea/hypopnea inductor” and functions as a bypasser to prevent apnea and hypopnea. Oral breathing with increased nasal resistance leads to mouth opening and oral breathing, but it does not induce apnea or hypopnea. SpAr-related OFs in patients with nasal obstruction may disturb sleep. We usually do not focus much attention on patients with mild SDB with nasal obstruction, but their abnormal breathing and sleep quality might be improved by nasal treatment. Thus, physicians should be concerned about nasal obstruction not only in continuous positive airway pressure-intolerant users but also in patients with mild SDB.

OF Hidden in Respiratory Events

Physicians should be aware that OF can be hidden in obstructive respiratory events. It is difficult, however, to distinguish during-event OFs due to nasal flow reduction from obstructive respiratory events. First, during-event OFs may cause an arousal through oronasal transition⁵ that meets the definition of a RERA or hypopnea. Second, during-event OFs could be accompanied by desaturation. Oral and nasal breathing may occur simultaneously, and during-event OFs accompanied by desaturation could be scored as hypopnea events. The fraction of time spent in NREM sleep significantly predicted during-event OF incidence. One possible explanation for this finding is that there were episodes of flow reduction associated with OF that did not meet the criteria for obstructive respiratory events

during NREM sleep, whereas apnea or hypopnea did occur during REM sleep. An obstructive respiratory event could be a manifestation of OF. We can recognize these respiratory events by introducing OF scoring. Clinicians and sleep laboratory technologists should be aware of OF events hidden in obstructive respiratory events. Oral breathing during sleep is abnormal, and measuring OF may supplement AHI assessment.

OF Patterns, the Nasal Airway, and SDB

Upper airway collapse during sleep may occur because of negative intraluminal pressure due to occlusion in the upper airway. The Starling resistor model, which works in accordance with the Bernoulli principle, explains this mechanism. The model predicts that an upstream obstruction in the nasal cavity generates a suction force and negative intraluminal pressure downstream at the pharynx under a closed-mouth condition. However, this model fails to take oral breathing into account. Mouth opening is associated with increased upper airway collapsibility during sleep.¹ It has been reported that upper airway collapsibility and resistance during sleep were significantly higher in subjects who were breathing through the mouth than in those who were breathing through the nose, which is different from that seen during the conscious state.^{2,3} Other reasons for nasal breathing over mouth breathing during normal sleep are based on the physiological effects of decreased nasal airflow. First, bypassing the nasal airway can lead to reduced nasal receptor activation, deactivation of the nasal ventilatory reflex, and reduced spontaneous ventilation. Douglas et al.¹² found that nasal breathing activates nasal receptors, which have a direct positive effect on spontaneous ventilation, resulting in higher minute ventilation and resting breathing frequency. Furthermore, ventilation is significantly greater during obligate nasal breathing than during predominant oral breathing in normal subjects.¹³ Second, decreased nasal ventilation may result in reduced nitric oxide delivery to the lungs and reduced oxygen exchange capability.^{14,15} Nitric oxide is produced in significant amounts in the nose and sinuses, and has been shown to be a potent lung vasodilator that improves overall blood oxygenation.

Taken together, the balance of evidence suggests that the nasal route of breathing during sleep is physiologic. The physiology of the upper and lower airways and respiratory control encourage nasal breathing during sleep rather than bypassing nasal obstruction.

If nasal airway obstruction is severe with high inspiratory resistive loads, nasal resistance exceeds a certain threshold and nose breathing is switched to oral breathing to bypass the nasal airway obstruction. This case of OF may be SpAr-related OF. However, in patients with airways susceptible to collapse or habitual oral breathing, postevent or during-event OFs would occur and induce respiratory events. Nasal resistance is an important factor if it exceeds a certain threshold and triggers the switch to oronasal or oral breathing. Pressure receptors in the nose and other parts of the upper airway are responsible for sensing increased resistance to nasal airflow, and activation of these receptors alters the movement of palatopharyngeal, palatoglossal, and palatal elevator muscles, thereby changing the breathing route, but at a high physiological cost. Mild SDB may be attributed to an adaptive response to reversible

nasal airway obstruction with a change in the breathing route.¹⁶ However, the pathological role of the pressure receptors and their pathways in the nose and other parts of the upper airway is not fully understood, especially during sleep. Further exploration in this area is needed.

A limitation of this study is that we were not able to use the ideal methods to measure the parameters under investigation, namely, nasal resistance measurement during sleep by PSG and nasal and oral flow measurement with a sealed mask and two pneumotachometers. Nevertheless, our methodology clearly revealed distinct OF patterns and their relationships with nasal airway obstruction and obstructive respiratory events.

In conclusion, OF events during sleep could be divided into three main patterns: postevent OF, during-event OF, and SpAr-related OF. SpAr-related OF events were significantly more common in patients with nasal obstruction than in those without nasal obstruction. SpAr-related OF events were not associated with obstructive respiratory events but functioned as a “nasal obstruction bypass” predominantly in normal subjects and patients with mild SDB. By contrast, postevent and during-event OF events were related to obstructive respiratory events and were more frequently observed in patients with moderate to severe SDB.

ABBREVIATIONS

AHI, apnea-hypopnea index
 BMI, body mass index
 ECG, electrocardiography
 EEG, electroencephalography
 EMG, electromyography
 EOG, electrooculography
 NR, nasal resistance
 NREM, non-rapid eye movement
 OF, oral flow
 OSA, obstructive sleep apnea
 PSG, polysomnography
 REM, rapid eye movement
 RERA, respiratory effort-related arousal
 SBD, sleep disordered breathing
 SpAr-related, spontaneous arousal-related
 SpO₂, oxygen saturation

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DISCLOSURE STATEMENT

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