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Association Between Breathing Route, Oxygen Desaturation, and Upper Airway Morphology

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Objectives/Hypothesis: This study aimed to assess the role of capnography in objectively evaluating breathing routes during drug-induced sleep endoscopy (DISE) and further elucidate the relationship between breathing route, obstructive sleep apnea (OSA) severity, and DISE findings.

Study Design: Prospective observational study.

Methods: Nighty-five patients with established OSA were recruited for this study from May 2017 to May 2019. DISE was performed in the operating room. Sedation was maintained with propofol using a target-controlled infusion system and the depth of sedation was monitored based on the bispectral index. The breathing routes, which included oral breathing, oronasal breathing, and nasal breathing, were detected using capnography. DISE findings were recorded using the VOTE (velum, oropharynx, base of tongue, and epiglottis) classification.

Results: Patients with mouth breathing were associated with increased OSA severity, worse oximetric variables, and higher body mass index in comparison with those with other breathing routes. Mouth breathing was associated with a higher degree and higher prevalence of lateral pharyngeal wall collapse and tongue base collapse during DISE.

Conclusions: Mouth breathing was significantly associated with worse oxygen desaturation and increased degree of upper airway collapse. Therefore, patients with mouth breathing during propofol-based intravenous anesthesia should be carefully monitored.

Key Words: Sleep apnea, upper airway, oxygen desaturation, breathing route, propofol, drug-induced sleep endoscopy.

Level of Evidence: 4

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INTRODUCTION

Several meta-analyses have indicated that obstructive sleep apnea (OSA) is associated with an increased risk of perioperative respiratory complications such as reintubation, acute respiratory distress syndrome, airway obstruction, and hemodynamic instability.[1,2] Hypoxemia is frequently observed in OSA patients during intravenous sedation or anesthesia, especially in obese patients.[3,4] Practice guidelines for the perioperative management of OSA patients have been proposed by the American Society of Anesthesiologists. These guidelines aimed at reducing perioperative adverse outcomes due to difficulty in maintaining an adequate airway in OSA patients during sedation, analgesia, or anesthesia. They strongly recommended that ventilation should be closely monitored using capnography to prevent unpredictable upper airway collapse.[5] However, it is unclear whether OSA patients with different breathing routes may have distinct presentations of oxygen desaturation and upper airway collapse, which may help physicians identify patients susceptible to upper airway obstruction.

Healthy subjects preferentially breathe almost exclusively via the nasal route with the purpose of heating, air conditioning, and cleaning the inspired air.[6] Nasal breathing is essential in maintaining normal craniofacial growth and dental occlusion due to its interaction with mastication and swallowing.[7] On the other hand, mouth breathing can result in craniofacial maldevelopment and dental malocclusion, which include longer facial and dentoalveolar heights, more narrowed maxillary and palatal widths, some forms of incisor crowding, and a tendency toward open bite or crossbite.[8,9] Aging has a potential effect on breathing routes, and older age is associated with an increased occurrence of mouth breathing during sleep.[10]

Previous studies have indicated that nasal occlusion may trigger obstructive apneas and hypopneas.[11] However, in patients with a sleep disorder, the alleviation of nasal obstruction is usually not accompanied by a significant reduction in OSA severity.[12] This indicates that nasal obstruction alone cannot account for the main cause of OSA severity. Because mouth breathing is frequently

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associated with nasal obstruction, assessing the relationship between different breathing routes and OSA severity may provide a better understanding of upper airway pathophysiology.

In the present study, drug-induced sleep endoscopy (DISE) and breathing routes were recorded. The aim of this study was to assess the role of capnography in objectively evaluating breathing routes during DISE, and to further evaluate the relationship between breathing routes, OSA severity, and DISE findings.

MATERIALS AND METHODS

Study Design

We conducted a prospective observational study that included 95 patients with OSA from May 2017 to May 2019. This study was approved by the institutional review board of Taipei Tzu Chi Hospital (IRB No: 05-X06-014). Patients were recruited if they were aged >18 years and had an apnea-hypopnea index (AHI) ≥5. The exclusion criteria were as follows: 1) American Society of Anesthesiologists score of III or higher; 2) previous surgery involving the nose, oral cavity, or maxillomandibular complex; 3) neuromuscular or neurodegenerative diseases; 4) congenital anomalies; and 5) pulmonary disease. All participants underwent a thorough clinical evaluation, including physical examinations, nasal endoscopy with Müller's maneuver, standard polysomnography (PSG), and DISE.

Sleep Studies

Standard PSG was performed on all patients in the sleep lab. Sleep measurements were based on the guidelines of the American Academy of Sleep Medicine.[13] The AHI was defined as the number of obstructive apneas plus hypopneas per hour of sleep. OSA severity was classified based on AHI. Apnea was scored when the peak signal excursions dropped by ≥90% of the preevent baseline for ≥10 seconds. Hypopnea was scored when there were drops in the peak signal excursion by ≥30% of the preevent baseline for ≥10 seconds, which was associated with either ≥3% arterial oxygen desaturation or an arousal. The oxygen desaturation index (ODI) was the average number of oxygen desaturation episodes per hour of sleep, which was described as a decrease in the mean oxygen saturation of ≥3% that lasted for at least 10 seconds.

DISE and Capnography

Patients underwent DISE in a dim and quiet operating room. Patients were placed in the dorsal decubitus position. Topical anesthesia was applied to the nostrils with cotton pledgets soaked in phenylephrine and lidocaine prior to the procedure. Drug-induced sleep was achieved with intravenous administration of propofol via a target-controlled infusion system, which determined the infusion rate to maintain the optimal concentration by computing the absorption, distribution, and excretion of propofol automatically. The ideal sedation level was achieved when the bispectral index (BIS) score was between 50 and 70. The velum, oropharynx, tongue base, and epiglottis were thoroughly evaluated using a flexible nasal endoscope.[14–16]

The breathing routes, which included oral breathing, oronasal breathing, and nasal breathing, were detected using capnography. Exhaled CO_2 from the mouth was sampled using a respiratory module (E-sCAiOE; GE Healthcare, Helsinki, Finland), and capnography was monitored using an anesthetic gas

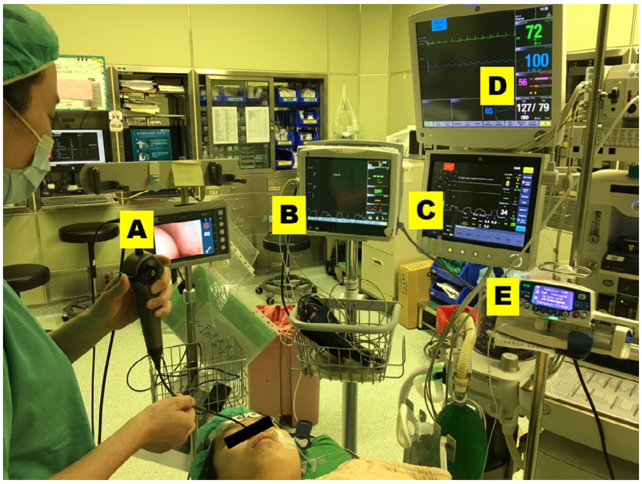

Fig. 1. Example of the drug-induced sleep endoscopy arrangement in the operating room. (A) Endoscope. (B) Capnograph used to detect CO_2 exhaled from the nose. (C) Capnograph used to detect CO_2 exhaled from the mouth. (D) Anesthetic gas monitor that displays the bispectral index recording. (E) Target-controlled infusion system. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

monitor (G1500213; GE Healthcare). Exhaled CO_2 from the nose was sampled using another respiratory module (E-miniC-00; GE Healthcare) and capnography was monitored using a portable monitor (CARESCAPE B450; GE Healthcare). To detect the exhaled CO_2 from the mouth and nose, the intravenous T-connectors attached to the gas sampling lines were placed in the mouth and left nostril. During the entire procedure, cardiopulmonary status was closely monitored by the anesthesia care team. An example of the DISE arrangement in the operating room is illustrated in Figure 1. An example of how the authors performed endoscopy and detected oral and nasal breathing simultaneously is illustrated in Figure 2.

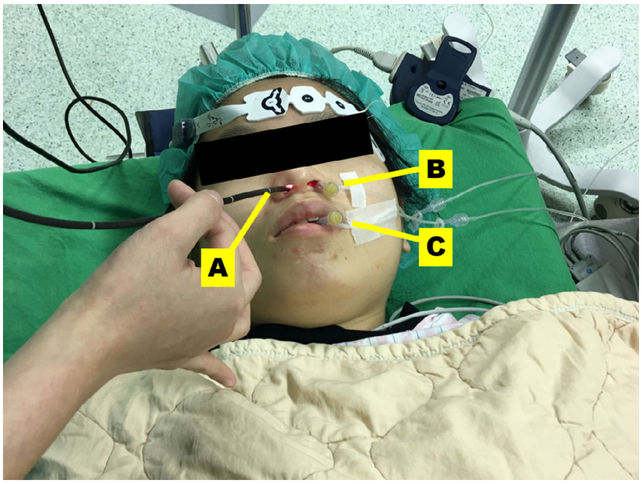

Fig. 2. Example of how the authors performed endoscopy and detected oral and nasal breathing simultaneously. (A) Endoscope. (B) Intravenous (IV) T-connector connected to the gas sampling line to detect CO_2 exhaled from the nose. (C) IV T-connector connected to the gas sampling line to detect CO_2 exhaled from the mouth. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

TABLE I.
Comparison of Demographic Data and Polysomnography Data Between Subgroups of Different Breathing Route During Drug-Induced Sleep Endoscopy.

Variables	Mouth Breathing, Mean ± SD	Oronasal Breathing, Mean ± SD	Nasal Breathing, Mean ± SD	*P* Value*
Subjects, no. (%)	11 (11.6%)	49 (51.6%)	35 (36.8%)	
Demographic data				
Age, yr	45.00 ± 11.51	51.12 ± 10.72	48.06 ± 13.24	.252
BMI, kg/m^2	28.58 ± 3.56	27.08 ± 3.89	25.65 ± 4.12	.037
Neck circumference, cm	38.77 ± 3.25	37.93 ± 3.56	36.73 ± 3.68	.143
Epworth Sleepiness Scale	11.36 ± 5.22	10.71 ± 4.88	9.45 ± 4.59	.598
Polysomnography data				
Sleep efficiency, %	82.76 ± 8.55	76.01 ± 17.09	75.65 ± 14.17	.296
AHI, events/hr	52.15 ± 24.49	42.09 ± 24.41	27.40 ± 15.14	.002
ODI, events/hr	45.95 ± 23.93	36.46 ± 24.92	20.51 ± 14.84	.003
Minimal SaO_2, %	64.18 ± 16.73	77.10 ± 13.41	78.15 ± 14.82	.022
T < 90%, %	36.41 ± 27.96	15.97 ± 18.07	5.76 ± 7.24	.001
Arousal index, events/hr	42.83 ± 24.48	34.70 ± 23.65	19.78 ± 12.97	.003

*Kruskal-Wallis test.
AHI = apnea-hypopnea index; BMI = body mass index; Minimal SaO_2 = minimal oxygen saturation; ODI = oxygen desaturation index; SD = standard deviation; T < 90% = percentage of total time with oxygen saturation level <90%.

VOTE Classification

The results of upper airway obstruction were recorded using VOTE classification, a classification system proposed by Kezirian et al. for characterizing DISE findings.[17] The levels, configuration, and degree of obstruction were reported. The four main anatomical levels are the velum, oropharynx, base of tongue, and epiglottis. The configuration of upper airway obstruction is classified as anteroposterior, lateral, or concentric. Velum obstruction occurs substantially in the anteroposterior or concentric pattern. The configuration of the oropharynx collapse is only in the lateral direction. The configuration of tongue base collapse is only in the anteroposterior direction. The configuration of collapse at the epiglottis level can be in the anteroposterior or lateral direction. The severity of airway collapse can be classified as no obstruction (0, no vibration, <50% obstruction), partial obstruction (1, vibration, 50%–75% obstruction), and complete obstruction (2, >75% obstruction).

Statistical Analysis

Statistical calculations were carried out using SPSS version 20.0 (IBM, Armonk, NY). Continuous data are expressed as mean ± standard deviation, and categorical data are expressed as number and percentage. A comparison of demographic data and

TABLE II.
Associations Between Collapse Patterns and Breathing Routes During Drug-Induced Sleep Endoscopy.

Collapse Patterns			Breathing Routes			
Level	Configuration	Degree	Mouth Breathing	Oronasal Breathing	Nasal Breathing	*P* Value*
Velum, n (%)	A-P	0	10 (90.9%)	41 (83.7%)	23 (65.7%)	.082
		1 or 2	1 (9.1%)	8 (16.3%)	12 (34.3%)	
	Concentric	0	3 (27.3%)	8 (16.3%)	12 (34.3%)	.161
		1 or 2	8 (72.7%)	41 (83.7%)	23 (65.7%)	
Oropharynx, n (%)	Lateral	0	2 (18.2%)	13 (26.5%)	20 (57.1%)	.007
		1 or 2	9 (81.8%)	36 (73.5%)	15 (42.9%)	
Tongue base, n (%)	A-P	0	2 (18.2%)	6 (12.2%)	18 (51.4%)	<.001
		1 or 2	9 (81.8%)	43 (87.8%)	17 (48.6%)	
Epiglottis, n (%)	A-P	0	7 (63.6%)	42 (85.7%)	28 (80.0%)	.238
		1 or 2	4 (36.4%)	7 (14.3%)	7 (20.0%)	
	Lateral	0	11 (100.0%)	44 (89.8%)	34 (97.1%)	.386
		1 or 2	0 (0.0%)	5 (10.2%)	1 (2.9%)	

Degree of collapse during drug-induced sleep endoscopy: sorted as no obstruction (score 0, no vibration, <50%), partial obstruction (score 1, vibration, 50%–75%), and complete obstruction (score 2, >75%).
*χ^2 and Fisher exact test.
A-P = anteroposterior.

polysomnography data between different breathing routes was analyzed using the Kruskal-Wallis test. The correlation between collapse patterns during DISE and breathing routes was estimated using the χ^2 test and Fisher exact test. Significance was set at $P < .05$.

RESULTS

The study population consisted of 95 patients, including 65 males and 30 females. Of all the patients, 11.6% had mouth breathing, 51.6% had oronasal breathing, and 36.8% had nasal breathing as detected using capnography. Multilevel obstruction of the upper airway was observed in most patients (85.3%).

A comparison of demographic data and polysomnography data between groups of different breathing routes is shown in Table I. Patients with mouth breathing were associated with higher body mass index (BMI) (P = .037), higher AHI (P = .002), and higher arousal index (P = .003) than those with oronasal or nasal breathing. Oximetric variables were significantly different among the three groups. Patients with mouth breathing were associated with significantly higher ODI (P = .003), lower minimal SaO_2 (minimal oxygen saturation, P = .022), and higher T < 90% (the percentage of total time with oxygen saturation level lower than 90%, P = .001) compared with those with oronasal or nasal breathing (Table I).

Associations between breathing routes and collapse patterns during DISE are shown in Table II. The Pearson χ^2 test and Fisher exact test showed a significant relationship between mouth breathing and lateral pharyngeal wall collapse (P = .007). Additionally, a significant relationship was noted between mouth breathing and tongue base collapse ($P < .001$). In summary, mouth breathing was associated with a higher prevalence and higher degree of lateral pharyngeal wall collapse and tongue base collapse in comparison with those in other breathing routes (Table II).

DISCUSSION

The Take Home Message of the Present Study

The present study indicated that patients with mouth breathing were associated with increased OSA severity, worse oximetric variables, and higher BMI. In addition, mouth breathing was associated with a higher degree and higher prevalence of lateral pharyngeal wall collapse and tongue base collapse.

Breathing Route Versus OSA Severity

In the present study, patients with mouth breathing and oronasal breathing were associated with worse AHI and oximetric variables in comparison with nasal breathing. Similar findings were reported by Koutsourelakis et al.[18] They showed that OSA patients had a higher percentage of oral and oronasal breathing epochs than simple snorers, which were positively correlated with AHI and negatively correlated with mean oxygen saturation. The possible mechanisms for the relationship between mouth breathing and OSA severity can be explained as follows. First, mouth breathing was associated with higher upper airway resistance, as compared with that of nasal breathing during sleep. Higher upper airway resistance may lead to an increase in obstructive apneas and hypopneas.[19] Second, the surface tension of the upper airway lining liquid plays an important role in regulating upper airway reopening and closing pressures. Mouth breathing during sleep may decrease upper airway mucosa wetness and increase wall stickiness, which in turn increases the surface tension and results in difficulty of reopening the upper airway.[20] Therefore, the severity of sleep-disordered breathing increases with mouth breathing. Third, activation of nasal receptors during nasal breathing is important in maintaining spontaneous ventilation and oropharyngeal muscle tone.[21,22] Deactivation of the nasal-ventilatory reflex during mouth breathing may decrease breathing frequency and minute ventilation, which leads to oxygen desaturation. In addition, reduced activation of nasal receptors results in loss of genioglossal activity, which in turn causes instability of the upper airway.

In this study, patients with mouth breathing had a higher BMI than those with oronasal or nasal breathing. Similar to a previous report, Koutsourelakis et al. also showed that BMI was a potential determinant of oral breathing.[18] It was hypothesized that obesity may result in more adipose tissue accumulation under the jaw, which in turn causes jaw opening and further mouth breathing.

Breathing Routes Versus DISE Findings

This is the first study to utilize DISE to evaluate the morphology change of the upper airway between different breathing routes. We observed that mouth breathing was associated with a higher degree and a higher prevalence of lateral pharyngeal wall collapse and tongue base collapse in comparison with other breathing routes. Previous studies have reported a correlation between mouth breathing and upper airway anatomy. Kim et al. reported a significant decrease in the minimal cross-sectional area of the upper airway with a significant increase in upper airway length during mouth breathing, whereas the volume of the upper airway space examined using three-dimensional computed tomography remained unchanged. They hypothesized that a more restricted and lengthened airway could lead to faster airflow and more deterioration of negative intraluminal pressure, which in turn aggravates upper airway collapse.[23] Lee et al. have shown that the upper airway space was reduced with mouth breathing on lateral cephalometry and fiberoptic nasopharyngoscopy.[24] Hu et al. demonstrated that the cross-sectional area of the upper airway, especially the anterior–posterior diameter of the retroglossal space, was significantly decreased with mouth breathing on computed tomography scans,[25] which is in agreement with our study.

OSA Severity Versus DISE Findings in the Literature

The correlations between DISE findings and OSA severity have been studied in the literature. Lan et al. indicated that lateral pharyngeal wall collapse was significantly associated with increased OSA severity, reflected by a higher AHI and worse oximetric variables.[26] Similar results were reported by Koo et al. in a study of Korean men with OSA.[27] Ravesloot et al. reported that tongue base collapse was significantly associated with a higher AHI.[28] In another study of a large cohort of patients with DISE findings, the results reported that a higher AHI value was associated with a higher probability of complete concentric velum collapse, complete concentric hypopharyngeal collapse, and complete lateral hypopharyngeal collapse.[29] In summary, patients with severe OSA are associated with a higher prevalence of lateral pharyngeal wall collapse, tongue base collapse, and concentric velum collapse.

Breathing Routes Versus OSA Severity Versus DISE Findings

In this study, patients with mouth breathing had significantly higher AHI/ODI than patients with nasal breathing. In addition, previous studies have demonstrated that a higher AHI was associated with a higher probability of lateral pharyngeal wall collapse and tongue base collapse. Based on the above description, it seems logical that patients with mouth breathing were associated with a higher prevalence of lateral pharyngeal wall collapse and tongue base collapse. However, the causal relationship between breathing routes and DISE findings may require a further large-scale population study with subgroups matched by OSA severity to observe if breathing routes play a role in DISE findings.

Limitations

This study has several limitations. First, DISE is a relatively subjective and experience-dependent examination, and the results may be prone to inconsistency. However, previous reports indicated acceptable interrater and test–retest reliability.[30,31] Second, breathing routes during drug-induced sleep may not truly represent the conditions of natural sleep. Nevertheless, the distinct presentation of different breathing routes during DISE could help physicians identify patients susceptible to upper airway collapse during intravenous sedation. Therefore, perioperative complications may be prevented. Finally, the possible effect of propofol on decreasing muscle tone should be addressed.[32] However, the depth of sedation was closely monitored using the BIS to maintain a constant level of sedation. Therefore, the possibility of oversedation was attenuated.

CONCLUSION

Patients with mouth breathing were associated with increased OSA severity and worse oximetric variables in comparison with other breathing routes. Additionally, mouth breathing was associated with a higher degree and higher prevalence of lateral pharyngeal wall collapse and tongue base collapse compared with those in other breathing routes. To avoid the development of upper airway compromise, physicians should be aware of the correlation between mouth breathing and increased OSA severity and be familiar with the use of the chin lift and jaw thrust maneuver. Patients with mouth breathing during propofol-based intravenous anesthesia need to be carefully monitored due to a higher degree of oxygen desaturation and upper airway collapse.

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