Palatal Sensory Threshold Reflects Nocturnal Hypoxemia and Airway Occlusion in Snorers and Obstructive Sleep Apnea Patients

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Study Objectives: Upper airway sensory deficit has been reported to be associated with snoring or obstructive sleep apnea. There are limited data on the correlation between disease severity and upper airway sensation. In this study, we investigated the relationship between clinical parameters and standardized palatal sensory threshold (SPST) using Semmes Weinstein monofilaments.

Methods: We recruited 40 snorers and 19 control subjects. Palatal sensory threshold was measured in all study subjects, using Semmes Weinstein monofilaments. Standardized palatal sensory threshold was determined by subtraction of hard palate sensation from uvular sensation. All subjects with snoring underwent a modified Muller maneuver during wakefulness before polysomnography.

Results: SPST was higher in snorers than in control subjects, but did not differ according to the severity of obstructive sleep apnea. Patients with higher SPST (≥ 0.45 g/mm²) were older and had more severe hypoxemia indices: lower nadir oxyhemoglobin saturation (SpO₂) and higher percentage

of sleep time at $< 90\%$ SpO₂. Adjusted for age, sex, neck circumference, and body mass index, SPST was correlated with the apnea-hypopnea index and hypoxemia indices. With a cutoff value ≥ 0.45 g/mm², the sensitivity of SPST for nocturnal hypoxemia (nadir SpO₂ $< 80\%$) was 81.3%. Patients with higher SPST (≥ 0.45 g/mm²) showed more airway occlusion in modified Muller maneuver, than those with lower values.

Conclusions: The SPST measured using Semmes Weinstein monofilaments reflects nocturnal hypoxemia and airway occlusion. This test provides a potential tissue marker of the severity of hypoxemia in patients who snore.

Keywords: Hypopnea, apnea, hypoxemia, sensation, threshold

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Obstructive sleep apnea hypopnea syndrome (OSAS) is characterized by recurrent episodes of upper airway obstruction during sleep leading to nocturnal hypoxemia or brief arousals, which result in sleep fragmentation and changes in sleep architecture. The underlying pathophysiology of OSAS is complex and not fully understood. However, it is generally accepted that an overall imbalance of upper airway luminal pressure and muscular activity during sleep induces airway collapsibility.¹ Among several pathomechanisms, defective upper airway reflexes, primarily sensory impairment, may be an abnormality in OSAS and make the balance difficult. Sensory dysfunction in the upper airway of patients with sleep disordered breathing has been documented²⁻⁶ and reported to be associated with the severity of disease in a few studies.^{2,3} Additionally, topical oropharyngeal anesthesia, leading to impaired airway reflex, can increase pharyngeal airflow resistance during wakefulness and sleep in normal subjects⁷ and in patients with obstructive sleep apnea.⁸ There are limited data on the clinical significance of pharyngeal sensory tests. Furthermore, sensory tests introduced previously may not be practical because they

BRIEF SUMMARY

Current Knowledge/Study Rationale: Although sensory dysfunction in the upper airway has been documented to play a role in the pathogenesis of obstructive sleep apnea, there are limited data on a clinical significance of pharyngeal sensory tests. In this study, the relationship between clinical parameters and standardized palatal sensory threshold was investigated.

Study Impact: This study showed that standardized palatal sensory threshold was reflective of both nocturnal hypoxemia and multiplicity of upper airway obstruction sites. The standardized palatal sensory threshold may be a marker for the severity of obstructive sleep apnea.

were developed for specific studies and may be difficult to use generally in the clinical setting.^{3,4,6}

To check palatal sensory threshold (PST), we used the Semmes Weinstein monofilament examination, which is a noninvasive, inexpensive, and easy-to-apply test for diabetic peripheral sensory neuropathy,^{9,10} and for sensory threshold determination in various clinical settings.¹¹⁻¹³ We also standardized the PST by subtracting the sensory threshold examined in

Figure 1—Semmes Weinstein monofilament examination for checking palatal sensory threshold

(A) Stars indicate the test sites: the center of the uvula (filled star) and both lateral walls of the palate (open stars). The dotted line indicates the border between the soft and hard palates. The solid curved line represents the lesser palatine nerve. (B) Semmes Weinstein monofilament examination (white arrow) for checking uvular sensation.

the non-collapsible hard palate area from the threshold in the uvula, the most collapsible area. The aim of this study was to investigate the relationship between clinical parameters and standardized palatal sensory threshold (SPST).

MATERIALS AND METHODS

Subjects

All snorers ($n = 40$) underwent full overnight polysomnography, including airflow, respiratory movements, body position, snoring, and pulse oximetry (Somte; Compumedics, Melbourne, Australia). Apnea was defined as a drop in peak thermal sensor excursion by $\geq 90\%$ of baseline for ≥ 10 s; hypopnea was defined as a drop in nasal pressure signal excursion by $\geq 30\%$ of baseline for ≥ 10 s with $\geq 4\%$ desaturation, according to the 2007 recommendations of the American Academy for Sleep Medicine. The proportion of snoring was expressed as the number of epochs with $> 50\%$ snoring signal/total number of epochs. Thirty snorers with OSAS (15 mild apnea patients, with an apnea-hypopnea index [AHI] between 5 and 20 events/h; 15 moderate-to-severe apnea patients with AHI ≥ 20 events/h), 10 simple snorers (AHI < 5 events/h), and 19 non-snorers were included. Snorers with suspicion of OSAS were recruited consecutively from our sleep apnea clinic. Among the patients who visited our rhinology clinic, non-snorer volunteers ($n = 19$) with no symptoms compatible with OSAS, including habitual snoring, daytime sleepiness, and morning headache, as confirmed by their bed partners, were enrolled for control data on PST. A medical history and clinical data, including tonsil size and body mass index (BMI), were obtained from all subjects. Tonsil size

was graded on a 5-point scale: 0 = absent, 1+ = small within the tonsillar fossa, 2+ = extends beyond the tonsillar pillar, 3+ = hypertrophic but not touching in the midline, 4+ = hypertrophic and touching in the midline.

Exclusion criteria were as follows: neurological illness or medical disease, including diabetes mellitus capable of causing peripheral neuropathy; previous soft palate surgery; previous treatment for OSAS; recent upper airway infection or inflammation; exaggerated gag reflex that prevented pharyngeal examination; and no visible soft palate. This study was approved by the Institutional Review Board of Gyeongsang National University Hospital.

Palatal Sensory Threshold

One investigator (WSJ), who was blinded to the study groups, used Semmes Weinstein monofilaments to examine the PST in patients and control subjects at 3 sites: the center of the uvula, and the right and left lateral walls of the hard palate, 2 mm from the border between the hard and soft palates (**Figure 1A, 1B**). One set of the test consists of 20 monofilaments ranging from the lightest (0.008 g/mm^2) to the heaviest (300 g/mm^2). The monofilaments were applied perpendicularly to the 3 sites in random order until they bent for 1 s. Starting with the lightest monofilament, the value of the monofilament that caused the patient to feel the sensation for the first time was determined as the PST. The uvular sensory threshold was defined as the lightest monofilament value recognized at the uvula, and the reference sensory threshold was the average value of the lightest monofilaments recognized at the lateral walls of the hard palate. We calculated SPST by subtracting the reference sensory threshold from the uvular sensory threshold, to minimize individual sensitivity

Table 1—Demographic data and clinical characteristics of the study population

	Non-snorers (N = 19)	Simple snorer (N = 10)	Mild apneic patient (N = 15)	Moderate to severe apneic patient (N = 15)
Age, years	41.5 (13.3)	39.8 (13.4)	47.5 (13.9)	44.7 (12.9)
Male/Female	13/6	9/1	10/5	15/0
HT	3	3	6	5
Neck circumference, cm	37.8 (2.6)	38.8 (1.8)	37.5 (2.8)	39.8 (3.8)*
Tonsil size, grade	2.2 (0.3)	2.2 (0.4)	2.4 (0.5)	2.0 (0.6)
BMI, kg/m ²	23.3 (2.2)*	25.4 (3.3)	24.6 (3.2)	27.2 (5.4)
PSG				
AHI, events/h	NA	2.8 (0.9)	11.9 (4.8)*	42.7 (15.2)†
Mean awake SpO ₂ , %	NA	95.1 (1.8)	95.6 (1.6)	95.1 (1.9)
Nadir SpO ₂ , %	NA	89.2 (5.0)	82.7 (4.8)*	66.6 (12.9)†
ODI (> 4%), events/h	NA	3.0 (2.6)	11.9 (8.4)*	42.8.0 (16.7)†
Percentage of time spent below 90% of SpO ₂ , %	NA	0.8 (1.0)	5.2 (10.3)*	28.6 (25.5)†
Proportion of snoring, %	NA	23.9 (17.3)	22.5 (12.8)	43.2 (13.4)*

HT, hypertension; BMI, body mass index; PSG, polysomnography; SpO₂, oxygen saturation; AHI, apnea-hypopnea index; ODI, oxygen desaturation index; NA, not applicable. Proportion of snoring is expressed as the ratio of the number of epochs including > 50% snoring signal/total number of epochs. Analysis of variance (Kruskal-Wallis test or post hoc pair-wise Mann-Whitney U test) between the control and three patient groups, or only among the three patient groups when control data were not available. Values represent mean (SD). Parameters with symbols (*, †) differed significantly from those in other groups.

differences. Test-retest reliability of PST testing for 3 sites was assessed in non-snorers volunteers. The time span between the first and second tests was 30 minutes.

Endoscopic Airway Examination

Because topical anesthesia can influence the results of polysomnography, a modified Muller maneuver was conducted to snorers at the first visit to the sleep apnea clinic. The procedure was performed with the patient in the supine position after application of topical nasal anesthesia (4% lidocaine plus 0.5% ephedrine spray). A flexible nasopharyngoscope was inserted through anesthetized nasal cavity. Redundancy of the soft palate, lateral pharyngeal wall, and tongue base was evaluated during a maximal inspiratory effort against a closed mouth and sealed nose.¹⁴ Redundancy was graded by examiners on a 5-point scale: 0 = no obstruction, 1 = ~25% obstruction, 2 = ~50% obstruction, 3 = ~75% obstruction, and 4 = complete obstruction. Before polysomnographic data were obtained, consensus was reached by our research team by reviewing representative photos. Grade 3 or 4 redundancy was considered to be significant airway occlusion. The number of sites showing airway occlusion were counted and compared between groups.

Statistical Analyses

The results are expressed as means $\pm$ SD. Test-retest reliability of the PST testing was assessed by the intraclass correlation coefficients (ICC). Group analysis was performed using the Mann-Whitney U test or Kruskal-Wallis test. Correlations between clinical parameters and polysomnographic data were evaluated with Pearson correlation coefficient or partial correlation coefficient adjusted for confounding factors. Fisher exact test was used to compare qualitative data. All data were analyzed with SPSS software (ver. 13.0; SPSS, Inc., Chicago, IL, USA). Statistical significance was set at $p < 0.05$.

RESULTS

Subject characteristics are summarized in **Table 1**. Briefly, subjects with moderate-to-severe OSA had wider neck circumference than other subjects. The severity of OSA was well correlated with some polysomnography parameters related to oxygen saturation, including lowest oxygen saturation and oxygen desaturation index ([ODI] $p < 0.05$). Control subjects showed significantly lower BMI than other subjects, which might result in the distinct appearance of patients among groups. To avoid potential bias, therefore, the PST test was conducted by an independent investigator blinded to the design and goal of the study.

Test-Retest Reliability of the PST Test

At all 3 test sites, the PST test was fairly reproducible. The ICC (95% CI) was 0.95 (0.88-0.98), 0.97 (0.93-0.99), and 0.98 (0.94-0.99) at the right and left reference areas and uvula, respectively. Because the PST test showed high test-retest reliability for non-snorers volunteers, it was not performed on snorers or sleep apneic patients.

Palatal Sensory Threshold Values in Each Group

In control subjects, the uvular sensory threshold was 0.25 ± 0.31 g/mm², the reference sensory threshold was 0.24 ± 0.26 g/mm², and SPST was 0.00 ± 0.14 g/mm². Although there were individual differences, the standard deviation of the mean decreased from 0.31 g/mm² to 0.14 g/mm² after standardization.

Differences in Palatal Sensory Threshold by OSAS Severity

In simple snorers, the uvular sensory threshold was 2.06 ± 2.69 g/mm², the reference sensory threshold was 0.96 ± 0.10 g/mm², and the SPST was

Figure 2—Difference in palatal sensory threshold according to severity of apnea-hypopnea index

After standardization, snorers and obstructive sleep apnea patients had higher palatal sensory threshold than simple snorers. *p < 0.05, **p < 0.001.

Figure 4—Receiver operating characteristic curve

The sensitivity of the standardized palatal sensory threshold for nadir $\text{SpO}_2 < 80\%$ was 81.3% at the cutoff level of standardized palatal sensory threshold = 0.45 g/mm².

1.10 ± 1.81 g/mm². Mild apneic patients had a uvular sensory threshold of 2.42 ± 2.69 g/mm², reference sensory threshold

Figure 3—Difference in standardized palatal sensory threshold according to nocturnal hypoxemia

Severely hypoxemic subjects showed higher standardized palatal sensory threshold (SPST) than mildly hypoxemic and non-snoring subjects. This difference was seen regardless of age, but tended to be greater in the elderly.

of 1.29 ± 1.32 g/mm², and SPST of 1.13 ± 1.59 g/mm². Moderate-to-severe apneic patients exhibited a uvular sensory threshold of 5.26 ± 4.76 g/mm², reference sensory threshold of 1.50 ± 1.17 g/mm², and SPST of 3.76 ± 4.71 g/mm². Snorers had higher uvular and reference sensory thresholds than control subjects. Subjects with moderate-to-severe apnea had higher uvular sensory threshold than simple snorers. After standardization, additionally, the differences between simple snorers and control subjects were more significant (Figure 2; all p-values < 0.01).

Sensitivity of SPST for Nocturnal Hypoxemia Screening

The SPST results of snorers with nocturnal hypoxemic events are shown in Figure 3. Snorers with severe hypoxemia (nadir $\text{SpO}_2 < 80\%$) had higher SPST than those with mild hypoxemia (nadir $\text{SpO}_2 \geq 80\%$; $p = 0.008$), and the difference tended to be greater in the elderly. With a cutoff level of 0.45 g/mm², the sensitivity of the SPST test for screening nocturnal hypoxemia (nadir $\text{SpO}_2 < 80\%$) was 81.3% (Figure 4). The area under the receiver operating characteristic curve was 0.719 (95% CI 0.540-0.898; $p = 0.023$).

Differences in Clinical Characteristics by SPST

When snorers were divided into 2 groups in terms of SPST, the higher threshold group (≥ 0.45 g/mm²) were older ($p = 0.005$) and had a lower nadir SpO_2 ($p = 0.009$) and higher percentage of time spent < 90% SpO_2 ($p = 0.023$). There was no difference in any other polysomnographic parameter between the 2 groups (Table 2). However, a correlation analysis showed an association between SPST and additional clinical parameters such as AHI, BMI, neck circumference, and ODI, as well as percentage of time spent below 90% SpO_2 and nadir SpO_2 . Furthermore, when adjusted for confounding factors such as age, neck circumference, and BMI, SPST showed a significant correlation with AHI and 3 hypoxemia indices (Table 3).

Table 2—Comparison of clinical characteristics according to standardized palatal sensory threshold in snorers with and without obstructive sleep apnea

Standardize palatal sensory threshold	< 0.45 g/mm ² (N = 19)	≥ 0.45 g/mm ² (N = 21)	p-value
Age	39.53 (12.50)	49.15 (12.78)	0.005*
Male/Female	15/4	19/2	0.398*
Polysomnography			
Mean awake SpO ₂ , %	95.29 (1.40)	95.13 (1.80)	0.897*
AHI, events/h	14.90 (14.35)	27.63 (22.68)	0.095*
Nadir SpO ₂ , %	82.58 (7.62)	72.16 (14.67)	0.009*
ODI (> 4%), events/h	11.89 (12.56)	28.23 (24.69)	0.252*
Percentage of time spent below 90% of SpO ₂ , %	4.89 (8.88)	20.77 (25.76)	0.023*
Proportion of snoring, %	29.12 (16.66)	31.02 (17.57)	0.622*
Clinical characteristics			
Hypertensive subjects	25% (5/20)	50% (10/20)	0.101†
BMI, kg/m ²	25.55 (2.71)	26.01 (5.68)	0.754*
Neck circumference, cm	38.32 (2.19)	39.21 (3.75)	0.518*
Tonsil size, grade	2.16 (0.37)	2.15 (0.59)	0.886*

BMI, body mass index; SpO₂, oxygen saturation; AHI, apnea-hypopnea index; ODI, oxygen desaturation index. Proportion of snoring is expressed as the ratio of the number of epochs including > 50% snoring signal/total number of epochs. †Fisher exact test to compare qualitative data. *Mann-Whitney U test to compare between groups. Bold type, p < 0.05.

Table 3—Correlation between palatal sensory threshold and clinical parameters in snorers with and without obstructive sleep apnea

	Age	AHI	NC	BMI	Nadir SpO ₂	SpO ₂ < 90%	ODI	Snoring
Correlation coefficient								
Sense (U)	0.449**	0.387*	0.278	0.283	-0.482*	0.415*	0.435*	0.196
Sense (R)	0.366*	0.130	-0.167	-0.167	-0.141	0.184	0.158	0.022
Sense (S)	0.380*	0.393*	0.375*	0.371*	-0.528**	0.405*	0.440*	0.215
Partial correlation coefficient adjusted by age, gender, neck circumference, and BMI								
Sense (U)	NA	0.431*	NA	NA	-0.413*	0.429*	0.489**	0.212
Sense (R)	NA	0.268	NA	NA	-0.190	0.234	0.291	0.169
Sense (S)	NA	0.407*	NA	NA	-0.431*	0.438*	0.465**	0.173

AHI, apnea-hypopnea index; NC, neck circumference; BMI, body mass index; Min. SpO₂, minimal oxygen saturation; SpO₂ < 90%, percentage of time spent below 90% SpO₂; ODI, oxygen desaturation index; Sense (U), uvular sensory threshold; Sense (R), sensory threshold in the reference area; Sense (S), standardized sensory threshold [Sense (U) – Sense (R)]; NA, not applicable. Values are expressed as Pearson's correlation coefficients or partial correlation coefficients. *p < 0.05, **p < 0.01. Bold type, p < 0.05.

Difference in Airway Occlusion by OSAS Severity and SPST

Although there was no difference in tonsil size between groups according to SPST or OSAS severity (**Tables 1, 2**), the percentage of cases with ≥ 2 airway occlusion sites by the Muller maneuver was significantly higher for the higher SPST group (≥ 0.45 g/mm²) compared with the lower SPST group (< 0.45 g/mm²; 76% vs. 31%, respectively; p = 0.015). In contrast, there was no difference between groups by OSAS severity (**Figure 5**).

DISCUSSION

To sum up our results, the PST test using Semmes Weinstein monofilament was a reliable method. Standardized PST values by subtracting the sensory threshold value at the hard palatal

reference point from uvular sensory threshold were significantly different between control subjects and snorers/OSA patients. The level of SPST was closely related to the severity of nocturnal hypoxemia, and the SPST of ≥ 0.45 g/mm² indicated the occurrence of nadir SpO₂ < 80% with a sensitivity of 81.3%. Additionally, higher SPST level was associated with airway occlusion at multiple sites.

Methodological Issues

To our knowledge, no reported study has attempted to standardize sensory threshold values because the control sites used, i.e., the lip, tongue, and hand, are innervated differently compared with the palatal mucosa.^{2-5,15} In this study, a non-collapsible area innervated by the lesser palatine nerve, which also innervates the uvula, was used as a control site. Standardized palatal sensory threshold was calculated by subtracting the

Figure 5—Difference in number of airway occlusion sites by OSAS severity (AHI) and standardized palatal sensory threshold (SPST)

The higher SPST group (≥ 0.45 g/mm²) showed multiple (≥ 2) airway occlusion sites more frequently than the lower SPST group (< 0.45 g/mm²) being identified by the Muller maneuver. * $p < 0.05$.

sensory threshold in this non-collapsible area from that in the center of the uvula. Control subjects had nearly the same sensory threshold in the uvula and hard palate: SPST = 0.00 ± 0.14 g/mm². Less variability in the standard deviation of SPST, compared with that of the uvular sensory thresholds, indicates that this method may compensate for individual differences in factors such as age, gender, and race. Thus, SPST may reflect OSAS-specific sensory dysfunction more precisely than other sensory threshold tests previously reported.

The center of the uvula was chosen as the test site in this study because it had been reported to show histopathological findings such as disorganization of epithelial and connective tissues and decreased number of nerves in OSAS.¹⁶⁻¹⁹ The Semmes Weinstein monofilaments we used are an excellent tool for targeting the center of the uvula. As mentioned above, this method has been validated for checking sensory thresholds in many clinical studies.¹¹⁻¹³

Airway collapsibility can be estimated by assessing electromyographic activity in response to negative pressure²⁰ or changes in esophageal pressure during sleep.⁸ Airway collapsibility is influenced by not only deficits in respiratory neuromuscular control but also redundant anatomical structures such as palatine tonsils and edema of pharyngeal tissues.²¹ Several previous studies have documented that snoring-induced chronic inflammation can cause upper airway mucosal thickening^{22,23} and peripheral nerve injury,^{24,25} which represent anatomical redundancy and deficits in neuromuscular reflexes, respectively. The modified Muller maneuver could not reflect true collapsibility of the upper airway observed during natural sleep because, of course, it was conducted in awake patients. Given previous findings, however, redundancy identified by the modified Muller maneuver was presumed to mirror airway collapsibility to some

extent. In the present study, subjects with higher SPST showed multilevel airway obstructions more frequently than those with lower SPST (Figure 5), indicating that higher sensory deficit is associated with broader redundancy in the soft tissues of the upper airways. As no significant difference in tonsil size was found between subjects with higher and lower SPSTs (Table 2), it was assumed that redundancy of the upper airway may be due to the sensory deficits and anatomical factors other than palatine tonsils (i.e., mucosal thickening). Despite these results, further methods such as drug-induced sleep endoscopy are needed to confirm an association between airway collapsibility and sensory deficits in the upper airway.

Pathomechanism of Sensory Dysfunction

Obstructive sleep apnea is characterized by repetitive upper airway collapse, causing nocturnal hypoxemia and sleep fragmentation. Obstructive sleep apnea or snoring is well known to be associated with sensory deficits.²⁻⁶ A few studies have demonstrated that the severity of OSAS is correlated with the degree of sensory deficit in the upper airway.² Our study is consistent with these studies. Standardized palatal sensory threshold showed a positive association with AHI when adjusted for age, BMI, and neck circumference (Table 3). However, no difference in the severity of snoring was found between subjects with higher and lower SPST values (Table 2). This may be because the percentage of epochs having $> 50\%$ snoring signal was used as a snoring parameter without considering the total number of years for which subjects had snored. Obtaining reliable data on a snoring period is difficult because total snoring years are not remembered correctly by most patients. As a marker for the severity of snoring, in addition, the intensity may be a better one compared to the proportion of snoring time. In our polysomnography system, however, the intensity of snoring could not be evaluated because snoring was measured by nasal pressure transducer, not by microphone or sound level meter, which is a limitation of this study.

Several pathomechanisms that could lead to nerve or sensory receptor injury in the upper airway have been suggested. Airway edematous inflammation, presumably related to repetitive snoring-induced vibration and forceful suction collapse of the upper airway during sleep, could potentially damage the nerve endings in the upper airway mucosa.^{16,18} Another possible explanation is that nocturnal hypoxemia in OSAS patients may induce peripheral neuropathy. Chronic hypoxemia, like chronic obstructive pulmonary disease and diabetes mellitus, is well known to induce peripheral neuropathy.²⁶ Although there is no confirmatory evidence of peripheral neuropathy caused by intermittent hypoxemic condition occurring at night in OSA patients, some studies have provided evidence of peripheral neuropathy in OSA patients.^{27,28} In a previous case-control study, median nerve conduction was examined in OSA and control subjects. Preischemic sensory and mixed nerve potential amplitudes and sensory conduction velocity were lower in OSA patients than in control subjects, and the severity of peripheral nerve dysfunction was partly related to the level of nocturnal hypoxemia.²⁷ Similarly, in another case-control study, OSA patients had significantly more clinical signs of polyneuropathy than control subjects. Furthermore, the severity of nerve damage was correlated with the percentage of the night time with oxygen

saturation below 90%.²⁸ Our study also showed a close relationship between nocturnal hypoxemia and the SPST, indicating that chronic intermittent hypoxemia may play a role in aggravating sensory defects. In addition to differences in the sensory threshold at the uvula, there were also differences in the sensory threshold at a non-collapsible reference area between snorers/apneic patients and control subjects (**Figure 2**). These findings could be evidence of hypoxemia-induced neuropathy in OSAS, although further study is required to exclude the possibility that chronic inflammation due to snoring-induced trauma, and not hypoxemia, influenced the non-collapsible area.

The consistent association between SPST and hypoxemia parameters (**Table 2**) prompted us to try to simplify the diagnosis of nocturnal hypoxemia. According to the dissociation curve of oxyhemoglobin, when blood is 70% to 80% saturated, the partial pressure of oxygen is 40 mm Hg, which is the normal case at capillaries in resting tissues.²⁹ This indicates that oxygen is not efficiently released from hemoglobin and is delivered to the tissues at under 70% to 80% SpO₂, which is associated with hypoxemic tissue injury. Thus, we chose a nadir SpO₂ < 80% as the criterion for nocturnal hypoxemia in the receiver operating characteristic curve analysis. Consequently, the severity of nocturnal hypoxemia was associated with the level of SPST (**Figure 3**), and a cutoff level of 0.45 g/mm² was useful for predicting the existence of nocturnal hypoxemia (nadir SpO₂ < 80%) with a sensitivity of 81.3% (**Figure 4**).

One limitation of this study is that control subjects did not undergo polysomnography. Although no control subjects reported history of witnessed snoring or apnea, some of them might have had undiagnosed snoring or apnea. Additionally, our study design does not provide information whether the sensory dysfunction in the upper airway region is primary or acquired. A longitudinal cohort study on OSA patients with no sensory dysfunction will be needed to prove it. If the sensory dysfunction is acquired, it can possibly be reversible by long-term treatment with nasal continuous positive airway pressure therapy.

In conclusion, SPST using Semmes Weinstein monofilaments reflected nocturnal hypoxemia and airway occlusion assessed using the modified Muller maneuver. This noninvasive and easy-to-use test may provide a potential tissue marker of the severity of hypoxemia in snorers/OSA patients.

ABBREVIATIONS

AHI, apnea-hypopnea index
 BMI, body mass index
 ODI, oxygen desaturation index
 OSAS, obstructive sleep apnea/hypopnea syndrome
 PST, palatal sensory threshold
 SPST, standardized palatal sensory threshold

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