

Sleep Magnetic Resonance Imaging as a New Diagnostic Method in Obstructive Sleep Apnea Syndrome

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Objectives/Hypothesis: Although precise localization of obstruction sites in the upper airway during sleep is essential in subjects with obstructive sleep apnea syndrome (OSAS), no gold standard diagnostic method has been established. This study aimed to evaluate the dynamic collapse inside the upper airway by using cine magnetic resonance imaging (MRI), also called sleep MRI.

Study Design: Cross-sectional study with retrospective data.

Methods: The changes in the transverse and anteroposterior diameters of the retrolingual airway were studied during a respiratory cycle in 35 snoring subjects. The collapsibility of the airway was calculated by using axial images, and the actual obstruction sites were also identified by using sagittal images.

Results: Airway collapse occurred in the retropalatal area in 13 (37.1%) of 35 subjects and in both the retropalatal and retrolingual regions in 20 subjects (57.1%). The respiratory disturbance index (RDI) and supine RDI were higher and the minimal oxygen saturation during sleep (MinSaO₂) value was lower in subjects with both retropalatal and retrolingual obstruction than in those with only retropalatal

obstruction. Airway collapse analyzed by using axial images was classified into four subgroups: patent group (five of 35, 14.2%), anteroposterior collapse group (one of 35, 2.9%), transverse collapse group (14 of 35, 40%) and circumferential collapse group (15 of 35, 42.9%). Supine RDI, MinSaO₂, and age were significantly different between these four groups. In addition, anteroposterior, transverse, and circumferential collapses correlated well with MinSaO₂. Significant correlation was also found between RDI/supine RDI and transverse collapse.

Conclusions: Sleep MRI is a valuable method for evaluating dynamic obstruction during sleep and may be helpful in selecting the appropriate treatment approaches.

Key Words: Obstructive sleep apnea, magnetic resonance imaging, diagnosis, oropharynx, hypopharynx.

Level of Evidence: 2c

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INTRODUCTION

Obstructive sleep apnea syndrome (OSAS) is the most common type of sleep-disordered breathing caused by recurrent collapse of the upper airway. It usually leads to sleep disturbance, including sleep fragmentation, reduced blood oxygen levels, and excessive daytime sleepiness. Moreover, many studies have established that OSAS is a risk factor for various diseases such as hypertension, ischemic heart diseases, and diabetes mellitus.^{1–3} Because the clinical significance of OSAS is gradually increasing, accurate diagnosis and subsequent proper treatment are crucial.

Obstruction or collapse of different sites of the upper airway, from the nose and oropharynx to the hypopharynx, can lead to OSAS. Therefore, clinical evaluation of the entire upper airway to detect obstruction sites accurately is the most important part of OSAS assessment. Numerous treatment approaches have been developed to enlarge the upper airway or keep the airway from collapsing during sleep.⁴ Most of them are site-specific treatments, such as enlarging the nasal,

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retropalatal, or retrolingual airway space. Inaccurate identification of the obstruction sites can lead to suboptimal outcomes.

Various techniques, including nasopharyngoscopy, sleep videofluoroscopy (SVF), pressure measurements, computed tomographic scanning, or magnetic resonance imaging (MRI), have been used in an attempt to localize the obstruction site accurately.⁵⁻⁹ However, each technique has limitations, and no gold standard method has been established until now. A validated investigation capable of identifying the obstruction site during sleep accurately would enable appropriate patient selection for surgery and other treatment modalities and improve treatment outcomes.

MRI of the airway with cine sequence is considered a good alternative method to examine dynamic upper airway conditions during sleep.^{8,10,11} MRI sleep studies are noninvasive and allow dynamic abnormalities of the entire airway to be assessed at once. We recently developed a novel study protocol using cine MRI to identify obstruction sites of the upper airway during sleep in patients with OSAS. The objective of this study was to evaluate the usefulness of this novel technique, called sleep MRI.

MATERIALS AND METHODS

Subjects

From February 2009 to November 2009, 35 consecutive subjects (30 men, five women; mean age, 51.54 ± 10.52 years) who visited the sleep clinic at the Healthcare Gangnam Center of Seoul National University Hospital for treatment of severe snoring or sleep apnea were retrospectively included in this study. All subjects underwent evaluation with Watch-PAT (Itamar Medical Ltd., Caesarea, Israel) and sleep MRI. Thirty-three subjects were diagnosed with OSAS (30 men, three women; mean age, 52.63 ± 8.76 years), and two subjects were diagnosed as simple snorers (two women; mean age, 32.5 ± 24.75 years). The subjects' mean (\pm standard deviation) body mass index (calculated as weight in kilograms divided by the square of height in meters) was 25.5 ± 3.46 , the respiratory disturbance index (RDI) was 23.1 ± 13.87 , minimal oxygen saturation during sleep (Min-SaO₂) was $83.8\% \pm 6.33\%$, and snoring decibel was 47.9 ± 5.50 dB. This study was approved by the institutional review board of the Seoul National University Hospital.

Watch-PAT

Respiratory events (REs) during sleep and sleep-related arousal were analyzed by using the Watch-PAT. The definition of arousal was a 40% drop in the pulse arterial tone (PAT) signal amplitude related to pulse rate increase. REs were defined as PAT attenuation related to pulse rate elevation and/or a drop in oxygen saturation in blood greater than 4%.¹² Body position was checked with sleep recordings, and subjects with a supine RDI at least two times higher than lateral RDI were defined as positional patients. Subjects with a supine RDI not reaching values double the lateral RDI were defined as nonpositional patients.

Sleep MRI

All subjects underwent sleep MRI. The subjects were in the supine position with the neck in the neutral position during imaging. They were instructed to breathe in and out naturally.

Respiratory rate, oxygen saturation, pulse rate, and blood pressure were monitored continuously throughout the procedure. Normal respiration before sedation was recorded for 140 seconds. Thereafter, sleep was induced in each subject with intravenously administered midazolam 2.5 mg. After the subjects fell asleep, cine images were obtained when the patient exhibited snoring and oxygen desaturation of more than 4%. All patients were monitored by a radiologist and a physician during sedation and MRI with an emergency kit. No complications occurred during the study.

An MRI system (Intera Achieva 1.5T; Philips Medical Systems, Best, The Netherlands) was used to obtain the images. The upper airway was classified into two levels. The airway from the inferior border of the hard palate to the inferior border of the uvula was classified as the retropalatal area. The airway from the inferior border of the uvula to the superior border of the epiglottis tip was defined as the retrolingual area.

A balanced fast field-echo sequence and turbo field-echo mode were used to create the cine MR images. Technical parameters included 3.6 msec/1.8 msec (repetition time/echo time), a 45° flip angle, and an 8-mm section thickness without gap. One hundred consecutive cine MR images were obtained at the same midline sagittal location in approximately 100 seconds. These images were obtained in the midline sagittal plane and in the transverse plane at the retrolingual area and displayed in a cine format to create a real-time "movie" of dynamic airway motion during sleep.

Image Analysis

Obtained images were reviewed in stack mode on a picture archiving and communications system (Maroview; Marotech, Seoul, Korea), and patterns of upper airway obstruction were analyzed by two otolaryngologists (i.j.m., d.h.h.). Sagittal images were used to identify the obstruction levels, which were classified as retropalatal, retrolingual, or both, whereas axial images were used to evaluate airway collapsibility.

To determine airway size and collapsibility, the minimum and maximum diameters of the upper airway in the transverse (ADmin_Trans, ADmax_Trans) and anteroposterior directions (ADmin_AP, ADmax_AP) were measured by a blinded observer using Maroview. The transverse collapsibility of the upper airway (Col_Trans) was defined as a dynamic change of the upper airway diameters over a respiratory cycle and was calculated as $[(ADmax_Trans - ADmin_Trans)/ADmax_Trans] \times 100$ (%). The anteroposterior collapsibility (Col_AP) was calculated by using the same method used for the Col_Trans. In addition, circumferential collapsibility of the upper airway (Col_Cir) was calculated as $[(Col_Trans + Col_AP)/2]$, which is a reflection of the degree of dynamic obstruction.

Patients with Col_AP of more than 50% were classified into the anteroposterior obstruction group (Obst_AP group), whereas those with Col_Trans of more than 50% were classified into the transverse obstruction group (Obst_Trans group). In addition, patients with both Col_AP and Col_Trans of more than 50% were classified into the circumferential obstruction group (Obst_Cir group), and those with both Col_AP and Col_Trans of less than 50% were classified into the patent group.

Statistical Analysis

The Kruskal-Wallis test, the Mann-Whitney *U* test, and the independent *t* test were used to compare the parameters according to obstruction sites/patterns and the severity of OSAS. The χ^2 test was used to assess the relationship between obstruction pattern and position dependency of OSAS.

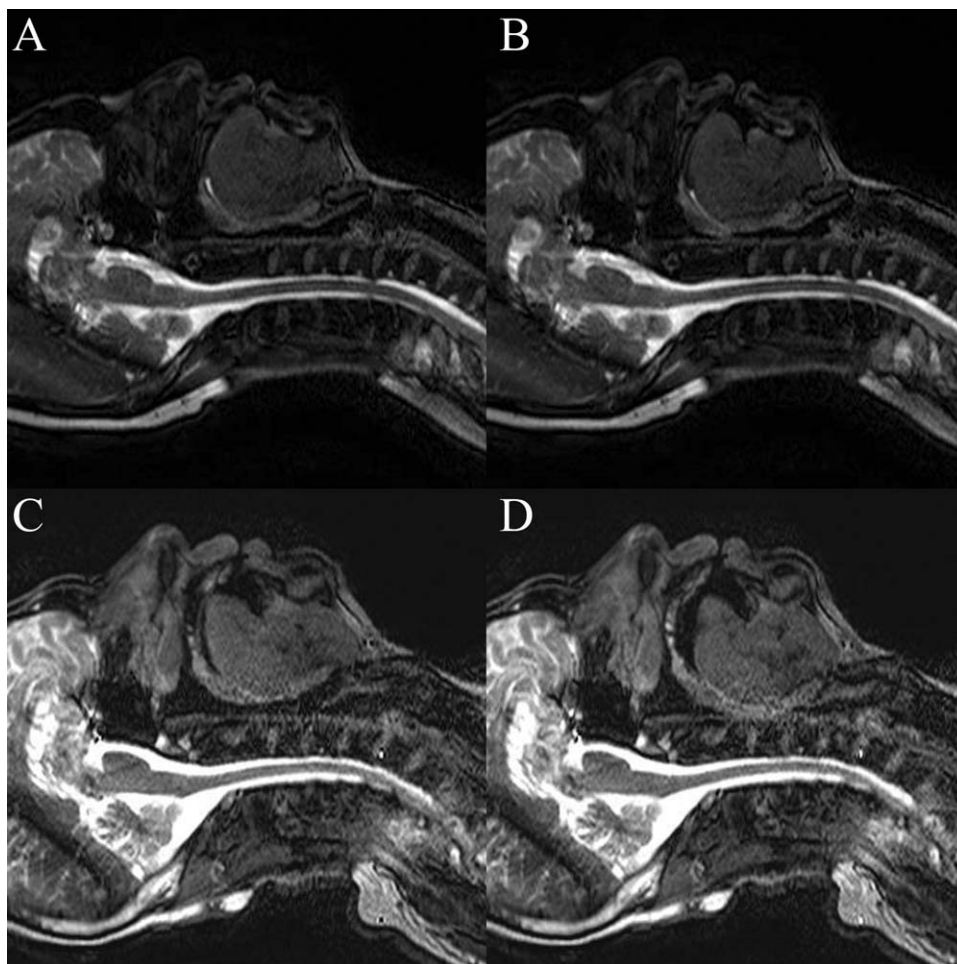


Fig. 1. Midsagittal magnetic resonance images of upper airway obstruction at the retropalatal level only (A, B) and at both the retropalatal and retrolingual levels (C, D).

Statistical significance was set at $P < .05$. All statistical analyses were performed using SPSS (SPSS Inc., Chicago, IL).

RESULTS

The upper airway of subjects did not show obstruction in both axial and sagittal images while subjects were awake. However, after sedation, the cine images in sagittal section showed collapse of the upper airway at

various levels in 33 (94.3%) of 35 subjects. In 13 (37.1%) subjects, airway collapse occurred in the retropalatal area (Fig. 1A and 1B); both the retropalatal and retrolingual areas were obstructed in the remaining 20 (57.1%) subjects (Fig. 1C and 1D). No upper airway collapse was found in two (5.7%) subjects. Demographic and sleep parameters according to the obstruction sites of the upper airway are summarized in Table I. Subjects with both retropalatal and retrolingual obstruction showed higher

TABLE I.
Sleep Parameters According to the Obstruction Sites of the Upper Airway Identified by Sagittal Images of Sleep Magnetic Resonance Imaging.

	Patent (n = 2)	Retropalatal Obstruction Only, n = 13	Retropalatal and Retrolingual Obstruction, n = 20	P^*	P^\dagger
RDI	3.89 ± 4.00	20.47 ± 11.71	26.68 ± 14.14	.049	.281
Supine RDI	7.50 ± 9.76	27.81 ± 19.63	42.23 ± 19.63	.017	.029
MinSaO ₂	93.50 ± 0.71	86.46 ± 3.80	81.15 ± 6.36	.004	.013
Snoring, dB	45.00 ± 1.41	47.27 ± 5.68	48.55 ± 5.68	.646	.611
Age, yr	28.50 ± 19.09	51.46 ± 6.33	53.68 ± 9.70	.058	.257
BMI	23.60 ± 0.29	25.52 ± 3.46	25.61 ± 3.06	.361	.600

*Comparison between the three groups; data were analyzed with the Kruskal-Wallis test.

†Comparison between the retropalatal obstruction group and the retropalatal and retrolingual obstruction group; data were analyzed with the Mann-Whitney U test.

RDI = respiratory disturbance index; MinSaO₂ = minimal oxygen saturation during sleep; BMI = body mass index.

TABLE II.
Correlation Between the Sagittal Obstruction Pattern and Positional Dependence of Obstructive Sleep Apnea Syndrome.

	Retropalatal Obstruction Only	Retropalatal and Retrolingual Obstruction	Total
Position-dependent OSAS	3	13	16
Non-position-dependent OSAS	10	7	17
Total	13	20	33

$P = .019$, odds ratio = 1.973 (95% confidence interval, 1.067–3.650); data were analyzed with the χ^2 test.

OSAS = obstructive sleep apnea syndrome.

supine RDI and lower MinSaO₂ levels than those with retropalatal obstruction only (42.23 ± 19.63 vs. 27.81 ± 19.63 and 81.15% ± 6.36% vs. 86.46% ± 3.80%; $P = .029$ and $P = .013$, respectively).

There was a statistically significant correlation between obstruction sites and positional dependency in OSAS patients (Table II). Most subjects (10 of 13, 76.9%) whose airway collapse occurred at the retropalatal level only were nonpositional. However, those with retrolingual obstruction had a tendency to be positional (13 of 20 patients, 65%). For patients with both retropalatal and retrolingual obstruction, the odds ratio of the risk for the development of positional dependency was 1.973 (95% confidence interval, 1.067–3.650).

The subjects' mean Col_Trans and Col_AP values calculated with axial images were 68.34% ± 27.03% and 51.18% ± 34.04%, respectively. This difference was statistically significant ($P = .021$, by independent t test). The demographic and sleep parameters according to the classification with axial images are summarized in Table III. No airway collapse occurred in five (14.2%) of 35 subjects. Only one (2.9%) of 35 subjects showed prominent anteroposterior collapse of the upper airway without transverse collapse (Fig. 2A and 2B); 14 (40%) subjects showed transverse collapse without anteroposterior collapse (Fig. 2C and 2D). The remaining 15 subjects (42.9%) showed circumferential collapse (both transverse and anteroposterior collapse) of the upper airway (Fig. 2E and 2F). Taken together, transverse collapse was found in 82.9%(29 of 35) of subjects, and

anteroposterior collapse was seen in 45.7%(16 of 35). Supine RDI, MinSaO₂, and age showed a statistically significant difference according to the classification by axial images ($P = .038$, .029, and .029, respectively).

To identify the clinical implication of patent airway more clearly, comparisons between the patent group and obstruction group, including Obst_Trans, Obst_AP, and Obst_Cir, were performed. RDI and supine RDI were significantly higher in the obstruction group than in the patent group ($P = .019$ and .013, respectively). The average MinSaO₂ levels in arterial blood in the obstruction and patent groups were 82.60% ± 5.81% and 91.20% ± 4.09%, respectively; the difference was statistically significant ($P = .002$). Mean age was 54.00 ± 7.75 years in the obstruction group and 38.83 ± 14.33 years in the patent group; this difference was also statistically significant ($P = .006$).

Comparison between subjects with anteroposterior obstruction (Col_AP and Col_Cir groups) and those without anteroposterior obstruction (patent and Col_Trans groups) revealed no statistically significant differences in RDI, supine RDI, MinSaO₂, or age (Table IV). However, the mean snoring decibel was higher in subjects with anteroposterior obstruction than in the remaining subjects (50.80 ± 6.29 dB vs. 45.50 ± 3.28 dB, $P = .011$).

There were moderate but significant positive correlations between MinSaO₂ and the collapsibility of the upper airway, including Col_Cir, Col_AP, and Col_Trans (Fig. 3A, 3B, and 3C). The correlation coefficients (Spearman ρ) were 0.420 for MinSaO₂ and Col_Cir, 0.432 for MinSaO₂ and Col_AP, and 0.370 for MinSaO₂ and Col_Trans.

RDI and supine RDI correlated well with Col_Trans ($r = 0.390$ and $r = 0.365$; $P = .022$ and .037, respectively) (Fig. 4 and Fig. 5). However, there were no significant correlations between RDI/supine RDI and Col_AP/Col_Cir. In addition, age was well correlated with Col_Trans ($r = 0.436$, $P = .008$); no correlation was found between age and Col_Cir/Col_AP ($P = .069$ and $P = .308$, respectively) (Fig. 6).

DISCUSSION

This study was designed to accurately evaluate the obstructive sites and patterns of upper airway obstruction during low-dose midazolam-induced sleep by using

TABLE III.
Sleep Parameters According to the Obstruction Patterns of the Upper Airway Identified by Axial Images of Sleep Magnetic Resonance Imaging.

	Patent, n = 5	Transverse Collapse, n = 14	Anteroposterior Collapse, n = 1	Circumferential Collapse, n = 15	Obstruction Group, n = 30	P^*	P^\dagger	P^\ddagger
RDI	11.23 ± 15.30	25.22 ± 10.19	6.98	26.63 ± 15.28	25.04 ± 12.85	.059	.874	.019
Supine RDI	14.54 ± 17.23	37.30 ± 16.71	11.20	42.61 ± 22.05	39.03 ± 19.87	.038	.650	.013
MinSaO ₂	91.20 ± 4.09	83.00 ± 3.16	85.00	82.00 ± 8.02	82.60 ± 5.81	.029	.603	.002
Snoring, dB	44.40 ± 3.78	45.92 ± 3.12	48.00	51.00 ± 6.48	48.54 ± 5.57	.068	.033	.093
Age, yr	38.83 ± 14.33	55.57 ± 7.49	54.00	52.13 ± 8.24	54.00 ± 7.75	.029	.134	.006
BMI	23.04 ± 2.59	26.54 ± 3.74	24.20	25.57 ± 3.40	25.92 ± 3.45	.169	.780	.037

*Comparison between the following four groups: patent, transverse collapse, anteroposterior collapse, and obstruction groups; data were analyzed with the Kruskal-Wallis test.

†Comparison between transverse collapse group and circumferential collapse group; data were analyzed with the Mann-Whitney U test.

‡Comparison between patent group and obstruction group; data were analyzed with the Mann-Whitney U test.

RDI = respiratory disturbance index; MinSaO₂ = minimal oxygen saturation during sleep; BMI = body mass index.

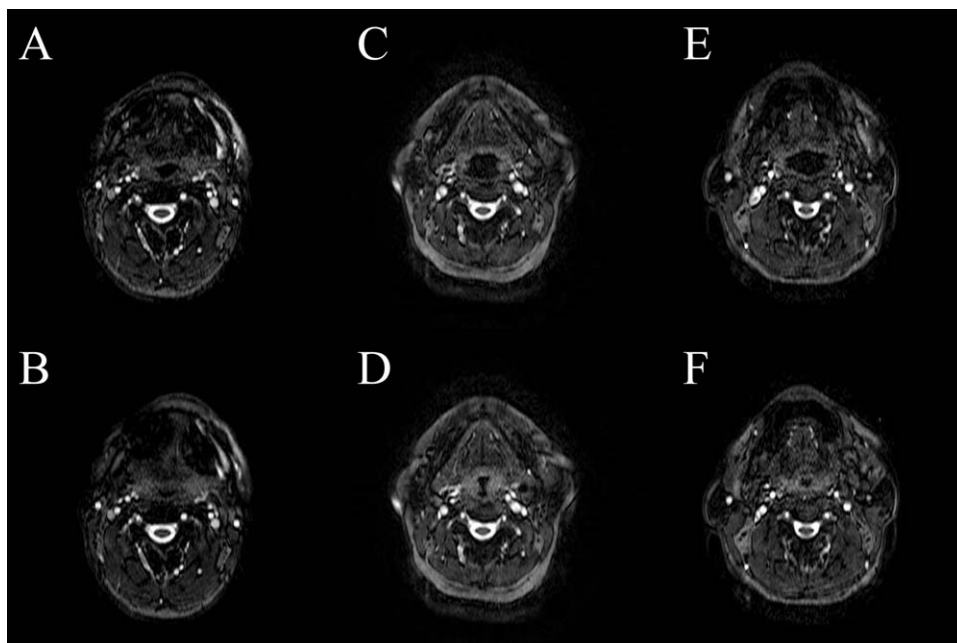


Fig. 2. Axial magnetic resonance images at the retrolingual level of representative anteroposterior collapse (A, B), transverse collapse (C, D), and circumferential collapse (E, F).

sleep MRI. Airway obstruction during sleep is due to structural-component and dynamic airway collapse. Multiple sites can be narrowed in patients with OSAS, including the retropalatal and retrolingual areas. Moreover, the obstruction patterns of the upper airway when a person is awake differ from those during sleep. Therefore, an ideal diagnostic method for OSAS patients should evaluate both the structural component and the dynamic changes in the upper airway during sleep.

Midsagittal images of sleep MRI allowed us to assess real-time obstruction sites of the upper airway. We found different types of upper airway obstruction, and we classified OSAS subjects into three groups: subjects without obstruction, those with retropalatal obstruction only, and those with both retropalatal and retrolingual obstruction. Sleep parameters such as supine RDI and MinSaO_2 were significantly different between the three groups. Subjects with both levels of obstruction showed higher supine RDI and lower MinSaO_2 than subjects without obstruction or with retropalatal obstruction only. It can be inferred that classifying the three groups according to sagittal images was a reliable and valid method because there were significant differences in various parameters between the groups.

No subjects showed retrolingual obstruction only. These results are consistent with those of earlier studies showing that single-site obstruction of the upper airway occurred only at the retropalatal level.^{13,14} Therefore, some have suggested making a combined effort to enlarge both the retropalatal and retrolingual airway in OSAS patients, even though these patients are supposed to have retrolingual obstruction only. In addition, the risk of position-dependent OSAS was higher in subjects with both retropalatal and retrolingual obstruction (odds ratio = 1.973; 95% confidence interval, 1.067-3.650). Therefore, physicians could advise subjects with both

retropalatal and retrolingual obstruction to lie in the lateral position to relieve apnea during sleep.

We found several different patterns of retrolingual airway obstruction with axial sleep MRI. Both the anteroposterior and lateral wall dimensions were altered by sleep in most subjects, but we were able to classify OSAS subjects according to the main pattern of the airway collapse as follows: subjects with transverse collapse, those with anteroposterior collapse, those with circumferential collapse, and those without collapse. There were significant differences in regard to sleep parameters between subjects with and without obstruction, a finding which implies that airway patency determined by axial images is useful.

Of interest, transverse collapse was found in more than 80% of subjects in our study, and it is postulated that lateral pharyngeal wall collapse is a more significant contributor than anteroposterior wall collapse to

TABLE IV.

Comparison of Sleep Parameters Between the Subjects With Anteroposterior Collapse (Anteroposterior and Circumferential Collapse Groups) and Those Without Anteroposterior Collapse (Patent and Transverse Collapse Groups) Determined by Axial Images of Sleep Magnetic Resonance Imaging.

	Subjects With Anteroposterior Collapse, n = 16	Subjects Without Anteroposterior Collapse, n = 19	P*
RDI	25.32 ± 15.58	21.54 ± 12.92	.656
Supine RDI	40.52 ± 22.74	30.98 ± 19.42	.290
MinSaO ₂	82.20 ± 7.76	85.16 ± 4.97	.632
Snoring, dB	50.80 ± 6.29	45.50 ± 3.28	.011
Age, yr	52.25 ± 7.97	50.55 ± 12.42	.789
BMI	25.49 ± 3.30	25.62 ± 3.75	.832

*Data were analyzed with the Mann-Whitney U test.

RDI = respiratory disturbance index; MinSaO_2 = minimal oxygen saturation during sleep; BMI = body mass index.

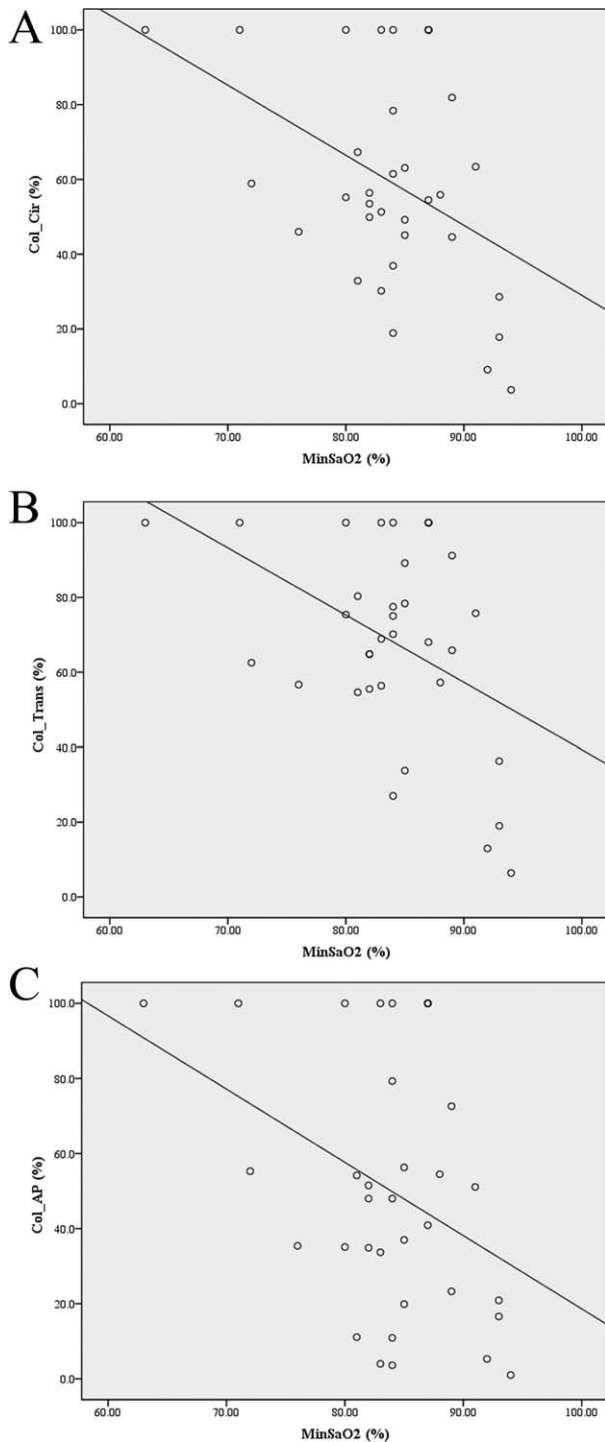


Fig. 3. Correlation between collapsibility of the retrolingual airway and minimum oxygen saturation (MinSaO₂). (A) Correlation between the levels of MinSaO₂ and circumferential collapsibility (Col_Cir) of the upper airway determined by means of axial images of sleep magnetic resonance imaging (MRI). A significant association was found between the levels of MinSaO₂ and Col_Cir (Spearman $\rho = 0.420$, $P = .013$). $\text{Col_Cir} = -1.874 \times \text{MinSaO}_2 + 216.38$; (B) Correlation between the levels of MinSaO₂ and transverse collapsibility (Col_Trans) determined by axial images of sleep MRI. A significant association was found between the levels of MinSaO₂ and Col_Trans (Spearman $\rho = 0.432$, $P = .011$). $\text{Col_Trans} = -1.797 \times \text{MinSaO}_2 + 219.06$; (C) Correlation between the levels of MinSaO₂ and anteroposterior collapsibility (Col_AP) determined by axial images of sleep MRI. A significant association was found between the levels of MinSaO₂ and Col_AP (Spearman $\rho = 0.370$, $P = .031$). $\text{Col_AP} = -1.951 \times \text{MinSaO}_2 + 213.737$.

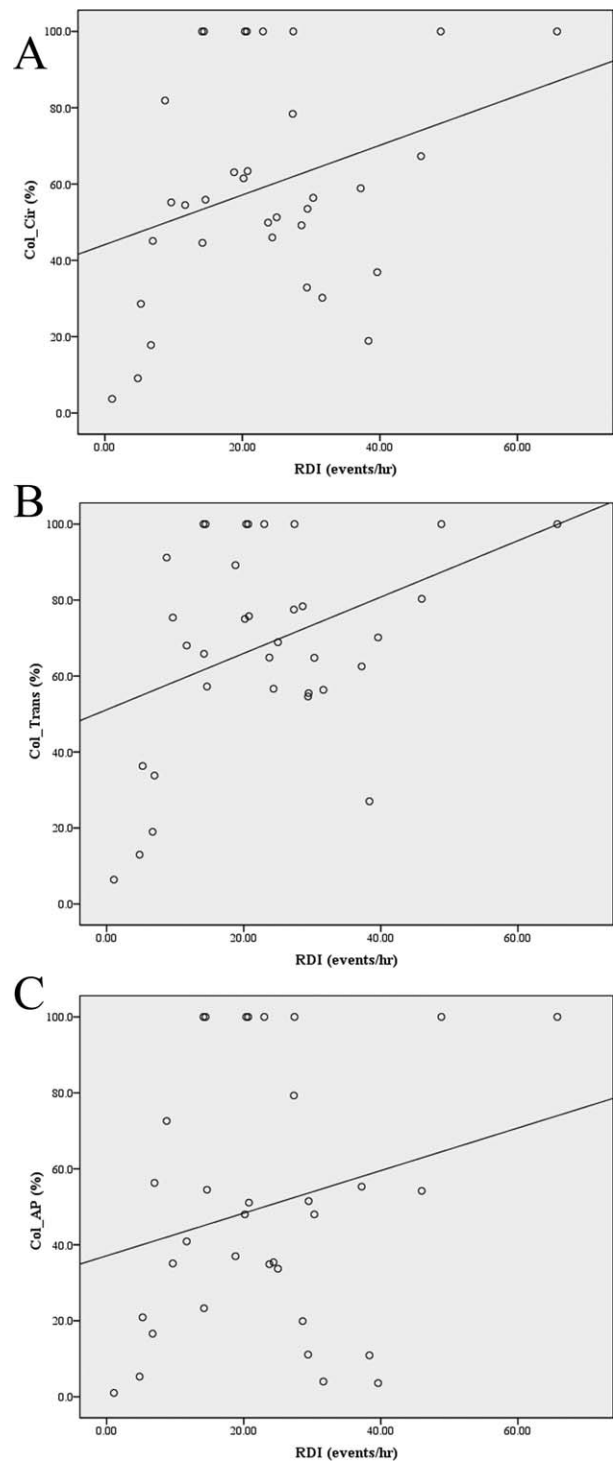


Fig. 4. Correlation between collapsibility of the retrolingual airway and respiratory disturbance index (RDI). (A) Correlation between the levels of RDI and circumferential collapsibility (Col_Cir) of the upper airway determined by axial images of sleep magnetic resonance imaging (MRI) (Spearman $\rho = 0.319$, $P = .066$); (B) Correlation between the levels of RDI and transverse collapsibility (Col_Trans) determined by axial images of sleep MRI. A significant association was found between the levels of RDI and Col_Trans (Spearman $\rho = 0.390$, $P = .022$). $\text{Col_Trans} = 0.742 \times \text{RDI} + 51.141$; (C) Correlation between the levels of RDI and anteroposterior collapsibility (Col_AP) determined by axial images of sleep MRI (Spearman $\rho = 0.232$, $P = .186$).

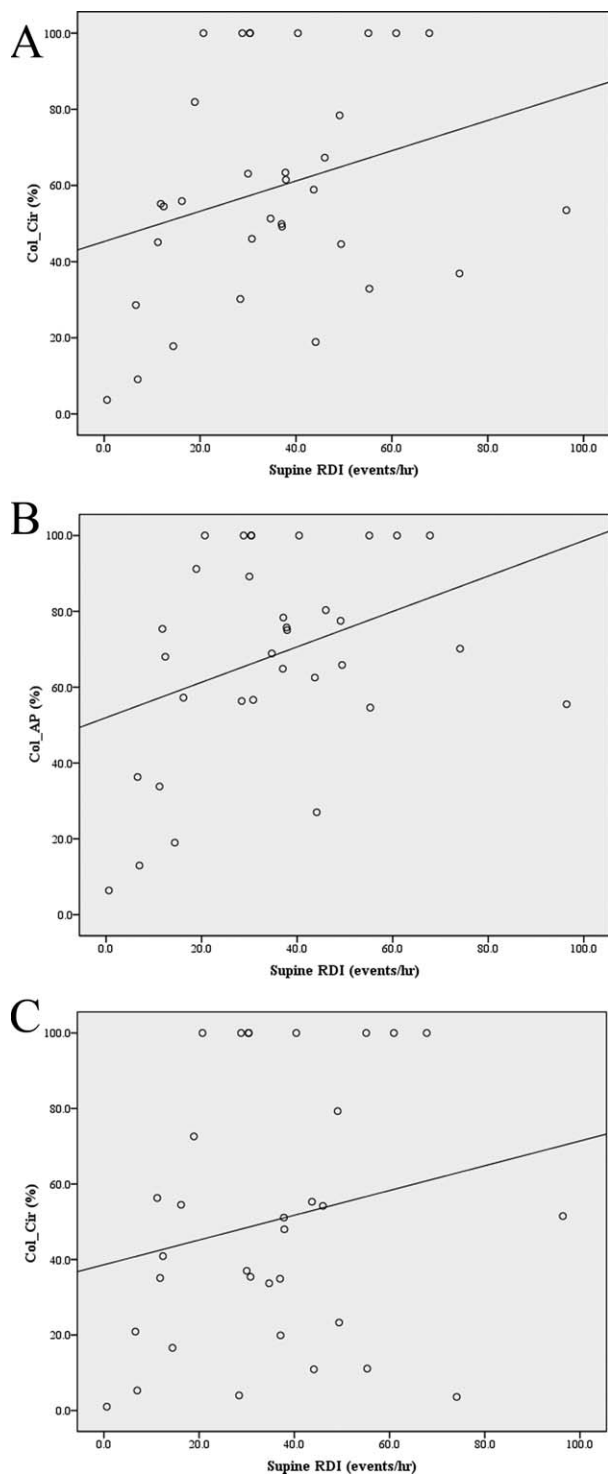


Fig. 5. Correlation between collapsibility of the retrolingual airway and supine respiratory disturbance index (RDI). (A) Correlation between the supine RDI and circumferential collapsibility (Col_Cir) of the upper airway determined by axial images of sleep magnetic resonance imaging (MRI) (Spearman $\rho = 0.278$, $P = .117$); (B) Correlation between the supine RDI and transverse collapsibility (Col_Trans) determined by axial images of sleep MRI. A significant association was found between the supine RDI and Col_Trans (Spearman $\rho = 0.365$, $P = .037$). $\text{Col_Trans} = 0.467 \times \text{supine RDI} + 51.972$; (C) Correlation between the supine RDI and anteroposterior collapsibility (Col_AP) determined by axial images of sleep MRI (Spearman $\rho = 0.202$, $P = .260$).

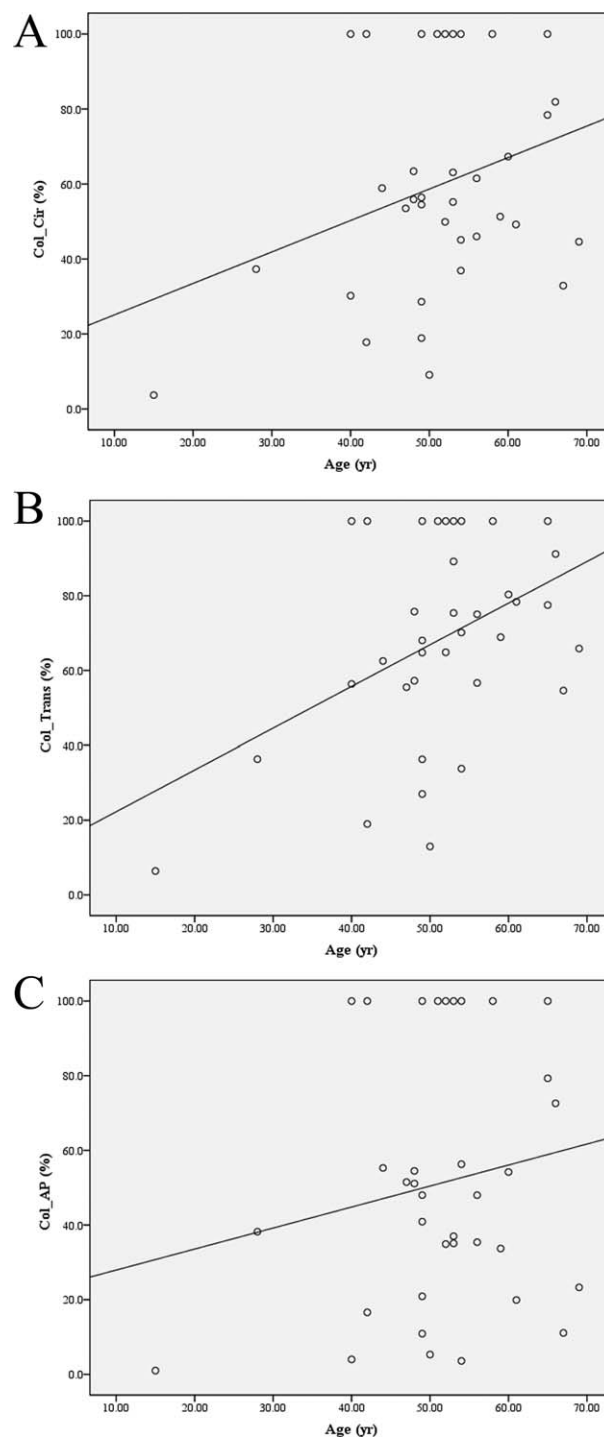


Fig. 6. Correlation between collapsibility of the retrolingual airway and age. (A) Correlation between age and circumferential collapsibility (Col_Cir) determined by axial images of sleep magnetic resonance imaging (MRI) (Spearman $\rho = 0.307$, $P = .069$); (B) Correlation between age and transverse collapsibility (Col_Trans) determined by axial images of sleep MRI. A significant association was found between age and Col_Trans (Spearman $\rho = 0.436$, $P = .008$). $\text{Col_Trans} = 1.115 \times \text{age} + 11.133$; (C) Correlation between age and anteroposterior collapsibility (Col_AP) determined by axial images of sleep MRI (Spearman's $\rho = 0.175$, $P = .308$).

hypopharyngeal obstruction. This result is consistent with that of a previous study, which showed that lateral pharyngeal wall collapse is important in the pathogenesis of OSAS.¹⁵ Moreover, the degree of transverse airway collapse correlated well with age in our study. It can be assumed that age-related changes in lateral pharyngeal muscle may be a contributory mechanism to the increased prevalence of OSAS with age. This hypothesis might be supported by a previous study that age-related histologic changes of the upper airway muscle in rats lead to airway collapse.¹⁶ Therefore, specific procedures such as lateral pharyngoplasty with tonsillectomy that address lateral pharyngeal wall collapse would be helpful for OSAS patients with transverse collapse of the airway.¹⁷

In our study, we did not find any obstruction in five subjects by analyzing the axial images of the retrolingual airway. In two of these five subjects, no obstruction was seen on the sagittal images; they were classified into the patent group, and their RDI was lower than 5. The remaining three subjects were put in the retropalatal obstruction group; in these subjects, retropalatal obstruction was only seen without retrolingual obstruction in sagittal images. Therefore, determining patency in the axial images was valid in this study, which was related to the findings in sagittal images.

In addition, retropalatal obstruction was shown only on sagittal images in 13 subjects. These 13 subjects' axial images at the retrolingual level were analyzed to identify the relationship between axial and sagittal images. For three of 13 subjects, no collapse of the retrolingual airway was shown on the axial images, whereas transverse collapse was observed for six and circumferential collapse was seen for four subjects. Thus, 10 (76.9%) of 13 subjects had some degree of lateral pharyngeal wall collapse on the axial images, although no retrolingual collapse was detected on the sagittal images. This result indicates that both axial and sagittal images should be analyzed together to assess airway obstruction accurately. Moreover, this result reveals the drawbacks of other diagnostic methods, such as SVF and lateral x-ray cephalometry, which investigate the lateral views of the airway only.

In our analysis, anteroposterior collapse of the retrolingual airway appeared to be associated with loud snoring. This result is consistent with that of a previous study showing that snoring is associated with reduction in pharyngeal cross-sectional area¹⁸; further studies will be necessary to elucidate the reason for this observation. Velopharyngeal structures have been considered to play an important role in the pathogenesis of snoring,¹⁹ but our results indicate that the dynamic change of retrolingual airway, especially anteroposterior collapse, may contribute to producing noise during sleep.

The lowest oxygen saturation level correlated well with the degree of dynamic obstruction of the upper airway. In contrast, RDI, supine RDI, and age correlated well with transverse collapse only. A previous study has shown a threefold increase in the frequency of lateral pharyngeal wall collapse in patients with severe OSAS compared to those with mild OSA. This finding is similar to our observation that transverse collapse of the upper

airway is an important parameter in predicting OSAS severity.²⁰ This result highlighted the importance of sleep MRI, as compared with other methods, which can detect transverse collapse of the upper airway easily.

This study was conducted with subjects who visited the clinic for a medical check-up, and most of them did not want to undergo standard polysomnography (PSG) in the hospital for one night. Therefore, Watch-PAT, rather than standard PSG, was used to diagnose OSAS in this study. The Watch-PAT device is a widely used portable device for home diagnosis of OSAS. It records wrist actigraphy, PAT, pulse rate, and pulse oximetry. Sleep state, arousals, and REs were automatically scored based on the built-in algorithm. Respiratory events such as apnea and hypopnea were assessed by detecting surges of sympathetic activation. A previous study evaluated the reliability and reproducibility of Watch-PAT compared to standard PSG and reported that RDI levels were highly correlated between the two groups.²¹

Sleep MRI has several advantages in assessing dynamic airway changes during sleep. However, there are some limitations to this method. Sleep MRI is still relatively expensive, and it takes about 30 minutes to complete the examination, although an ideal clinical evaluation would be cost-effective, fast, and comfortable. In addition, obtaining high-quality images with sleep MRI is critical for accurate interpretation and subsequent management decision-making, but image quality is still unsatisfactory. Future technical developments in this field may help overcome these drawbacks.

This study also has some limitations. First, because patients required a sedative to fall asleep during the examination, the results may have been biased by a drug effect. A previous study demonstrated that diazepam is associated with a reduction in minute ventilation and tidal volume and selectively decreases genioglossal electromyographic activity.²² Second, because the study time is relatively short as compared with the length of normal sleep, it does not reflect the actuality of sleeping. We could not monitor the various sleep stages in the study. It has been reported that sleep stage could affect upper airway resistance, the highest of which occurs in non-rapid eye movement sleep.²³ Third, follow-up data following treatment are lacking owing to the initial nature of this report. Fourth, evaluation of upper airway changes during sleep is needed in normal control and simple snoring subjects to determine the difference between them and OSAS patients. Further studies are needed to validate our results.

To the best of our knowledge, this is the first study to classify the obstruction pattern in the retrolingual area during sleep and compare various parameters according to the pattern. In addition, we examined a relatively large population of adult subjects with OSAS as compared with other studies using cine MRI to assess the obstruction level and patterns in the upper airway.

CONCLUSION

We suggest that sleep MRI is a reliable and useful approach to assess the structural and dynamic collapse

of the upper airway during sleep and to predict OSAS severity. This novel technique allows us to identify the narrowing sites of the upper airway precisely and to tailor treatment for OSAS patients.

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