Original Article

Relationship Between Cephalometric Characteristics and Obstructive Sites in Obstructive Sleep Apnea Syndrome

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Abstract: Patients with obstructive sleep apnea syndrome (OSAS) have characteristic dentofacial features, but the sites of obstruction differ greatly. The purpose of this study was to investigate the dentofacial characteristics of patients with OSAS with respect to the obstructive sites. The subjects consisted of 30 Japanese men with OSAS divided into 3 groups of 10 patients each. One group had obstruction at the retropalatal and retroglossal region (Rp + Rg group), a second group had obstruction at the retropalatal region (Rp group), and a third group had obstruction due to tonsillar hypertrophy (tonsillar hypertrophy group). To identify the Rp + Rg and Rp groups, dynamic magnetic resonance imaging (MRI) was used. To identify the tonsillar hypertrophy group, Mackenzie's classification, axial MRI, and the weight of the tonsils were used. A control group was composed of 10 Japanese men showing no symptoms suggestive of OSAS. Lateral cephalometric radiographs were obtained for all of the subjects, and analysis of variance was performed for the 46 cephalometric parameters. Among the many dentofacial characteristics of OSAS patients, the tendencies for retrognathia, micrognathia, and skeletal Class II were strongest in the Rp + Rg group and somewhat strong in the Rp group. The presence of a long soft palate was dominant in the Rp group, whereas the tendency for a long face was dominant in the tonsillar hypertrophy group. All of the groups shared the characteristic of having an inferior position of the hyoid bone. Based on the results of the current study, we conclude that many features of OSAS are specifically related to each obstructive type of OSAS. (*Angle Orthod* 2002;72:124–134.)

Key Words: Obstructive sleep apnea syndrome; Cephalometry; Obstructive site; Dynamic MRI

INTRODUCTION

Sleep apnea syndrome is a condition characterized by the episodic cessation of breathing during sleep. Examinations of the causes of apnea have produced several classifications. Apnea secondary to sleep-induced obstruction of the upper airway combined with simultaneous respiratory efforts is the most common type and has been classified as obstructive sleep apnea syndrome (OSAS). OSAS results in oxygen desaturation and arousal from sleep, thus bringing about a constellation of signs and symptoms related to oxygen desaturation and sleep fragmentation. The reduced blood oxygen saturation may give rise to hypertension, cardiac arrhythmia, nocturnal angina, and myocardial ischemia. The impaired sleep quality leads to excessive daytime sleepiness, deterioration of memory and judgment, altered personality, and reduced concentration.[1,2]

Abnormal cephalometric dentofacial morphologies have been extensively reported in patients with OSAS.[3–9] Tendencies toward retrognathia,[3,4,6,9] micrognathia,[5,6] long face,[3,4,6,9] and inferior positioning of the hyoid bone[4,6] in patients with OSAS are characteristic features that have been widely noted. In addition, tendencies toward reduced cranial base length and angle,[4,5] large ANB angle,[9] steep mandibular plane,[3,4] elongated maxillary and mandibular teeth,[3,9] narrowing of the upper airway,[5,6] long and large soft palate,[5–7] and large tongue[3,6] have also been reported.

Among patients with OSAS, however, the sites of obstruction and the narrowing of the upper airway differ greatly. The retropalatal (posterior to the soft palate) region and retroglossal (posterior to the base of tongue) region are commonly affected sites,[10] and multiple sites of obstruction and narrowing are not rare.[11,12] Detection and characterization of the sites of obstruction and narrowing of the upper

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Accepted: September 2001. Submitted: June 2001.

airway are of particular clinical importance in understanding the pathophysiology of OSAS as well as in the planning of therapy. Many recent studies have been performed concerning the diagnosis and physiology of obstructive sites in OSAS,[10–18] but there are few studies that mention the relationship between the dentofacial characteristics and obstructive sites in patients with OSAS. The purpose of this study was to investigate the dentofacial characteristics of patients with OSAS with respect to the obstructive sites to more accurately clarify the pathophysiologic features and the proper modalities for the correction of OSAS.

MATERIALS AND METHODS

Study subjects

The study group consisted of 40 Japanese men: 30 patients with OSAS and 10 healthy control subjects. The patients with OSAS were divided into 3 groups of 10 each according to their obstructive site: (1) obstruction at the retropalatal and retroglossal region (Rp + Rg group), (2) obstruction at the retropalatal region (Rp group), and (3) obstruction due to tonsillar hypertrophy (tonsillar hypertrophy group). The control subjects showed no symptoms or features suggestive of OSAS such as snoring, nocturnal apnea, or excessive daytime sleepiness. The Rp + Rg, Rp, and control subjects showed no clinical or radiographic signs or symptoms suggestive of tonsillar hypertrophy.

The Rp + Rg group had a mean age of 47.9 years (range, 28.9 to 66.9 years); the Rp group, 49.6 years (range, 25.1 to 64.8 years); and the tonsillar hypertrophy group, 40.2 years (range, 27.3 to 59.2 years). The mean age of the control group was 36.5 years (range, 27.1 to 47.5 years). Lateral cephalometric radiographs were used to evaluate the dentofacial features of all subjects.

Polysomnography

The sleep study was performed using overnight polysomnography (Alice 3: Healthdyne Technologies, Marietta, Ga) including EEG (electroencephalography), ECG (electrocardiography), EOG (electrooculography), submental EMG (electromyography), airflow, tracheal sound with microphone, arterial oxygen saturation (SpO_2), and respiratory effort.[19] Mesopharyngeal and esophageal pressures were recorded simultaneously with a microtip-type pressure transducer (MPC500: Millar, Houston, Tex) that was inserted 35 cm from the nostrils. Signals from the transducer were amplified by a signal conditioner and converted by a 4-channel A/D converter (Power Lab/4s: ADI instrument Pty Ltd, Castle Hill, Australia).

Identification of the obstructive site

To identify the Rp + Rg and Rp groups, patients in a definite sleeping state were scanned by dynamic magnetic resonance imaging (MRI).[20] In addition, we further confirmed the classification of these patients by endoscopic observation and a full-night measurement of the mesopharyngeal and esophageal pressure.[21] During the dynamic MRI, the patients were supine with the head placed in a neutral position to ensure consistent positioning. Each patient was examined during tidal breathing during natural sleep. To aid the onset of sleep, the imaging room was darkened. MRI was performed with a 1.5-T MR imager with a circular polarization coil (MAGNETOM VISION plus, Siemens Medical System, Erlangen, Germany). The pharyngeal airway was imaged in a median sagittal plane. We obtained 2 transverse plane sections at the retropalatal (posterior to the soft palate) level and retroglossal (posterior to the tongue base) level with T1-weighted turbo FLASH MRI using 180° preparation pulses (TR/TE: 4.5/2.2/1; FoV: 219 × 250 mm; Matrix: 112*128). Fifty images taken during 40 seconds were obtained at each location for the midsagittal and 2 transverse plane sections of the pharynx and were viewed as a cineloop display. To determine where the obstruction occurred, sagittal and transverse axial images were used for qualitative and quantitative analysis, respectively. The findings of the sagittal and axial images for the Rp + Rg and Rp groups are shown in Table 1. Figure 1 shows the sagittal images of the dynamic MRI. Patients whose sagittal images showed obstruction only at the retropalatal region, but no obstruction or narrowing at the retroglossal region were assigned to the Rp group (Figure

TABLE 1. Findings on Sagittal and Axial Images of the Dynamic MRI*

		Obstruction in Sagittal Image		Minimal Cross-sectional Area in Axial Image, mm²	
Group	Case	rp	rg	rp	rg
Rp + Rg	1	++	++	0	10.49
	2	++	+	0	11.40
	3	++	++	0	10.25
	4	++	++	5.61	16.82
	5	++	++	0	0
	6	++	++	0	3.74
	7	++	++	0	0
	8	++	+	18.69	13.08
	9	++	++	16.69	19.35
	10	++	++	0	0
Rp	1	++	−	0	110.28
	2	++	−	0	142.10
	3	++	−	19.20	269.17
	4	++	−	0	111.27
	5	++	−	0	140.19
	6	++	−	0	134.60
	7	++	−	0	175.25
	8	++	−	0	115.20
	9	++	−	13.08	190.66
	10	++	−	5.61	158.88

* MRI indicates magnetic resonance image; rp, retropalatal level; rg, retroglossal level; ++, complete obstruction; +, remarkable narrowing; and −, no obstruction or narrowing.

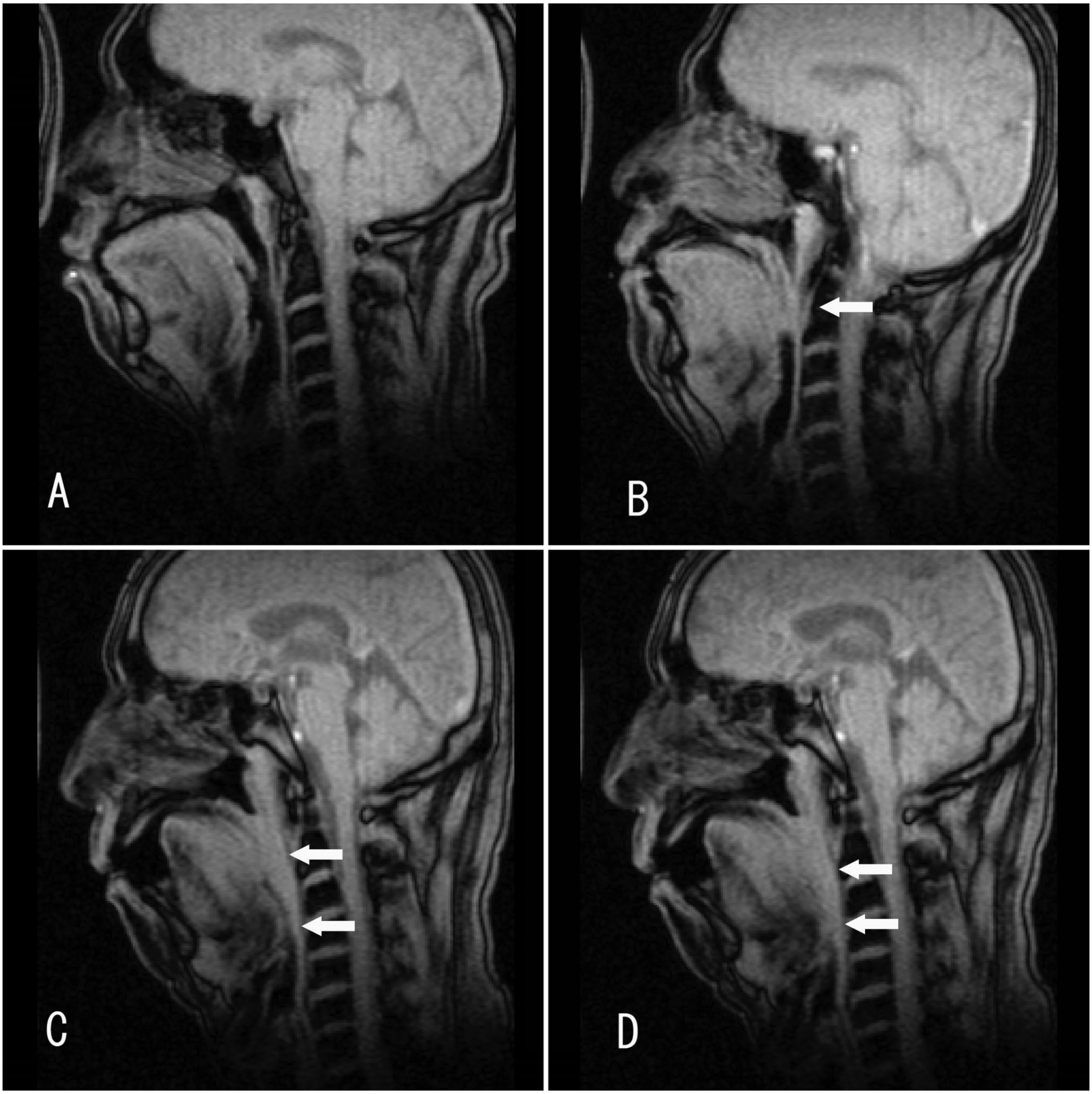

FIGURE 1. The sagittal images viewed of the dynamic magnetic resonance image (MRI). (A) No narrowing or obstruction. (B) Only the retropalatal (posterior to the soft palate) obstruction can be seen (Rp group). (C) Complete obstruction of the retropalatal region and remarkable narrowing of the retroglossal (posterior to the tongue base) region can be seen (Rp + Rg group). (D) Complete obstruction of the retropalatal and retroglossal region can be seen (Rp + Rg group).

1B). Patients whose sagittal images showed complete obstruction or remarkable narrowing at the retropalatal and retroglossal regions were assigned to the Rp + Rg group (Figures 1C,D). From the transverse axial image, the minimal cross-sectional areas of the airway at the retropalatal and retroglossal levels were measured with the aid of a National Institutes of Health image software package (NIH, Bethesda, Md). The levels for the retropalatal and retroglossal transverse sections are shown in Figure 2. Figure 3 shows the axial images of the retropalatal and retroglossal levels. For this study, obstruction was defined as a cross-sectional area at each level of the airway of less than 20 mm^2, and nonobstruction was defined as a cross-sectional area greater than 100 mm^2. Thus, the minimal cross-sectional area at the retroglossal level of the Rp group was at least 100 mm^2.

To identify the tonsillar hypertrophy group, we used Mackenzie's classification, axial MRI, the weight of the

FIGURE 2. The levels viewed for the transverse sections. (A) The level for the retropalatal transverse image. (B) The level for the retroglossal transverse image.

tonsils after surgical removal, and endoscopic observation during natural sleep. All of the patients included in the tonsillar hypertrophy group underwent tonsillectomy for the correction of OSAS. Patients were assigned to the tonsillar hypertrophy group when the appearance of their tonsils was Mackenzie's Class II or III (I: tonsils just visible beyond the palatal arch; II: intermediate enlargement; III: tonsils appearing to contact each other at the midline)[22]; when the maximal cross-sectional area of a tonsil in the axial image was greater than 200 mm^2; and when the bilateral weight of the tonsils was more than 8 g. The tonsillar group assignment was also confirmed by endoscopic observation during natural sleep and full-night measurements of the esophageal and mesopharyngeal pressure.

Cephalometric analysis

All of the lateral cephalometric radiographs were taken with a UD 150L (Shimadzu Co, Kyoto, Japan). Ear rods were inserted into the external auditory meati to stabilize the head posture during exposure. The distance from the focus to the film was 250 cm, and the magnification was 1.06746. The patients were seated upright with a natural head posture in the intercuspal position. The patients were instructed not to swallow during the cephalometric procedure. The dorsum of the tongue was coated with barium sulfate cream (Baritopsol: BaS 150 wt/vol%, Sakai Chemical Co, Osaka, Japan) to enhance the outline of the tongue.

Conventional cephalometric tracing methods were employed. The mandibular condyle was traced using a wide-open mouth view. Some of the anatomic landmarks are shown in Figure 4. Cephalometric measurements were made for the cranial base, maxilla, mandible, dental, facial height, anterior-posterior intermaxillary relation, airway (Figure 5), soft tissue (tongue and soft palate), oral area, and hyoid bone[23] (Figure 6). A total of 46 measurement variables were used. All of the cephalometric tracings were analyzed with software (WinCeph 6, Rise Co, Sendai, Japan).

Statistical analysis

Analysis of variance (ANOVA) was performed for the cephalometric variables for all testing groups. Fisher's PLSD (protected least-significant difference) test was applied for the multiple comparison when the results of ANOVA were significant.

RESULTS

Demographic and sleep data

Demographic and sleep data are summarized in Table 2. The control group had a mean body mass index (BMI) of 24.81 kg/m^2 (range, 20.57 kg/m^2 to 28.73 kg/m^2); the Rp + Rg group, 26.80 kg/m^2 (range, 21.14 kg/m^2 to 37.87 kg/m^2); the Rp group, 31.10 kg/m^2 (range, 24.91 kg/m^2 to 47.83 kg/m^2); and the tonsillar hypertrophy group, 26.42 kg/m^2 (range, 23.66 kg/m^2 to 31.40 kg/m^2). The mean BMI of the Rp group was significantly greater than that of the other groups.

The mean apnea-hypopnea index (AHI) of the 3 patient groups was more than 35 per hour. There were no significant differences in the sleep data (AHI, oxygen desaturation index [ODI $<$3%], and SpO_2 $<$90%) for the 3 patient groups.

Cephalometric variables

The results of cephalometric measurements and comparisons are shown in Table 3. The mandible was located the most posteriorly and was the smallest in the Rp + Rg group. When the Rp + Rg group was compared with the control group, the mandible was shorter in total length (Cd-Gn), body length (Go-Pog′), and ramus height (Cd-Go) by 12.01 mm, 10.99 mm, and 6.82 mm, respectively. In the Rp group, the size of the mandible, especially the body length (Go-Pog′), was also smaller, but larger than that of the Rp + Rg group. There was no significant difference between the tonsillar hypertrophy group and the control group in the size of the mandible.

In the parameters that represent the anterior-posterior intermaxillary relation (ANB, Wit′s appraisal, CdGn-CdA), the Rp + Rg group had the strongest skeletal Class II tendency. All 3 patient groups had steeper mandibular plane angles (FMA, $<$MP-SN) than the control group.

In the measurements of facial height, the tonsillar hypertrophy group showed a tendency toward having the lon-

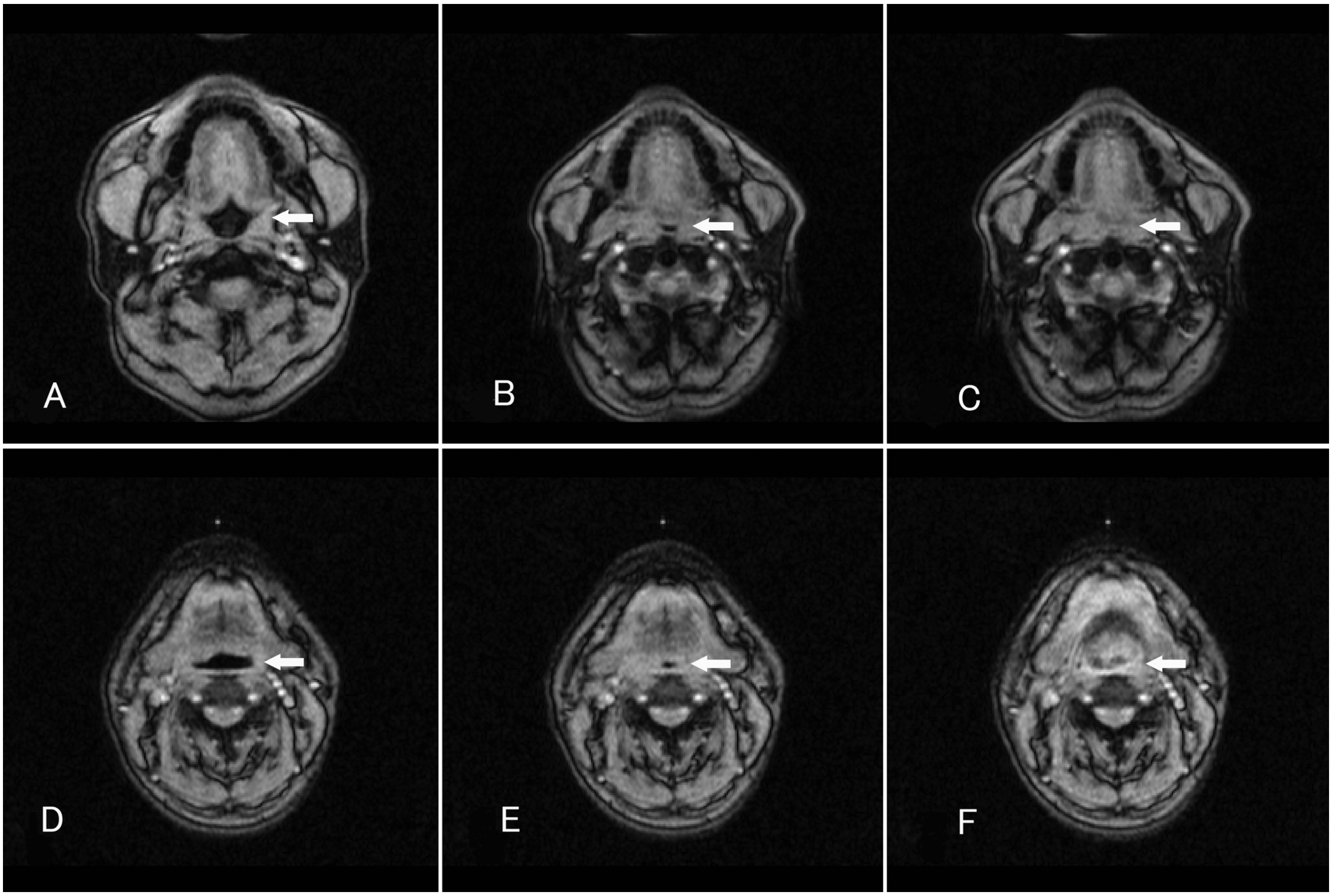

FIGURE 3. The axial images viewed at the retropalatal and retroglossal level. (A) No narrowing or obstruction (retropalatal level). (B) Remarkable narrowing (retropalatal level). (C) Complete obstruction (retropalatal level). (D) No narrowing or obstruction (retroglossal level). (E) Remarkable narrowing (retroglossal level). (F) Complete obstruction (retroglossal level).

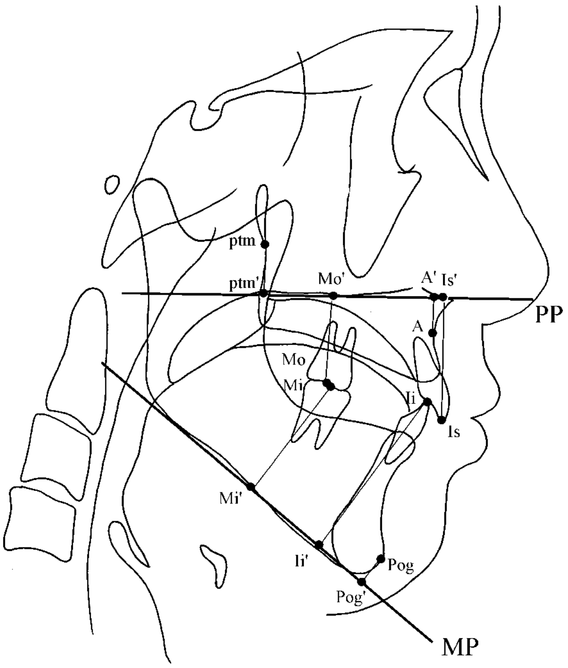

FIGURE 4. Representative cephalometric landmarks used.

gest faces. The tonsillar hypertrophy group also had the largest anterior facial height (AFH) ratio, the longest lower anterior facial height (LAFH), and the highest lower anterior dental height (Ii-Ii′).

In the measurements for airway, the Rp + Rg group had the narrowest inferior airway spaces (Ias), and the tonsillar hypertrophy group had the widest middle and inferior airway space (Mas and Ias, respectively). The Rp group had the greatest soft palate length (soft pal L) and the largest soft palate area (SPA). The 3 patient groups had more inferiorly positioned hyoid bones (MP-H) and a longer oropharyngeal airway length (Ph L) than the control group.

DISCUSSION

The pathogenesis of OSAS is complex. It is caused by the interaction of many factors such as age, gender, and obesity, but an abnormal dentofacial pattern is also considered to be one of the important factors. However, many of the previous studies of the dentofacial patterns of patients with OSAS did not take the other factors into consideration. Recently, studies of the dentofacial features of patients with OSAS have attempted to view these patients from a differ-

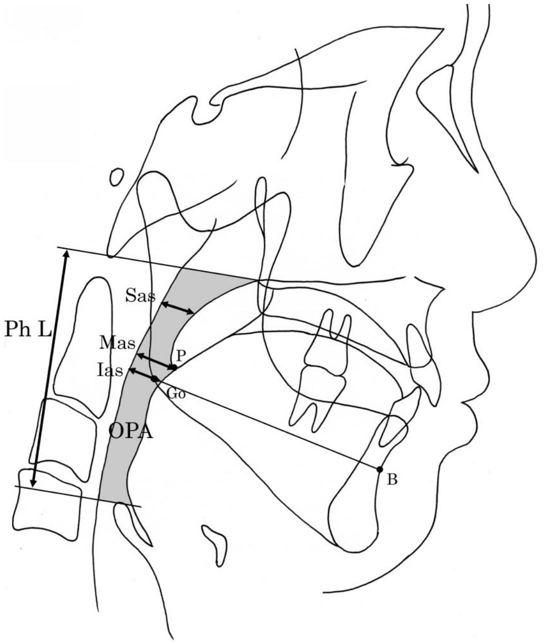

FIGURE 5. Airway measurements recorded. Sas indicates superior airway space (distance from the posterior wall of soft palate to the posterior pharyngeal wall at the level of the midpoint of the soft palate along a line parallel to B-Go); Mas, middle airway space (distance from the tongue base to the posterior pharyngeal wall at the level of P along a line parallel to B-Go); Ias, inferior airway space (distance from the tongue base to the posterior pharyngeal wall measured along a line B-Go); Ph L, pharyngeal length (oropharynx); and OPA, oropharyngeal area.

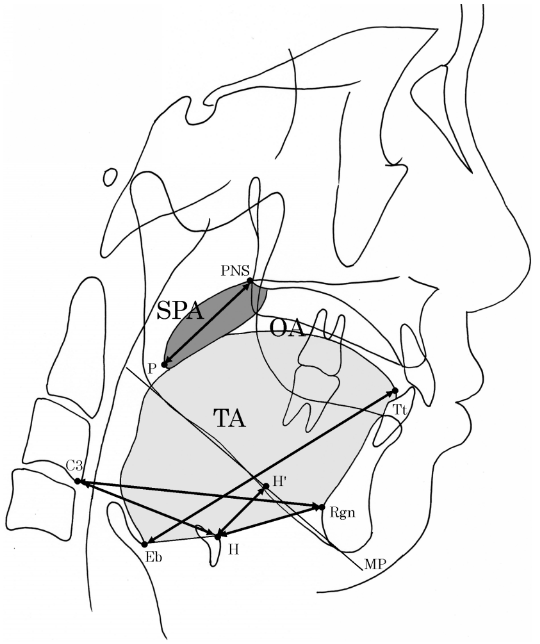

FIGURE 6. Soft tissue, oral area, and hyoid bone landmarks used. PNS-P indicates soft palate length; SPA, soft palate area; Eb-Tt, tongue length; TA, tongue area; and OA, oral area (including TA and extending superiorly to the outline of the soft and hard palate). For the hyoid bone, Rgn-H indicates horizontal position of hyoid bone; C3-H, horizontal position of hyoid bone; MP-H, vertical position of hyoid bone (the shortest distance from the hyoid bone [H] to the mandibular plane [MP]); and C3-Rgn, cervical column to the lingual aspect of the symphysis.

ent perspective by subgrouping them[24] and have studied features of OSAS for snorers,[25] patients with severe vs mild OSAS,[24] obese vs nonobese patients,[24,26] and patients of different ethnicities.[27] However, we found few studies that identified the obstructive sites in patients with OSAS. It is very important to know the location of the obstructive site in order to increase the success rate of treatments, especially when using surgical approaches. Many treatment methods for OSAS that involve the soft palate, such as uvulopalatopharyngoplasty (UPPP) or laser-assisted uvulopalatoplasty (LAUP), are able to eliminate the obstruction at the level of the soft palate, but not at the base of the tongue or the other sites. In the report of Fujita et al[28] focusing on surgical treatments for OSAS, the investigators found palatopharyngoplasty to be partially effective for eliminating or alleviating sleep apnea. If UPPP were performed only when the presurgical evaluation showed obstruction localized to the level of the soft palate, the success rate would be much higher.[29] A search for the relationship between the obstructive site and dentofacial pattern would provide the fundamental basis for further studies to establish proper treatment modalities for OSAS.

TABLE 2. Demographic and Sleep Data for Each Group#

	Control	Rp + Rg	Rp	Tonsillar Hypertrophy
Age, y	36.5 ± 6.3	47.9 ± 12.9*	49.6 ± 13.1†	40.2 ± 9.9
Height, cm	170.8 ± 3.84	166.0 ± 6.58*	167.8 ± 4.14	172.6 ± 5.29§‖
Weight, kg	72.5 ± 8.44	74.15 ± 16.92	87.99 ± 22.35*	78.85 ± 10.98
BMI, kg/m^2	24.81 ± 2.31	26.80 ± 4.47	31.10 ± 7.11‡	26.42 ± 2.65‖
AHI, No./h		35.51 ± 21.68	44.28 ± 18.01	47.29 ± 10.96
ODI >3%, No./h		33.45 ± 16.26	43.95 ± 25.94	42.88 ± 12.61
SpO_2 <90%, %		24.31 ± 26.24	26.96 ± 19.10	23.81 ± 17.08

Values are expressed as the mean ± SD. Rp indicates retropalatal; Rg, retroglossal; BMI, body mass index; AHI, apnea-hypopnea index; ODI >3%, oxygen desaturation index greater than 3%; SpO_2 <90%, oxygen saturation less than 90%.

* $P < .05$, † $P < .01$ compared with control group.

‡ $P < .05$, § $P < .01$ compared with Rp + Rg group.

‖ $P < .05$, compared with Rp group.

TABLE 3. Cephalometric Measurements and Comparison#

Variable	Control	Rp + Rg	Rp	Tonsillar Hypertrophy
Cr base				
S-N, mm	70.33 ± 2.80	67.91 ± 2.86	69.25 ± 2.63	71.13 ± 2.98
S-Ba, mm	49.7 ± 3.03	49.14 ± 4.17	48.56 ± 2.71	48.61 ± 3.37
<B-S-N, degrees	129.5 ± 3.42	125.67 ± 2.98	130.30 ± 4.63	127.28 ± 7.92
Maxilla				
SNA, degrees	84.98 ± 3.65	84.55 ± 2.66	83.43 ± 2.56	83.48 ± 4.14
A′-Ptm′, mm	53.68 ± 3.86	50.58 ± 2.56	51.89 ± 3.16	52.11 ± 2.82
Cd-A, mm	91.64 ± 5.00	87.04 ± 3.14	89.29 ± 3.71	90.83 ± 3.80
Is-Is′, mm	29.09 ± 2.81	32.45 ± 3.60*	31.25 ± 2.50	33.89 ± 3.36†
Mo-Ms′, mm	25.82 ± 2.47	25.37 ± 2.17	26.02 ± 1.79	26.44 ± 2.00
Mandible				
SNB, degrees	83.43 ± 3.78	77.31 ± 2.62†	79.55 ± 2.40†	79.76 ± 3.59*
Sd-Gn, mm	127.65 ± 8.42	115.64 ± 3.55†	122.58 ± 5.57‡	127.03 ± 5.57§
Go-Pog′, mm	83.76 ± 5.63	72.77 ± 4.35†	76.55 ± 4.41†	79.64 ± 5.10§
Cd-Go, mm	68.78 ± 5.72	61.96 ± 5.44†	65.25 ± 4.57	65.08 ± 5.02
Ii-Ii′, mm	46.56 ± 3.48	48.82 ± 3.38	48.61 ± 1.69	49.53 ± 2.80*
Mi-Mi′, mm	37.24 ± 2.41	37.59 ± 3.10	39.07 ± 2.16	38.25 ± 2.18
Go angle, degrees	118.57 ± 5.76	124.10 ± 9.42	125.30 ± 8.65	128.24 ± 5.42†
<MP-SN, degrees	28.26 ± 3.38	37.08 ± 6.25†	34.15 ± 4.89*	36.82 ± 6.05†
FMA, degrees	21.87 ± 2.91	30.94 ± 6.70†	27.64 ± 6.02*	31.17 ± 3.53†
Dental				
U1 to SN, degrees	111.02 ± 6.30	106.13 ± 8.55	108.33 ± 5.85	112.68 ± 10.16
U1 to FH, degrees	117.42 ± 6.87	112.04 ± 10.51	114.77 ± 6.68	118.32 ± 7.90
L1 to MP, degrees	90.25 ± 8.41	98.82 ± 8.53	93.60 ± 7.34	93.77 ± 8.05
FMIA, degrees	65.90 ± 9.24	49.02 ± 4.91†	57.22 ± 6.33‡	54.57 ± 8.24†
Interincisal, degrees	128.47 ± 9.80	116.98 ± 11.85	122.35 ± 9.00	116.19 ± 13.19
Overbite, mm	3.45 ± 1.91	3.03 ± 2.91	2.24 ± 1.51	2.32 ± 2.17
Overjet, mm	3.70 ± 3.05	6.25 ± 3.30	4.05 ± 2.65	5.22 ± 2.80
Facial height				
UAFH, mm	58.48± 2.82	57.54 ± 3.16	56.61 ± 3.53	58.10 ± 3.32
LAFH, mm	72.07 ± 4.74	72.84 ± 4.61	75.02 ± 2.99	77.80 ± 4.05†‡
AFH ratio	1.23 ± 0.06	1.27 ± 0.12	1.33 ± 0.08*	1.34 ± 0.06†
PFH, mm	91.31 ± 6.18	85.34 ± 5.54	87.76 ± 5.79	88.13 ± 6.40
AFH/PFH	1.43 ± 0.06	1.53 ± 0.10	1.50 ± 0.09	1.55 ± 0.13
Anterior-posterior intermaxillary relation				
ANB, degrees	1.55 ± 3.73	7.24 ± 2.62†	3.88 ± 1.91§	3.73 ± 2.19§
Wit’s, mm	−1.20 ± 3.58	5.85 ± 4.02†	1.25 ± 3.29§	0.25 ± 3.45§
CdGn-CdA, mm	36.01 ± 6.38	28.60 ± 4.86†	33.29 ± 3.78‡	36.20 ± 5.26§
Airway				
Sas, mm	10.20 ± 2.29	9.05 ± 2.85	8.20 ± 2.45	10.70 ± 1.90
Mas, mm	13.10 ± 3.86	10.55 ± 2.99	10.25 ± 3.24	15.75 ± 4.76§¶
Ias, mm	12.60 ± 3.99	8.50 ± 3.95*	9.15 ± 3.29	14.50 ± 5.06§¶
Ph L, mm	58.20 ± 5.67	65.80 ± 9.87*	68.70 ± 5.85†	67.90 ± 5.37†
OPA, cm^2	7.28 ± 1.03	6.79 ± 1.44	6.94 ± 1.41	8.46 ± 1.99
Soft tissue and oral area				
Soft pal L, mm	40.45 ± 3.62	39.86 ± 4.28	47.40 ± 4.85†§	43.80 ± 6.52
SPA, cm^2	3.59 ± 0.50	3.69 ± 0.59	5.14 ± 0.88†§	4.50 ± 1.15‡
Tongue L, mm	79.11 ± 5.87	88.47 ± 4.94†	85.47 ± 6.87*	85.18 ± 6.33*
TA, cm^2	33.12 ± 2.87	35.03 ± 2.36	36.44 ± 2.86*	36.89 ± 3.86†
OA, cm^2	35.86 ± 3.01	38.67 ± 3.32	39.20 ± 3.53*	40.74 ± 3.80†
Hyoid				
Rgn-H, mm	33.80 ± 5.44	38.76 ± 4.46	38.69 ± 8.75	36.51 ± 7.35
C3-H, mm	42.64 ± 3.21	43.75 ± 5.38	46.21 ± 3.93	49.31 ± 5.83†‡
MP-H, mm	11.17 ± 4.70	28.80 ± 7.67†	25.80 ± 11.11†	24.92 ± 6.71†
C3-Rgn, mm	72.80 ± 7.63	68.71 ± 6.23	67.25 ± 5.69	71.60 ± 7.11

Values are expressed as the mean ± SD. Rp indicates retropalatal; Rg, retroglossal; AFH, anterior facial height; UAFH, upper anterior facial height; LAFH, lower anterior facial height; Mas, middle airway space; Ias, inferior airway space; Soft pal L, soft palate length; and SPA, soft palate area.

* $P < .05$, † $P < .01$ compared with control group.

‡ $P < .05$, § $P < .01$ compared with Rp + Rg group.

¶ $P < .01$ compared with Rp group.

The methods for identifying the obstructive sites of OSAS are physical examination, cephalometry, fiberoptic nasopharyngoscopy,[15] fiberoptic endoscopy with the so-called Müller's maneuver,[13] computed tomography (CT), cine CT,[12] dynamic MRI,[11,14,17,18] and multipoint pressure measurements of the pharynx and esophagus.[16] Endoscopic observation during the night provides direct observation of the obstructive site, but it is difficult to describe the findings objectively. Since the shape of upper respiratory tract continuously changes with the respiratory movement, complete obstruction or severe narrowing may be overlooked or not fully detected by imaging techniques lacking sufficient temporal resolution, such as conventional CT or MRI.[12] In this respect, the cine CT[12] and dynamic MRI[18] provide excellent temporal resolution and the ability to define dynamic changes of the upper airway. The dynamic MRI is especially advantageous. It requires no exposure to ionizing radiation and provides a pharyngeal airway view on the sagittal plane, whereas the cine CT is limited to views on the transverse plane.[11,17] Thus, many researchers have reported the superiority of the dynamic MRI for determining the obstructive site of OSAS.[11,14,17,18] Accordingly, we used dynamic MRI and double-checked the findings by endoscopic examination to identify the retropalatal and retroglossal obstruction.

With dynamic MRI, both sagittal and transverse images were obtained. Although sagittal images showed the gross sagittal view of the entire upper airway, they did not show the actual dimensions of the airway, such as asymmetric or vertical narrowing and occlusions.[11] Therefore, we examined images of both the sagittal and transverse sections. By using retropalatal and retroglossal transverse images, the cross-sectional area of the airway could be measured to quantify the degree of narrowing of the airway. Galvin et al[12] measured the cross-sectional area of the upper airway in an OSAS group using ultrafast CT and showed that the minimal cross-sectional area at the retropalatal level (nasopharynx) was 40.4 $\pm$ 44.5 mm^2 (range, 0 mm^2 to 161 mm^2) and at the retroglossal level (oropharynx) was 31.3 $\pm$ 30.2 mm^2 (range, 0 mm^2 to 77 mm^2). They noted that in the control group, the corresponding minimal cross-sectional areas were 177.8 $\pm$ 88.6 mm^2 (range, 74 mm^2 to 433 mm^2) and 134.2 $\pm$ 56.6 mm^2 (range, 42 mm^2 to 240 mm^2). Ikeda et al[20] measured the cross-sectional area of the airway in patients with and without OSAS using an axial view of the dynamic MRI. They reported that the cross-sectional area at the oropharynx level in patients without OSAS varied from 50 mm^2 to 70 mm^2. In the study of Shellock et al[11] using dynamic MRI, the minimal cross-sectional area of the airway of patients with OSAS was larger than 20 mm^2. In the present study, we defined areas measuring less than 20 mm^2 as obstructions and areas measuring greater than 100 mm^2 as nonobstructions based on the previous studies. Since the obstruction was determined without definite numerical criteria, our criteria were sufficient to make a differential diagnosis of the obstructive sites.

Any part of the upper airway might be obstructed, and most patients with OSAS can be categorized into the 3 types of obstruction noted in this study (Rp + Rg, Rp, and tonsillar hypertrophy). Only patients with isolated retroglossal obstruction were lacking in this study. However, the retropalatal region seemed to be an obstructive site of central importance.[4,6] The retropalatal obstructive type is the most common of all of the obstructive types of OSAS.[20,30] This prevalence was seen in the present study. However, we chose only 10 patients for balancing the subject number of the Rp group against the other groups. It has been reported that, similar to hypertrophy of the palatine tonsils in children, hypertrophy of the palatine tonsils in adults might cause OSAS.[31]

Among the many dentofacial characteristics of patients with OSAS described in previous reports, micrognathia, skeletal Class II tendency, and inferior position of the hyoid bone have been the most common features.[3,4,6,9] In the present study, we found that micrognathia and skeletal Class II tendency were dominant features in the Rp + Rg group and were somewhat common in the Rp group. These abnormal facial skeletal patterns might be involved in the airway abnormality since the pharyngeal musculature is intimately related to the bony structure.[3]

Respiratory muscles can be categorized into 2 groups: pumping muscles that generate negative pressure and airway dilating muscles, which are coordinated with high precision. Airway obstruction in patients with OSAS may be caused by a lack of airway-dilating muscle activity and tissue compliance against the intraluminal negative pressure and gravity on inspiration.[32] Among the airway-dilating muscles, the genioglossus, geniohyoid, and mylohyoid muscles are the main large muscles. They are attached to the body and symphysis of the mandible, tongue, and hyoid bone. Thus, retrognathia or micrognathia results in posterior displacement of the tongue, an inferior position of the hyoid bone, and narrowing of the airway, which can predispose to the obstruction of the upper airway.[3] The results of this study suggest that not only the retropalatal obstruction but also retroglossal obstruction have to be examined carefully when a patient with OSAS shows more than a certain level of micrognathia and skeletal Class II tendency. To relieve obstruction at the retroglossal site, site-specific surgery (reduction of the base of the tongue and other procedures) may be effective. Further, it is hypothesized that mandibular advancement therapy such as therapy with an oral appliance or orthognathic surgery would be effective.

In the Rp group, a long and large soft palate (soft pal L, SPA) were the most distinguishing features, and these features have been described as common features among patients with OSAS in previous studies.[4] A long and large soft palate droops down in the supine position during sleep and obstructs the retropalatal space of the upper airway. In this case, among the possible surgical treatments, reducing the volume of the soft palate would be effective. We noted micrognathia and a Class II tendency in the Rp group, which implies that mandibular advancement therapy would be more or less efficient to treat retropalatal obstruction. In the tonsillar hypertrophy group, however, micrognathia was not found.

The hyoid bone plays an important role in maintaining the upper airway dimension.[23] Because it serves as an anchor for the lingual musculature, it has received considerable attention, and inferior positions of this bone have been widely reported in patients with OSAS.[4,6] Recent studies have suggested that the inferior position of the hyoid bone might not be a predisposing factor for airway obstruction, but rather a compensatory response.[8,33] Tourne[34] noted that a drop in the hyoid position represents an attempt to secure a relatively constant anterior-posterior dimension of the airway. In the present study, the inferior position of the hyoid bone was most pronounced in the Rp + Rg group but was also found in the Rp and tonsillar hypertrophy groups as well. Moreover, the oral area (OA) and tongue area (TA) of the Rp + Rg group were not smaller than those of the control group due to the inferior position of the hyoid bone and epiglottis. This was true despite the fact that this group had the smallest body length of the mandible. These results could be explained by the idea that the inferior position of the hyoid bone might be the result of the airway obstruction. Additionally, the oropharynx (Ph L) was longer in the 3 patient groups than in the control group. Due to the longer pharynx, the oropharyngeal area (OPA) of the Rp + Rg group was not smaller than that of the control group in spite of the fact that it was the narrowest. Pae et al[35] explained the longer pharynx in the patient with OSAS as necessary since air in a longer pharynx should travel faster than air in a shorter one because the same volume of tidal air must pass during the same respiratory duration. The faster air stream in a longer pharynx generates more negative intraluminal pressure, which would cause the pharynx to become more collapsible. It is not yet established whether an inferior position of the hyoid bone and a longer pharyngeal length are causes or results of OSAS. These features may be self-reinforcing.

The tendency toward a long face is another important characteristic of patients with OSAS.[3,9] In the present study, a long face was most pronounced in the tonsillar hypertrophy group. In many studies,[36–38] the respiratory problem resulting from tonsillar hypertrophy have been related to a long face. Song and Pae[32] have suggested that enlarged tonsils increase the upper airway resistance, which might facilitate the activity of oropharyngeal muscles (genioglossus, mylohyoid, etc) through mechanoreceptors in the upper airway. This action would bring the tongue forward and downward, opening the mouth for better respiration. And it could also result in a downward and backward rotation of the mandible, an upward and backward growth of the mandibular condyle, an obtuse gonial angle, an anterior open bite, a narrow upper dental arch, and excessive molar height.[39] The results of the present study showed an increased AFH ratio, LAFH, Ii-Ii′, upper anterior dental height (Is-Is′), and gonial (Go) angle and a steeper mandibular plane ($\angle$MP-SN, FMA) in the tonsillar hypertrophy group. In fact, the LAFH was 5 mm longer than that in the control group. However, we did not observe the open bite. This could be explained by the fact that overbite was increased by dentoalveolar compensation, as shown by the elongation of Is-Is′ and Ii-Ii′. Thus, when we treat a patient with OSAS showing a long face, it is necessary to confirm the presence of tonsillar hypertrophy. If it is confirmed, we must consider removal of the tonsils above all things because the long face may not be the cause, but rather the result. In addition, a steep mandibular plane ($\angle$MP-SN, FMA) was also observed in the Rp + Rg group. However, it was considered to be somewhat different from the long face in the tonsillar hypertrophy group. The Rp + Rg group did not have a significantly elongated Ii-Ii′ and LAFH or an increased Go angle, but this group had a very short mandibular ramus height (Cd-Go). These findings suggest that the steep mandibular plane in the Rp + Rg group was related more to a short mandibular ramus than to a long face. But some of the results of the present study could not be explained, such as the absence of any elongation in molar height (Mo-Ms′, Mi-Mi′). There are still many controversies concerning the effects of tonsillar hypertrophy on dentofacial morphology.[36–38,40,41] To clarify these problems, more research is needed with larger numbers of subjects.

One of the biggest drawbacks of this study was the lack of cephalometric radiographs taken in the supine and sleep positions. Because upper airway obstruction usually occurs during sleep, cephalometric radiographs taken in the supine position have the advantage of closely resembling those of the sleep position.[6] It has been reported that when a patient changes posture from erect to supine, the superior airway space (Sas) decreases, and the tongue length and soft palate length increase because of the gravitational pull, but the Ias remains unchanged or widens.[25,39,42] In these respects, Ias was more meaningful than Sas and Mas. The presence of the narrowest Ias in the Rp + Rg group suggests that obstruction of the retroglossal airway space is primarily related to micrognathia and a Class II tendency. But to investigate the facial skeletal pattern, cephalometric radiographs in the erect posture are thought to be more useful. The reproducibility of the head position in the supine position is difficult[6] and, in a study that compared supine and erect cephalometric radiographs, there was no significant difference in the skeletal pattern.[25,42] Moreover, when patients fall asleep, the jaw opens, making it difficult to identify the exact facial skeletal pattern.[43]

We must not disregard the weaknesses of measuring airway space by means of cephalometric radiographs. These radiographs are not capable of providing exact 3-dimensional information and are influenced very much by head position, swallowing, respiration, tension, and other factors. Moreover, the large middle and inferior airway spaces (Mas, Ias) of the tonsillar hypertrophy group in this study were not meaningful because the hypertrophied tonsils narrowed the real airway space.

CONCLUSIONS

Three groups of patients with OSAS were studied to clarify the relationships between the cephalometric characteristics and the obstructive sites. Among the many cephalometric characteristics of patients with OSAS, the features of retrognathia, micrognathia, and skeletal Class II tendency were most pronounced in the Rp + Rg group and pronounced to a somewhat lesser extent in the Rp group. The tendency for a long face was dominant in the tonsillar hypertrophy group, and the presence of a long and large soft palate was very pronounced in the Rp group. All of the groups shared the characteristics of having an inferior position of the hyoid bone. We therefore conclude that many features of OSAS are specifically related to each obstructive type of OSAS.

ACKNOWLEDGEMENTS

The authors want to express their deepest appreciates to Dr Hida W, Associate Professor, Department of Internal Medicine 1, Tohoku University School of Medicine; Dr Okebe S, Department of Internal Medicine 1, Tohoku University School of Medicine; and Dr Higano S, Department of Radiology, Tohoku University School of Medicine for providing an ideal environment for this research to proceed.

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