Original Article

Measurement Techniques Predicting the Effectiveness of an Oral Appliance for Obstructive Sleep Apnea Hypopnea Syndrome

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Abstract: The purpose of this study is to determine the measurement techniques that can predict the effectiveness of an oral appliance (OA) for the treatment of patients with obstructive sleep apnea hypopnea syndrome (OSAHS). Split-night polysomnography and esophageal pressure (Pes) were recorded, and cephalometric tracings were superimposed for 25 OSAHS patients. The patients were classified into good and poor responders according to their apnea hypopnea index (AHI) and mean nadir Pes. When the degree of anterior displacement of the mandible was expressed by vector resolution, it was significantly different between the good and poor responders, whereas there was no significant difference in downward and total mandibular displacement between the two groups. Among the good responders evaluated on the basis of mean nadir Pes, their apnea index, hypopnea index, and mean nadir Pes were significantly different. However, AHI alone cannot predict the effectiveness of OA treatment. Good responders defined by mean nadir Pes also had short soft palates and a wide pharyngeal airway space. Conversely, no significant differences were observed in these parameters when good responders and poor responders are defined by AHI. Logistic regression analysis revealed that the degree of anterior displacement of the mandible showed a significant odds ratio of 1.97. In conclusion, evaluations based on Pes and analyses of the mandibular displacement expressed by vector resolution using a cephalometric superimposition technique can provide important clinical information in evaluation measurements and may be useful for the prediction of the efficacy of OA treatment for patients with OSAHS. (*Angle Orthod* 2005;75:1003–1011.)

Key Words: Obstructive sleep apnea hypopnea syndrome; Oral appliance; Cephalometrics; Esophageal pressure

INTRODUCTION

Obstructive sleep apnea hypopnea syndrome (OSAHS) is characterized by the repeated obstruction or reduction of breathing during sleep. This syndrome is caused by pharyngeal collapse against increasing respiratory effort during sleep. OSAHS leads to the deterioration of the quality of sleep associated with the clinical complaint of excessive daytime sleepiness and to unfavorable effects on the cardiovascular system.

Noninvasive treatments for OSAHS are the application of nasal continuous positive airway pressure and an oral appliance (OA). The OA maintains the mandible in an anterior position during sleep and is

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FIGURE 1. The structure of an oral appliance.

attractive for the treatment of OSAHS because it is simple to use. Research data concerning OA treatment have been accumulating for the last decade, but the characteristics of patients who would benefit from OA treatment as the first choice have not been determined sufficiently. Only a few studies estimated the effectiveness of OA by measuring esophageal pressure (Pes). In addition, several previous reports on the relationship between mandibular displacement and the efficacy of OA suggest that the efficacy of OA treatment depends on the change in the mandibular position and that an OA causing no protrusion was not effective.[1–3] However, most of these studies provided no two-dimensional and quantitative analyses of mandibular displacement.

The purpose of this study was to determine measurement techniques that can predict the efficacy of OA treatment.

SUBJECTS AND METHODS

Study subjects and OA treatment

The study population consisted of 25 Japanese male OSAHS patients. Patients were excluded from the study if there was evidence of severe periodontal diseases or they were edentulous. The study protocol was approved by the Institutional Ethics Committee of our institute, and informed consent was obtained from all patients.

A custom-made OA made of self-cured acrylic resin was used for each patient (Figure 1). After taking impressions of the maxillary and mandibular dental arches, the maxillary and mandibular portions were prepared separately and joined in the patient's mouth so that the mandible would be in an anteriorly protruding position. The degree of mandibular protrusion was set at slightly less than the maximum anterior position so as not to exceed the limit the patient could comfortably tolerate. Usually, the position was determined at 70–80% of the distance between the intercuspal position and complete protrusion position. If the patient complained of any discomfort in the temporomandibular joints or muscles after using the OA for one week, the maxillary and mandibular portions were separated and joined again at less-protruding positions. This adjustment was repeated until the patient could wear the OA continuously without any problems, usually three times on average, for six weeks, before the sleep study was conducted.

Polysomnography and evaluation of OA treatment

Split-night polysomnography (PSG) was carried out, and Pes was recorded in all patients. The total recording time for split-night study was nine hours, from nine PM to six AM. After the attachment of the sensors and electrodes, a recording was first carried out without the OA to determine the severity of OSAHS. Diagnostic PSG was usually continued for the initial four hours until the detection of at least one rapid eye movement sleep period. The OA was set for the latter half of the night to estimate the improvement of OSAHS.

Standard polysomnographic equipment (Alice 3: Healthdyne Technologies, Marietta, Ga) was used. The predominant sleep stage was scored according to the international standard criteria of Rechtschaffen and Kales. Potential apneas were identified as airflow $<$20% of baseline, and hypopneas were identified as airflow of $<$70% of the baseline associated with either an oxygen desaturation of $>$3% or an arousal for at least 10 seconds. Arousals were identified according to the criteria of the American Sleep Disorders Association.

Pes was recorded simultaneously using 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 four channel A/D converter (Power Lab/4s: ADI Instrument Pty. Ltd., Castle Hill, Australia).

Criteria for classification of good responders and poor responders defined by apnea hypopnea index and mean nadir Pes

The patients were classified into good responders and poor responders according to apnea hypopnea index (AHI) and mean nadir Pes. Good responders defined by AHI were defined as showing a $>$50% reduction in AHI and an AHI $<$10 events/h when using OA. Those who did not satisfy these criteria were defined as poor responders. Good responders defined by

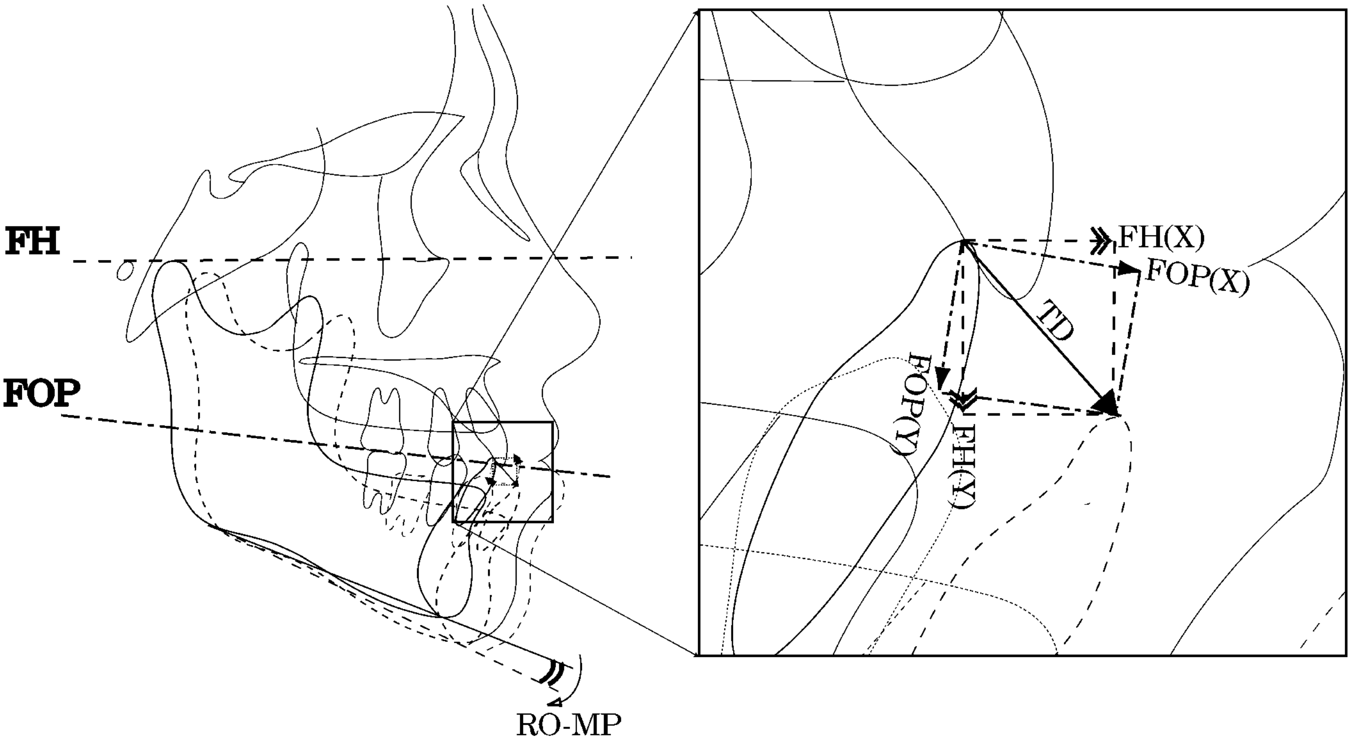

FIGURE 2. Superimposed lateral cephalometric radiograph tracing. Solid line, intercuspal position; dotted line, OA-wearing position.

mean nadir Pes showed $<$20 cm H_2O when using OA, and those who did not satisfy this criterion were considered poor responders.

Cephalometric analysis

Lateral cephalometric radiographs were taken of the intercuspal position, wide-open mouth position, and OA-wearing position, all in an upright position. The wide-open mouth view was subserved to trace the mandibular condyle and all the teeth in the intercuspal position. To evaluate the craniofacial morphology, 41 cephalometric variables were measured, as described in our previous study.[4]

To assess the change in mandibular position, the cephalometric tracings at the intercuspal position and the OA-wearing position were superimposed to match the bone structures except the mandible. The change in the mandibular position was represented by the displacement of the lower central incisor tip and the rotation of the mandibular plane angle (Figure 2). The Frankfort horizontal plane (FH) was adopted as the anteroposterior reference plane for the evaluation of the displacement of the lower central incisor tip.

We also used the functional occlusal plane (FOP) in the evaluation, which was the line connecting the middle point of the occlusal surface of the maxillary first molars and the middle point of the line between the maxillary and mandibular first premolar cusps. Total mandibular displacement (TD), anterior displacement on FH (FH[X]), anterior displacement on FOP (FOP[X]), downward displacement in a direction perpendicular to FH (FH[Y]), downward displacement in a direction perpendicular to FOP (FOP[Y]), and rotation of the mandibular plane angle were measured to evaluate mandibular displacement.

Statistical analyses

All descriptive statistics are presented as median and interquartile range (IQR). Descriptive statistics were calculated for each variable, and unpaired and paired subjects were evaluated by the Mann-Whitney *U*-test and Wilcoxon *t*-test, respectively, and all *P* value tests were two-tailed. A *P* value of less than .05 was considered to indicate statistical significance.

Logistic regression analysis was adopted to verify the possibility of variables, which were detected by bivariate analysis and were estimated as clinically important, to predict the good response to OA treatment. Statistical analyses were performed on a personal computer using the statistical package SPSS (SPSS Inc, Release 12.1).

RESULTS

The PSG study of 25 patients showed they had moderate to severe OSAHS with median (IQR) AHI of 37.5(26.8)/h, and median (IQR) mean nadir Pes of 31.7(17.6) cm H_2O. OA treatment significantly reduced

TABLE 1. The Comparison of Physiologic and PSG Parameters Without OA Between GRs and PRs Defined by (A) AHI and (B) MNPes[a]

	GR			PR	
	Median	IQR[b]		Median	IQR
A[c]					
Age (y)	51.0	18.5	$P = .25$	57.0	18.5
BMI (kg/m^2)	23.8	5.5	$P = .94$	28.2	12.4
AHI (/h)	35.9	16.9	$P = .22$	51.6	28.9
Nadir Pes (cm H_2O)	31.2	15.3	$P = .83$	33.4	20.1
Apnea index (/h)	13.1	20.1	$P = .17$	26.8	38.4
Hypopnea index (/h)	19.6	13.7	$P = .31$	8.7	19.8
ODI $>$ 3% (/h)	18.6	17.4	$P = .35$	25.4	16.9
Slow-wave sleep (%)	6.1	10.4	$P = .033$*	0.0	3.4
Stage REM (%)	8.0	13.4	$P = .83$	3.5	15.3
Arousal index (/h)	27.0	10.3	$P = .55$	29.7	23.6
B[d]					
Age (y)	52.0	18.5	$P = .85$	52.5	21.3
BMI (kg/m^2)	23.8	4.6	$P = .94$	25.5	3.2
AHI (/h)	31.7	14.2	$P = .14$	47.2	26.7
Nadir Pes (cm H_2O)	28.1	7.4	$P = .039$*	41.5	28.0
Apnea index (/h)	7.5	12.1	$P = .009$**	29.0	34.7
Hypopnea index (/h)	20.3	7.1	$P = .025$*	8.7	15.5
ODI $>$ 3% (/h)	18.6	16.0	$P = .83$	22.9	21.0
Slow-wave sleep (%)	5.2	4.4	$P = .17$	0.0	5.6
Stage REM (%)	7.6	13.2	$P = .81$	5.7	14.6
Arousal index (/h)	30.9	16.1	$P = .67$	27.9	16.3

[a] PSG indicates split-night polysomnography; IQR, interquartile range; OA, oral appliance; GR, good responder; PR, poor responder; AHI, apnea hypopnea index; MNPes, mean nadir esophageal pressure; BMI, body mass index; and REM, rapid eye movement.
[b] IQR = (75% percentile) − (25% percentile).
[c] AHI: GR (n = 15); PR (n = 10).
[d] MNPes: GR (n = 11); PR (n = 14).

median (IQR) AHI to 8.2(15.9)/h ($P < .001$, Wilcoxon *t*-test), although 10 of the 25 patients did not satisfy the criteria of showing a >50% reduction in AHI and an AHI of <10/h for identifying poor responders defined by AHI in our protocol. OA treatment also reduced median (IQR) to 22.9(8.2) cm H_2O percentiles ($P < .001$, Wilcoxon *t*-test), although 14 of the 25 patients did not satisfy the criterion of the mean nadir Pes of <20 cm H_2O for identifying poor responders defined by mean nadir Pes in our protocol.

Table 1 shows the comparison of physiologic and PSG parameters without OA between good and poor responders defined by AHI and mean nadir Pes. There were no differences in age and body mass index between good and poor responders in AHI and mean nadir Pes. In terms of mean nadir Pes, good responders had a lower apnea index (AI), higher hypopnea index (HI), and lower mean nadir Pes than poor responders, whereas there was no significant difference in AHI between the two groups. AI showed the largest significant difference ($P < .01$) among these parameters. In terms of AHI, there was a significant difference only in slow-wave stages (stages 3 and 4) between good and poor responders.

The comparisons of the craniofacial morphology and the displacement of the mandible with OA between good and poor responders are shown in Tables 2A,B. The morphological analysis of the cephalometric radiographs revealed that although there were only a few parameters that showed significant differences, good responders defined by mean nadir Pes had short soft palates and a wide superior airway space and inferior airway space. A significant difference was observed in Mo-Mi′ between good and poor responders defined by AHI and mean nadir Pes. Good responders defined both by AHI and mean nadir Pes had less erupted mandibular molars. Good responders defined by AHI had incisors greatly inclined toward the lips (L1 to MP).

When the degree of anterior displacement was expressed by vector resolution, it was significantly different between good and poor responders defined both by AHI and mean nadir Pes. Good responders tended to have significantly more anterior displacements on FH(X) and FOP(X). On the other hand, there were no significant differences in the total displacement (TD) and downward displacement (FH[Y], FOP[Y]) between good and poor responders defined both by AHI and mean nadir Pes. However, the rotation of the mandibular plane angle was smaller in good responders defined by mean nadir Pes. The comparison study revealed that AI, mean nadir Pes, and the degree of anterior displacement of the mandible (FH[X]) were important parameters that predict the effectiveness of OA in the case of good responders defined by mean nadir Pes.

For the next series of studies, a logistic regression analysis for good responders defined by mean nadir Pes was performed using these three variables. The odds ratios for each of the three predictive variables before and after adjustments for one another are shown in Table 3. The degree of anterior displacement of the mandible (FH[X]) showed a significant corrected odds ratio of 1.97 (95% confidence interval, 1.06 to 3.63; $P < .031$), whereas the corrected odds ratios of AI and mean nadir Pes were not significant.

DISCUSSION

Importance of Pes measurement

Cephalometrics has been used in a number of studies to predict treatment effects with OA. However, the results vary between studies. Menn et al[5] and Ferguson et al[6] have reported that evaluations using cephalometric variables cannot predict the treatment success.

On the contrary, there are many studies that concluded that evaluations using cephalometric variables are helpful to predict response to OA treatment. Eveloff et al[7] have reported that mandibular-hyoid distance was smaller in the good responders group. They also stated that posttreatment AHI could be predicted by baseline AHI and four cephalometric variables such as SNA, posterior airway space, mandibular-hyoid distance, and posterior facial height. Mehta et al[8] have formulated a congeneric model for outcome prediction using baseline AHI, neck circumference, and two cephalometric variables. Liu et al[9] have reported that the OA is more effective in younger and less obese patients with a long maxilla, a small oropharynx, a smaller overjet, less erupted maxillary molars, and a large ratio of vertical airway length to the cross-sectional area of the soft palate. Marklund et al[10] reported that apnea reduction using OA is associated with a normal mandibular plane angle and a small anterior lower anterior facial height. Skinner et al[11] reported that an increased perpendicular distance between the hyoid bone and a mandibular plane is the only cephalometric variable associated with a good clinical outcome.

In this study, we found that there were significant differences in soft palate length, superior airway space, and inferior airway space between good and poor responders defined by mean nadir Pes but none between good and poor responders defined by AHI. These morphological characteristics of a long soft palate and narrow airway space may promote occlusion with increasing respiratory effort. The upper and inferior airways may collapse both anteroposteriorly and laterally. Therefore, in the case of a small airway, OA treatment is insufficient to maintain patency.

Good responders defined both by AHI and mean nadir Pes had less erupted mandibular molars than poor responders. It may be because the amount of downward component of the mandible was large and the forward displacement of the mandible on the reference plane was small in patients with a high molar height. Although multivariate analysis did not show any significant corrected odds ratio, the comparison study of the severity of OSAHS between good and poor responders defined by mean nadir Pes indicated that AI, HI, and mean nadir Pes were significant in the evaluation of the efficacy of OA treatment compared with AHI.

Good and poor responders defined by mean nadir Pes demonstrated significant differences in these variables, whereas only the slow-wave sleep showed a significant difference between these groups defined by AHI. These results suggest that Pes measurement should be performed concomitantly with PSG to improve the diagnostic accuracy for determining the indications for treatment. The Pes swing at the inspiratory peak during sleep is an absolute value and rarely influenced by interscorer differences or the method of detection. An increasing negativity of Pes directly reflects the energy of respiratory effort during sleep and is thus important in the evaluation of sleep-related breathing events.[12]

Our previous study demonstrated that upper airway surgeries such as uvulopalatoplasty or tonsillectomy change apneas to hypopneas, reducing Pes rather than AHI. This suggests that AHI alone does not always reflect the severity of the disease in patients with OSAHS.[13]

Importance of forward displacement of mandible

In this study, the adaptation of FH and FOP was beneficial as reference planes and vector resolution, respectively. The FH was chosen as the base plane of the anteroposterior displacement of the mandible because when the cephalometric radiographs are taken at the natural head position, the FH will be the anatomical plane closest to the true horizontal plane.[14] The FOP was chosen because it can eliminate any positional variations of the upper and lower incisors and can be used a standard to determine the mandibular position of OA by the naked eye at the chairside without using a cephalometric tracing. One-dimensional vectors such as TD may not be appropriate because the displacement of the mandible showed complicated three-dimensional pathways such as right/left, forward,

TABLE 2A. The Comparisons of Cephalometric Variables Between Good and Poor Responders Defined by AHI[a]

	Good Responder (n = 15)			Poor Responder (n = 10)	
Variables	Median	IQR[b]		Median	IQR
Displacement of the mandible					
FH(X) (mm)	3.2	2.6	*P* = .008**	1.4	1.7
FOP(X) (mm)	6.1	3.1	*P* = .005*	2.8	2.2
FH(Y) (mm)	10.0	4.3	*P* = .765	9.4	2.5
FOP(Y) (mm)	8.7	4.2	*P* = .978	8.5	2.2
TD (mm)	11.0	2.1	*P* = .428	9.9	2.8
Ro-MP (°)	3.0	1.8	*P* = .108	4.2	1.5
Cr base					
S-N (mm)	70.2	3.9	*P* = .397	70.7	4.1
S-Ba (mm)	51.1	4.3	*P* = .177	48.5	4.2
<Ba-S-N (°)	133.6	7.0	*P* = .160	128.6	8.4
Maxilla					
SNA (°)	82.6	5.4	*P* = .062	84.1	3.1
A′-Ptm′ (mm)	51.1	7.7	*P* = .643	51.7	3.0
Cd-A (mm)	92.7	11.6	*P* = .531	93.9	4.4
Is-Is′ (mm)	30.9	3.6	*P* = .531	30.7	2.2
Mo-Ms′ (mm)	25.1	3.2	*P* = .935	25.3	1.8
Mandible					
SNB (°)	76.7	3.5	*P* = .080	79.5	5.7
Cd-Gn (mm)	121.5	9.8	*P* = .461	126.0	10.3
Go-Me (mm)	76.5	6.1	*P* = .643	77.8	2.0
Cd-Go (mm)	61.8	5.9	*P* = .177	66.1	7.4
Ii-Ii′ (mm)	48.9	6.0	*P* = .605	49.4	2.1
Mo-Mi′ (mm)	36.1	3.9	*P* = .023*	39.8	3.6
Go angle (°)	121.3	10.7	*P* = .428	122.7	10.2
<MP-SN (°)	39.4	6.2	*P* = .129	35.8	9.3
FMA (°)	29.5	5.4	*P* = .567	30.2	11.2
Dental					
U1 to SN (°)	107.8	16.7	*P* = .849	107.5	4.3
U1 to FH (°)	114.5	17.6	*P* = .978	113.4	2.5
L1 to MP (°)	93.6	11.9	*P* = .048*	102.4	10.2
FMIA (°)	56.2	9.4	*P* = .338	54.4	1.9
Interincisal (°)	123.2	22.5	*P* = .567	120.7	7.2
Overbite (mm)	3.0	1.8	*P* = .495	2.8	2.0
Overjet (mm)	4.0	3.5	*P* = .311	3.0	1.7
Facial height					
UAFH (mm)	58.8	3.8	*P* = .643	58.4	3.5
LAFH (mm)	76.2	7.4	*P* = .935	77.2	5.1
FH (ratio)	1.3	0.2	*P* = .894	1.3	0.2
PFH (mm)	86.7	7.2	*P* = .461	88.6	3.5
AFH/PFH (ratio)	1.6	0.1	*P* = .311	1.5	0.1
Anterior posterior intermaxillary relation					
ANB (°)	5.3	3.5	*P* = .978	3.8	3.7
Wit's appraisal (mm)	1.0	3.5	*P* = .683	0.0	5.3
CdGn-CdA (mm)	32.9	6.1	*P* = .849	32.3	4.9
Airway		0.0			
Sas (mm)	10.1	3.8	*P* = .103	9.0	2.0
Mas (mm)	12.0	5.5	*P* = .196	10.5	3.6
Ias (mm)	12.0	4.7	*P* = .436	10.0	4.3
Soft tissue					
Soft pal L (mm)	42.7	5.6	*P* = .428	43.9	6.4
Tongue L (mm)	83.9	5.4	*P* = .643	83.3	11.2
Hyoid					
Rgn-H (mm)	41.4	4.6	*P* = .567	43.9	10.4
C3-H (mm)	43.4	7.5	*P* = .397	45.4	8.0
MP-H (mm)	25.1	5.3	*P* = .643	27.0	9.0
C3-Rgn (mm)	69.4	11.2	*P* = .935	69.4	10.8

[a] AHI indicates apnea hypopnea index; FH, Frankfort horizontal plane; FOP, functional occlusal plane; and IQR, interquartile range.
[b] IQR = (75% percentile) − (25% percentile).

TABLE 2B. The Comparisons of Cephalometric Variables Between Good and Poor Responders Defined by mean nadire Pes[a]

	Good Responder (n = 11)			Poor Responder (n = 14)	
Variables	Median	IQR[b]		Median	IQR
Displacement of the mandible					
FH(X) (mm)	4.7	1.8	*P* = .006**	2.1	1.3
FOP(X) (mm)	6.9	2.3	*P* = .003**	3.6	2.5
FH(Y) (mm)	10.0	2.6	*P* = .609	9.8	3.6
FOP(Y) (mm)	8.6	2.9	*P* = .317	9.4	3.6
TD (mm)	10.3	1.8	*P* = .609	10.0	3.9
Ro-MP (°)	3.1	1.4	*P* = .041*	3.9	1.4
Cr base					
S-N (mm)	69.0	3.5	*P* = .107	71.1	4.7
S-Ba (mm)	51.1	3.8	*P* = .434	48.9	6.3
<Ba-S-N (°)	131.6	8.0	*P* = .936	133.7	8.5
Maxilla					
SNA (°)	82.7	4.7	*P* = .317	83.7	4.6
A′-Ptm′ (mm)	49.6	7.3	*P* = .434	51.5	2.4
Cd-A (mm)	90.2	10.7	*P* = .149	93.8	6.6
Is-Is′ (mm)	30.5	2.3	*P* = .432	31.4	2.8
Mo-Ms′ (mm)	25.1	1.4	*P* = .344	25.4	3.3
Mandible					
SNB (°)	77.4	4.5	*P* = .809	77.3	5.0
Cd-Gn (mm)	121.5	9.8	*P* = .811	123.0	10.9
Go-Me (mm)	77.7	5.6	*P* = .936	77.6	4.3
Cd-Go (mm)	61.5	7.0	*P* = .609	65.4	4.2
Ii-Ii′ (mm)	49.9	5.4	*P* = .851	49.0	3.1
Mo-Mi′ (mm)	36.1	3.2	*P* = .005**	39.8	4.8
Go angle (°)	127.2	9.3	*P* = .107	120.3	13.0
<MP-SN (°)	37.6	6.2	*P* = .403	36.4	10.0
FMA (°)	30.0	5.7	*P* = .501	29.5	10.0
Dental					
U1 to SN (°)	111.4	15.9	*P* = .467	106.6	9.1
U1 to FH (°)	118.8	16.2	*P* = .344	112.7	4.3
L1 to MP (°)	94.9	11.6	*P* = .166	99.6	12.3
FMIA (°)	55.6	8.8	*P* = .687	54.4	6.1
Interincisal (°)	114.8	25.4	*P* = .609	121.7	6.9
Overbite (mm)	3.0	2.3	*P* = .687	2.8	1.9
Overjet (mm)	2.5	2.0	*P* = .149	4.0	3.1
Facial height					
UAFH (mm)	58.8	3.7	*P* = .291	58.4	3.2
LAFH (mm)	76.2	4.5	*P* = .687	77.2	8.1
FH (ratio)	1.3	0.2	*P* = .373	1.3	0.2
PFH (mm)	87.8	5.6	*P* = .687	87.2	9.4
AFH/PFH (ratio)	1.5	0.1	*P* = .727	1.6	0.1
Anterior posterior intermaxillary relation					
ANB (°)	3.1	2.5	*P* = .149	5.8	4.0
Wit's appraisal (mm)	−0.5	3.8	*P* = .809	1.8	5.6
CdGn-CdA (mm)	35.0	5.9	*P* = .149	30.7	7.1
Airway		0.0			0.0
Sas (mm)	10.0	3.0	*P* = .018*	7.5	3.5
Mas (mm)	13.5	3.0	*P* = .183	11.8	3.9
Ias (mm)	12.5	4.0	*P* = .044*	9.0	4.5
Soft tissue					
Soft pal L (mm)	39.1	6.0	*P* = .018*	44.3	4.3
Tongue L (mm)	83.0	4.2	*P* = .609	85.0	11.8
Hyoid					
Rgn-H (mm)	41.8	7.5	*P* = .572	41.2	7.5
C3-H (mm)	46.5	6.9	*P* = .267	43.0	8.0
MP-H (mm)	25.3	4.4	*P* = .809	24.3	6.7
C3-Rgn (mm)	75.6	10.5	*P* = .202	67.2	10.9

[a] FH indicates Frankfort horizontal plane; FOP, functional occlusal plane; IQR, interquartile range; and Pes, esophageal pressure.
[b] IQR = (75% percentile) − (25% percentile).

TABLE 3. Logistic Regression Analysis for GRs Defined by MNPes[a]

Variables	OR for GRs Defined by MNPes (95% CI)	*P* Value	Corrected OR for GRs Defined by MNPes (95% CI)	Adjusted *P* Value
FH(X)	2.34 (1.20–4.52)	.012*	1.97 (1.07–3.63)	.031*
AI	0.92 (0.86–0.99)	.033*	0.98 (0.90–1.06)	.577
MNPes	0.92 (0.84–0.99)	.048*	0.92 (0.80–1.04)	.176

[a] GR indicates good responders; MNPes, mean nadir esophageal pressure; OR, odds ratio; CI, confidence interval; FH, Frankfort horizontal plane; AI, apnea index.

and downward directions and rotation. The displacement of the mandible on the sagittal plane should be measured for the OA treatment at least two dimensionally.

On the FH(X) and FOP(X), the degrees of anterior displacement of the mandible were shown to be significantly larger in good responders than poor responders defined both by AHI and mean nadir Pes. Furthermore, logistic regression analysis revealed that the degree of anterior displacement of the mandible showed a significant corrected odds ratio of 1.97.

Although the mechanical influences of mandibular advancement on pharyngeal patency are still unexplained, the reason is speculated as follows. Because the tongue is connected to the mandible, the forward displacement of the mandible caused by OA may improve the airway patency of the retroglossal space by reducing folds and compression in the upper airway. In addition, mandibular advancement was confirmed to enlarge not only the retroglossal space but also the retropalatal space. Isono et al[15] have explained the mechanism in their hypothesis that the lateral wall of the soft palate anatomically connects to the base of the tongue through the palatoglossal arch, so the mandibular advancement stretches the soft palate through the mechanical connection, stiffening the velopharyngeal segment.

In this study, TD and downward displacement were not significantly different between good responders and poor responders defined both by AHI and mean nadir Pes. A recent study using OAs inducing four and 14 mm of interincisal opening revealed the absence of correlation between the degree of bite opening and a high treatment efficacy identified in terms of AHI, although vector resolution methods were not performed.[16] These findings suggest that longitudinal downward vectors or total displacement vectors cannot predict the efficacy of OA treatment compared with anterior displacement. However, the rotation of the mandibular plane angle was shown to be significantly smaller in good responders defined by mean nadir Pes. It may be influenced by the downward rotation of the mandible, which causes the downward displacement and also posterior displacement on the reference plane, so the forward displacement becomes relatively small.

CONCLUSIONS

- Because some variables with insignificant differences when defining poor responders in terms of AHI showed significant differences when defining in terms of mean nadir Pes, Pes measurement must provide important clinical information.
- Multivariate analysis demonstrated that the anterior displacement of the mandible is the most accurate factor predicting the efficacy of OA treatment.
- The evaluation techniques using cephalometric superimposition to analyze the changes in the mandibular position expressed by vector resolution on the reference plane may be useful for the prediction of the efficacy of OA treatment for patients with OSAHS.

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