Original Article

An evaluation of two different mandibular advancement devices on craniofacial characteristics and upper airway dimensions of Chinese adult obstructive sleep apnea patients

Finn Geoghegan[a]; Anika Ahrens[b]; Colman McGrath[c]; Urban Hägg[d]

ABSTRACT

Objectives: To evaluate the effects of two different mandibular advancement devices (MADs) on craniofacial characteristics and upper airway dimensions of Chinese adult patients with obstructive sleep apnea (OSA).

Materials and Methods: Forty-five patients with OSA were recruited as part of a prospective randomized crossover trial for treatment with two different MADs. Lateral cephalograms were taken, and the Epworth Sleepiness Scale and the Sleep Apnea Quality of Life Index were completed at baseline.

Results: The Apnea-Hypoxia Index was highly significantly reduced with the monoblock ($P < .001$) and significantly reduced with the twin block ($P < .01$). The monoblock demonstrated a superior result than the twin block ($P < .05$). A significant reduction was found in the distances between the hyoid bone to retrognathia (monoblock, $P < .01$; twin block, $P < .001$) as well as the distance between the hyoid bone and mandibular plane angle ($P < .001$). Furthermore, soft palate length increased significantly ($P < .05$) with both MADs. However, the changes did not differ in favor of either MAD.

Conclusion: Monoblock was the better MAD to improve OSA severity. No difference could be found in changes of subjective OSA indicators. Significant but similar cephalometric changes were observed, indicating both MADs alter the position of the surrounding musculature and improve upper airway patency. Therefore, the different design features of the MADs suggest an impact on some OSA indicators. (*Angle Orthod.* 2015;85:962–968.)

KEY WORDS: Sleep apnea; MAD; Adult; Chinese

INTRODUCTION

Obstructive sleep apnea (OSA) is the most common sleep-related breathing disorder. Population-based studies estimate a prevalence of approximately 3% to 7% in middle-aged men and 2% to 5% in middle-aged women.[1–4] However, the lack of awareness among the general public and health professionals means an estimated 80% to 90% of people with OSA are as yet undiagnosed.[4,5] OSA is increasingly recognized as a serious public health issue[6] as there is growing evidence that untreated OSA is associated with a range of adverse cardiovascular health outcomes, such as hypertension,[7] stroke, congestive heart failure, arterial fibrillation[8]; increased risk of motor vehicle accidents[9]; and excessive daytime sleepiness and impaired quality of life and social life.[8,10]

Continuous positive air pressure (CPAP) is the current treatment of choice as it has been successfully used to treat the symptoms of most patients with

[a] Former postgraduate student, Department of Orthodontics, Faculty of Dentistry, Prince Philip Dental Hospital, University of Hong Kong, HKSAR, China.

[b] Former postgraduate student, Department of Dental Public Health, Faculty of Dentistry, Prince Philip Dental Hospital, University of Hong Kong, China.

[c] Professor, Department of Dental Public Health, Faculty of Dentistry, Prince Philip Dental Hospital, University of Hong Kong, HKSAR, China.

[d] Emeritus Professor, Department of Orthodontics, Faculty of Dentistry, Prince Philip Dental Hospital, University of Hong Kong, HKSAR, China.

Corresponding author: Dr Finn Geoghegan, Departments of Orthodontics and Dental Public Health, Faculty of Dentistry, Prince Philip Dental Hospital, University of Hong Kong, 34 Hospital Road, Hong Kong, HKSAR, China
(e-mail: fgeoghegan@yahoo.com)

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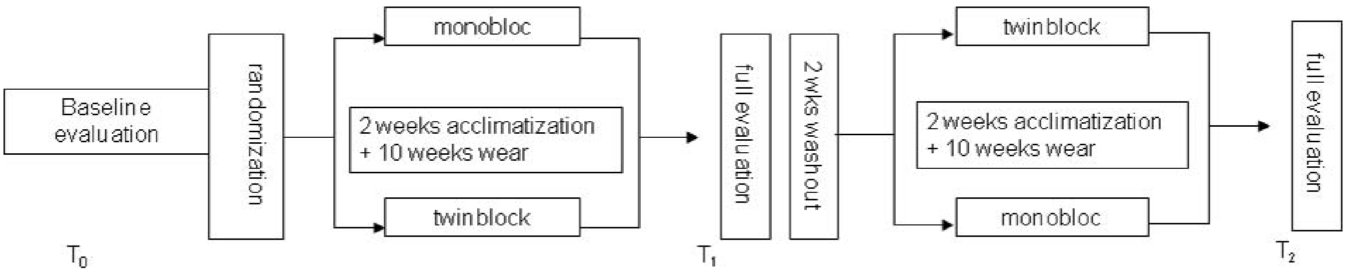


Figure 1. Schematic diagram summarizing the study design.

OSA[11]; however, because of cumbersome nature, many patients fail to comply. This, combined with poor tolerability, often outweighs perceived treatment benefit.[8,10,12–14] Oral appliances offer a noninvasive treatment option for patients with OSA; they are considered less cumbersome than CPAP[15] and evidence of similar efficacy as CPAP supports the use of oral appliances in clinical practice.[3]

Lateral cephalographs have been extensively used in orthodontics to provide information about the sagittal and vertical relationships of the craniofacial skeleton, the soft tissue profile, the dentition, the pharynx, and the cervical vertebrae. The relationships among these structures are examined by linear or angular measurements.[16] Attempts have been made to determine any morphologic associations with OSA using cephalometry, and some have proposed that it be used as an assessment aid.[17–19]

Several groups have studied the anatomy of the upper airways using more sophisticated techniques, such as cone-beam computed tomography, fluoroscopy, acoustic reflection, fiber-optic pharyngoscopy, and magnetic resonance imaging.[20] However, these techniques may be too time consuming and expensive for routine clinical use and may require relatively high doses of radiation. The findings of studies using lateral cephalometry compared with studies that used more sophisticated techniques indicate that cephalometry can be used to accurately evaluate the craniofacial soft and hard tissue structures.[21] A 2005 American Academy of Sleep Medicine report suggested using cephalograms at the initial dental examination of every patient receiving an oral appliance.[22]

In this study, lateral cephalograms were used to provide a simple, inexpensive, low-radiation, readily accessible method to evaluate the treatment effects of two different mandibular advancement devices (MADs) on craniofacial characteristics and upper airway dimensions of Chinese adult patients with OSA. The effects on subjective OSA indicators were also examined so as to evaluate how OSA can affect patients' quality of life; however, this is beyond the scope of this article and can be found in a separate report.[23]

MATERIALS AND METHODS

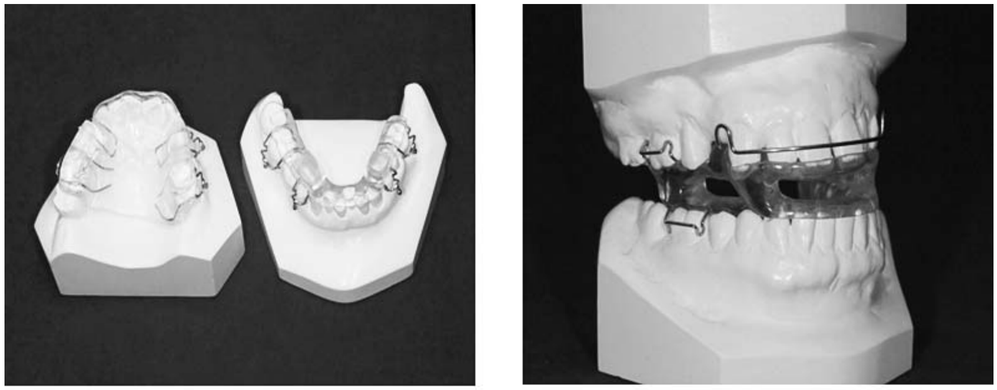
This single-blind, prospective, randomized, crossover trial involved a sample of 45 consecutively referred Chinese adult patients with OSA (confirmed by overnight polysomnography) from the Queen Mary Hospital Sleep Disorders Centre for treatment with oral appliances at Prince Philip Dental Hospital, Faculty of Dentistry, the University of Hong Kong. By setting the significance level at .05 and a sample power of 80% and allowing for a dropout rate of 15%, a sample size of about 45 subjects was deemed adequate. Patients were block randomized to one of two study arms by a computer-generated randomization schedule (Figure 1). Ethical approval was obtained from the ethics institutional review board of the University of Hong Kong/Hospital Authority Hong Kong West Cluster (UW 08-058). Participants gave their verbal and written consent. The study was registered with the HKU Clinical Trial Register (HKCTR-699) and the US National Institutes of Health Clinical Trial Register (NCT01209468).

Clinical and Subjective Assessment

OSA was established by overnight polysomnography at baseline and after treatment arm 1 and treatment arm 2. The primary outcome measure was the indicator of severity, the Apnea-Hypopnea Index (AHI). Subjective treatment efficacy was assessed by the disease-specific Sleep Apnea Quality of Life Index and daytime sleepiness was measured using the Epworth Sleepiness Scale at the same time points.

Oral Appliances

Both oral appliances evaluated in this study were custom-made mandibular advancement devices (MADs) with a laboratory-controlled protrusion. They were fabricated at the dental laboratory of the Faculty of Dentistry at the University of Hong Kong by a designated dental technician from individually made plaster casts taken by the treating orthodontist at



2.a) Twinblock appliance 2.b) Monobloc appliance

Figure 2. Images of the mandibular advancement devices used in the study.

baseline (T_0) and the end o arm 1 (T_1). In order to standardize the amount of protrusion and the vertical opening for each patient, the same wax-bite registration taken at T_0 was used to fabricate both appliances. The wax bite followed the guidelines proposed by Bonham et al.[24] Patients were asked to open and protrude the mandible as far as possible and then to relax and retract it slowly to a comfortable position. This action was repeated several times until patients were able to obtain the same position without difficulty. The bite registration of the protruded mandible was then taken with warm softened wax. The MADs were two-piece (twin block; Figure 2A) and one-piece (monoblock; Figure 2b) appliances made out of dental acrylic.

Lateral Cephalograms

Lateral cephalometric radiographs (Orthoralix SD Ceph, Gendex Dental Systems, Hatfield, Penn, USA) were taken at baseline, after treatment arm 1, and after treatment arm 2 with patients were standing in an upright position with natural head posture and posterior teeth in light contact at a standardized exposure distance of 5 feet. To determine the sagittal and vertical dimensions, radiographs were traced on acetate paper. All cephalometric measurements (Figure 3; Table 1) were made twice at an interval of 10 days, and the mean values from the two tracings were used for statistical analysis. To determine the method error, 10 radiographs were randomly selected and traced twice at 10-day intervals. The mean values from the first two tracings (all radiographs), together with the mean values of the second two tracings (10 randomly selected radiographs), were applied to the formula $SE = \sqrt{\sum d^2 \div 2n}$ in which $\sum d^2$ stands for the sum of the squared differences between the two mean values and n is the number of double measurements. For linear measurements, 0.4 mm ($P > .1$) was set as method error, and for angular measurements it was 0.5° ($P > .1$).

Statistical Analysis

After calibration, the same orthodontist traced and measured each cephalometric radiograph. Statistical analysis was carried out using the software Statistical Package for Social Sciences (SPSS version 16, SPSS Inc, Chicago, Ill). Clinical and subjective OSA indicators were recorded as mean and standard deviation or median and interquartile ranges (where appropriate). The mean and standard deviation of cephalometric measurements were recorded. Pretreatment variables were compared with posttreatment variables using a paired *t*-test with Bonferroni correction or Wilcoxon signed rank test (where appropriate). All tests were carried out using *P* values $<.05$ as the level of significance.

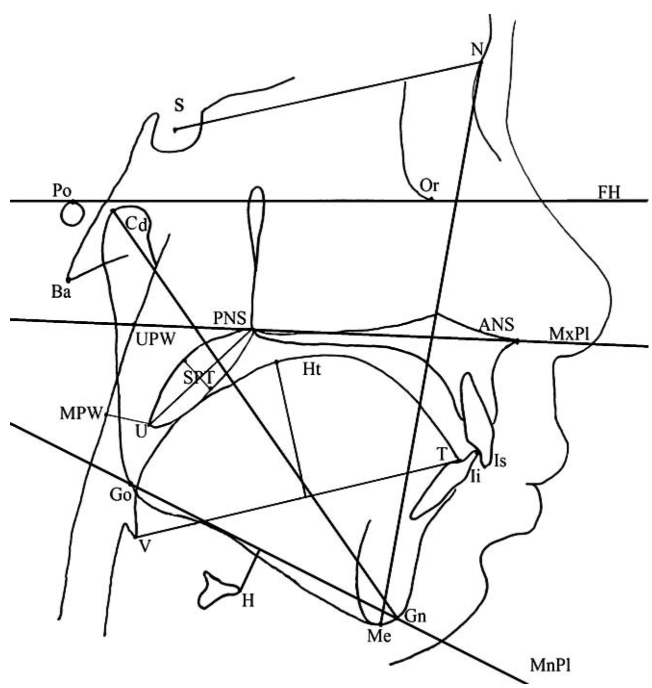


Figure 3. Diagrammatic representation of landmarks and variables (for definitions, see Table 1).

Table 1. Cephalometric Landmarks Used in this Study[16]

Variable (Landmark)	Definition
S	Center of the sella turcica; the center of the pituitary fossa of the sphenoid bone
N	Nasion—the most anterior point of the frontonasal suture
Ba	Basion—the most posteroinferior point on the anterior margin of the foramen magnum
Po	Porion—the most superior point of the external auditory meatus
Or	Orbitale—the most inferior point of the orbit
ANS	Anterior nasal spine the apex of the anterior nasal spine
PNS	Posterior nasal spine—the tip of the posterior nasal spine, that is, the most posterior point at the sagittal plane on the bony hard palate
Cd	Condylion—the most posterosuperior point of the condylar head
Go	Gonion—the most posteroinferior point on the angle of the mandible
Gn	Gnathion—the most anteroinferior point on the bony chin
Me	Menton—the most inferior point on the bony chin
Rgn	Retrognathia—the most posterior point of the symphysis
U	The tip of the uvula
V	Vallecula—the most posteroinferior base of the tongue or the intersection of epiglottis and base of the tongue
H	Also known as hy—the most superior and anterior point on the body of the hyoid
FH	Frankfort horizontal plane—the line connecting the points porion (Po) and orbitale (Or)
MnPl	Mandibular plane, also known as ML or mandibular line—the tangent line to the lower border of the mandible (on point go) through gnathion (gn)
MxPl	Maxillary plane, also known as NL or nasal line—the line connecting the anterior nasal spine (ans or sp) and posterior nasal spine (pns)
Ht	Superior part of the tongue, also known as H—the most superior point of the tongue in relation to the line from points V to T
LPW	Lower pharyngeal wall—the intersection of the perpendicular line from V to the posterior pharyngeal wall
MPW	Middle pharyngeal wall—the intersection of the perpendicular line from point U to the posterior pharyngeal wall
T	The tip of the tongue
UPW	Upper pharyngeal wall—the point of intersection of the line perpendicular to the posterior pharyngeal wall from the posterior nasal spine
Hyoid position	
H-MnPl (mm)	The perpendicular distance from the point H to the line MnPl
Tongue base position	
H-VT (mm)	Tongue height, measured as the perpendicular distance from point H to the VT line
Soft palate	
PNS-U (mm)	Soft palate length—the distance between PNS and U
PNS-UPW (mm)	Depth of nasopharyngeal airway space from PNS to UPW
SPT (mm)	Soft palate thickness—represents the maximal thickness of soft palate measured perpendicular to PNS-U line
U-MPW (mm)	Depth of oropharyngeal airway space from U to MPW
Craniofacial structures	
MnPl/SN (°)	Mandibular plane angle—the angle between the MnPl and the S-N line
Overjet (mm)	The distance between the Is and the Ii parallel to the upper occlusal plane (positive if the upper incisor is in front of the lower incisor, negative if the lower incisor is in front of the upper incisor)
Upper anterior facial height (UAFH) (mm)	Distance from N to MxPl along the N-Me line
Lower anterior facial height (LAFH) (mm)	Distance from Mxpl to Me, along the N-me line
Mandibular length (mm)	Distance between the points Cd and Gn
Anterior cranial base length (SN) (mm)	Distance between the points S and N

RESULTS

The subjects' ages ranged from 27 to 79 years (mean = 52 years old). Most patients were men (76%; n = 34). Subjects' mean body mass index was 27.0 (SD = 3.9). Baseline clinical OSA indicators included a median AHI of 34.4 (range = 10.0–102.0) (Table 2). Twenty-two subjects were randomly allocated to treatment sequence AB (monoblock/twin block) and 23 subjects to treatment sequence BA (twin block/monoblock). No differences were found between the groups' demographic variables, OSA cephalometric measurements, and clinical OSA indicators Three subjects withdrew during the first phase of the trial, and four subjects withdrew during the second phase of the treatment, citing time constraints in making appointments. This left 38 subjects included in the final per-protocol analysis.

After treatment, there was a highly significant reduction in AHI with the monoblock ($P < .001$) and a significant reduction in AHI with the twin block ($P < .01$). The monoblock demonstrated a significantly better result than the twin block ($P < .05$) (Table 2).

Several significant changes were noted in the cephalometric measurements between baseline and the posttreatment period with both appliances. These included reduction in the distances between the hyoid bone to the point retrognathia on the mandible (monoblock, $P < .01$; twin block $P < .001$) as well as the distance between hyoid bone and the mandibular plane angle ($P < .001$). In the soft tissue, the soft palate length increased significantly ($P < .05$). Changes were also seen in several other measurements (SNB, mandibular plane angle, overjet, overbite, and face height) with both MADs ($P < .001$). No significant differences were found between the MADs for any of the measurements (Table 2).

DISCUSSION

The clinical characteristics of the 45 patients included in this study at baseline are similar to those reported in other studies[25–27]; therefore, this sample can be described as typical for the condition under investigation and type of intervention. No difference was found in any variables between the two MAD groups at baseline, which suggests that the reasons for possible variations between the two MADs are likely to be attributable to the appliances themselves rather than patient characteristics at baseline. The seven subjects who withdrew stated that a lack of time to commit to appointments as reason for compliance failure and were referred back to the University of Hong Kong's Sleep Disorders Center for alternative treatment.

The results of this study show that both MADs proved to be effective in reducing the clinical OSA severity indicator, the AHI. This result is supported by other studies investigating the efficacy of MADs, which showed a reduction in clinical OSA indicators for the MADs.[8,26,27] Following on from this finding, the question to pursue was whether there are differences in efficacy between MADs of different designs. In the present study, the monoblock proved to be more efficacious than the twin block in reducing AHI. As the advancement and vertical opening of the two MADs were the same for standardization, the differences in treatment success are likely to be attributed to the different design features.

Differences in the skeletal and soft-tissue structures of the craniofacial anatomy have been associated with OSA.[28] With respect to craniofacial measurements; this study shows that the MADs changed some cephalometric features of the subjects while appliances were in situ. Significant increases were found in facial height, overjet, mandibular plane angle, and soft palate length as well as in reduction of the position of the hyoid bone in relation to the mandible. In particular, the hyoid bone and its musculature have a key role in regulating the position of the pharyngeal airway, and its position is affected by the tongue and the mandible.[29] The distance of the hyoid to mandibular plane was significantly reduced by an average of 3.9 mm (monoblock) and 3.7 (twin block) ($P < .05$). This cephalometric observation concurs with similar findings in the literature.[30,31] In a cephalometric study on Chinese patients, the distance of mandibular plane to hyoid bone was significantly correlated with the severity of OSA.[32]

Mechanisms proposed to explain the reduction in hyoid to mandibular plane distance include the possibility that the MAD that positioned the mandible forward also pulled forward the muscles attached to the hyoid, thus reducing the distance of the hyoid bone to the mandibular plane and improving the pharyngeal airway patency. Also, mandibular advancement via the MAD may alter the position function of associated muscles and affect the tendency of upper airway restriction/collapse. There were no interappliance effects of significance that would indicate that the use of a one-piece or two-piece MAD had no effect on the cephalometric parameters we measured.

Limitations of This Study

Although the crossover design has the advantage of allowing within-subject comparison, this design also has limitations, so results have to be analyzed accordingly. To minimize carryover effects, an adequate washout period is required between the treatment arms to allow subjects to return to their baseline state; this approach was incorporated in this study and has shown to be preventive as no carryover effect or period effect was demonstrated. OSA is a relatively stable disease (in the short term) and MAD therapy a reversible intervention, characteristics that lend themselves to a crossover trial, particularly one like the present study. Nevertheless, there is a need to assess and monitor the efficacy of MAD therapy in the long term as OSA has been shown to deteriorate with age, and MAD efficacy may deteriorate with long-term use. This study was only short-term (6 months total) and demonstrated the efficacy of MAD therapy, particularly the monoblock. However, this study was not sufficient in length to reflect the average life span of a patient with OSA. Long-term

Table 2. Effect of Monoblock and Twin Block Mandibular Advancement Devices on Clinical OSA Indicators, Craniofacial Structures, and Upper Airway Dimensions (n = 38)[a]

	Baseline (B)	Monoblock (M)	Twin Block (T)	B vs M	B vs T	M vs T
	Median (IQR)	Median (IQR)	Median (IQR)	*P* Value	*P* Value	*P* Value
Clinical OSA indicators						
AHI	21.1(14.2–50.1)	5.9(1.6–20.4)	15.2(4.0–38.1)	.000***	.005**	.02*
Cephalometrics						
Hyoid	Mean (SD)	Mean (SD)	Mean (SD)	*P* value	*P* value	*P* value
Rgn-H	40.0 (5.8)	37.9 (6.4)	37.2 (6.3)	.005**	.000***	.201
H-MnPl	21.8 (5.5)	17.9 (7.5)	18.1 (7.5)	.000***	.000***	.816
H-C4ia	44.1 (7.5)	42.8 (5.4)	43.1 (5.1)	.165	.302	.487
AH-FH	106.9 (7.9)	108.0 (9.6)	107.8 (9.1)	.183	.245	.640
S-H	125.7 (10.1)	124.6 (9.8)	125.9 (9.6)	.429	.812	.219
Tongue base position						
PNS-V	76.6 (7.2)	78.6 (8.0)	78.9 (7.9)	.090	.244	.611
V-FH	100.3 (11.7)	103.0 (13.2)	102.9 (10.6)	.241	.206	.902
V-C4ia	30.3 (10.8)	28.2 (6.3)	28.3 (6.0)	.228	.261	.611
VT	85.8 (8.9)	82.9 (6.7)	82.9 (7.6)	.124	.165	.970
H-VT	38.6 (7.0)	40.1 (5.0)	40.3 (5.5)	.101	.070	.680
Soft palate						
PNS-U	41.9 (4.9)	43.8 (4.9)	43.6 (5.1)	.014*	.022*	.472
Soft palate angle	127.6 (7.5)	127.5 (6.3)	128.2 (6.7)	.943	.599	.295
Craniocervical extension						
OPT-SN	112.8 (6.8)	113.5 (7.2)	113.7 (6.5)	.152	.376	.159
C2sp.C4ip-SN	113.6 (8.4)	113.7 (7.8)	114.2 (7.1)	.935	.642	.325
Craniocervical structures						
NSBa	130.4 (5.0)	130.3 (5.0)	130.4 (5.3)	.665	.911	.597
SNA	81.5 (3.7)	81.8 (3.5)	81.9 (3.8)	.192	.091	.692
SNB	77.3 (3.2)	78.2 (3.5)	78.2 (3.3)	.006**	.006**	1.000
ANB	4.2 (2.4)	3.5 (2.9)	3.7 (2.7)	.045*	.347	.155
MnPl-SN	35.9 (6.4)	43.3 (6.9)	43.8 (7.5)	.000***	.000***	.118
MxPl-SN	12.3 (3.7)	11.6 (3.3)	11.8 (3.3)	.245	.416	.178
Overjet	4.0 (2.3)	−0.6 (3.5)	−0.1 (3.6)	.000***	.000***	.097
Overbite	2.5 (1.7)	−7.4 (4.4)	−7.4 (5.4)	.000***	.000***	.982
UPFH	47.4 (3.6)	47.4 (3.6)	47.3 (3.5)	1.000	.524	.160
ULPFH	40.5 (5.7)	44.5 (5.5)	44.8 (5.6)	.000***	.000***	.819
TPFH	88.1 (6.6)	91.8 (6.8)	92.1 (6.7)	.000***	.000***	.115
UAFH	61.7 (4.6)	61.2 (4.5)	61.3 (4.5)	.522	.056	.147
LAFH	73.8 (4.2)	85.2 (4.8)	85.6 (4.9)	.000***	.000***	.447
TAFH	135.0 (6.8)	146.0 (7.2)	146.5 (7.3)	.000***	.000***	.230
Mandibular length	120.0 (7.5)	119.7 (7.5)	119.7 (7.5)	.107	.183	.571
Ramus length	60.8 (5.9)	60.6 (5.9)	60.6 (5.9)	.057	.051	.324
Mandibular body length	82.3 (4.9)	82.2 (5.1)	82.3 (5.1)	.133	.534	.051
Maxillary length	52.8 (3.4)	51.6 (8.9)	52.8 (3.4)	.339	.786	.344
SN length	72.9 (4.3)	72.9 (4.2)	73.0 (4.2)	.822	.133	.160
Upper airway measurements						
PASmin	10.8 (4.0)	10.5	10.0	.526	.164	.071
PNS-UPW	27.4 (3.3)	27.4 (3.1)	27.5 (3.2)	.936	.635	.442
SPT	11.4 (2.8)	10.3 (2.1)	12.6 (14.5)	.183	.608	.339
U-MPW	8.6 (2.6)	8.7 (2.8)	8.5 (2.6)	.788	.852	.482
V-LPW	18.8 (4.8)	18.6 (6.1)	18.7 (5.8)	.831	.854	.916

[a] IQR indicates interquartile range; OSA, obstructive sleep apnea.
* Significant at $P < .05$; ** Significant at $P < .01$; *** Significant at $P < .001$.

follow-up assessments are vital to ensure the continued efficacy of MAD therapy for OSA.

CONCLUSIONS

- The monoblock proved to be the better MAD to improve objective OSA severity.
- Both MADs resulted in similar significant cephalometric changes around the hyoid bone position and soft palate length, which indicates that both MADs may alter the position of the surrounding musculature and improve upper airway patency.
- Therefore, the different design features of the MADs in this trial may affect some OSA indicators and

cephalometric landmarks; however, further studies are required to support or refute the claim that the monoblock MAD is the preferred MAD.

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