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ARTICLE

Clinical Effect of Personalized Adjustable Mandibular Advancement Device on Obstructive Sleep Apnea

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Abstract

Aims/Background Mandibular advancement devices are effective in treating mild or moderate obstructive sleep apnea (OSA), but such devices that are commonly used in clinical settings require further improvement. In this study, we evaluated the clinical effects of personalized adjustable mandibular advancement devices on mild or moderate OSA.

Methods Forty patients with mild or moderate OSA were randomly divided into experimental (personalized adjustable device) and control (traditional device) groups. Side effects, including increased salivation, dry mouth, muscle aches, and temporomandibular joint discomfort, were assessed. Respiratory markers during sleep, including the apnea-hypopnea index, mean blood oxygen saturation, lowest blood oxygen saturation and maximum apnea time, were evaluated using polysomnography. The upper airway cross-sectional area and temporomandibular joint morphology and motion trajectory were evaluated using cone beam computed tomography.

Results Side effects were significantly lower in the experimental group than in the control group. Respiratory marker levels were significantly restored post-treatment. Soft palate- and tongue-pharyngeal cross-sectional areas were significantly increased in both groups, but temporomandibular joint morphology or motion trajectory remained unchanged.

Conclusion The personalized adjustable mandibular advancement devices may reduce side effects and are effective in treating patients with OSA.

Clinical Trial Registration The study was registered and approved by the Chinese Clinical Trial Registry (ChiCTR2400080306). https://www.chictr.org.cn/showproj.html?proj=206538.

Key words: obstructive sleep apnea; adjustable mandibular advancement device; side effects; polysomnography; upper airway; temporomandibular joint

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Introduction

Obstructive sleep apnea (OSA) syndrome is a common sleep-related breathing disorder characterized by recurrent apnea or hypopnea during sleep (Anitua et al, 2023). This syndrome affects 9–38% of middle-aged adults and approximately 88–90% of older adults aged 65–85 years (Iannella et al, 2020). OSA causes a decrease in blood oxygen concentration and carbon dioxide retention, which can lead to various complications such as high blood pressure, diabetes, heart disease, cerebrovascular accidents, and even sudden death during sleep (Li et al, 2018; Ou

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et al, 2023; Tang et al, 2022). OSA has become a public health problem, which warrants early prevention and necessitates effective treatment.

Continuous positive airway pressure (CPAP) is the most reliable and widely used treatment for OSA; however, many patients reject receiving CPAP and only a fraction of the patients can tolerate this type of treatment (Barnes et al, 2004; Luzzi et al, 2020). Since 2015, the American Academy of Sleep Medicine and the American Academy of Dental Sleep Medicine have recommended the prescription of a mandibular advancement device (MAD)—a simple and effective method for treating patients with mild or moderate OSA or those with severe OSA who reject or do not tolerate CPAP (Bernhardt et al, 2023). This recommendation has since set an increasing trend in the usage of MADs for clinically treating OSA. However, the clinical efficacy and side effects associated with MADs vary. Previous studies have shown that a proportion of patients prematurely stop receiving the traditional MADs therapy due to the emergence of side effects such as dry mouth, chewing muscle soreness, or temporomandibular joint (TMJ) disorders (Alessandri-Bonetti et al, 2019; Langaliya et al, 2023; Mezzofranco et al, 2024). Hoffstein (2007) concluded that approximately 8–41% of patients experienced TMJ discomfort, and 45% suffered from masticatory muscle soreness after MAD therapy. Several studies have demonstrated that inappropriate mandibular protrusion distance was a major cause of MAD-associated side effects (Anitua et al, 2017; Ng and Yow, 2020). Nonetheless, a standardized mandibular advancement protocol is lacking. Moreover, the accuracy of the mandibular protrusion distance measured is usually dependent on the clinician's experience. The traditional MADs commonly used in clinical practice maintain the amount of mandibular advancement at 70–75% of the maximal mandibular protrusion (MMP) (Ferguson et al, 2006; Ma et al, 2020). Therefore, to avoid the side effects of traditional MADs therapy, Fleury proposed that the mandibular advancement should be individualized rather than simply an empirical therapy indiscriminately applied to all patients (Fleury et al, 2004). In the present study, we designed a personalized, adjustable MAD, which is associated with a lower incidence of side effects and boasts higher clinical efficacy for patients with OSA, relative to the traditional MADs.

To examine the clinical effects of the personalized, adjustable MAD, we first investigated the occurrence of side effects, including increased salivation, dry mouth, chewing muscle aches, and TMJ discomfort during treatment. Next, we used polysomnography (PSG) to monitor the patient's sleep parameters, including the apnea-hypopnea index (AHI), mean blood oxygen saturation ($MSaO_2$), lowest blood oxygen saturation ($LSaO_2$), and maximum apnea time (MAT). Lastly, we used cone beam computed tomography (CBCT) to determine the cross-sectional area of the upper airway, TMJ morphology, and TMJ motion trajectory.

Methods

Study Participants

Between November 2023 and March 2024, 40 patients with mild or moderate OSA, who had been monitored and diagnosed using PSG in Air Force Hospital

from Northern Theater of PLA, were enrolled in this study. The sample consisted of 38 men and 2 women, aged 30–75 years. The patients' body mass index (BMI) ranged from 23.1 to 28.67 kg/m^2. Inclusion criteria applied in this study were determined according to the previous studies (Bosschieter et al, 2022; Lu et al, 2020): (1) patients with mild OSA ($5 < \text{AHI} \leq 15$ events/h of sleep) or with moderate OSA ($15 < \text{AHI} \leq 30$ events/h of sleep) (Gottlieb and Punjabi, 2020); (2) patients with no posterior tooth loss; (3) patients with no less than 10 teeth in a single jaw; (4) patients experiencing alveolar bone absorption due to periodontitis of no more than second degree; and (5) patients who were not afflicted with TMJ diseases. Exclusion criteria include: (1) patients with severe OSA (AHI >30 events/h of sleep); (2) patients affected by the throat and nasal diseases leading to airway obstruction; (3) patients with a history of sex hormone therapy, pharyngeal surgery, or use of medications such as bronchodilators; and (4) individuals who had received stimulation treatment for the respiratory nerves.

Prior to the enrollment, potential study participants were subjected to PSG examination, CBCT examination for detecting TMJ disorders, and comprehensive oral examination, and systemic medical history was obtained from each of the patient. Our sample for this study was recruited based on the outcomes of the above-mentioned procedures. We also worked with respiratory and otolaryngologists to assess the patient's condition. The study procedures were as follows: First, the baseline data including respiratory PSG indexes and CBCT-derived upper airway cross-sectional area were measured. Second, the patients were randomly divided into the experimental group (n = 20) and the control group (n = 20). The patients in the experimental group wore a personalized, adjustable MAD, whereas those in the control group wore a traditional MAD. The device was worn for no less than 7 hours during sleep. Thereafter, patients' complaints were recorded using side effects questionnaires completed at 1, 2, and 4 weeks of follow-up. Lastly, the same PSG and CBCT examinations were conducted during the 4-week follow-up visit (Fig. 1). All procedures were performed in accordance with the principles of the Declaration of Helsinki and approved by the Ethics Committee of the Air Force Hospital from Northern Theater of PLA (approval number 2021-001). All the participants had given their informed consent before joining the study.

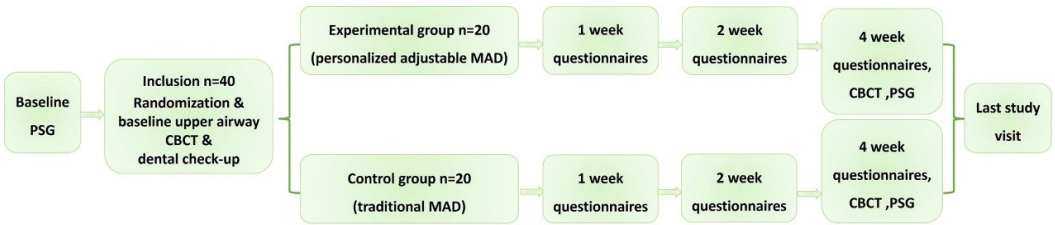

Fig. 1. Flow diagram of the study. Abbreviations: CBCT, cone beam computed tomography; MAD, mandibular advancement device; PSG, polysomnography.

Fabrication of MADs

The patients' MMP was measured and recorded. Soft wax (BASE PLATE WAX FOR GENERAL USE C, Shanghai New Century Dental Materials, Shanghai, China) was placed in the patients' mouth. The patients were instructed to extend the mandibular protrusion to the maximum protrusion, and the vertical distance between the upper and lower incisors was maintained at 3 mm. Thermocoagulated polymethyl acrylate was used to prepare a denture base, which was applied to the control group. The base of the resin covered the entire palatal cap, mandibular gum, and dentition. A triangular baffle was placed on the buccal side of the first molars of the maxilla and mandible, and the mandible was fixed at 70% MMP. On the other hand, a denture base comprising resin and metal plates was applied to the experimental group. Metal clasps were placed between the first and second premolars to increase retention. Crew spring expanders were placed on both buccal sides of the maxillary molars of the oral appliances. The starting forward mandibular distance was 50% of the MMP, as recommended by Bernhardt et al (2023). On this basis, the patient's mandible was adjusted 0–6.5 mm forward using screw spring expanders (600-300-30, Tamas, DENTAURUM GmbH &CO.KG, Turnstr, Ispringen, Germany). The model was prepared by the same dentist and the MADs were created by the same dental processing technician (Fig. 2).

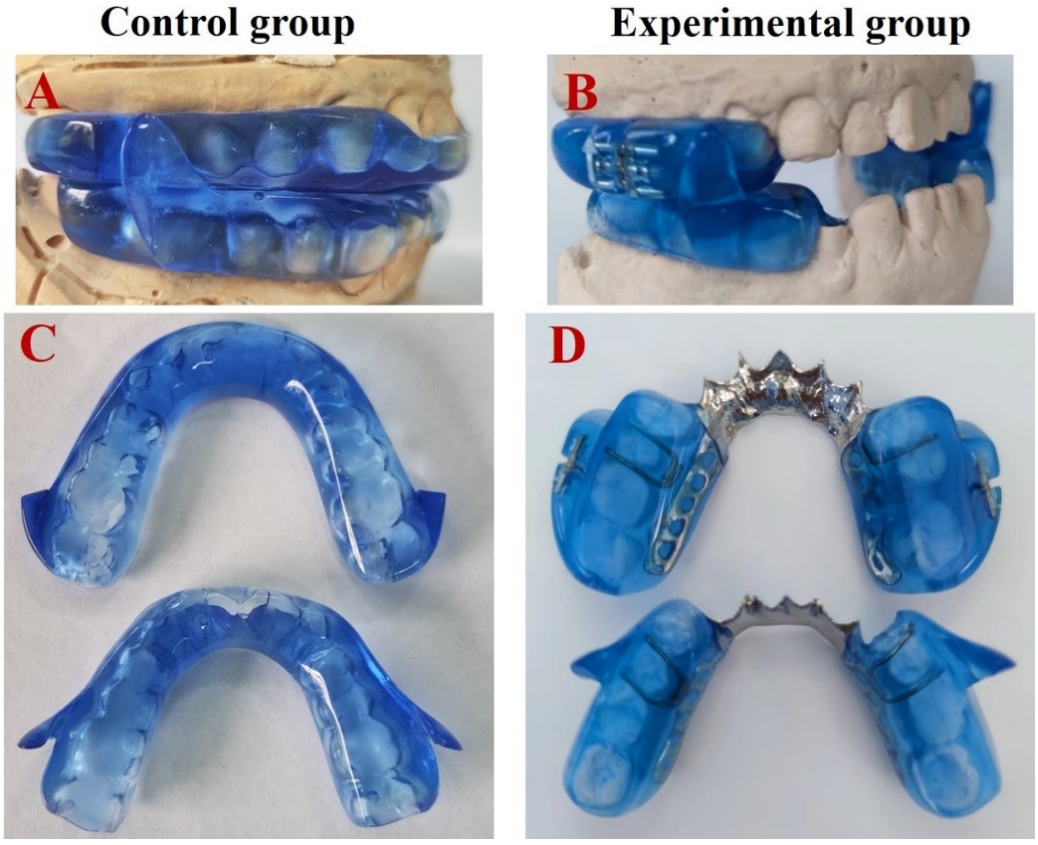

Fig. 2. Two types of MADs. (A,C) Traditional MAD utilized in the control group. (B,D) Personalized adjustable MAD utilized in the experimental group. Abbreviations: MAD, mandibular advancement device.

Comparison of Side Effects

Questionnaires were administered to gather data on side effects, including dry mouth, increased salivation, muscle aches, and TMJ discomfort after 1, 2, and 4 weeks of treatment. The outcomes were compared between the two groups.

PSG Monitoring

PSG (Embla S4500, Atus Medical Incorporated, San Carlos, CA, USA) was performed to detect overnight changes in respiratory indices. The detection indicators included the AHI, $MSaO_2$, $LSaO_2$, and MAT.

CBCT Examination of the Upper Airway and TMJ Morphology

The morphologies of the upper airway and TMJ were examined using CBCT (KaVo 3DXam, KaVo Dental Company, Biberach, Swabia, Germany). The patients sat upright and looked ahead, with the posterior teeth biting into the intercuspal position. During the continuous upper airway scan, the patients were instructed to refrain from swallowing. The measurement marker points were the posterior nasal spinous point (PNS), uvula apex point (U), the point at which the tongue root is closest to the posterior pharyngeal wall (T), and epiglottis apex point (Ep). All four planes were parallel to the Frankfort horizontal plane and passed through the points PNS, U, T, and Ep (Fig. 3). The cross-sectional area of each plane was measured using *In Vivo* Dental 5 software (Ver.5.2, Anatomage Inc, Santa Clara, CA, USA), and each indicator was measured three times and averaged. CBCT was also used to observe condylar morphology, cortical continuity, and condyle movement trajectory.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics (version 29, SPSS Inc., Chicago, IL, USA). The Shapiro-Wilk test was used to analyze whether the variables were normally distributed. The data are expressed as mean ± standard deviation when normally distributed or as median (lower quartile [Q1]–upper quartile [Q3]) when not normally distributed. To compare the intra-group pre- and post-treatment therapeutic effects, a paired samples *t*-test was used in the case of normally distributed data, and the Wilcoxon signed-rank test was used in the case of non-normally distributed data. To analyze between-group differences in the baseline and 4-week follow-up data, an independent *t*-test was used in the case of normally distributed data, and the Mann–Whitney U test was performed in the case of non-normally distributed data. Results with a p-value < 0.05 were considered statistically significant.

Results

Patient Characteristics

In total, 40 patients were included (38 men and 2 women). The mean age was 51.8 years and the BMI was 25.33 kg/m^2. The mean AHI at baseline was 19.65. The mean $MSaO_2$ and $LSaO_2$ were 92.05% and 82.73%, respectively. The baseline MAT was 48.77 s (Table 1). The patient characteristics of each group are shown in

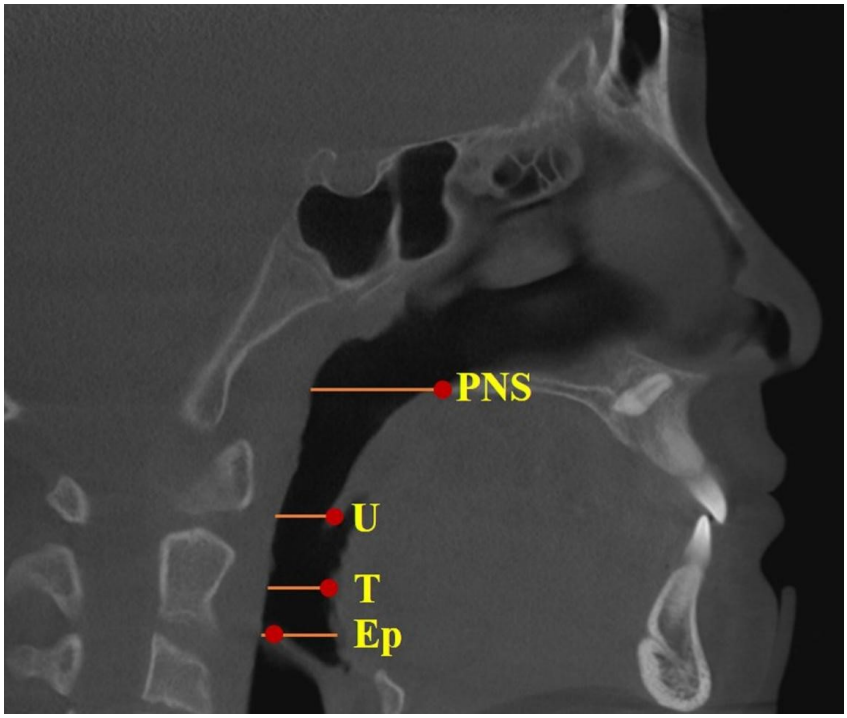

Fig. 3. The CBCT cephalometric landmarks and lines on the midsagittal plane. Abbreviations: PNS plane, poster nasal spinous point plane; U plane, uvula apex point plane; T plane, the point at which the tongue root is closest to the posterior pharyngeal wall; Ep plane, epiglottis apex point plane; CBCT, cone beam computed tomography.

Table 2. There were no significant differences in any of the baseline data between groups.

Comparison of Two Types of MADs

The traditional and personalized adjustable MADs applied in this study present differences in three main features, with their mandibular protrusions being the most important disparity. The protrusive mechanism of the control group was a fixed location at a mandibular protrusion distance of 70–75% of the MMP, whereas, in the experimental group, clinicians and patients could move the mandibular protrusion position by a screw spring expender. The mandible could be moved forward by 6.5 mm based on 50% of the MMP. The second important disparity is the material and size of the MADs. The MAD in the control group consisted of two separate trays of plastic framework, which completely covered the lower and upper dental arches, whereas the MADs used in the experimental group were made of metal and plastic. A metal base was placed in the lingual position of the incisors, while plastic was used in the molar position. The experimental MAD is much smaller than that of the control, thus reducing the sensation of a foreign body in the mouth. The third difference is retention; the experimental group MAD used metal clasps on the premolars, which provided better retention and prevented the device from dislodging from the teeth (Fig. 2).

Table 1. Patient characteristics (n = 40).

Demographic characteristics	Total
Sample size (n)	40
Sex (male:female)	38:2
Age (years), mean ± SD	51.80 ± 12.6
BMI (kg/m^2), mean ± SD	25.33 ± 1.56
Baseline AHI (events/h), mean ± SD	19.65 ± 4.71
Baseline $MSaO_2$ (%), mean ± SD	92.05 ± 2.42
Baseline $LSaO_2$ (%), mean ± SD	82.73 ± 4.36
Baseline MAT (second), mean ± SD	48.77 ± 8.07

Abbreviations: BMI, body mass index; AHI, apnea-hypopnea index; $MSaO_2$, mean blood oxygen saturation; $LSaO_2$, lowest blood oxygen saturation; MAT, maximum apnea time; SD, standard deviation.

Table 2. Comparison of patient characteristics between experimental and control groups.

Demographic characteristics	Baseline measurements		*t*-value	*p*-value
	Experimental group	Control group		
Sample size	n = 20	n = 20		
Age (years), mean ± SD	53.10 ± 12.83	50.50 ± 12.59	–0.65	0.52
BIM (kg/m^2), mean ± SD	25.32 ± 1.49	25.33 ± 1.67	–0.01	0.99
Baseline AHI (events/h), mean ± SD	19.46 ± 4.96	19.84 ± 4.57	0.252	0.80
Baseline $MSaO_2$ (%), mean ± SD	92.14 ± 2.56	91.96 ± 2.32	–0.23	0.82
Baseline $LSaO_2$ (%), mean ± SD	82.44 ± 3.83	83.02 ± 4.90	0.42	0.68
Baseline MAT (second), mean ± SD	50.89 ± 6.52	46.65 ± 9.04	–1.7	0.10

Abbreviations: BMI, body mass index; AHI, apnea-hypopnea index; $MSaO_2$, mean blood oxygen saturation; $LSaO_2$, lowest blood oxygen saturation; MAT, maximum apnea time; SD, standard deviation.

Comparison of Side Effects

Side effects in the experimental group were significantly reduced during treatment. The probability of adverse reactions occurring in the control group was twice that in the experimental group. In the experimental group, one patient experienced increased salivation; three, dry mouth; one, muscle soreness; and one, TMJ discomfort after 1 week of treatment. After more than 2 weeks, the symptoms gradually subsided, and all symptoms except dry mouth disappeared after 4 weeks of treatment. In the control group, three patients experienced increased salivation; four, dry mouth; three, muscle aches; and three, TMJ discomfort after 1 week of treatment. These symptoms persisted for 4 weeks in four patients with dry mouth and one patient with TMJ discomfort (Table 3).

Changes in Respiratory Indexes

The PSG indices significantly improved in both experimental and control groups ($p < 0.05$) after 4 weeks of treatment. In the experimental group, the AHI de-

Table 3. Comparison of side effects after MAD treatments.

	Experimental group			Control group		
	1 week	2 weeks	4 weeks	1 week	2 weeks	4 weeks
Increased salivation	1	0	0	3	1	0
Dry mouth	3	2	2	4	4	4
Muscle aches	1	0	0	3	1	0
TMJ discomfort	1	0	0	3	2	1

Abbreviations: MAD, mandibular advancement device; TMJ, temporomandibular joint.

creased by 60.74% (from 19.46 ± 4.96 to 7.64 ± 3.08), the $MSaO_2$ increased by 2.94% (from 92.14 ± 2.57% to 94.85 ± 2.10%), and the $LSaO_2$ increased by 5.83% (from 82.44 ± 3.84% to 87.25 ± 2.88%), whereas the MAT shortened by 29.85% (from 50.89 ± 6.53 s to 35.70 ± 7.33 s). There were no significant differences in these respiratory indexes between the experimental and control groups ($p > 0.05$) (Table 4).

Changes in Upper Airway Cross-Sectional Area

CBCT showed that the morphology of the upper airway changed after 4 weeks of MADs treatment. The increase in the U-plane cross-sectional area in the experimental group was greater than that in the control group; however, the difference did not reach statistical significance ($p > 0.05$). No noticeable changes were observed in the PNS and Ep planes during treatment ($p > 0.05$) (Figs. 4,5 and Table 5).

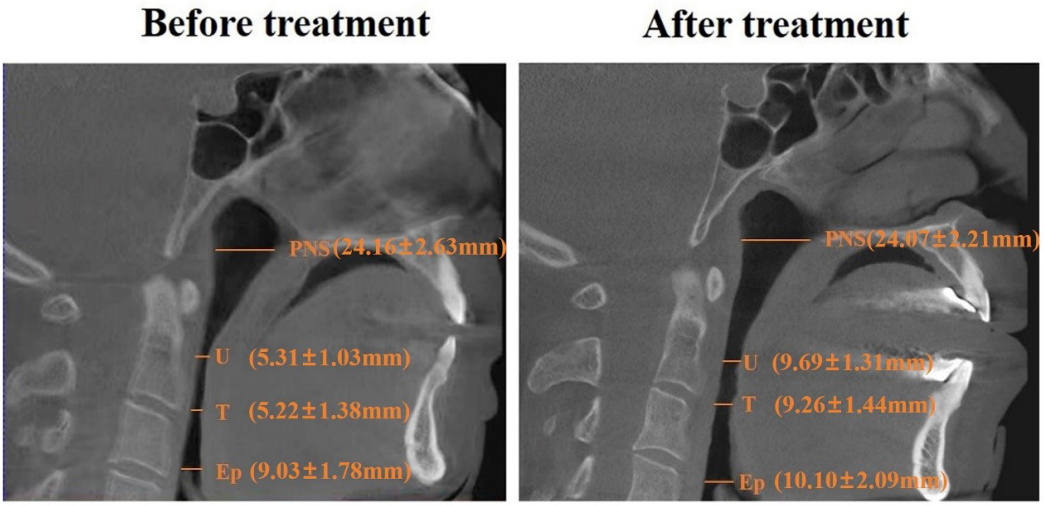

Fig. 4. Changes of CBCT cephalometric parameters of upper airway on the midsagittal plane after 4 weeks of personalized adjustable MAD treatment in the experimental group. Abbreviations: PNS plane, poster nasal spinous point plane; U plane, uvula apex point plane; T plane, the point at which the tongue root is closest to the posterior pharyngeal wall; Ep plane, epiglottis apex point plane; CBCT, cone beam computed tomography; MAD, mandibular advancement device.

Table 4. PSG test after 4 weeks of MAD treatments.

	AHI		*t*-value	*p*-value
	Before treatment	After treatment		
Experimental group (n = 20)	19.46 ± 4.96	7.64 ± 3.08	9.05	<0.01*
Control group (n = 20)	19.84 ± 4.57	7.50 ± 3.53	9.16	<0.01*
t-value	0.25	0.13		
p-value	0.80	0.89		
	$MSaO_2$		*t*-value	*p*-value
	Before treatment	After treatment		
Experimental group (n = 20)	92.14 ± 2.57	94.85 ± 2.10	3.65	<0.01*
Control group (n = 20)	91.97 ± 2.32	94.79 ± 1.69	4.40	<0.01*
t-value	0.23	0.08		
p-value	0.82	0.93		
	$LSaO_2$		*t*/z-value	*p*-value
	Before treatment	After treatment		
Experimental group (n = 20)	82.44 ± 3.84	87.25 ± 2.88	*t* = 4.49	<0.01*
Control group (n = 20)	83.02 ± 4.90	83.15 (83.90–89.90)	z = 3.92	<0.01*
t/z-value	*t* = 0.42	z = 0.27		
p-value	0.68	0.98		
	MAT		*t*-value	*p*-value
	Before treatment	After treatment		
Experimental group (n = 20)	50.89 ± 6.53	35.70 ± 7.33	6.92	<0.01*
Control group (n = 20)	46.65 ± 9.04	33.53 ± 6.97	5.14	<0.01*
t-value	1.70	0.96		
p-value	0.10	0.34		

Data are presented as mean ± SD or median (Q1–Q3), * $p < 0.05$.
Abbreviations: AHI, apnea-hypopnea index; $LSaO_2$, lowest blood oxygen saturation; MAD, mandibular advancement device; MAT, maximum apnea time; $MSaO_2$, mean blood oxygen saturation; PSG, polysomnography.

Changes in TMJ Morphology and Motion Trajectory

CBCT showed that the morphology and continuity of the bone cortex of the condylar process did not undergo significant changes after 4 weeks of treatment in the experimental group. The anterior position of the condyle did not exceed the physiological range of movement in the maximum mouth opening position (Fig. 6).

Discussion

This study evaluated the differences in therapeutic efficacy between personalized adjustable MAD (experimental group) and traditional MAD (control group). Our findings indicated that the personalized adjustable MAD could significantly

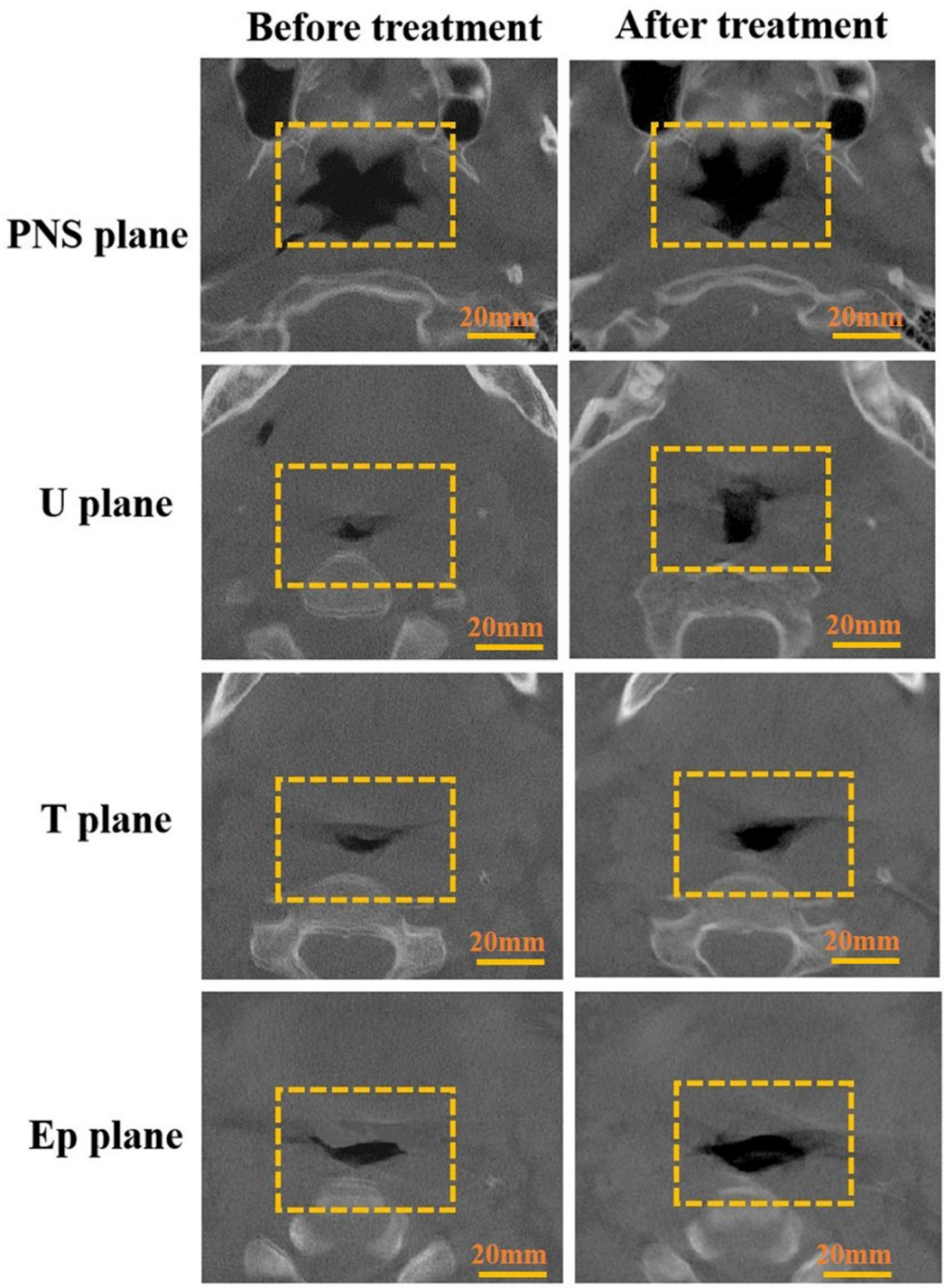

Fig. 5. Changes of CBCT measurements of upper airway cross-section after 4 weeks of personalized adjustable MAD treatment in the experimental group. Abbreviations: PNS plane, poster nasal spinous point plane; U plane, uvula apex point plane; T plane, the point at which the tongue root is closest to the posterior pharyngeal wall; Ep plane, epiglottis apex point plane; CBCT, cone beam computed tomography; MAD, mandibular advancement device.

reduce occurrence of the side effects, especially TMJ discomfort and chewing muscles soreness. The two MAD types tested in this investigation demonstrated comparable outcomes concerning PSG-based respiratory indexes and upper airway en-

Table 5. CBCT measurements of upper airway cross-sectional area after 4 weeks of treatments.

	PNS plane		*t*-value	*p*-value
	Before treatment	After treatment		
Experimental group (n = 20)	517.30 ± 66.12	521.63 ± 58.62	0.219	0.828
Control group (n = 20)	490.57 ± 87.55	499.49 ± 85.83	0.319	0.752
t-value	1.090	0.964		
p-value	0.283	0.341		
	U plane		*t*-value	*p*-value
	Before treatment	After treatment		
Experimental group (n = 20)	92.77 ± 26.04	140.81 ± 33.24	5.089	<0.001*
Control group (n = 20)	83.99 ± 35.86	124.83 ± 42.91	3.267	0.002*
t-value	0.886	1.317		
p-value	0.381	0.196		
	T plane		*t*-value	*p*-value
	Before treatment	After treatment		
Experimental group (n = 20)	125.09 ± 36.12	171.01 ± 40.67	3.775	<0.001*
Control group (n = 20)	113.07 ± 39.56	162.22 ± 53.47	3.305	0.002*
t-value	1.004	0.585		
p-value	0.322	0.562		
	Ep plane		*t*/z-value	*p*-value
	Before treatment	After treatment		
Experimental group (n = 20)	163.18 (125.79–235.55)	162.68 (141.55–255.59)	z = 1.232	0.218
Control group (n = 20)	173.38 ± 86.02	180.19 ± 88.38	*t* = 0.247	0.806
t/z-value	z = 0.649	z = 0.622		
p-value	0.516	0.534		

Data are presented as mean ± SD or median (Q1–Q3), *$p < 0.05$.
Abbreviations: PNS plane, poster nasal spinous point plane; U plane, uvula apex point plane; T plane, the point at which the tongue root is closest to the posterior pharyngeal wall; Ep plane, epiglottis apex point plane; CBCT, cone beam computed tomography.

largement. These results are in line with the study by Bosschieter et al (2022), which reported that the non-custom and custom MADs had similar effects for patients with OSA, although the non-custom MAD was cheaper and directly ready for use.

The most important distinguishing feature between the two MAD types was the mandibular protrusion. The mandibular protrusion in the experimental group could be easily adjusted by the doctors and patients using screw spring expenders, whereas it was fixed at 70–75% MMP in the control group. The adjustable horizontal distance of the new device type was as fine as 0.25 mm on the basis of 50% MMP. Therefore, patients could adjust their mandible as they wish. Another dif-

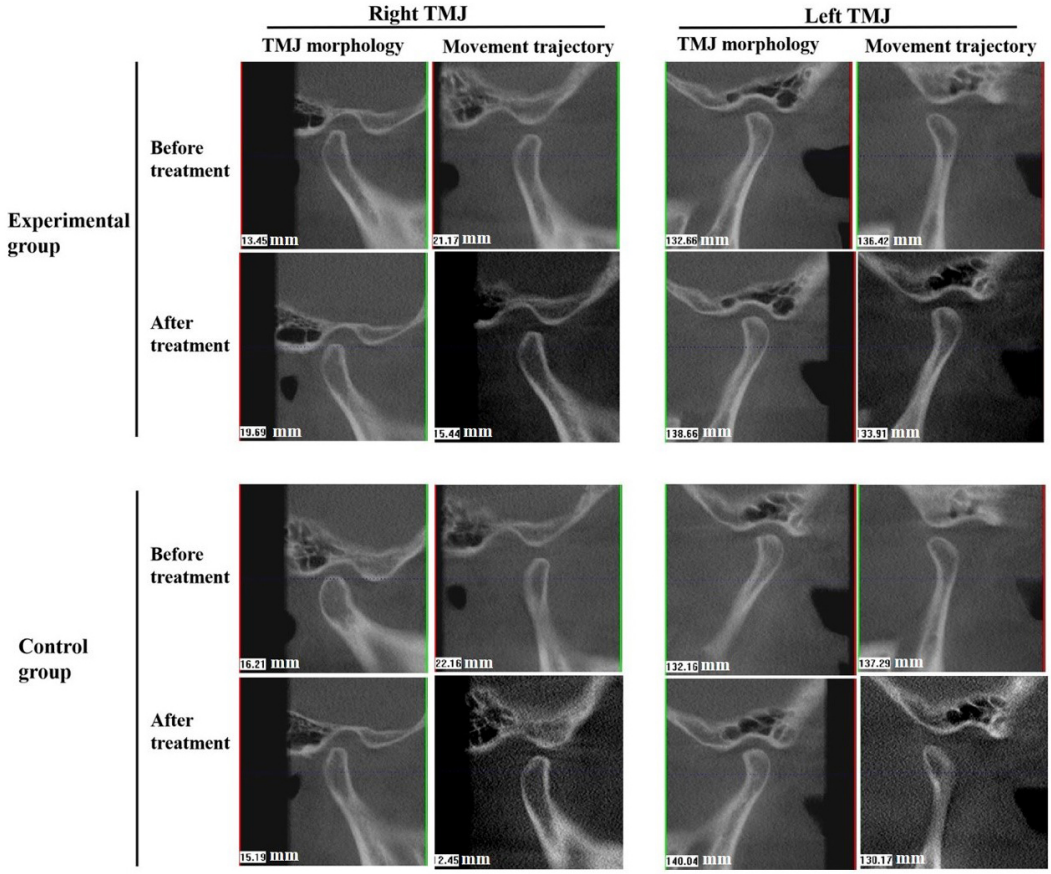

Fig. 6. Changes of TMJ morphology and motion trajectory after 4 weeks of MAD treatment in the experimental group. Abbreviations: MAD, mandibular advancement device; TMJ, temporomandibular joint.

ference between the two groups was the material and volume of the device. The MAD used in the experimental group had a metal base and metal clasps; thus, the volume of the device was significantly reduced. Consequently, the sensation of foreign bodies and the phenomenon of increased salivation were noticeably reduced. Our data showed that the occurrence of side effects in the experimental group decreased by 50% compared with that in the control group after the first week of treatment. Most patients experienced TMJ discomfort the first night or chewing muscle soreness and dry mouth the next morning. However, with the extension of treatment time, the patient's adaptability showed improvements, accompanied by diminishing side effects. After 4 weeks of treatment, all side effects, excluding dry mouth, in the experimental group disappeared. Aarab et al (2010) assessed the effects of MADs with different mandibular protrusion positions and found that the incidence of side effects was higher with MADs starting at the 50% protrusion position. Therefore, the compromise between side effects and efficacy should be considered when choosing different MADs.

In this study, the personalized adjustable MAD utilized in the experimental group afforded greater feelings of comfort and better retention features and was associated with more favourable adherence and superior therapeutic outcomes than that used in the control group. We further evaluated the TMJ morphology and mo-

tion trajectory across 4 weeks of therapy in the experimental group. The CBCT examination showed no significant changes in the anterior and posterior spaces of the TMJ discs after 4 weeks of treatment in the experimental group. The morphology and integrity of the condylar bone cortex showed no noticeable changes, and the condyle was positioned within the physiological range of motion after treatment in the experimental group. These results were consistent with a previous study (Knappe et al, 2017) that no significant radiological changes in TMJ were detected after 3 years of MAD treatment for OSA. Thus, the personalized, adjustable design can remarkably curtail chewing muscle and TMJ problems. According to the American Academy of Sleep Medicine guidelines, the development of TMJ disorders is recognized as the main reason for the cessation of MAD therapy among patients (Kushida et al, 2006). Therefore, the personalized adjustable MAD can provide a more comfortable and precise treatment for patients with OSA. Patients treated with a personalized adjustable MAD are less likely to prematurely stop the therapy and more likely to cooperate with the doctor.

To monitor whether the design of the individualized adjustable MAD can achieve the desired therapeutic outcome, we compared respiratory indicators between the two groups. Our data showed that the personalized adjustable MAD could significantly improve respiratory indicators based on the PSG test. The AHI decreased by 60.74%, MAT shortened by 29.85%, $MSaO_2$ increased by 2.94%, and $LSaO_2$ increased by 5.83% after 4 weeks of treatment. No significant differences were found between the two groups. Compared to our study, Sutherland et al (2015) and Marco-Pitarch et al (2021) found no definite association between the different magnitudes of mandibular advancement of the MADs and the reduction in the AHI in patients with mild or moderate OSA. Despite the small differences in follow-up respiratory PSG data between the two groups monitored in the current study, the experimental group showed excellent therapeutic effects regarding breathing improvement. The major difference between the two groups is the mandibular protrusion advancement, but our data suggested that the extent of mandibular advancement is not the only factor influencing MADs efficacy. It is worth noting that the variability from one night to another in patients with moderate OSA, mandibular morphological features, and different body positions of the patient during sleep may also play a role (Bernhardt et al, 2023).

Soft tissue collapses, narrowing of the upper airway, and velopharyngeal and glossopharyngeal plane stenosis are the main causes of OSA (Shete and Bhad, 2017; Verma and Jain, 2023). The MAD fixes the mandible in a forward-down position, enlarging the upper airway volume. In the present study, CBCT was used to accurately measure the cross-sectional area of the upper airway. After 4 weeks of treatment, the cross-sectional areas of the posterior soft palate (U palate) and postlingual regions (T plane) increased by 51.78% and 36.71%, respectively, in the experimental group. The results showed that the palatal and glossopharyngeal air passages of patients with mild or moderate OSA were significantly enlarged. Our data were consistent with those of previous studies on MADs treatment for older adults (Yılmaz et al, 2016) and concerning the spiral computed tomography and magnetic resonance imaging analyses (Lu et al, 2020). The increased cross-sectional area of

the upper airway, which indicates improved airflow, is beneficial for ameliorating the patients' symptoms.

This study had some limitations. First, the sample size was too small, potentially causing data discrepancy as compared to other studies and reducing the generalizability and reliability of the current set of data. Second, the CBCT was conducted while the patient was awake in an upright position; therefore, the measurement was unable to fully simulate the state of the lower oropharyngeal nerves and muscles in the sleeping and lying positions. Third, owing to the small number of patients studied and short observation time, the effects of long-term adverse reactions on the TMJ, masticatory muscles, and occlusal relationship were not deeply analyzed in this investigation. In future studies, other side effects, including decreased salivation, occlusal changes, and tooth pain, should be further investigated.

Conclusion

In conclusion, the personalized adjustable MAD delivers improved comfort and better clinical efficacy, while significantly ameliorating side effects, such as TMJ discomfort and chewing muscle soreness. This device could also improve the PSG indexes by enlarging the upper airway cross-sectional area. The personalized adjustable MAD is a better choice for patients with mild or moderate OSA compared to the traditional MAD.

Key Points

- The personalized adjustable mandibular advancement device (MAD) adjusted the mandibular protrusion distance using screw spring expanders.
- The personalized adjustable MAD significantly reduced the occurrence of side effects, such as increased salivation, dry mouth, temporomandibular joint discomfort, and chewing muscle soreness.
- The personalized adjustable MAD significantly improved the PSG indices of obstructive sleep apnea (OSA), such as AHI, $MSaO_2$, $LSaO_2$ and MAT.
- The personalized adjustable MAD improved clinical symptoms of OSA by increasing the cross-sectional area of the upper airway.

Availability of Data and Materials

The data presented in this study are available on request from the corresponding author.

Author Contributions

WW: Experiment design, drafting and editing the manuscript; JP: Design the experiment, supervision; YXZ: Patients recruitment and data collection; YMM: Interpretation of data and the analysis of CBCT image; JZ: Data collection and data analysis; ZHW: Experiment design. All authors contributed to important editorial

changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

All procedures were performed in accordance with the principles of the Declaration of Helsinki and approved by the Ethics Committee of the Air Force Hospital from Northern Theater of PLA (approval number 2021-001). All the participants had given their informed consent prior to joining the study.

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Conflict of Interest

The authors declare no conflict of interest.

References

Aarab G, Lobbezoo F, Hamburger HL, Naeije M. Effects of an oral appliance with different mandibular protrusion positions at a constant vertical dimension on obstructive sleep apnea. Clinical Oral Investigations. 2010; 14: 339–345. https://doi.org/10.1007/s00784-009-0298-9

Alessandri-Bonetti A, Bortolotti F, Moreno-Hay I, Michelotti A, Cordaro M, Alessandri-Bonetti G, et al. Effects of mandibular advancement device for obstructive sleep apnea on temporomandibular disorders: A systematic review and meta-analysis. Sleep Medicine Reviews. 2019; 48: 101211. https://doi.org/10.1016/j.smrv.2019.101211

Anitua E, Durán-Cantolla J, Almeida GZ, Alkhraisat MH. Minimizing the mandibular advancement in an oral appliance for the treatment of obstructive sleep apnea. Sleep Medicine. 2017; 34: 226–231. https://doi.org/10.1016/j.sleep.2016.12.019

Anitua E, Mayoral P, Almeida GZ, Durán-Cantolla J, Alkhraisat MH. A Multicenter Prospective Study on the Use of a Mandibular Advancement Device in the Treatment of Obstructive Sleep Apnea. Dentistry Journal. 2023; 11: 247. https://doi.org/10.3390/dj11110247

Barnes M, McEvoy RD, Banks S, Tarquinio N, Murray CG, Vowles N, et al. Efficacy of positive airway pressure and oral appliance in mild to moderate obstructive sleep apnea. American Journal of Respiratory and Critical Care Medicine. 2004; 170: 656–664. https://doi.org/10.1164/rccm.200311-1571OC

Bernhardt O, Giannakopoulos NN, Heise M, Meyer A, Norden D, Schlieper J, et al. Mandibular advancement device: prescription in adult dental sleep medicine - guideline of the German Society of Dental Sleep Medicine. Sleep & Breathing = Schlaf & Atmung. 2023; 27: 389–397. https://doi.org/10.1007/s11325-022-02601-6

Bosschieter PFN, Uniken Venema JAM, Vonk PE, Ravesloot MJL, Hoekema A, Plooij JM, et al. Equal effect of a noncustom vs a custom mandibular advancement device in treatment of obstructive sleep apnea. Journal of Clinical Sleep Medicine: JCSM: Official Publication of the American Academy of Sleep Medicine. 2022; 18: 2155–2165. https://doi.org/10.5664/jcsm.10058

Gottlieb DJ, Punjabi NM. Diagnosis and Management of Obstructive Sleep Apnea: A Review. JAMA. 2020; 323: 1389–1400. https://doi.org/10.1001/jama.2020.3514

Ferguson KA, Cartwright R, Rogers R, Schmidt-Nowara W. Oral appliances for snoring and obstructive sleep apnea: a review. Sleep. 2006; 29: 244–262. https://doi.org/10.1093/sleep/29.2.244

Fleury B, Rakotonanahary D, Petelle B, Vincent G, Pelletier Fleury N, Meyer B, et al. Mandibular advancement titration for obstructive sleep apnea: optimization of the procedure by combining clinical and oximetric parameters. Chest. 2004; 125: 1761–1767. https://doi.org/10.1378/chest.125.5.1761

Hoffstein V. Review of oral appliances for treatment of sleep-disordered breathing. Sleep & Breathing = Schlaf & Atmung. 2007; 11: 1–22. https://doi.org/10.1007/s11325-006-0084-8

Iannella G, Maniaci A, Magliulo G, Cocuzza S, La Mantia I, Cammaroto G, et al. Current challenges in the diagnosis and treatment of obstructive sleep apnea syndrome in the elderly. Polish Archives of Internal Medicine. 2020; 130: 649–654. https://doi.org/10.20452/pamw.15283

Knappe SW, Bakke M, Svanholt P, Petersson A, Sonnesen L. Long-term side effects on the temporomandibular joints and oro-facial function in patients with obstructive sleep apnoea treated with a mandibular advancement device. Journal of Oral Rehabilitation. 2017; 44: 354–362. https://doi.org/10.1111/joor.12485

Kushida CA, Morgenthaler TI, Littner MR, Alessi CA, Bailey D, Coleman J, Jr, et al. Practice parameters for the treatment of snoring and Obstructive Sleep Apnea with oral appliances: an update for 2005. Sleep. 2006; 29: 240–243. https://doi.org/10.1093/sleep/29.2.240

Langaliya A, Alam MK, Hegde U, Panakaje MS, Cervino G, Minervini G. Occurrence of Temporomandibular Disorders among patients undergoing treatment for Obstructive Sleep Apnoea Syndrome (OSAS) using Mandibular Advancement Device (MAD): A Systematic Review conducted according to PRISMA guidelines and the Cochrane handbook for systematic reviews of interventions. Journal of Oral Rehabilitation. 2023; 50: 1554–1563. https://doi.org/10.1111/joor.13574

Li M, Li X, Lu Y. Obstructive Sleep Apnea Syndrome and Metabolic Diseases. Endocrinology. 2018; 159: 2670–2675. https://doi.org/10.1210/en.2018-00248

Lu RJ, Tian N, Wang JZ, Zou X, Wang JJ, Zhang M, et al. The effectiveness of adjustable oral appliance for older adult patients with obstructive sleep apnea syndrome. Annals of Palliative Medicine. 2020; 9: 2178–2186. https://doi.org/10.21037/apm-20-1300

Luzzi V, Brunori M, Terranova S, Di Paolo C, Ierardo G, Vozza I, et al. Difficult-to-treat OSAS: Combined continuous positive airway pressure (CPAP) and mandibular advancement devices (MADs) therapy. A case report. Cranio: the Journal of Craniomandibular Practice. 2020; 38: 196–200. https://doi.org/10.1080/08869634.2018.1496628

Ma Y, Yu M, Gao X. The effect of gradually increased mandibular advancement on the efficacy of an oral appliance in the treatment of obstructive sleep apnea. Journal of Clinical Sleep Medicine: JCSM: Official Publication of the American Academy of Sleep Medicine. 2020; 16: 1369–1376. https://doi.org/10.5664/jcsm.8556

Marco-Pitarch R, García-Selva M, Plaza-Espín A, Puertas-Cuesta J, Agustín-Panadero R, Fernández-Julián E, et al. Dimensional analysis of the upper airway in obstructive sleep apnoea syndrome patients treated with mandibular advancement device: A bi- and three-dimensional evaluation. Journal of Oral Rehabilitation. 2021; 48: 927–936. https://doi.org/10.1111/joor.13176

Mezzofranco L, Zalunardo F, Savin S, Agostini L, Gracco ALT. Patients' perceptions of the importance of improvements and side effects from mandibular advancement device therapy for obstructive sleep apnea and snoring. Cranio: the Journal of Craniomandibular Practice. 2024; 1–7. https://doi.org/10.1080/08869634.2024.2325405

Ng JH, Yow M. Oral Appliances in the Management of Obstructive Sleep Apnea. Sleep Medicine Clinics. 2020; 15: 241–250. https://doi.org/10.1016/j.jsmc.2020.02.010

Ou YH, Colpani JT, Chan SP, Loke W, Cheong CS, Kong W, et al. Mandibular advancement device versus CPAP in lowering 24-hour blood pressure in patients with obstructive sleep apnoea and hypertension: the CRESCENT trial protocol. BMJ Open. 2023; 13: e072853. https://doi.org/10.1136/bmjopen-2023-072853

Shete CS, Bhad WA. Three-dimensional upper airway changes with mandibular advancement device in patients with obstructive sleep apnea. American Journal of Orthodontics and Dentofacial Orthopedics. 2017; 151: 941–948. https://doi.org/10.1016/j.ajodo.2016.09.025

Sutherland K, Takaya H, Qian J, Petocz P, Ng AT, Cistulli PA. Oral Appliance Treatment Response and Polysomnographic Phenotypes of Obstructive Sleep Apnea. Journal of Clinical Sleep Medicine: JCSM: Official Publication of the American Academy of Sleep Medicine. 2015; 11: 861–868. https://doi.org/10.5664/jcsm.4934

Tang B, Bai Y, Zhao J, Yang H, Avolio A, Zuo J. The Severity of Obstructive Sleep Apnea Increases the Risk of Arteriosclerosis. Reviews in Cardiovascular Medicine. 2022; 23: 94. https://doi.org/10.31083/j.rcm2303094

Verma A, Jain S. Efficacy of Mandibular Advancement Device in the Treatment of Obstructive Sleep Apnoea by Evaluating Upper Airway Space Volume Using CBCT. Journal of the College of Physicians and Surgeons–Pakistan: JCPSP. 2023; 33: 1194–1197. https://doi.org/10.29271/jcpsp.2023.10.1194

Yılmaz Z, Voyvoda N, İnan E, Şirinocak PB, Terzi R. Factors affecting executive functions in obstructive sleep apnea syndrome and volumetric changes in the prefrontal cortex. SpringerPlus. 2016; 5: 1934. https://doi.org/10.1186/s40064-016-3609-z