The Effect of a Mandibular Advancement Splint on Electromyographic Activity of the Submental and Masseter Muscles in Patients with Obstructive Sleep Apnea

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Purpose: The effectiveness of an appliance for the treatment of obstructive sleep apnea (OSA) shows inordinate interindividual differences. Also, its therapeutic effects still remain unresolved. This study examined and compared the effects of a mandibular advancement splint (MAS) on the masseter and submental muscles of patients with mild and moderate OSA. ***Materials and Methods:*** Twenty OSA patients (10 mild and 10 moderate) who refused or did not tolerate nasal continuous positive airway pressure were randomly selected among individuals whose apnea-hypopnea indices (AHIs) were determined at the sleep laboratory of the Department of Chest Diseases, Ege University, before the study. Two polysomnography (PSG) sessions were performed and evaluated: the first without an MAS for the first half of the night to determine baseline muscle activity and the second with an MAS for the other half of the night to follow the condition of muscle activity. Electromyograms (EMGs) of the sum of the submental musculature and masseter muscle were measured with PSGs. The highest EMG amplitudes of the muscles and their AHIs were recorded before and after use of the appliance. Data were analyzed statistically using a *t* test. ***Results:*** After insertion of the MAS device, EMG amplitudes increased significantly in the submental ($P < .05$) and masseter muscles ($P < .05$) of both mild and moderate OSA patients. However, the increase in muscle activity in the mild OSA group was significantly different from the moderate OSA group ($P < .05$). Accordingly, the mean EMG amplitude during moderate apnea episodes was lower than mild both with and without the appliance. After insertion of the MAS, the mean AHI in both mild and moderate OSA patients decreased significantly from baseline recordings ($P < .05$). Patients reported a favorable sleeping pattern and no dislodgement of the appliance during sleep. ***Conclusion:*** The MAS activated the masseter and submental muscles during sleep and prevented the upper airway from collapsing. The prosthetic appliance was useful in the treatment of both mild and moderate OSA syndrome. *Int J Prosthodont 2009;22:586–593.*

Obstructive sleep apnea (OSA) is a common disorder related to the narrowing of the upper airways. Many treatment methods have been tried over the years to treat snoring and OSA.[1] Today, three approaches seem to be the most effective: *(1)* nasal continuous positive airway pressure (nCPAP), *(2)* surgical techniques, and *(3)* use of intraoral appliances (OAs).[2] Since its introduction in the 1980s, nCPAP is considered to be the primary treatment method for moderate-to-severe OSA.[3] However, side effects associated with nCPAP usage are frequently reported.[4] These problems eventually lead to noncompliance, especially in younger and less severe patients.[5]

OAs are indicated for patients with primary snoring or in mild OSA patients who do not respond to or are not appropriate candidates for treatment with behavioral measures, such as weight loss or a change in sleep position. On the other hand, OAs have been advised for patients with moderate-to-severe OSA who can not tolerate or refuse treatment with nCPAP, or for subjects who are not suitable surgical candidates.[6,7]

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OAs are an effective therapy method for patients with OSA. In recent years, a number of these devices have been developed. OAs are worn in the mouth during sleep to prevent the oropharyngeal tissues and the base of the tongue from collapsing and obstructing the airway. There are three basic ways to create and maintain a patent upper airway during sleep. First, the appliance can actually reposition certain anatomical parts that are causing the obstruction. Depending on the specific appliance, the tongue, mandible, soft palate, and hyoid bone may be repositioned to create airway patency. Second, the appliance serves to stabilize the mandible, tongue, and hyoid bone to prevent collapse during sleep. Third, the appliance may increase baseline genioglossus muscle activity via a downward and forward rotation of the mandible, resulting in a tongue that is less likely to relax and fall back, causing an obstruction. Hereby, the OAs are classified by mode of action into one of three categories. They increase the oropharyngeal space by advancing the mandible or the tongue. These appliances subsequently assist in reducing the obstruction.[8–10]

Mandibular repositioners (MRs) function to reposition and maintain the mandible in a protruded position during sleep. It is felt that this serves to open the airway in several different ways: by indirectly pulling the tongue forward by virtue of its attachment to the geniotubercles, by increasing the baseline genioglossus muscle activity, or by stabilizing the mandible and hyoid bone to prevent jaw opening and retrolapse of the tongue. Much of the available research showing the effectiveness of oral appliances is focused on MRs.[9–11]

The objective of using a mandibular advancement splint (MAS), which is a nonadjustable monoblock (one-piece) appliance, and an MR is to advance the mandible and tongue base, and thus, to increase the space between the base of the tongue and the posterior pharyngeal wall in an OSA patient. An MAS functions to repose and maintain the mandible in a protruded position and to keep vertical opening between 5 and 7 mm during sleep.[2,8,11–13]

This study aimed to investigate the effects of an MAS on surface electromyographic (EMG) activities of the submental and masseter muscles during OSA, to compare its efficiency in mild and moderate OSA patients who underwent a polysomnography (PSG) throughout an entire night, and to evaluate patient compliance within the given time interval. The tested null hypotheses were that mean EMG values of muscle activity without an MAS would be lower than those with an MAS for all groups, and that the EMG value of the mild group would be greater than the moderate group.

Materials and Methods

Diagnosis

A sleep study with overnight PSG was carried out to diagnose the severity of OSA at the sleep laboratory of the Department of Chest Diseases, Ege University, Izmir, Turkey, and revealed an obstructive apnea-hypopnea index (AHI) of between 5 and 30 events per hour of sleep in the patients, including no central or mixed OSA patients. A total of 20 patients whose diagnostic PSG results were selected randomly[14] and who were controlled according to the indication criteria of the Academy of Dental Sleep Medicine (ADSM) and American Academy of Sleep Medicine (AASM)[14] were referred to the Department of Prosthodontics, Ege University, for OA therapy

According to the ADSM and AASM, oral appliances are primarily used to treat simple snoring, mild OSA, and moderate-to-severe OSA when nCPAP treatment is not tolerated or when the patient rejects it as a secondary therapeutic option.[14] Hence, mild OSA was present in 10 of the 20 patients who were selected for this study and moderate OSA in the other 10 patients who were included but refused or did not tolerate the nCPAP device. According to the AASM,[9,13] an AHI of 5 to 15 indicates mild OSA and an AHI of 15 to 30 indicates moderate OSA. The subjects (5 women, 15 men) were between the ages of 45 and 72 years old (mean age: 54.0 ± 8.4).

Inclusion criteria were as follows: patients who only snored while in the lying position, were not using any sedatives or alcohol, were not smoking, and patients who have not been treated for hypertension or diabetes mellitus type 2.

Exclusion criteria consisted of persons with a chronic illness (other than OSAs), an AHI above 40 with pathophysiologic symptoms, edentulousness, and persons who had previous surgical attempts to correct their snoring or apnea. Other subjects excluded were those with significant nonOSA sleep disorders, those who were using sedative or hypnotic medication regularly, and those on rotating or night shifts.

Examination of the patient histories showed that the patients had severe snoring and daytime drowsiness. They stated unrefreshness on awakening, chronic forgetfulness, and defective concentration. The patients witnessed apneas, a blockage feeling, and perspiration during sleep and insomnia. They also had morning headaches and dryness of the mouth.

Dental, temporomandibular joint, and muscle examinations and inspections resulted in usual or normal findings. All patients had more than 10 teeth in each arch and had no symptoms related to temporomandibular disorder, according to the Helkimo

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Fig 1 The MAS fabricated as an intraoral device.

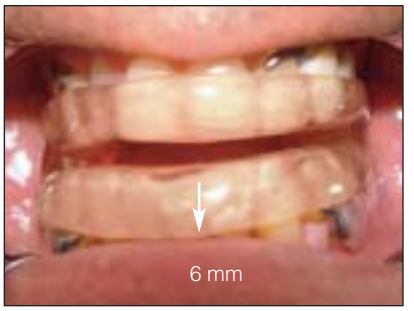

Fig 2a Frontal view, MAS in situ. Note: 6-mm interincisal distance as vertical open.

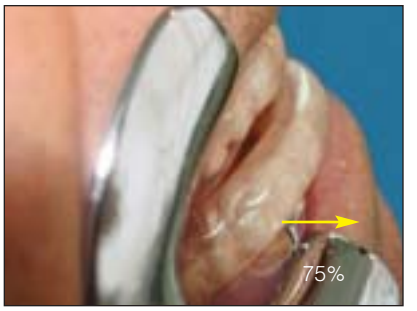

Fig 2b Lateral view, MAS in situ. Note: 75% of maximum protrusive position.

anamnestic and clinical pain-dysfunction index (Helkimo Index: 0°).[2,12,13] Patients with acute problems completed appropriate basic dental treatment before participation in the study.

Other examination parameters were neck size, obesity (measured by the body mass index [BMI]), oropharyngeal tissues, size of the tongue (ie, enlarged tongue), length of the soft palate, size of the uvula and tonsils, and crowding of the oropharyngeal area. The mean BMI was 32.3 ± 5.1 kg/m^2 and mean neck size was 42 ± 3.5 cm.

After explaining the purpose and procedures of the study, informed consent and signed patient release forms were received. The experiment was conducted in accordance with the principles of the Declaration of Helsinki for Human Experimentation.

MAS Fabrication

MAS appliances were designed to increase the size of the upper airway by advancing the mandible (Fig 1) and were fabricated individually for each patient as previously described.[2,8,11,13–15]

The usual clinical procedures were applied to register both impressions of the teeth and a therapeutic jaw position as described in the literature,[2,8,11,13–15] which were then sent to an outside laboratory for construction of the appliance.

The MAS appliance was fabricated with a 75% to 80% protrusion and a 5- to 7-mm vertical dimension and anterior airway (Figs 2a and 2b).

Instructions on use and care were provided at insertion of the MAS. Patients were advised to wear the appliance for at least 6 hours during the night and were recalled for any necessary adjustments 1 day later.

Protocol

The experiment was carried out 1 week after the patients started wearing the MAS. For evaluation of the sleep apnea and EMGs of submental and masseter muscles,[14] patients underwent two more PSG episodes to create an objective measurement of respiration and muscle activity during obstruction.

One full-night PSG recording was perfomed in the study. In other words, half-night PSG recordings were simultaneously performed at once. In the first PSG, 20 OSA patients went half of the night without the device to establish baseline amplitudes of EMG activities of the muscles. In the second PSG, EMG recordings were perfomed for the other half of the night on the same 20 patients following insertion of the MAS appliance.

EMG Performance

EMG recordings of the routine PSG scores were taken using two-channel EMG equipment at both the first and second PSG events. Resting surface EMG activity from the right masseter muscle and submental muscles were recorded simultaneously according to the diagram in the literature.[14,15] Records of the EMG amplitudes of each muscle (submental and masseter) during the obstructive apnea were performed without (first PSG) and with the appliance (second PSG).

Pre-gelled, self-adhesive, disposable surface electrode pairs with a 15 × 20 mm recording area (Medtronic Dantec) were used for all recordings. For the submental muscles, the active electrode was positioned midsagittally, midway between the mental protuberentia and lower lip, and the reference electrode was midway between the inner aspect of the mandible and the hyoid bone. Two electrodes were placed over the masseter muscle in the direction of the muscle fibers and were placed 15 mm apart,[14] where both electrodes were used to record the potential in the muscles of interest, each with respect to the reference electrode. The low and high cut-off frequencies of the amplifier filter were set at 20 Hz and 3 kHz, respectively. Amplifier gain was held between 0.2 μV (± 4 μV) and 10 μV (± 4 μV) per division. The ossiloscope trace was set for a sweep speed of 16 seconds per division, allowing an analysis time of approximately 160 seconds

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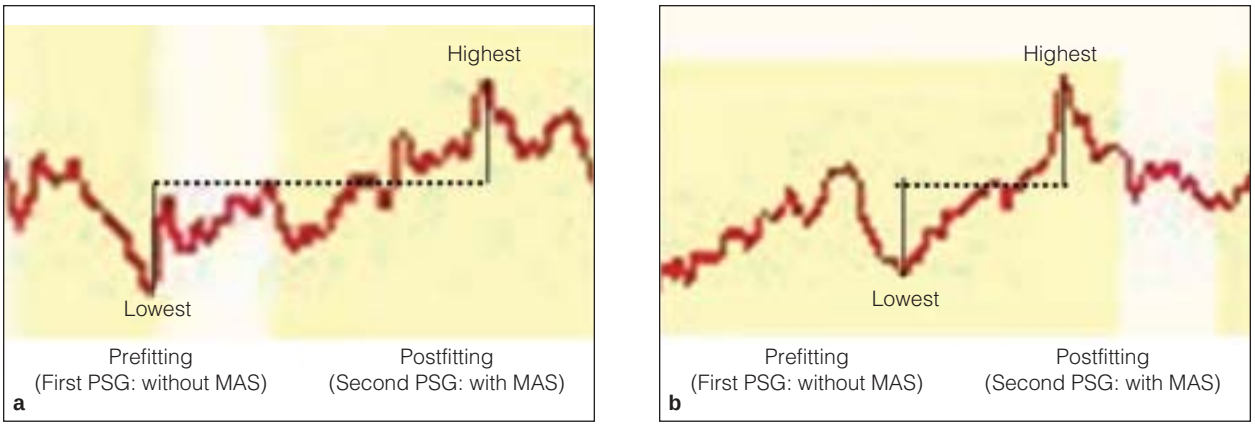

Fig 3 Example EMG activity for **(a)** the masseter and **(b)** submental muscles.

during the obstructive periods. All records were digitized, rectified, stored, and converted to the integrated EMG using a software within the EMG apparatus. The highest amplitudes were used to express the muscle EMG activity in μV (Figs 3a and 3b).

Statistical Analysis

Data (EMG tension of muscle activity during the obstruction and AHI) were analyzed statistically. Data were established in the following groups: a = mild OSA without the MAS at the masseter muscle, b = mild OSA with the MAS at the masseter muscle, c = mild OSA without the MAS at the submental muscles, d = mild OSA with the MAS at the submental muscles, e = moderate OSA without the MAS at the masseter muscle, f = moderate OSA with the MAS at the masseter muscle, g = moderate OSA without the MAS at the submental muscles, and h = moderate OSA with the MAS at the submental muscles.

First, descriptive statistics for each group were performed and graphics were prepared. The Kolmogorov–Smirnov test was used to examine whether the groups were normally distributed. Then, paired *t* tests were used to investigate whether there was a difference between the pairings of groups (a and b, c and d, e and f, and g and h). Then, independent sample *t* tests were used to investigate whether there were differences between each independent group (a and e, b and f, c and g, and d and h). SPSS 11.0 (SPSS) was used for all analyses ($\alpha = .05$)

Results

The Kolmogorov-Smirnov test revealed that the data were normally distributed.

Each subject underwent two sleep studies for one night; one before and one after the appliance was inserted in situ.

The obstructive AHI was analyzed on the first and second PSG following insertion of the device and was calculated both with and without the appliance in situ. The mean AHI in the patients with mild OSA was 10.9 ± 4.5 and showed a significant decrease (2.8 ± 0.5) after insertion of the device ($P < .05$). When AHI measurements between the first and second PSG were compared, a significant decrease was observed in the AHI of the mild group ($P = .001$). The mean AHI in patients with moderate OSA was 18.6 ± 5.8 and decreased significantly (6.6 ± 1.8) after insertion of the device ($P < .05$). When the decrease in AHI at the second PSG was compared with the AHI at the first, the values at the second PSG were also found to be statistically significant in the moderate group ($P = .009$).

The muscles demonstrated significantly lower EMG amplitudes without the MAS ($P < .05$), and significantly higher EMG amplitudes with the device in both mild and moderate OSA patients ($P < .05$). In other words, the EMG amplitude of the submental muscles in the patients with moderate OSA (3.20 ± 1.85 μV) was significantly increased by the appliance (15.44 ± 2.05 μV) during the obstructive apnea ($P < .05$), and the EMG amplitude of the submental muscles in the patients with mild OSA (16.90 ± 6.13 μV) was also significantly increased by the appliance (29.32 ± 4.36 μV) during the obstructive apnea ($P < .05$) (Table 1, Fig 4). Similarly, the masseter muscle in the patients with moderate OSA showed significantly higher EMG amplitudes with (9.70 ± 5.31 μV) than without (2.70 ± 1.42 μV) the device ($P < .05$), and the masseter muscle in the patients with mild OSA also showed significantly higher EMG amplitudes with (31.60 ± 10.81 μV) than without (18.30 ± 3.23 μV) the device ($P < .05$) (Table 1, Fig 4).

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Table 1 Results of the Paired *t* Test

Group	n	Mean	SD	*P*
Pair 1				
a	10	18.30	3.23	.003
b	10	31.60	10.81	
Pair 2				
c	10	16.90	6.13	.000
d	9*	29.32	4.36	
Pair 3				
e	10	2.70	1.42	.002
f	10	9.70	5.31	
Pair 4				
g	10	3.20	1.85	.000
h	9*	15.44	2.05	

SD = standard deviation.
*Outlier values removed from data and kept exclusive of the statistical evaluation.

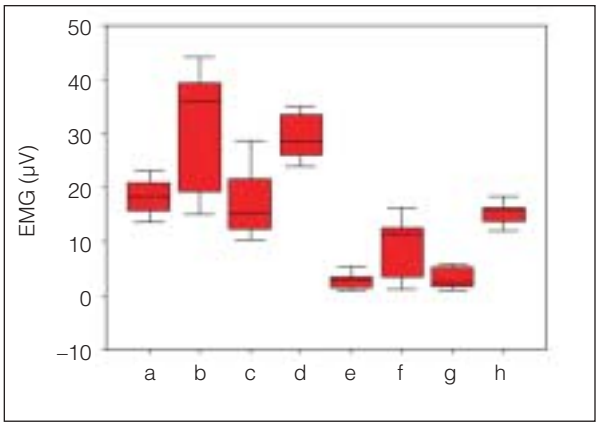

Fig 4 Box plot of EMG activity of the masseter and submental muscles in mild and moderate OSA patients both before and after use of an MAS.

Table 1 shows the paired *t* test, which revealed that the means of the paired samples were equal and the activities of both muscles increased from the first PSG to the second (after placement of the device).

The data show significantly lower submental and masseter EMG activities in moderate OSA patients than corresponding muscle activities in mild OSA patients. Therefore, the independent sample *t* test was used when testing these two independent groups. Briefly, independent sample *t* test results revealed that EMG values of mild groups were greater than those of the moderate groups ($P < .05$) (Table 2).

Table 2 Results of the Independent Sample *t* Test

Group	Mean difference	*P*
a vs e	15.60	.00
b vs f	21.90	.00
c vs g	13.70	.00
d vs h	13.88	.00

The favorable sleeping pattern described by the patients was the one that provided a refreshed feeling on awakening. Their discomforts, such as number of times awakened during night, gasping and choking, morning headaches, sour taste in the mouth, and dry mouth, were reduced. Patients reported that their sleep had improved at night. The appliance did not disturb the patients and compliance was very high.

Discussion

This study showed that EMG amplitudes of the masseter and submental muscles were increased significantly by the application of an MAS during mild and moderate apnea. The results indicate that the device activated the muscles in both patient groups during the obstruction. The EMG amplitudes of the submental muscles were significantly increased by the appliance of the MAS. The masseter muscle showed significantly higher EMG amplitude with the appliance (Fig 4). The results suggest that during mild and moderate obstructive apneas, the tonus of the muscles protracting the tongue and mandible was maintained with an MAS, as stated in the literature.[13,14,16–18] Therefore, relaxation of muscle contraction did not occur, which resulted in a significant increase in mean EMG amplitude during mild and moderate OSA. For this reason, it has been thought that the activated muscles that protract the tongue and mandible during use of an MAS may be preventing the upper airway from collapsing.[13,14,16–18] Although MAS application increased EMG activities of both the mild and moderate groups, the mild group showed greater EMG values when compared to those of the moderate group (Table 2).

According to Meyer and Knudson,[17] sleep induces relaxation of the musculature in the upper airway. As a result, the opening of the airway shrinks and breathing becomes more labored. The most prevalant explanation of OSA is that the obstruction occurs when the tongue retrudes back against the posterior pharyngeal wall. Whether the airway remains patent or collapses depends on the amount of negative pressure in the airway and the counterbalancing muscle tonus of the dilators of the oropharynx, particularly the genioglossi in the suprahyoid and submental localizations.[2,6,14,15] It was reported that the apnea index or apneic episodes per hour decreased significantly and increased EMG activity of genioglossal muscle between the submental and suprahyoid areas after insertion of such a prosthetic appliance.[2,6,13–16,19–26]

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Several authors[13,14,16,25–27] stated that the pretreatment EMG values of genioglossus and masseter muscles were lower than after treatment. However, an MAS seemed to be effective in gaining the contraction level that was lost. There was an increase in the EMG levels of the muscles with an MAS, and the results of the present study support those previous reports. However, the stable tonus of both muscles during the apneas was evaluated due to the presence of continuous measurement throughout an entire night's sleep. The phasic activity of muscles was not assessed and measured, since any motion could not be recorded at night.

Remmers et al[28] reported that the genioglossal EMG of patients with OSA consistently revealed periodicity, a low level of activity during the obstruction. Hollowell and Suratt[29] found that the masseter muscle was activated in patients with OSA in a manner similar to that of the submental muscles. Similarly, in the current study, the masseter and submental muscles showed relatively low EMG amplitudes without the appliance during mild and moderate obstructive apnea and high EMG amplitudes with the appliance.

The MAS acts to increase the size of the pharyngeal airway or otherwise reduce its collapsibility.[2,6,16,24] Although its therapeutic effects are still unclear,[14,15,25-29] an MAS may be worn to correct the malfunction of the genioglossus and masseter muscles and to protect and even promote the contraction level of the patient in a conscious state. Fundamentally, surface electrodes can pick up facial muscle activities that can influence the reading of the masseter muscle. As also recognized by the authors, the surface EMG can not isolate suprahyoid muscle activity so it can only be supposed that there is increased activity in the genioglossus. In OSA patients, the literature says that there is a decrease in the activation of the genioglossus and masseter muscles during the period of relaxation.[25] The treatment mechanism depends on the idea of maintaining or increasing the activity levels of the genioglossus and masseter muscles.[26] It should be pointed out that, as in the case of the masseter muscle, the decreased activity of the genioglossus muscle should be regained.[27] In order to prevent shrinkage or obstruction, a simultaneous activity of both muscles is needed. Yoshida[14] also found that the MAS activated the masticatory and tongue muscles and prevented the upper airway from collapsing.

Also in this study, the coactivation of the agonist (submental muscles) and antagonist (the masseter muscle) was postulated to stabilize the mandible and tongue position to prevent the upper airway from collapsing.

Several studies have used intraoral appliances for the treatment of sleep apnea syndrome.[7,14,15,20,30–44] The intraoral devices posture the mandible at a more vertically open and protrusive position.[7] The mandibular position of the appliance in this study as well as the technique for its fabrication and design was based on data reported by Yoshida.[14]

Finally, the low levels of activity recorded in both muscle areas are assumed to be the cause of airway collapse, and thus the cause of snoring and sleep apnea. When patients were found to have less OSA and more activity in those muscles after wearing the MAS, it can be assumed that the increased muscle activity is responsible for the improved sleep pattern.

However, there have been method limitations to this study. The submental region can technically include the suprahyoid muscles, such as the genioglossus, geniohyoid, mylohyoid, and anterior belly of the digastric and the platysma. Therefore, contrary to other studies,[14,30,31] the authors have preferred to use the term "submental muscles" rather than genioglossus muscle or suprahyoid and tongue muscles in this study. Several muscles, which are included in the suprahyoid muscles, underlie any surface electrodes placed in the submental area, but the genioglossi were presumed to be the only ones measured according to the references.[14,31] The study was planned with surface EMGs. Surface EMGs were used due to their comfort and patient complaince rather than using fishhook EMGs during sleep. However, Sauerland et al[31] reported that geniglossus muscle activity can be followed closely by submental surface recordings in the study of sleep and breathing disorders. Yoshida[14] also used and supported the same process. Therefore, in this study, a similiar method was applied for surface measurements of EMG recordings of the submental muscles, as described in the literature.[14,18,32,33] The age range of the subjects was a variable not controlled in this study in order to prevent the disappearence of the study's basic goal due to excessive details. Besides, obesity, confirmed by the BMI, and neck size were not planned in the initial stage of the study. Further research is needed to prevent the influence of these parameters on AHI and OSA, such as the relationship between the age range and OSA and between BMI and AHI. Separately and within the limitations of this study, the following comments should not be forgotten:

- The increased activity in the masseter and submental muscles can be a result of having the mandible pulled forward all night.
- Other muscles, such as the mylohyoid or anterior belly of the digastric, can be more important in producing the desired outcome.
- The improvement in airway patency may be due to the simple mechanical action of dragging the mandible forward.

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The MAS was worth applying because treatment with the device was easy to perform, noninvasive, inexpensive, and easy to produce and apply in situ.

Patients were scheduled for control appointments every 6 months to evaluate the effectiveness of the appliance. In this study, PSG recordings were employed to monitor the clinical success of the appliance. The EMG and AHI evaluations in the PSG were compatible. According to these results, there was an improvement with the MAS. More importantly, EMG evaluation confirmed the measurements of AHI evaluation.

Conclusion

An MAS is an effective treatment method for mild and moderate apneas and can be used for the treatment of sleep apnea syndrome, such as mild and moderate OSA, as described in the literature.[32,36–41]

An MAS stimulates the masseter and submental muscles in mild and moderate OSA patients and prevents the airway from collapsing during sleep.

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Literature Abstract

Is adhesive cementation of endodontic posts necessary?

The use of adhesive systems for the cementation of endodontic posts can be advantageous. There are, however, some limitations associated with this technique. Since there is only partial visual access to the post space, remnants of the post space preparation or acid could remain within the canal. The configuration of the root canal system also may not be favorable in terms of polymerization shrinkage stresses. The purpose of this study was to investigate the feasibility of fiber post cementation using zinc-phosphate cement. Human maxillary incisors were divided into four groups of 10 teeth each. The teeth were endodontically treated and sectioned 2 mm coronal to the cementoenamel junction. They were then restored with glass fiber posts cemented using different cement–composite resin core combinations: RelyX Unicem–Clearfil core, RelyX Unicem–LuxaCore, zinc-phosphate–Clearfil core, and LuxaCore–Dual-Clearfil core with a pretreatment of phosphoric acid and a bonding agent. The teeth were prepared to receive all-ceramic crowns with a 2-mm ferrule. Thermocycling and cyclic loading were performed (6,000 cycles, 5°C/55°C, and 1.2×10^6 mastication cycles with a force of 50 N applied at 135 degrees), after which the specimens were loaded in a universal testing machine with a cross-head speed of 1 mm/min until failure. The results from cyclic loading were compared using log-rank analysis and Kaplan-Meier survival plots revealed significant differences between groups, with RelyX Unicem–Clearfil the best and zinc-phosphate–Clearfil the worst. After static loading, a pair-wise comparison between groups using the Mann-Whitney test also showed significant differences between RelyX Unicem–Clearfil and Rely X Unicem–LuxaCore ($P = .005$), RelyX UniCem–Clearfil and zinc-phosphate–Clearfil ($P = .043$), and RelyX Unicem–Clearfil and LuxaCore–Dual-Clearfil ($P = .016$), with RelyX Unicem–Clearfil having the highest median fracture load. Failures were classified as crown fracture, oblique fracture above or at the crestal bone level facially, or below the crestal bone level facially. The conclusion of this study was that the conventional nonadhesive post cementation was not as reliable as the adhesive self-etch or total-etch bonding systems under simulated clinical function for the cementation of glass fiber posts.

Naumann M, Sterzenbach G, Rosentritt M, Beuer F, Frankenberger R. *J Endod* 2008;34:1006–1010. **References:** 41. **Reprints:** Dr Michael Naumann, Department of Dental Prosthodontics and Material Science, Univerisity of Leipzig, Nürnberger Str. 57, 04103 Leipzig, Germany. Email: micha.naumann@gmx.de—*Clarisse Ng, Singapore*

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