Effect of Vertical Dimension on Efficacy of Oral Appliance Therapy in Obstructive Sleep Apnea

Andrew J. Pitsis, M. Ali Darendeliler, Helen Gotsopoulos, Peter Petocz, and Peter A. Cistulli

Department of Respiratory Medicine, Centre for Sleep Disorders and Respiratory Failure, St. George Hospital, University of New South Wales, Kogarah; Discipline of Orthodontics, Faculty of Dentistry, University of Sydney; and Department of Mathematical Sciences, University of Technology, Sydney, New South Wales, Australia

The aim of this study was to assess the effect of bite opening induced by a mandibular advancement splint (MAS) on efficacy and side effects in the treatment of obstructive sleep apnea. In a randomized crossover fashion, 23 adult patients received either MAS-1 (4 mm of interincisal opening) or MAS-2 (14 mm of interincisal opening) for 2 weeks, followed by the alternate treatment for 2 weeks, with an intervening 1-week washout. Complete response was defined as a resolution of symptoms and a reduction in apnea/hypopnea index (AHI) to less than 5 per hour. Partial response was defined as improved symptoms and a reduction in AHI of 50% or more, with the AHI remaining at a value of 5 or more per hour. Both MAS-1 and MAS-2 produced similar reductions in mean (± SEM) AHI from baseline: 21 ± 2 versus 8 ± 1/hour and 21 ± 2 versus 10 ± 2/hour, respectively ($p < 0.001$). Either complete response or partial response occurred in 74 and 61% of patients with MAS-1 and MAS-2, respectively. Subjective improvements were reported with both appliances by the majority of patients. Patients preferred MAS-1 (78 versus 22%, $p = 0.007$). This study suggests that the amount of bite opening induced by MAS does not have a significant impact on treatment efficacy but does have an impact on patient acceptance.

Keywords: obstructive sleep apnea; oral appliance; vertical dimension

Over the last decade, numerous studies have reported the use of oral appliances in the treatment of obstructive sleep apnea (OSA) (1–6). These removable oral appliances are thought to act primarily by advancing the mandible during sleep (7). Although published reports indicate variable efficacy, oral appliances do appear to be a viable alternative to continuous positive airway pressure treatment in some patients with OSA, including those with moderate to severe disease (6). Reliable evidence supporting the role of these oral appliances in clinical practice is only just emerging (8). Most of the published studies have several shortcomings, including small sample sizes, with no control or comparison group, and are usually retrospective in design, and treatment outcome criteria are usually poorly defined, weak, and subjective (6, 8). A consistent observation is that patients prefer mandibular advancement splint (MAS) therapy over continuous positive airway pressure treatment because MAS are less costly, easy to transport, silent, less obtrusive, and do not require a power supply (2–4). However, some patients appear to derive a placebo effect from the treatment (6); hence, it is important to follow patients carefully using objective techniques.

The influence of appliance design on treatment outcome has received very little attention. The variable success rate of the numerous types of oral appliances available to treat OSA may, at least in part, be related to design differences. There are conflicting data regarding the effect of the degree of bite opening (vertical dimension of opening [VDO]) induced by oral appliances on treatment outcome. Although some studies have shown that appliances that promote an increased VDO are effective (5, 7, 9), physiologic evidence suggests that the VDO should be kept to a minimum to optimize treatment outcome (10). Hence, the aim of this study was to systematically assess the effect of the vertical dimension of an oral appliance on efficacy and side effects in the treatment of OSA.

METHODS

Study Population

Patients were recruited from a Sleep Disorders Clinic in a University Teaching Hospital. Criteria for inclusion were the presence of at least two symptoms of OSA (snoring, fragmented sleep, witnessed apneas, daytime sleepiness) and evidence of OSA on polysomnography (apnea/hypopnea index [AHI] > 5/hour). Patients were excluded if there was evidence of central sleep apnea, periodontal disease, or edentulism. The institutional ethics committee approved the study, and written informed consent was obtained from all patients.

Mandibular Advancement Splints

Dental impressions and an interocclusal record with the mandible in the most comfortable protrusive position were used to fabricate two configurations of the MAS (Figure 1). MAS-1 was a modified version of an appliance previously reported (6) and induced an interincisal opening of 4 mm. Once the final level of advancement was determined for each patient, a removable acrylic overlay was constructed and fitted between the upper and lower appliances to achieve an interincisal distance of 14 mm (MAS-2). The extent of mandibular advancement with each MAS remained constant along the advanced arc of opening and closing, which was designed to parallel the normal arc of opening and closing for each patient. This was achieved through the design of the coupling mechanism between the two plates (Figure 1).

Study Design

A randomized, crossover design (AB/BA) was used. At baseline, patients completed two questionnaires assessing OSA symptoms and underwent overnight polysomnography. They were advised that the aim of the study was to compare MAS-1 and MAS-2 during the crossover phases. Patients underwent an acclimatization period with MAS-1 for 4 to 6 weeks, during which incremental advancement of the mandible occurred until the maximum comfortable limit was reached. The absolute amount of protrusion was measured with a stainless steel ruler as the horizontal distance from the lower central incisors in maximum intercuspation to the maximum comfortable protrusion position. Symptomatic responses were not assessed during this period to avoid preconditioning patients to MAS-1. After acclimatization, patients were

(*Received in original form April 17, 2002; accepted in final form June 25, 2002*)

Supported by grants from the National Health and Medical Research Council of Australia and the Australian Society of Orthodontists Foundation of Research and Education Inc.

Correspondence and requests for reprints should be addressed to Dr. Peter A. Cistulli, Department of Respiratory Medicine, Centre for Sleep Disorders and Respiratory Failure, St. George Hospital, University of New South Wales, Kogarah 2217, NSW, Australia. E-mail: p.cistulli@unsw.edu.au

Am J Respir Crit Care Med Vol 166. pp 860–864, 2002
DOI: 10.1164/rccm.200204-342OC
Internet address: www.atsjournals.org

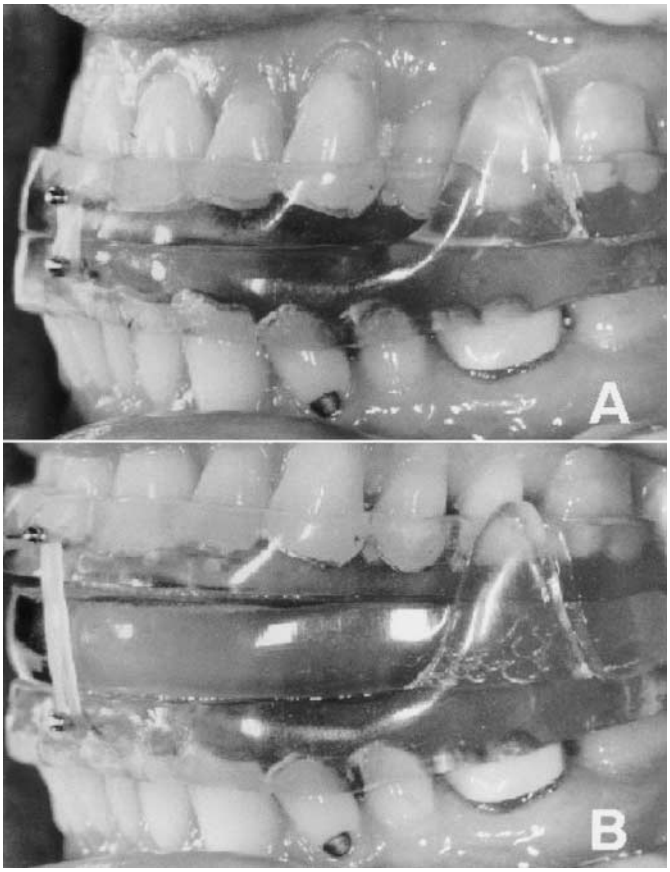

Figure 1. Photograph of the MAS with (*A*) 4 mm of interincisal opening (MAS-1) and (*B*) with an additional 10 mm of interincisal opening (MAS-2). The design features of MAS-1 (*A*) included: (*1*) upper and lower removable acrylic appliances using tooth undercuts for retention; (*2*) buccal flanges angled at 80° on the lower appliance, which fitted against buccal blocks on the upper appliance to prevent posterior movement of the mandible; (*3*) ball clasps embedded in the anterior aspect of the appliances to ensure that they were kept together during sleep, by use of an orthodontic elastic band; and (*4*) the average thickness of each upper and lower appliance at the incisor region was 2.0 mm, producing an interincisal distance of 4 mm. MAS-2 (*B*) featured an added removable acrylic overlay 10-mm thick at its most anterior aspect, which fitted between the upper and lower appliances. It was retained by acrylic protrusions fitting against two retentive grooves in the lower appliance.

randomized into either Group I (AB) or Group II (BA), and after a 1-week washout period during which no appliance was worn to avoid carryover (6), patients were treated with either MAS-1 (A) or MAS-2 (B) for 2 weeks and with the alternate treatment for another 2 weeks, with an intervening washout period of 1 week. Outcomes were assessed at the end of each treatment period.

Outcome Measures

Questionnaires. A detailed, self-administered questionnaire was completed by patients, assessing the frequency, severity, and duration of side effects as well as treatment compliance and satisfaction with each MAS. Daytime sleepiness was determined using the Epworth sleepiness scale (11).

Polysomnography. Polysomnography was performed in a standardized fashion, as previously described by our group (6). Complete response to treatment was defined as a resolution of OSA symptoms and a reduction in AHI to less than 5 per hour. Patients with a baseline AHI of 6 to 10 per hour (n = 5) were required to fulfill the additional criterion of a reduction in AHI of more than 50% compared with the baseline value. Partial response was defined as improved symptoms and a reduction in AHI of 50% or more, with the AHI remaining at a value of 5 or more per hour. Treatment failure was defined as presence of ongoing clinical symptoms and/or less than 50% reduction in AHI.

Statistical Analysis

Data were analyzed using SPSS software (Version 10.0; SPSS Inc., Chicago, IL). Unpaired *t* tests were used to compare baseline characteristics between Groups I and II. A general linear model with univariate analysis of variance and Type-I sums of squares was used to analyze Epworth sleepiness scale scores and polysomnographic data and to assess carryover and sequence effects. Questionnaire data were analyzed using *Z* tests and chi-square tests. On the basis of the results of a previous study (6), a sample size calculation suggested that 24 patients were required to achieve a power of 0.8 and an α value of 0.05. Descriptive statistics are presented as mean ± SD, whereas estimated mean values are presented as mean ± SEM. The level of significance used was 0.05.

RESULTS

Study Population

Of the 24 patients (21 men, 3 women) recruited in this study, 23 completed the protocol, with 1 male patient withdrawing after initial dental examination due to time constraints. Patient characteristics at baseline are outlined in Table 1. Body mass index did not change significantly during the study period. The mean mandibular advancement with MAS-1 was 7.3 ± 0.5 mm, representing 87 ± 4% of the maximal protrusion.

Subjective Outcomes

The MAS was well-tolerated by all patients. Although there was no significant difference in the proportion of patients who reported excessive salivation (48 versus 57%, $p = 0.55$), dry mouth (26 versus 22%, $p = 0.73$), tooth grinding (22 versus 13%, $p = 0.43$), and gum irritation (22 versus 13%, $p = 0.43$) between MAS-1 and MAS-2, there was a trend toward a greater proportion of patients reporting jaw discomfort with MAS-2 (48 versus 70%, $p = 0.13$). There was no significant difference in reported severity, frequency, or duration of side effects between appliances. Generally, side effects were reported to be mild in nature, to occur "sometimes" to "often," and to last for at least 1 week.

There was a highly significant and equal reduction in the Epworth sleepiness scale score from baseline values with each MAS (18 ± 1 versus 12 ± 1, $p < 0.0001$). The improvement in sleep quality in 87% of patients with MAS-1 and in 78% of patients with MAS-2 did not differ between appliances ($p = 0.43$). Similarly, there was no significant difference in the proportion of patients who reported an improvement in snoring with each MAS (100 versus 95%, $p = 0.31$).

Nightly use of MAS-1 and MAS-2 was reported by 91 and 78% of patients, respectively ($p = 0.21$). Ninety-six percent of patients stated that they would like to continue to use either MAS due to a perceived improvement in OSA symptoms. However, a significantly higher proportion of patients preferred to use MAS-1 in comparison with MAS-2 (78 versus 22%, $p = 0.007$).

Objective Outcomes

Polysomnographic outcomes are outlined in Table 2. Initial AHI improved significantly with both MAS-1 (by 62%) and MAS-2 (by 52%). Similarly, arousal index decreased significantly with MAS-1 (by 28%) and MAS-2 (by 33%). Of the remaining polysomnographic variables examined, none was found to differ with either treatment in comparison with baseline. The time spent supine with MAS-1 and MAS-2 was not significantly different.

TABLE 1. PATIENT CHARACTERISTICS AT BASELINE

Variables	All Subjects (*n* = *23*; *19M*:*3F*; *87%*:*13%*)	Group I (*n* = *12*; *9M*:*3F*; *75%*:*25%*)	Group II (*n* = *11*; *11M*:*0F*; *100%*:*0%*)	p Value*
Age, yr	50 ± 10 (29–64)	50 ± 10 (29–64)	50 ± 10 (39–64)	0.75
Height, cm	172 ± 7 (162–184)	172 ± 8 (162–184)	172 ± 5 (163–182)	1.00
Weight, kg	93 ± 17 (63–130)	96 ± 17 (63–127)	90 ± 18 (72–130)	0.45
BMI, kg/m^2	31 ± 5 (22–43)	32 ± 4 (24–43)	31 ± 6 (22–43)	0.48
AHI, /hour	21 ± 12 (6–47)	24 ± 14 (6–47)	18 ± 7 (6–30)	0.20
$MinSa_{O_2}$, %	87 ± 4 (80–94)	86 ± 3 (80–94)	88 ± 4 (82–94)	0.12

Definition of abbreviations: AHI = apnea/hypopnea index; BMI = body mass index; F = females; M = males; $MinSa_{O_2}$ = minimum arterial oxygen saturation level.

* p Value refers to comparison of Group I and Group II.

Values presented are mean ± SD (range).

No significant differences in estimated mean values, carryover, or sequence effects were found for any polysomnographic variables between appliances.

Treatment Outcome

Treatment outcomes for individual patients with each MAS are illustrated in Figure 2. Complete response was achieved in 52% of patients with MAS-1 and in 35% of patients with MAS-2 ($p = 0.23$). Complete response was achieved in 57% of patients with either MAS. Partial response occurred in 22% of patients with MAS-1 and in 26% of patients with MAS-2 ($p = 0.73$). Treatment resulted in either complete response or partial response in 74% of patients with MAS-1, in 61% of patients with MAS-2 ($p = 0.34$), and in 83% of patients with either MAS (taking the best result of either MAS-1 or MAS-2).

DISCUSSION

The optimum vertical dimension of an oral appliance required to achieve a successful treatment outcome in patients with OSA has been an issue of debate. Our randomized, controlled, crossover study examined this important aspect of appliance design by comparing the efficacy of two identical oral appliances, each producing equal mandibular advancement, but with one inducing minimal interincisal opening (4 mm) and the other producing an additional 10 mm of interincisal opening. Significant reductions in the AHI and arousal index were achieved with both oral appliances in comparison with no treatment, as reported in previous studies (1, 5, 6, 12), but these treatment effects were not statistically significantly different for the two appliances. Furthermore, no significant differences were found in any other polysomnographic variables between each appliance and baseline or between appliances.

Our study is the first to systematically evaluate two predetermined specific levels of mouth opening. In a small group of patients, Lamont and colleagues (9) compared an MAS that repositioned the mandible by 3–5 mm and produced 3–4 mm of interincisal opening with an MAS that produced up to 70% maximal advancement and 6–9 mm of interincisal opening. Only the latter MAS produced a significant reduction in AHI and minimum arterial oxygen saturation level ($MinSa_{O_2}$). However, possible contributors to this result may have been differences in protrusion levels between splints and/or variability in the amount of bite opening with each appliance, or between-subject variability due to the parallel group study design. In a randomized, crossover trial performed in 24 patients, Bloch and colleagues (5) compared a Herbst appliance that produced 4–6 mm of interincisal opening with a Monobloc device fixed at 5–10 mm of interincisal opening, both of which produced identical levels of protrusion. The two devices were found to be equally effective in decreasing AHI; however, significant reductions in arousal index and percent of sleep time spent with an oxygen saturation less than 90% were achieved only with the Monobloc. These findings must be considered in the context that the potential range of oral opening with the Herbst device was greater than 15 mm. In a case series by Henke and colleagues (13), the change in polysomnographic outcomes with and without a repositioning

TABLE 2. EFFECT OF EACH MANDIBULAR ADVANCEMENT SPLINT ON POLYSOMNOGRAPHIC VARIABLES

Variable	Baseline	MAS-1	p Value*	MAS-2	p Value†
Sleep variables					
TST, min	334 ± 12	363 ± 13	NS	361 ± 12	NS
REM sleep, min	58 ± 6	69 ± 6	NS	70 ± 6	NS
REM, %	17 ± 2	19 ± 2	NS	19 ± 2	NS
NREM sleep, min	273 ± 9	294 ± 10	NS	291 ± 10	NS
NREM, %	82 ± 1	81 ± 1	NS	81 ± 1	NS
Arousal index, /hr	36 ± 4	26 ± 4	< 0.001	24 ± 4	< 0.001
Sleep efficiency, %	79 ± 1	84 ± 2	NS	84 ± 3	NS
Respiratory variables					
AHI, /hr	21 ± 2	8 ± 1	< 0.001	10 ± 2	< 0.001
$MinSa_{O_2}$, %	87 ± 1	89 ± 1	NS	88 ± 1	NS

Definition of abbreviations: AHI = apnea/hypopnea index; MAS = mandibular advancement splint; $MinSa_{O_2}$ = minimum arterial oxygen saturation level; NREM = nonrapid eye movement; NREM% = time in NREM sleep as a percentage of TST; NS = not significant; REM = rapid eye movement; REM% = time in REM sleep as a percentage of TST; TST = total sleep time.

* Baseline versus MAS-1.

† Baseline versus MAS-2.

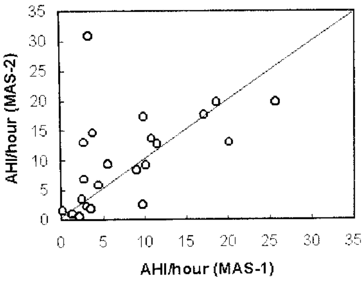

Figure 2. Comparison of AHI for each patient with MAS-1 and MAS-2. For the majority of patients, the effect on AHI was similar for both oral appliances, indicated by the proximity of data to the line of equality.

appliance causing bite opening to increase on average by 11.5 ± 1.8 mm (range 8.8–16.5) was not related to the amount of bite opening, which is consistent with our findings. The treatment outcome with each oral device in the current study was similar to that of previous studies, many of which used more liberal definitions of treatment success (3–6, 12, 14).

Both our MAS configurations were equally effective in significantly reducing the Epworth sleepiness scale score by an average of six points compared with the baseline. An equal improvement in Epworth sleepiness scale scores was also achieved by the two appliances used by Bloch and colleagues (5). The substantial improvements in reported quality of sleep and snoring with each appliance in the present study concur with previous findings (1, 3–6). Subjective tolerance to both devices was positive and also comparable to that found in other studies (1–4, 6). Interestingly, although there was no significant difference in the proportion of patients who reported side effects between appliances, a significantly higher proportion preferred to use the MAS inducing minimal bite opening. This is supported by a trend toward a higher compliance rate with MAS-1. A likely explanation for this finding was the greater comfort level in wearing MAS-1, indicated by a trend toward a smaller proportion of patients reporting jaw discomfort with this splint. Hence, it appears that the VDO with the MAS may play an important role in the acceptance and possibly adherence to such therapy, with the suggestion that minimal bite opening may be more conducive to better compliance. Moreover, the potential long-term impact of bite opening on temporomandibular joint function, which was not addressed by our study, warrants careful consideration. Bloch and colleagues (5) also reported side effects to be of equal prevalence with both their appliances; however, in contrast to our study, these investigators showed a greater preference among patients for the Monobloc device, which promoted a greater oral opening of the two splints.

The findings of our study do not support the hypothesis that minimal bite opening with oral appliances for OSA results in superior treatment effects (10, 15–17). Kuna and Remmers (18) propose that mouth opening causing dorsoventral movement of the angle of the mandible is associated with a decrease in pharyngeal lumen diameter. In a fluoroscopic study, L'Estrange and colleagues (10) demonstrated that jaw opening is associated with synchronous posterior movement of both tongue and soft palate, with consequent narrowing of the oropharyngeal airway in patients with OSA. Similarly, Meurice and colleagues (17) demonstrated in healthy volunteers that mouth opening at an interincisal distance of 15 mm during sleep was associated with an increase in upper airway collapsibility. However, Lowe (7) has proposed that advancement of the mandible displaces the tongue away from the posterior wall of the upper airway, whereas its inferior displacement shifts the tongue away from the soft palate. Hence, mandibular protrusion in combination with an increased VDO may negate pharyngeal closure induced by increased mandibular opening alone. According to George (19), choosing an appropriate VDO for an oral appliance requires the additional consideration of individual facial structure of patients. The author proposes that the downward stretch of the upper airway is at least as effective as anterior expansion in maintaining its patency. A recommendation of 5 mm of vertical opening is made on the basis of the premise that this would provide an individual with a short lower facial height sufficient downward stretch, whereas an opening of more than 5 mm would result in excessive backward compression in someone with a long lower facial height. Although craniofacial structure may be a significant determinant of treatment response (6, 14), the recommendation of a specific fixed level of vertical bite opening is not supported by our study. It is also postulated that oral appliances improve OSA by affecting upper airway muscle function (20). Altering the VDO with oral appliances may increase tongue activity, thereby improving sleep-disordered breathing (21). However, Ono and colleagues (22) found a reduction in tongue activity with the use of a tongue-retaining device in patients with OSA. Although genioglossus activity may be influenced by the VDO, the comparable treatment effects between appliances demonstrated in our study suggests that if this is so, its impact may be minimal.

Our study has a number of potential limitations. Patients were recruited from a sleep disorders clinic known for its interest in dental therapy research; hence, referral bias may have resulted. However, sample characteristics at baseline were comparable to those of the general OSA clinic population and hence may be extrapolated to it. An advantage of the crossover nature of the study design was the interpretation of MAS comparisons without the added potential influence of between-subject variability. Any subjective improvements in daytime sleepiness may have been influenced by response bias; hence, objective measures are required to confirm such findings. Importantly, although the observed 17% difference in complete response rate, favoring MAS-1, was not statistically significant, this could well represent a Type-II error. Hence, it is possible that a clinically important, albeit small, difference between the two appliances does exist.

In conclusion, this systematic study has confirmed the efficacy of MAS in the treatment of OSA, including patients with moderate and severe OSA. Our study suggests that the amount of vertical opening induced by the appliance does not have an impact on treatment efficacy to any great extent. However, the patients' preference for the MAS minimizing bite opening suggests that it is the better treatment option in the long term, particularly with the as yet unresolved concern about long-term side effects associated with greater amounts of bite opening.

***Acknowledgment*:** The authors thank M. Lazaris, J. Qian, M. Troth, and W. Eaglesham for their technical support with polysomnography.

References

1. Schmidt-Nowara W, Lowe A, Wiegand L, Cartwright R, Perez-Guerra F, Menn S. Oral appliances for the treatment of snoring and obstructive sleep apnea: a review. *Sleep* 1995;18:501–510.
2. Clark GT, Blumenfeld I, Yoffe N, Peled E, Lavie P. A crossover study comparing the efficacy of continuous positive airway pressure with anterior mandibular positioning devices on patients with obstructive sleep apnea. *Chest* 1996;109:1477–1483.
3. Ferguson KA, Ono T, Lowe AA, al-Majed S, Love LL, Fleetham JA. A short-term controlled trial of an adjustable oral appliance for the treatment of mild to moderate obstructive sleep apnoea. *Thorax* 1997; 52:362–368.
4. Ferguson KA, Ono T, Lowe AA, Keenan SP, Fleetham JA. A randomized crossover study of an oral appliance vs nasal-continuous positive airway pressure in the treatment of mild-moderate obstructive sleep apnea. *Chest* 1996;109:1269–1275.
5. Bloch KE, Iseli A, Zhang JN, Xie X, Kaplan V, Stoeckli PW, Russi EW.

A randomized, controlled crossover trial of two oral appliances for sleep apnea treatment. *Am J Respir Crit Care Med* 2000;162:246–251.
6. Mehta A, Qian J, Petocz P, Darendeliler MA, Cistulli PA. A randomized, controlled study of a mandibular advancement splint for obstructive sleep apnea. *Am J Respir Crit Care Med* 2001;163:1457–1461.
7. Lowe AA. Oral appliances for sleep breathing disorders. In: Kryger MH, Roth T, Dement WC, editors. Principles and practice of sleep medicine, 3rd ed. Philadelphia: Saunders; 2000. p. 929–939.
8. Ferguson K. Oral appliance therapy for obstructive sleep apnea: finally evidence you can sink your teeth into. *Am J Respir Crit Care Med* 2001;163:1294–1295.
9. Lamont J, Baldwin DR, Hay KD, Veale AG. Effect of two types of mandibular advancement splints on snoring and obstructive sleep apnoea. *Eur J Orthod* 1998;20:293–297.
10. L'Estrange PR, Battagel JM, Harkness B, Spratley MH, Nolan PJ, Jorgensen GI. A method of studying adaptive changes of the oropharynx to variation in mandibular position in patients with obstructive sleep apnoea. *J Oral Rehabil* 1996;23:699–711.
11. Johns MW. A new method for measuring daytime sleepiness: the Epworth sleepiness scale. *Sleep* 1991;14:540–545.
12. O'Sullivan RA, Hillman DR, Mateljan R, Pantin C, Finucane KE. Mandibular advancement splint: an appliance to treat snoring and obstructive sleep apnea. *Am J Respir Crit Care Med* 1995;151:194–198.
13. Henke KG, Frantz DE, Kuna ST. An oral elastic mandibular advancement device for obstructive sleep apnea. *Am J Respir Crit Care Med* 2000;161:420–425.
14. Eveloff SE, Rosenberg CL, Carlisle CC, Millman RP. Efficacy of a Herbst mandibular advancement device in obstructive sleep apnea. *Am J Respir Crit Care Med* 1994;149:905–909.
15. Johal A, Battagel JM. Current principles in the management of obstructive sleep apnoea with mandibular advancement appliances. *Br Dent J* 2001;190:532–536.
16. Battagel JM. Obstructive sleep apnoea: fact not fiction. *Br J Orthod* 1996;23:315–324.
17. Meurice JC, Marc I, Carrier G, Series F. Effects of mouth opening on upper airway collapsibility in normal sleeping subjects. *Am J Respir Crit Care Med* 1996;153:255–259.
18. Kuna ST, Remmers JE. Neural and anatomic factors related to upper airway occlusion during sleep. *Med Clin North Am* 1985;69:1221–1242.
19. George PT. Selecting sleep-disordered-breathing appliances: biomechanical considerations. *J Am Dent Assoc* 2001;132:339–347.
20. Yoshida K. Effect of a prosthetic appliance for treatment of sleep apnea syndrome on masticatory and tongue muscle activity. *J Prosthet Dent* 1998;79:537–544.
21. Ryan CF, Love LL, Peat D, Fleetham JA, Lowe AA. Mandibular advancement oral appliance therapy for obstructive sleep apnoea: effect on awake calibre of the velopharynx. *Thorax* 1999;54:972–977.
22. Ono T, Lowe AA, Ferguson KA, Pae EK, Fleetham JA. The effect of the tongue retaining device on awake genioglossus muscle activity in patients with obstructive sleep apnea. *Am J Orthod Dentofacial Orthop* 1996;110:28–35.