ORIGINAL ARTICLE

The Efficacy of a Mandibular Advancement Splint in Relation to Cephalometric Variables

Margot A. Skinner, M.Ph.Ed.,[1] Christopher J. Robertson, M.D.S.,[2] Ruth N. Kingshott, Ph.D.,[1] David R. Jones, R.P.S.G.T.,[3] and D. Robin Taylor, M.D.[1]

ABSTRACT

The efficacy of a titratable mandibular advancement splint (MAS) for the management of obstructive sleep apnea (OSA) was investigated in relation to supine cephalometric variables. Fourteen adults with diagnosed OSA were recruited following an initial polysomnogram. Supine cephalographic radiographs were taken at baseline and subjects wore the MAS nightly for 6 to 8 weeks. The polysomnogram and cephalogram were repeated with the MAS at maximal titration. The MAS resulted in complete or partial treatment response in all subjects as measured by the improvement in mean apnea/hypopnea index (AHI) (baseline AHI 34 ± 22/hr, with MAS 10 ± 5/hr; $p = 0.001$). The perpendicular distance between the hyoid bone and the mandibular plane (HYML) measured in awake subjects decreased with the MAS (baseline HYML 25.3 ± 7.8 mm, with MAS 16.5 ± 9.6 mm; $p = 0.002$). Baseline HYML was the only cephalometric variable associated with a successful clinical outcome. It was strongly linked to improvements in AHI (adjusted $R^2 = 0.37$, $p = 0.012$) and arousals (adjusted $R^2 = 0.455$, $p = 0.005$). We conclude that the MAS is an effective therapy for OSA and baseline HYML is an important predictor of improvement. Improvements in AHI may be explained by the MAS maintaining the new or existing relationship of the hyoid and its surrounding structures, thus preventing obstruction in the upper airway during sleep.

KEYWORDS: Obstructive sleep apnea, cephalometry, mandibular splint

Sleep and Breathing, volume 6, number 3, 2002. Address for correspondence and reprint requests: Margot A. Skinner, M.Ph.Ed., School of Physiotherapy, University of Otago, Dunedin, New Zealand. E-mail: mskinner@gandalf.otago.ac.nz. [1]Respiratory Research Unit, Dunedin School of Medicine, and [2]Department of Oral Sciences and Orthodontics, School of Dentistry, University of Otago, Dunedin, New Zealand; [3]Tom McKendrick Sleep Laboratory, Dunedin Hospital, Dunedin, New Zealand. 1520-9512,p;2002,06,03,115,124,ftx,en;sbr00211x.

Obstructive sleep apnea (OSA) includes repetitive periods of partial or complete airway obstruction during sleep and daytime symptoms such as hypersomnolence and decreased vigilance.[1] A wide spectrum of anthropometric, postural, pathophysiologic, and cervicocraniofacial features may contribute to OSA, some of which may be related to ethnic groupings.[2–7] Members of the Polynesian population, for example, have greater neck circumferences and more prognathic mandibles than Caucasians.[4] Continuous positive airway pressure (CPAP),[8] which provides a pneumatic splint for the upper airway, is the standard therapy and treatment of choice in moderate to severe OSA. However, the efficacy of oral appliances, used predominantly in the conservative management of mild to moderate OSA, has also been confirmed as an appropriate alternative treatment.[9–15]

Despite considerable variation in appliance design, the main objective of oral appliances is to draw the mandible forward and alter the dynamics of the upper airway by changing relationships between the pharyngeal space, hyoid bone, and tongue position.[10–18] The clinical benefits are remarkably consistent and approximately half of treated patients achieve an apnea hypopnea index (AHI) of fewer than 10 per hour slept (AHI < 10/hr)[15,19] with a device in situ.

Recently, new design features have been introduced in some oral devices in an attempt to reduce side effects such as discomfort from downward rotation of the mandible and a fixed jaw position. Oral splints, which enable the patient to gradually adjust the amount of anterior positioning of the mandible to achieve optimal position, have improved the biomechanical relationships between the mandible and the surrounding bony and soft-tissue structures.[14] Despite this, the optimal design and an objective means of predicting the therapeutic response to oral appliances have not been clarified.

The hyoid bone and its surrounding musculature play a key role in regulation of the pharyngeal airway, and a low position of the hyoid relative to the mandibular plane is a distinguishing feature of OSA.[20,21] In the upright posture, the cross-sectional area of the hypopharynx is smaller in OSA patients compared to snorers or normal subjects.[22,23] In the supine posture, awake OSA subjects maintain pharyngeal muscle tone in order to prevent the upper airway from collapsing further due to increased gravitational load on the tongue.[23] However, during sleep, loss of airway tone increases the risk of airway closure.

Investigators have used lateral cephalometry, fluoroscopy, and videoendoscopy to evaluate the effect of oral appliances on the upper airway dimensions of awake OSA subjects.[24–26] Anterosuperior elevation of the hyoid has been shown to occur with mandibular advancement.[17,25,27,28] However, studies have not standardized supine cephalometric measures using reliable bony landmarks, and in only one study using an oral device[26] have supine cephalometric measures been correlated with clinical outcomes. Perhaps for these reasons the role of cephalometry in predicting responses to treatment has not been fully evaluated.

The present study was designed to confirm the efficacy of a novel titratable mandibular advancement splint (MAS) in the management of OSA and to evaluate objective improvements in OSA in relation to supine cephalometric variables.

METHODS

Study Population

Sixteen subjects medically referred for suspected OSA underwent full-night polysomnography (PSG) at the Tom McKendrick Sleep Laboratory, Dunedin Hospital. The subjects were diagnosed with OSA and agreed to participate in the initial screening for the study.

Inclusion criteria: Subjects with mild to moderate sleep apnea (AHI 10 to 40/hr slept); subjects with moderate to severe OSA (AHI 30 to 80/hr) who were noncompliant with a trial of nasal continuous positive airway pressure (nCPAP).

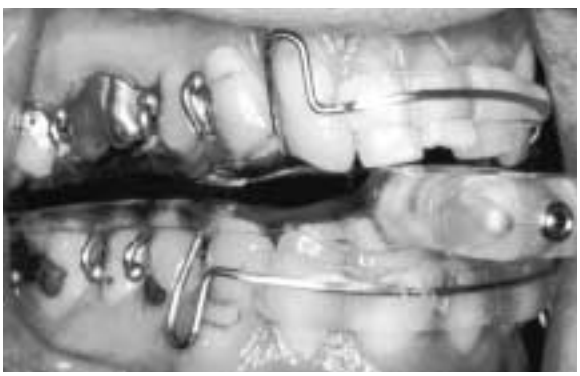

Figure 1 Titratable mandibular advancement splint (MAS) in situ.

Exclusion criteria: Subjects who were edentulous or had insufficient teeth on the maxillary and mandibular arches to support the MAS; had a medical history including severe cardiovascular, psychological, or neurological disorders affecting sleep; or had other coexisting sleep disorders.

Oral Appliance

The MAS (Fig. 1), made from a dental impression, was a modified Thornton anterior positioner appliance (TAP, Oral Appliance Technologies, Dallas, TX) of methyl methacrylic material with full upper and lower occlusal coverage. A stainless steel screw, hook, and bar arrangement connected the upper to the lower portion while still allowing for a small amount of lateral jaw movement and oral airflow. Clockwise turns of the screw enabled the mandibular section of the MAS to be titrated forward approximately 2 mm with each half turn to a maximum of 16 mm.

Subjects were instructed on how to fit and titrate the splint by rotating the screw clockwise, one half turn every 1 to 2 nights as tolerated. Subjects were also instructed in active exercises for the temporomandibular joint to assist with realignment of the bite on removal of the MAS in the mornings. The MAS was worn nightly for 6 to 8 weeks. End points for titration were partner-reported cessation of snoring and subjective improvement in daytime symptoms or maximal titration tolerance with subject-reported symptom improvement. Subjects were reviewed at the Orthodontic Clinic at least once during the trial period. They were also followed up by telephone during the trial to monitor for side effects or difficulties with the splint and seen again at the Orthodontic Clinic if further checks of the splint were deemed necessary. A telephone follow-up at 1 year was undertaken to ascertain the long-term compliance with the therapy and potential side effects.

Outcome Measures

Sleep habits, snore symptoms, exercise capacity, general health, and medications at presentation were recorded on a standardized questionnaire. The Epworth Sleepiness Scale (ESS) was used to measure the subject's daytime sleepiness,[29] and body height, weight, and neck circumference (at the fourth cervical vertebra) were measured at baseline and at the end of the trial. A self-reporting diary was used during treatment to record sleep habits, the period of time wearing the device at night, levels of sleepiness/alertness on waking, daytime hypersomnolence, and any other relevant symptoms.

Polysomnography

Each subject underwent full-night PSG prior to entering the study and had a second PSG with the splint in situ at the end of the study period. Data were recorded on a 16-channel Compumedics polysomnographic system (Compumedics, Victoria, Australia). OSA scoring criteria used were in accordance with standard definitions.[1] Apnea was defined as cessation of airflow lasting at least 10 seconds. Hypopnea was defined as a reduction in thoracoabdominal wall movement of greater than 50% of the baseline measurement for more than 10

seconds or as a reduction in thoracoabdominal movement with an accompanying oxygen desaturation of at least 3% and/or associated with arousal. Sleep was scored according to Rechtschaffen and Kales' guidelines.[30] Arousals were defined as a shift in electroencephalogram (EEG) frequency for a minimum of 3 seconds with a concurrent rise in electromyogram (EMG) in REM sleep.[31] All studies were manually scored in 30-second epochs for sleep stage, apnea type, and duration and arousals, by one scorer blinded to the study. These results were confirmed by a second independent scorer.

Treatment Outcomes

Treatment success was defined as an AHI less than or equal to 10/hr and resolution of symptoms; partial success as an AHI in the range of 10 to 15/hr, with improvement in symptoms; and treatment failure as an inability of the patient to continue to use the MAS.

Cephalometric Radiographs

Cephalograms were taken at baseline with each subject lying supine in the natural head position[32] using the orthoposition method.[33] A fluid level was used to register the head posture and care was taken to limit changes in cervical posture during the introduction of the cephalostats. A chain suspended from the film cassette registered the true vertical plane. Subjects were instructed to hold the teeth in occlusion and cephalograms were taken at the end of an expiration. The procedure was repeated for the cephalograms taken at the end of the self-titration period with the MAS in situ.

All lateral cephalometric landmarks were coordinated with true horizontal and vertical lines. Conventional bony landmarks (Fig. 2A) were marked on tracing film and digitized with a reflex metrograph. The landmarks and measures (Fig. 2B) were used to analyze pharyngeal relationships; postural relationships of the head in relation to craniovertical and craniocervical variables, and the inclination of the cervical column in relation to cervicohorizontal variables; and the hyoid bone position in relation to cephalometric variables of the head and neck. Reference lines and angles were measured to the nearest 0.01 mm or degree.

Statistical Analysis

Statistical analysis was carried out using the computer statistical package SPSS for Windows (SPSS Inc., Release 10.0). Variables were normally distributed. Paired t-tests were undertaken on all variables for the polysomnographic and cephalometric data. Stepwise linear regression analysis was undertaken to examine the relationships between changes in AHI and arousals and significant cephalometric variables including pharyngeal relationships, postural relationships of the head and neck, and relationships of the hyoid bone to the head and neck (Fig. 2). Because multiple comparisons were made, a significance level of 0.01 was used in the statistical analysis.

The study protocol was approved by the Otago Ethics Committee. All subjects gave written informed consent.

RESULTS

Study Population

Fourteen males and one female were enrolled in the study. One male subject failed to return for appointments, leaving 14 subjects who completed the study. New Zealand ethnic groupings included European (12), Maori (1), and Chinese (1). Other demographic and anthropometric variables at study entry are shown in Table 1. There was a significant relationship between body mass index (BMI) and

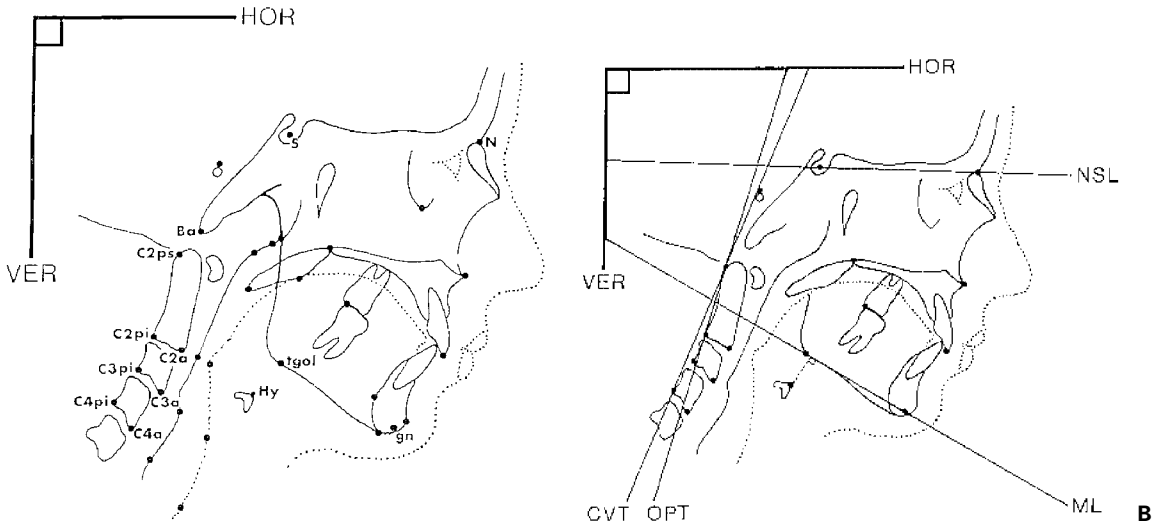

Figure 2 (A) Key landmarks identified on cephalometric radiographs and digitized with a reflex metrograph. Hy: the most anterior and superior point on the body of the hyoid bone; gn: the most anteroinferior point on the bony mandibular symphysis; tgol: the most lateral external point at the junction of the horizontal and ascending rami of the mandible; N: nasion, the most anterior point on the frontonasal suture; S: center of sella turcica, the center of the pituitary fossa of the sphenoid bone; Ba: basion, the most posteroinferior point on the anterior margin of the foramen magnum; c2a, c3a, c4a: most anteroinferior point on the corpus of the second, third, and fourth vertebral bodies, respectively; c2pi, c3pi, c4pi: most posteroinferior point on the corpus of the second, third, and fourth vertebral bodies. respectively; c2ps: most posterosuperior point on the corpus of the second cervical vertebra. (B) Key reference lines and angles measured on the cephalometric radiographs. HYML: the perpendicular distance from hyoid to mandibular plane (distance measured on the perpendicular line drawn from point Hy to the intersection of a line drawn between points gn and tgol). NSL: anterior cranial base line connecting the center of the sella turcica S and nasion N. Postural relationships of the head and craniovertical and craniocervical variables, and the inclination of the cervical column in relation to craniohorizontal variables. CVT: cervical vertebral tangent, posterior tangent on the odontoid process c2ps through c4pi; OPT: second cervical vertebral tangent on the odontoid process c2ps through c2pi. HYML was the only cephalometric measure to change significantly ($p = 0.001$) with the mandibular advancement splint (MAS) in situ; Hy was repositioned in an anterosuperior direction with the MAS in situ, thus decreasing the mean HYML distance.

neck circumference ($R^2 = 0.614$, $p = 0.001$). No significant change in body weight or neck circumference occurred during the study period.

Clinical Outcomes

The MAS resulted in complete or partial treatment response in all 14 subjects (Fig. 3). Treatment success (AHI < 10/hr) with the splint was achieved in 50% of the subjects (n = 7). The remaining subjects had AHIs in the sub-optimal range with improvement in symptoms. Four subjects (29%) had AHIs greater than 10 and less than 15/hr and for the remaining three subjects (21%), AHIs of 15.2/hr, 15.8/hr, and 15.9/hr were recorded.

Results of paired t-tests for polysomnographic data are presented in Table 2. Highly significant improvements were recorded for mean AHI

Table 1 Demographic Details of Study Participants

Measurement	Mean (SD) (n = 14)	Range
Age (years)	47.6 (10.9)	25–63
Body Mass Index ($kg.m^{-2}$)	29.3 (4.6)	18.5–35.6
Neck circumference (cm)	42.1 (4.6)	31.0–48.5

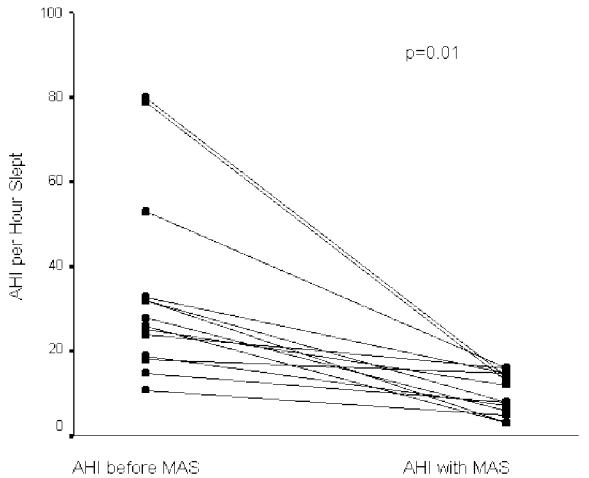

Figure 3 Changes in apnea hypopnea index (AHI) for individual subjects (n = 14) before and with the MAS.

(p = 0.001) (Fig. 3) and mean arousal frequency with the MAS. There was a significant improvement in the minimum oxygen desaturation with the MAS (p = 0.01). The proportion of time spent in REM sleep increased with the MAS, but there were no other significant changes in sleep architecture.

Cephalometric Outcomes

A comprehensive range of variables was measured from the supine cephalometric films taken before and with the MAS (n = 11), but for reasons of brevity only the significant results are reported. All cephalometric measures for the Maori and Chinese subjects fell within the mean ± SD for the European subjects. The only significant difference in any distances or angles measured for the hyoid bone position in relation to head and neck posture was a significant reduction in the perpendicular distance from the hyoid bone to the mandibular plane (HYML): without MAS, 25.3 ± 7.8 mm, with MAS 16.5 ± 9.6 mm; p = 0.002 (Fig. 2(B)). No significant differences were identified for pharyngeal relationships or for postural relationships of the head and craniovertical and craniocervical variables, or for the inclination of the cervical column in relation to craniohorizontal variables.

Linear regression analysis was used to examine the relationship between the changes in polysomnographic variables and supine cephalometric measurements at baseline. The decreases in both AHI and arousal index with the MAS were significantly related to the baseline HYML (adjusted $R^2 = 0.37$; p = 0.012, and adjusted $R^2 = 0.455$; p = 0.005, respectively). No other cephalometric measures were associated with improvement in polysomnographic variables.

Subjective Outcomes

The MAS was well tolerated by all subjects throughout the study period (Table 3). Thirteen subjects (93%) reported nightly use. The mean

Table 2 Mean (SD) and Range of Values for Polysomnographic Data Recorded Before and with the Mandibular Advancement Splint (MAS) in situ

	Before MAS	With MAS	p Value
Apneas + Hypopneas/hr slept	34 ± 22 (11–79)	10 ± 5 (3–16)	0.001
Arousal frequency/hr slept	37 ± 20 (15–77)	19 ± 7 (10–30)	0.001
% Minimum oxygen saturation	76 ± 6 (74–81)	82 ± 4 (80–85)	0.012
Total sleep time (min)	391 ± 64 (354–427)	389 ± 71 348–429	0.905
Sleep efficiency	81 ± 5 (70–89)	82 ± 9 (28–64)	0.75
% Stage 1*	9 ± 4 (3–18)	7 ± 2 (2–11)	0.09
% Stage 2*	59 ± 10 (46–83)	54 ± 8 (39–71)	0.09
% Slow wave sleep*	14 ± 7 (0–24)	18 ± 4 (12–25)	0.1
% REM*	17 ± 6 (5–24)	22 ± 7 (5–34)	0.03

*Sleep stage was calculated as a percentage (%) of total sleep time.

Table 3 Subjective Reporting by Patients at the Conclusion of the Trial

Question	Response (%)
Wore the MAS nightly for 5 or more hours	93%
Decreased snoring (partner report)	93%
Improved sleep quality	79%
Woke refreshed	50% always
	50% sometimes
Improved well-being	79%
Increased saliva	7%
MAS loose/fell off	21% sometimes
Short-term tooth discomfort	28%
Temperomandibular joint pain	0%

nightly use was 5.5 ± 1.9/hr. Daytime sleepiness as measured by the ESS significantly improved with the MAS (without MAS, ESS 12 ± 5; with MAS, ESS 6 ± 4; p = 0.0001). An improved sense of well-being was reported by 93% of subjects. None of the reported side effects precluded the subjects from wearing the splint.

Subjects were contacted 1 year after the completion of the trial. Eight subjects (57%) reported that they were continuing to use the splint on a nightly basis with good effect. One subject was wearing the splint "sometimes". Two subjects were wearing alternative, less bulky oral appliances; one had chosen to use nCPAP; one had chosen not to use any device; and one was having other medical therapy for an unrelated illness.

DISCUSSION

Our study confirms that a titratable MAS is an effective therapy in the management of OSA over a broad range of clinical severity (AHI 11 to 79/hr) and that efficacy is associated with specific changes in cephalometric variables. There were significant reductions in AHI and arousal index, and in 50% of subjects, the AHI improved to fewer than 10/hr. For the remaining subjects, the AHI was in the suboptimal range (> 10 < 16/hr). These outcomes compare favorably with the results obtained in other studies using oral appliances.[10,15,26,34]

Our results demonstrated that with the MAS in situ, subjects were able to obtain significant anterosuperior elevation of the hyoid bone (baseline HYML 25.3 ± 7.8 mm; with MAS 16.5 ± 9.6 mm; p = 0.002), thus achieving a more normal hyoid position. This suggests that significant improvements in AHI during sleep were achieved either by establishing a new anterosuperior HYML relationship or by maintaining the existing hypopharyngeal dimensions as measured while awake. Preventing the mandible from rotating posteroinferiorly during sleep, with subsequent hypopharyngeal occlusion, may be the principal mechanism of action for the MAS.[25]

Our study was also designed to evaluate whether any cephalometric measurements, obtained awake in the supine posture, might be used to assess likely clinical outcomes. The measures and angles taken from the cephalograms were in agreement with the findings in earlier studies of head form and postural angles in Caucasians with OSA.[4] However, the baseline HYML was the only cephalometric variable associated with PSG improvements, namely change in AHI (adjusted $R^2 = 0.37$; p = 0.012) and arousal index (adjusted $R^2 = 0.455$; p = 0.005). There were no significant relationships between any other cephalometric or anthropometric variables and treatment outcomes.

The results of previous investigations have been varied in this regard. In the study by Ferguson et al[35] no indicators of likely clinical success were identified in their study of 24 OSA subjects who used a mandibular advancement device. In an earlier study, the same authors reported that although neck circumference correlated with AHI, this was not true for any craniofacial or soft tissue measurement. Interestingly, they observed that an increased HYML distance was associated with a larger neck circumference (p < 0.05). In the study by Battagel et al,[28] of 58 OSA subjects, no cephalometric fea-

tures which could predict an improvement in AHI were identified. Similarly, in the study by Liu et al,[26] in which an adjustable appliance was assessed in 16 adult OSA patients, although a significant decrease in mean HYML was found with the appliance (before 22.7 ± 5.3 mm; with 19.7 ± 4.8 mm; $p = 0.05$), the reported results did not indicate the strength of any relationship between these changes and treatment response in terms of AHI.

The contrast between the present results and those obtained in previous studies may be due to methodological inconsistencies. The reproducibility of cephalometric measures in the natural head position while standing has previously been validated[33] but hitherto this has not been the case for measurements obtained in supine. The latter is likely to be more clinically relevant in OSA. One supine study reported by Hiyama et al[36] was on normal subjects and although there was no significant difference in the relationships reported it focused on the mandibular posture and did not include craniocervical angles and relationships. In the present study, subjects lay supine with their heads held in the natural head position, cephalostat rods were then placed carefully, a fluid level was used to check head position, and reliable bony landmarks were used for cephalometric measures. Using this standardized approach, reproducibility for cephalometry in the supine position was confirmed: there were no significant differences in the craniovertical and craniocervical variables, or in the inclination of the cervical column in relation to cervicohorizontal variables, between the films before and with MAS. The only significant difference was in the hyoid-mandibular relationship. In contrast, Battagel et al[28] reported that cephalometric rods could not be adequately positioned, and in the study by Liu et al,[26] subjects were asked to mimic their usual position rather than adopt a standard posture. The Frankfort Horizontal Plane, which is not a true horizontal plane, was used by Ryan et al[25] to fix the head position in order to measure upper airway cross-sectional area by videoendoscopy. However, it is not clear whether any of the measurements made by Battagel et al[28] and Ryan et al[25] in their studies were reproducible.

Our study had a number of shortcomings. First, titration of the splint was based on subjective rather than objective responses. This was considered appropriate so that patients might adjust gradually to wearing the splint. Given that significant improvement in AHI was obtained in the majority of patients, this appears to have been a justified approach. Second, the sample size in our study was small, and it was not possible to derive predictive values for changes in AHI based on changes in HYML. Nevertheless, by using a carefully standardized approach, we were able to confirm a strong association between HYML and treatment outcomes. Third, the sample was selected in that it included patients who had failed CPAP therapy, but such subjects would normally be offered an alternative therapy, such as a trial of a mandibular splint, in the clinical setting.

Compliance with treatment for OSA is a major clinical issue. Data regarding long-term compliance with the MAS are limited. In our study, a telephone survey 1 year after commencing treatment revealed that 57% continued to obtain therapeutic benefit from the MAS with improved quality of sleep and daytime function. Pancer et al[18] reported 86% of subjects had continued to use a mandibular appliance when followed up an average of 1 year later; Clark et al[37] reported that 50% of subjects in their study were continuing to use a mandibular device 3 years after commencing treatment.

In conclusion, our study has demonstrated that in patients with OSA, the treatment response to a titratable MAS is most likely to occur in subjects with an increased HYML. Although there was a wide individual variation in the extent or degree of anterosuperior hyoid repositioning with the MAS, it is postulated that either the reduction in HYML or the maintenance of an adequate hyoid position while asleep is the mechanism whereby upper airway patency is achieved. Supine cephalometry is therefore an important tool in determining relationships between craniofacial bony and soft-tissue structures and the likely outcomes of treatment for OSA. When adequately standardized, cephalograms provide clinically helpful imaging in

patients for whom mandibular advancement is being considered as a treatment option.

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REFERENCES

1. American Academy of Sleep Medicine. Sleep-related breathing disorders in adults: recommendations for syndrome definition and measurement techniques in clinical research. Report of an American Academy of Sleep Medicine Task Force. Sleep 1999;22:667–689
2. Ferguson KA, Ono T, Lowe AA, Ryan CF, Fleetham JA. The relationship between obesity and craniofacial structure in obstructive sleep apnea. Chest 1995;108:375–381
3. Pracharktam N, Nelson S, Hans MG, et al. Cephalometric assessment in obstructive sleep apnea. Am J Orthod Dentofacial Orthop 1996;109:410–419
4. Solow B, Ovesen J, Nielsen PW, Wildschiodtz G, Tallgren A. Head posture in obstructive sleep apnoea. Eur J Orthod 1993;15:107–114
5. Ozbek MM, Miyamoto K, Lowe AA, Fleetham JA. Natural head posture, upper airway morphology and obstructive sleep apnoea severity in adults. Eur J Orthod 1998;20: 133–143
6. Coltman R, Taylor DR, Whyte K, Harkness M. Craniofacial form and obstructive sleep apnea in Polynesian and Caucasian men. Sleep 2000;23:943–950
7. Liu Y, Lowe AA, Zeng X, Fu M, Fleetham JA, Cephalometric comparisons between Chinese and Caucasian patients with obstructive sleep apnea. Am J Orthod Dentofacial Orthop 2000;117:479–485
8. Sullivan CE, Issa FG, Berthon-Jones M, Eves L. Reversal of obstructive sleep apnoea by continuous positive airway pressure applied through the nares. Lancet 1981;1:862–865
9. American Sleep Disorders Association. Practice parameters for the treatment of snoring and obstructive sleep apnea with oral appliances. Sleep 1995;18:511–513
10. 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 1996:109:269–1275
11. Johal A, Battagel JM. An investigation into the changes in airway dimension and the efficacy of mandibular advancement appliances in subjects with obstructive sleep apnoea. Br J Orthod 1999:26:205–210
12. Schmidt-Nowara W. Recent developments in oral appliance therapy of sleep-disordered breathing. Sleep Breath 1999;3:103–106
13. Liu Y, Zeng X, Fu M, Huang X, Lowe AA. Effects of a mandibular repositioner on obstructive sleep apnea. Am J Orthod Dentofacial Orthop 2000;118:248–256
14. George, PT. Selecting sleep-disordered breathing appliances. Biomechanical considerations. J Am Dent Assoc 2001;132:339–347
15. 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
16. Clark GT, Arand D, Chung E, Tong D. Effect of anterior mandibular positioning on obstructive sleep apnea. Am Review Respir Dis 1993;147:624–629
17. 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(4 Pt 1):905–909
18. Pancer J, Al-Faifi S, Al-Faifi M, Hoffstein V. Evaluation of variable mandibular advancement appliance for treatment of snoring and sleep apnea [comments]. Chest 1999;116: 1511–1518
19. Schmidt-Nowara W, Lowe A, Wiegand L, et al. Oral appliances for the treatment of snoring and obstructive sleep apnea: a review. Sleep 1995;18:501–510
20. Van de Graff WB, Gottfried S, Mitra J, et al. Respiratory function of hyoid muscles and hyoid arch. J Appl Physiol 1984;57:197–204
21. Jamieson A, Guilleminault C, Partinen M, Quera-Salva MA. Obstructive sleep apneic patients have craniomandibular abnormalities. Sleep 1986;9:469–477
22. Schwab RJ, Gefter WB, Hoffman EA, Gupta KB, Pack AI. Dynamic upper airway imaging during awake respiration in normal subjects and patients with sleep-disordered breathing. Am Rev Respir Dis 1993;148:1385–1400
23. Martin SE, Marshall I, Douglas NJ. The effect of posture on airway caliber with the sleep-apnea/hypopnea syndrome. Am J Respir Crit Care Med 1995;152:721–724
24. L'Estrange PR, Battagel JM, Nolan PJ, Harkness B, Jorgensen GI. The importance of a multidisciplinary approach to the assessment of patients with obstructive sleep apnea. J Oral Rehabil 1996;23:72–77
25. 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
26. Liu Y, Park Y-C, Lowe AA, Fleetham JA. Supine cephalometric analyses of an adjustable oral appliance used in the treatment of obstructive sleep apnea. Sleep Breath 2000;4: 59–66
27. Robertson CJ. Obstructive sleep apnoea. Part II: treatment with a customised dental appliance. N Z Dent J 1997;93:4–9
28. Battagel JM, Johal A, L'Estrange PR, Croft CB, Kotecha B. Changes in airway and hyoid position in response to mandibular protrusion in subjects with obstructive sleep apnoea (OSA). Eur J Orthod 1999;21:363–376
29. Johns MW. A new method for measuring daytime sleepiness: the Epworth sleepiness scale. Sleep 1991;14:540– 545
30. US Department of Health. A manual of standardized terminology, techniques and scoring systems for sleep stages of human subjects. Rechtschaffen A, Kales A, eds. Bethesda, MD: National Institute of Neurological Disease and Blindness; 1968
31. American Sleep Disorders Association. EEG arousals: scoring rules and examples: a preliminary report from the Sleep Disorders Atlas Task Force of the American Sleep Disorders Association. Sleep 1992;15:173–184
32. Broca M. Sur les projections de la tête, et sur un nouveau procédé de cephalometric. Bull Soc Anthrop Paris, 1862;3: 514–544
33. Solow B, Tallgren A. Natural head position in standing subjects. Acta Odont Scand 1971;29:591–607
34. Lowe AA, Sjoholm TT, Ryan CF, et al. Treatment, airway and compliance effects of a titratable oral appliance. Sleep 2000;23(suppl 4):S172–S178
35. Ferguson KA, Ono T, Lowe AA, et al. 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
36. Hiyama S, Ono T, Ishiwata Y, Kuroda T. Supine cephalometric study on sleep-related changes in upper-airway structures in normal subjects. Sleep 2000;23:783–790
37. Clark GT, Sohn JW, Hong CN. Treating obstructive sleep apnea and snoring: assessment of an anterior mandibular positioning device. J Am Dent Assoc 2000;131: 765–771