



# A follow-up study of dental and skeletal changes associated with mandibular advancement splint use in obstructive sleep apnea

Roger J. Hammond,<sup>a</sup> Helen Gotsopoulos,<sup>b</sup> Gang Shen,<sup>c</sup> Peter Petocz,<sup>d</sup> Peter A. Cistulli,<sup>e</sup> and M. Ali Darendeliler<sup>f</sup>

Sydney, Australia

**Introduction:** Mandibular advancement splints (MAS) are a recognized therapeutic option in the treatment of obstructive sleep apnea (OSA). This study aimed to investigate side effects and possible changes in the dentofacial complex associated with long term use of MAS. **Methods:** The sample included 64 patients with OSA who had been using MAS on average for  $25.1 \pm 11.8$  months (range, 10.7-64.5 months). A specifically designed questionnaire was used to investigate the patients' self-assessment of the side effects of wearing MAS; cephalometric analyses and dental cast measurements were conducted to identify objectively dental and skeletal changes caused by MAS over time. **Results:** The most commonly reported side effects were jaw discomfort, tooth tenderness, excessive salivation, and dry mouth. Subjectively, snoring improved in 56 patients (88%), and daytime sleepiness (Epworth sleepiness scale) scores significantly decreased from pretreatment to follow-up ( $11.4-7.1$ ,  $P < .001$ ). Small subjective occlusal changes were experienced by 8 patients (12.5%). Reductions in overbite ( $-0.3 \pm 0.08$  mm,  $P < .01$ ) and overjet ( $-0.2 \pm 0.06$  mm,  $P < .05$ ) were found, and cephalometric analysis showed statistically significant but clinically insignificant changes limited to anterior movement of the mandibular incisors ( $0.5 \pm 0.12$  mm,  $P < .001$ ). **Conclusions:** Side effects of MAS use over long periods are common but mild and well tolerated by most patients, and dentofacial changes are negligible. (Am J Orthod Dentofacial Orthop 2007;132:806-14)

**M**andibular advancement splints (MAS) have been reported to be an effective treatment option for common upper airway disorders such as snoring and obstructive sleep apnea (OSA).<sup>1</sup> MAS therapy has gained increasing popularity over other treatment methods such as continuous positive

airway pressure and surgical procedures because of its high acceptance, noninvasiveness, cost effectiveness, and increased patient compliance.<sup>2</sup> The efficacy of oral appliances in OSA was shown by improvements in sleep-related parameters, such as apnea and hypopnoea frequency and duration, arousal frequency, and oxygen saturation.<sup>3</sup> However, little is known about the exact mechanism of their effect. These oral appliances hold the mandible in a forward position, changing the dimensions of the upper airway, including the hypopharynx, the oropharynx, and the nasopharynx. This action improves upper airway patency and reduces its collapsibility.<sup>4</sup> It has been suggested that MAS therapy increases the passive muscle tension in the pharyngeal wall, thereby reducing the vibration of the soft tissues and the turbulent airflow.<sup>5</sup>

There are many MAS designs with variable efficacies. Most MAS are modified functional appliances used routinely in orthopedic treatment for growth modification in children and adolescents. The usual method of securing the MAS to provide mandibular protrusion is full-arch occlusal coverage with acrylic. Appliances can be 1 piece or 2 piece and might include

<sup>a</sup>Former postgraduate student, Discipline of Orthodontics, Faculty of Dentistry, Sydney Dental Hospital, University of Sydney, Sydney, Australia.

<sup>b</sup>Research officer, Department of Respiratory Medicine, St. George Hospital and University of New South Wales, Sydney, Australia.

<sup>c</sup>Associate Professor, Discipline of Orthodontics, Faculty of Dentistry, Sydney Dental Hospital, University of Sydney, Sydney, Australia.

<sup>d</sup>Associate professor, Department of Statistics, Macquarie University; Honorary associate lecturer, Discipline of Orthodontics, Faculty of Dentistry, University of Sydney, Sydney, Australia.

<sup>e</sup>Professor, Department of Respiratory Medicine, Royal North Shore Hospital, University of Sydney and St George Clinical School, University of New South Wales; Honorary Associate Lecturer, Discipline of Orthodontics, Faculty of Dentistry, University of Sydney, Sydney, Australia.

<sup>f</sup>Professor and chair, Discipline of Orthodontics, Faculty of Dentistry, Sydney Dental Hospital, University of Sydney, Sydney, Australia.

Supported by the ASO Foundation for Research and Education.

Reprint requests to: M. Ali Darendeliler, Department of Orthodontics, Sydney Dental Hospital, Level 2, 2 Chalmers St, Surry Hills 2010, NSW, Australia; e-mail, adarendel@mail.usyd.edu.au.

Submitted and accepted, August 2005.

0889-5406/\$32.00

Copyright © 2007 by the American Association of Orthodontists.

doi:10.1016/j.ajodo.2005.08.047

**Table I.** Relative frequency distribution (patients' percentages) of ratings of severity, frequency, and changes in symptoms and side effects of patients with OSA (n = 64; 50 men)

Side effect	Severity			Frequency			Changes			
	Mild	Moderate	Severe	Rarely	Sometimes	Often	Better	None	Worse	Never a problem
Jaw discomfort	75	21	4	25	57	18	11	34	22	33
Jaw joint pain	67	20	13	47	33	20	9	38	15	38
Tooth tenderness	79	14	7	21	61	18	9	30	23	38
Excessive salivation	69	31	0	21	58	21	13	30	25	32
Dry mouth	66	30	4	33	48	19	22	34	17	27
Teeth grinding	60	40	0	22	64	14	19	36	3	42
Gum irritation	80	10	10	70	10	20	6	28	6	60
Jaw joint noises	37	63	0	25	63	12	9	25	2	64
Headaches	50	40	10	60	40	0	13	27	5	55
Bite	N/A	N/A	N/A	N/A	N/A	N/A	10	53	20	17
MAS fit	N/A	N/A	N/A	N/A	N/A	N/A	17	28	16	39

N/A, Not applicable.

clasps for retention.<sup>6</sup> Some designs enable adjustments, and the activation ranges from opening 2 to 9 mm vertically and advancing 3 to 16 mm sagittally.<sup>7</sup>

Dental and bony changes with the use of functional appliances in growing patients are well documented.<sup>8,9</sup> Mandibular unit length increases, restriction of forward maxillary growth, retroclination of the maxillary incisors, and proclination of the mandibular incisors have been reported with appliances resembling MAS designed for full-time wear during growth.<sup>10</sup> However, MAS are prescribed for OSA in adults for use during sleep only, and dental and skeletal changes are undesirable. Considering the chronic nature of OSA and consequent length of time of MAS wear, published data are limited on dentofacial changes and side effects associated with long-term MAS use.

Excessive salivation and transient discomfort for a brief time after awakening are commonly reported with initial use and might prevent early acceptance of an oral appliance.<sup>11</sup> Temporomandibular joint (TMJ) discomfort, occlusal changes, mouth dryness, gum irritation, and headaches are other side effects that were investigated.<sup>12,13</sup> Dental and skeletal changes associated with MAS use were evaluated with cephalometric analysis in 100 patients by Robertson<sup>14</sup> and in 30 patients by Bondemark and Lindman.<sup>13</sup> The authors of both studies found significant changes in dental relationships and in the position or size of the mandible. The aim of our study was to investigate the long-term effects of MAS for the treatment of OSA on the dentition and bony structures and other side effects affecting MAS use.

## MATERIAL AND METHODS

The sample included 64 patients (50 men, 14 women) recruited from the patient data bank at a

multidisciplinary sleep disorders clinic in St George University Hospital. All patients had been assessed by a respiratory physician and an orthodontist associated with the sleep disorders clinic and had been prescribed MAS for their OSA. A selection criterion for this follow-up study was the issue of a MAS at least 6 months before the study. Overnight polysomnography was undertaken before treatment with a MAS (T1) to confirm the degree of severity of the OSA and again after acclimatization (T2) to assess MAS efficacy. Patients received a questionnaire and were contacted as soon as practicable for a clinical and radiographic examination. The study was approved by the institutional ethics committee, and written informed consent was obtained from all patients.

All patients used the same appliance: a unique 2-piece acrylic design, as described previously by Mehta et al,<sup>1</sup> providing full occlusal coverage and a screw device to titrate the advancement. The efficacy of this appliance was demonstrated in a randomized controlled study with rigorous criteria for treatment success.<sup>1</sup> Significant improvements in sleep parameters were found compared with inactive control devices. The apnea/hypopnea index (AHI, number of apneas and hypopneas per hour of sleep) more than halved on average, and minimum oxyhemoglobin saturation (minSaO<sub>2</sub>) levels increased on average from 87% to 91%.

A custom questionnaire was mailed to each patient to obtain subjective ratings of overall satisfaction with the MAS, treatment compliance, appliance fracture, and the severity and frequency of various side effects associated with its use (Table I). The severity of a side effect was rated as mild, moderate, or severe. The frequency of a side effect was rated as rarely, some-

times, or often. The patients were asked to consult their bed partner when responding to the questions.

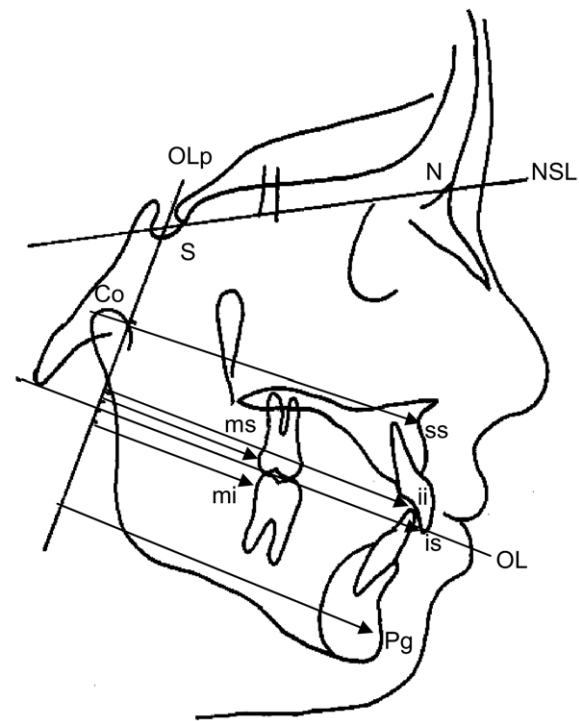
The questionnaire was collected and followed by a clinical examination (T3), consisting of medical and dental histories, anthropometric measurements, extraoral and intraoral examinations, and evaluations of mandibular and TMJ function. Anthropometric measurements included neck circumference at the cricothyroid cartilage, and height and weight measurements to calculate body mass index. These measurements were compared with data taken at T1. The extraoral examination was carried out by 1 operator (R.J.H.), assessing the TMJ as outlined by Zarb and Carlsson.<sup>15</sup> A history of pain and joint noises was included followed by palpation of the joint and the muscles of mastication according to the method of Okeson.<sup>16</sup> The intraoral examination included identification of discrepancy between centric relation and centric occlusion, maximum opening, protrusion, and left and right lateral movements.<sup>17</sup> The patient's functional evaluation was graded by using the clinical dysfunction ( $D_i$ ) and anamnestic dysfunction ( $A_i$ ) indexes and the index for occlusal state ( $O_i$ ) according to Helkimo.<sup>18</sup> In addition, a measure was taken of the vertical opening of the incisal edges and the overjet with the MAS in place with a dial caliper, to the closest 0.05 mm (Mitutoyo, Kanagawa, Japan). The caliper was also used to measure mandibular protrusion (MAS Pro) and maximum protrusion (Mx MAS Pro) with the MAS in place. Alginate impressions and a centric relation wax bite were taken to produce dental study models.

Dental measurements obtained from the dental study models were compared with T1 measurements in a subset of patients whose T1 records were available. These measurements included overjet (OJ), overbite, maxillary arch length, and mandibular arch length. The vertical distance from centric relation was calculated as the sum of the overbite and the vertical distance between the incisors with the MAS in place. The percentage of maximal protrusion from centric relation (% Max Pro) provided by the MAS was calculated by the following formula:

$$\% \text{ Max Pro} = \frac{\text{MAS Pro} + \text{OJ}}{\text{Mx MAS Pro} + \text{OJ}} \times 100$$

Lateral cephalometric radiographs were taken of each patient in centric occlusion at T1 and T3 in natural head position with a barium mouthwash with Orthoralix SD (Phillips, Monza, Italy). All radiographs were traced by 1 operator (R.J.H.) and digitized using Image Pro/Quick Ceph 2000 (Quick Ceph Systems, San Diego, Calif).

The cephalometric analysis was based on the meth-



**Fig 1.** Cephalometric linear measurements indicating sagittal changes.

ods described by Pancherz<sup>19</sup> and Forsberg et al.<sup>20</sup> Sagittal changes were measured parallel to occlusal plane (Fig 1). Vertical changes were measured parallel to the line perpendicular to the constructed plane 7° with NS line (Fig 2). Soft-tissue and angular measurements are detailed in Figure 3.

Overnight polysomnographs were recorded for all patients at T1 and for 95% of the patients at T2. Variables were recorded continuously on a 20-channel computerized sleep monitoring system (Compumedics, Victoria, Australia). Calculated respiratory variables were AHI and minSaO<sub>2</sub>. Follow-up sleep studies (T3) were performed on a smaller subset of patients with a portable sleep study machine (Autoset Portable II; ResMed, Ryde, Australia). Air pressure through a nasal cannula and percutaneous oxygen saturation levels through a noninvasive finger probe were measured, and AHI and minSaO<sub>2</sub> calculated.

#### Statistical analysis

The data were compiled and analyzed by using statistical analysis software (version 8; SPSS, Chicago, Ill). The data are expressed as means and standard deviations at T1, and means and standard errors of the



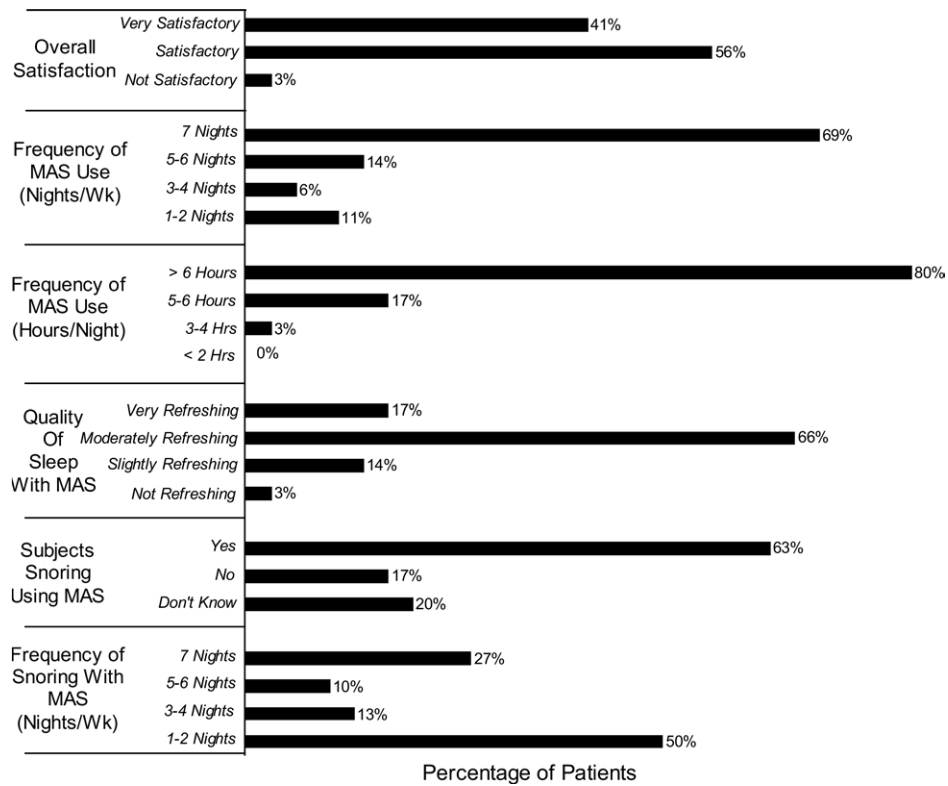


Fig 4. Patients' subjective ratings overall satisfaction with the MAS.

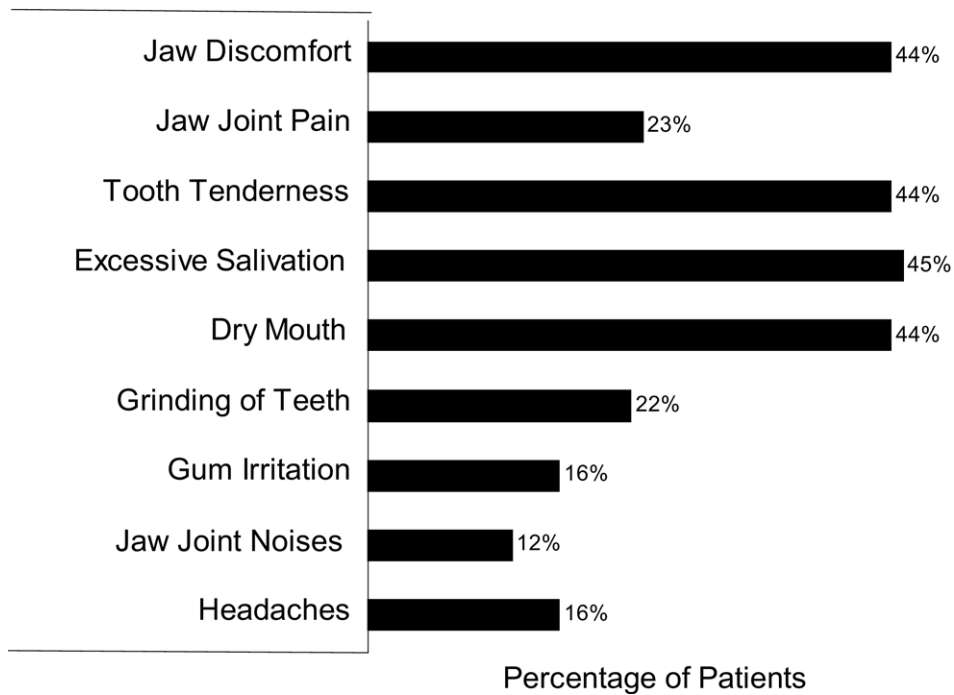


Fig 5. Patients' subjective ratings of the symptoms and side effects associated with use of the MSA.

**Table II.** Anthropomorphic and dental changes in OSA patients at T3 (n = 57; 44 men) and study model analysis (n = 45; 33 men)

Variable	T1		T3		P value
	Mean (SD)	Range	Mean (SE)	Range	
Age (y)	49.4 (9.82)	29.4-72.5	2.1 (0.13)	0.9-5.4	NS
BMI (kg/m <sup>2</sup> )	29.1 (4.99)	19.9-42.4	0.2 (0.23)	-8-5.4	NS
Neck circumference (mm)	39.9 (3.18)	34.5-48.0	1.1 (0.23)	-3.0-5.0	<.001
Maxillary arch length (mm)	25.2 (3.71)	17.3-35.6	0.0 (0.10)	-2.1-1.5	NS
Mandibular arch length (mm)	21.5 (3.76)	13.5-31.7	-0.2 (0.11)	-1.6-1.9	NS
Overbite (mm)	2.8 (2.28)	-3.6-9.8	-0.3 (0.08)	-1.2-1.7	<.01
Overjet (mm)	2.9 (1.32)	0.0-6.1	-0.2 (0.06)	-0.9-1.3	<.05

NS, Not significant; BMI, body mass index.

**Table III.** Effect of long term use of MAS on cephalometric measurements in OSA patients (n = 46; 34 males)

Measurements	T1	T3	Mean absolute % error	P value
	Mean (SD)	Mean (SE)		
Sagittal (mm)				
ss-OLp	80.4 (5.68)	-0.09 (0.10)	0.64	NS
Pg-OLp	87.9 (7.83)	0.05 (0.15)	0.94	NS
Co-Pg	121.7 (7.65)	0.38 (0.23)	1.05	NS
Is-OLp	89.0 (6.46)	-0.12 (0.13)	0.77	NS
ii-OLp	85.1 (6.13)	0.52 (0.12)	0.90	<.001
ms-OLp	50.6 (5.88)	0.01 (0.12)	1.07	NS
mi-OLp	51.5 (6.58)	0.26 (0.11)	1.74	<.01
Vertical (mm)				
n'-Me'	126.2 (7.47)	0.10 (0.22)	0.93	NS
S-Go'	85.2 (7.86)	0.15 (0.19)	1.18	NS
n'-is'	86.2 (5.22)	-0.12 (0.08)	0.67	NS
ii'-ms'	42.8 (3.76)	-0.12 (0.15)	2.08	NS
n'-ms'	76.8 (5.38)	-0.14 (0.13)	1.02	NS
mi'-Mo'	43.8 (3.74)	0.01 (0.12)	1.48	NS
Angles (°)				
SNA	81.3 (3.84)	0.08 (0.10)	0.66	NS
SNB	78.5 (3.69)	0.17 (0.10)	0.69	NS
ANB	2.8 (3.10)	-0.09 (0.10)	1.46	NS
MP/SN	32.8 (5.44)	0.01 (0.19)	3.33	NS
is/SN	99.9 (9.46)	0.06 (0.20)	1.15	NS
is/PP	106.8 (10.51)	-0.22 (0.20)	1.09	NS
ii/MP	92.4 (9.07)	0.96 (0.30)	2.19	<.01
ii/is	134.7 (15.73)	-1.69 (0.58)	2.68	<.01
ii/OL	73.5 (9.05)	-1.02 (0.34)	3.15	<.01
Soft tissues (mm)				
H-MP	21.3 (5.96)	0.62 (0.57)	6.63	NS
C2C4-SN	108.6 (6.84)	0.71 (0.77)	0.50	NS
PhW-spt	11.3 (3.13)	0.44 (0.35)	7.70	NS
MinPhW	9.6 (3.05)	-0.01 (0.40)	6.81	NS
pm-P	42.0 (4.85)	0.05 (0.46)	1.84	NS

NS, Not significant.

tion and the dental study model analysis completed for 45 patients (33 men, 12 women) are detailed in Table II. The cephalometric analysis completed on 46 patients (34 men, 12 women) is summarized in Table III. The average length of MAS use was 25.1 ± 11.8 months, with a minimum of 10.7 months and a maximum of

64.5 months. The maximum protrusion provided by the MAS was on average 72.9% ± 11.9% (range, 12.5%-92.3%). The average vertical distance from the centric relation with the MAS in place was 7.1 ± 2.2 mm (range, 2.7-12.7 mm).

Clinical TMJ assessment at T3 showed that 16

patients were clinically symptom free ( $D_i 0 = 28\%$ ); 38 patients were experiencing mild symptoms ( $D_i I = 67\%$ ); 3 patients were experiencing moderate symptoms ( $D_i II = 5\%$ ). No patients had severe symptoms ( $D_i III = 0\%$ ). The patients' subjective assessment of their TMJ status at T3 showed that 35 patients were symptom free ( $A_i 0 = 61\%$ ); 20 patients were experiencing mild symptoms ( $A_i I = 35\%$ ); 2 patients were experiencing severe symptoms ( $A_i II = 4\%$ ). Assessment of the occlusal status showed that, at T3, 1 subject had no occlusal disturbances ( $O_i 0 = 2\%$  percent); 13 patients had moderate occlusal disturbances ( $O_i I = 23\%$ ); 43 patients had severe occlusal disturbances ( $O_i II = 75\%$ ).

Subjective occlusal and jaw functional changes were reported by 8 patients (12.5%) and 2 patients (3%), respectively. The occlusal changes were slight and nonspecific except in 3 patients who described them in terms of inability to chew nails, cut cotton thread, or open packets with incisors since using the MAS. The jaw functional changes were described by the 2 patients as more forward habitual posture and decreased jaw-muscle power.

AHI and minSaO<sub>2</sub> data at T1 were available for all 57 patients (100%) who were examined clinically. At T1, the average AHI was  $25.3 \pm 17.74$  per hour (range, 3.0-81.0), and the average minSaO<sub>2</sub> was  $86.7\% \pm 6.9\%$  (range, 54.0%-96.0%). Data at T2 were available for 54 patients (95%) and at T3 for 16 patients (28%). There were significant differences for both AHI ( $P = .001$ ) and minSaO<sub>2</sub> ( $P = .003$ ). Within-subjects comparisons for AHI showed significant differences for both T2 vs T1 ( $P = .001$ ) and T3 vs T1 ( $P = .012$ ). The mean AHI values from T1 to T2 to T3 were 25.4 to 7.8 to 13.7 per hour. Within-subjects comparisons for minSaO<sub>2</sub> showed a significant difference for T2 vs T1 ( $P = .002$ ), but T3 vs T1 was not significant ( $P = .59$ ). The mean minSaO<sub>2</sub> values from T1 to T2 to T3 were 86.7% to 90.9% to 83.1%.

## DISCUSSION

In this study, we found that MAS therapy is subjectively effective and well tolerated despite the side effects reported by many (87.5%) patients. Most patients (97%) found control of OSA symptoms to be satisfactory or better after an average of  $25.1 \pm 11.8$  months. Sleep quality was reported as moderately or very refreshing in 83% of patients, and the subjective improvements in snoring and daytime sleepiness agree with data from other studies.<sup>5,10,21</sup> Although the questionnaire was not validated, the reduction in subjective daytime sleepiness was supported by the significant decreases in ESS scores. A small study of covertly

measured compliance showed an average of 6.8 hours of MAS use per night.<sup>22</sup> Compliance of 5 nights per week or greater was reported by 83% of our sample. Furthermore, 97% tolerated the MAS longer than 5 hours per night. This is a relatively high level of compliance compared with some long-term studies.<sup>7,23</sup>

The most commonly reported side effects were jaw discomfort, tooth tenderness, excessive salivation, and dry mouth. The patients reported that the side effects were temporary or transient, especially during the early stages of MAS use. The proportion of the sample (<45%) experiencing these side effects was similar to that in other studies.<sup>24,25</sup> In general, the side effects were rated as mild with the exception of joint noises and headaches, which, along with craniomandibular problems such as feelings of fatigue in the jaws and facial pain, increase with age in the general population.<sup>17</sup> Increases in joint noises and improvements in headache suffering with MAS use were reported previously.<sup>13</sup> Our data showed that joint noises and headaches subjectively affected a small proportion of the sample at T3 (12% and 16%, respectively) and that the changes in these symptoms during MAS use were rated as "better" in 9% and 13%, respectively. These symptoms were "never a problem" or did not change for more than 82% of the patients during MAS use.

Sleep bruxism was shown to occur at least weekly in over 8% of the general population and in a higher percentage of patients with OSA and to have a significant effect on quality of life.<sup>26</sup> The study found that bruxism had significant consequences (muscular discomfort on awakening, disturbing tooth grinding, necessity of dental work) in half of the patients.<sup>26</sup> We found that only 2 patients were sufficiently concerned about tooth damage to stop using MAS, and 22% indicated bruxing as a side effect, with 3% rating it as worse during MAS use. This information further supports findings that MAS therapy does not appear to have a major adverse effect on the stomatognathic system in the long term.<sup>7,13</sup>

Dental study model measurements showed statistically significant reductions in both overbite ( $-0.3 \pm 0.08$  mm;  $P < .01$ ) and overjet ( $-0.2 \pm 0.06$  mm;  $P < .05$ ) with MAS use, although the changes were clinically insignificant. This finding was supported in the cephalometric analysis; dental changes were limited to the mandibular anterior teeth and the mandibular molars moving anteriorly a statistically significant but clinically insignificant amount. Specifically, the mandibular anterior teeth proclined an average of  $0.96^\circ \pm 0.30^\circ$  ( $P < .01$ ), and the incisal edge moved anteriorly  $0.52 \pm 0.12$  mm ( $P < .001$ ). The mean absolute

percentage errors for these 2 measurements were 2.19% and 0.90%, respectively, indicating accurate reproducibility of the cephalometric analysis. This contrasts with the findings of Robertson,<sup>14</sup> who found as much as 4.9° of proclination of the mandibular incisors after 30 months of appliance wear. That sample included only patients who stated compliance of 5 to 6 hours per night and 7 nights per week of appliance wear; this, in conjunction with the treatment time, might account for the markedly different result in our study. Full occlusal coverage with acrylic might account for the mandibular molar anterior movement of  $0.3 \pm 0.77$  mm ( $P < .05$ ). There was no significant effect on the maxillary dentition, mandibular length (Co-Pg), or mandibular position (Pg-OLp), indicating neither an orthopedic effect nor a functional adaptation. Similar results were shown in a series of case reports of tissue-borne functional appliances in adults by McNamara.<sup>27</sup> However, Bondemark<sup>28</sup> found a small but statistically significant increase in mandibular length and position after 2 years of nocturnal treatment with a MAS and speculated that the cause was condylar or glenoid fossa remodeling. Similarly, Robertson<sup>14</sup> showed vertical repositioning of the condyle relative to the cranial base as early as 6 months into MAS use. Neither study investigated vertical movements of the molars as a factor in the change in mandibular position. We found no significant vertical changes either dentally or skeletally, but the anterior dental movements were similar to those in other studies.<sup>13,23</sup> No soft-tissue measurement showed a statistically significant change. Therefore, long-term MAS use does not appear to affect pharyngeal shape or hyoid position.

Little subjective awareness of occlusal change has been shown in previous studies. Awareness of occlusal changes was found in only 8 of 15 patients with a measurable change in a sample of 106 patients by Pantin et al,<sup>7</sup> in no patients in a sample of 30 by Bondemark,<sup>28</sup> and in 3 patients from a sample of 69 by Marklund et al.<sup>23</sup> We found that 8 patients (12.5%) were aware of a permanent occlusal change and up to 43 patients (69%) endured occlusal disturbance indicated by an increased index for occlusal state ( $O_i = II$ ). This adverse effect, however, was not enough to cause the patients to discontinue MAS use. The assessment of the occlusal changes was made immediately after the removal of MAS at T3. The occlusal disturbance might be a temporary adverse condition that will diminish without the MAS. This is justified in this study, because 20% of the patients who indicated that a change in “the way [their] teeth bite together” was “worse” reported the condition to be transient and limited normally to 2 hours at most after MAS removal. Furthermore, ceph-

alometric and dental study model analysis showed that the dental and skeletal changes were minimal, indicating a lack of structural changes to sustain the occlusal disturbance (Table II).

A limitation of the clinical data is the lack of a standardized pretreatment TMJ assessment. Nevertheless, examined by 1 operator (R.J.H.) at T3, more patients were symptom free with less severe occlusal disturbances than found in a general population sample studied by Helkimo<sup>29</sup> in the development of the index. In addition, the 61% of symptom-free patients ( $A_i 0$ ) at T3 in our study compares well with the 69% of symptom-free patients found by Bondemark and Lindman<sup>13</sup> after 2 years of nocturnal MAS use. The latter study also showed similar results in the clinical dysfunction index with  $D_i 0/D_i I$  and  $D_i II$  in 84% and 9% of the patients, respectively, compared with 95% and 5% in our sample. Although TMJ problems are considered a risk in long-term MAS use,<sup>2</sup> our findings show that jaw joint pain and joint noises are indicated by fewer than 25% of the sample as a long-term problem, with severity rated as mild and the frequency low in most cases. Furthermore, the scores in the study of Helkimo<sup>29</sup> suggest that symptoms of TMJ problems are less than or equivalent to those in the general population, and, therefore, long-term MAS use is not detrimental to TMJ health and function.

Evaluation of the changes in polysomnographic variables was limited by the small number of patients undergoing T3 sleep tests and the different methods of polysomnograph recordings. Measures of AHI and  $\text{minSaO}_2$  with portable monitors were shown to vary compared with overnight polysomnography.<sup>30</sup> Nevertheless, comparison of the results indicated a significant improvement in AHI and  $\text{minSaO}_2$  from T1 to T2, with a trend toward T1 levels for both parameters at T3. Mean AHI values were almost halved from T1 to T3, but mean  $\text{minSaO}_2$  at T3 decreased to below T1 levels. MAS effectiveness might diminish over time, with weight gain and MAS degradation considered important factors.<sup>23</sup> More studies are needed to understand the reported impressive subjective responses and compliance that contrast with the objective responses of some sleep parameters. Negligible improvement in  $\text{minSaO}_2$  was shown previously with MAS therapy.<sup>31</sup> Further investigations with follow-up overnight polysomnographs are needed to more accurately examine the long-term effectiveness of MAS on sleep parameters.

## CONCLUSIONS

MAS therapy in the treatment of OSA has been found to provide subjective and objective benefits with minimal dental and skeletal side effects. Compliance

levels in this study attest to patients' satisfaction with MAS therapy in spite of some minor side effects associated with its use by most of the sample. The extent to which this is influenced by design features of the MAS remains to be determined. Management by a multidisciplinary team, consisting of orthodontic, OSA, and prosthetic professionals, is essential to adequately assess the various facets of treatment progress and address problems specific to the operators' skills. A recall program is recommended to monitor symptoms and the effects of the MAS on both the stomatognathic and the respiratory systems.

We thank J. Qian, E. Noakes, and G. Hughes for their assistance in data collection.

## REFERENCES

- 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;163:1457-61.
- 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;18:501-10.
- Nakazawa Y, Sakamoto T, Yasutake R, Yamaga K, Kotorii T, Miyahara Y, et al. Treatment of sleep apnea with prosthetic mandibular advancement (PMA). *Sleep* 1992;15:499-504.
- Gale DJ, Sawyer RH, Woodcock A, Stone P, Thompson R, O'Brien K. Do oral appliances enlarge the airway in patients with obstructive sleep apnoea? A prospective computerized tomographic study. *Eur J Orthod* 2000;22:159-68.
- 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;151:194-8.
- 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;20:293-7.
- Pantin CC, Hillman DR, Tennant M. Dental side effects of an oral device to treat snoring and obstructive sleep apnea. *Sleep* 1999;22:237-40.
- Ruf S, Pancherz H. Long-term TMJ effects of Herbst treatment: a clinical and MRI study. *Am J Orthod Dentofacial Orthop* 1998;114:475-83.
- Ruf S, Pancherz H. Temporomandibular joint remodeling in adolescents and young adults during Herbst treatment: a prospective longitudinal magnetic resonance imaging and cephalometric radiographic investigation. *Am J Orthod Dentofacial Orthop* 1999;115:607-18.
- Illing HM, Morris DO, Lee RT. A prospective evaluation of Bass, Bionator and Twin Block appliances. Part I—the hard tissues. *Eur J Orthod* 1998;20:501-16.
- Schmidt-Nowara WW, Meade TE, Hays MB. Treatment of snoring and obstructive sleep apnea with a dental orthosis. *Chest* 1991;99:1378-85.
- Aldrich MS, Chauncey JB. Are morning headaches part of obstructive sleep apnea syndrome? *Arch Intern Med* 1990;150:1265-7.
- Bondemark L, Lindman R. Craniomandibular status and function in patients with habitual snoring and obstructive sleep apnoea after nocturnal treatment with a mandibular advancement splint: a 2-year follow-up. *Eur J Orthod* 2000;22:53-60.
- Robertson CJ. Dental and skeletal changes associated with long term mandibular advancement. *Sleep* 2001;24:531-7.
- Zarb G, Carlsson G. Examination and differential diagnosis of occlusal problems. In: Mohl ND, Zarb GA, Carlsson GE, Rugh JD, editors. *A textbook of occlusion*. Chicago: Quintessence; 1988. p. 198-207.
- Okeson J. Management of temporomandibular disorders and occlusion. 4th ed. St Louis: Mosby; 1998. p. 242-61.
- Helkimo M. Studies on function and dysfunction of the masticatory system. I. An epidemiological investigation of symptoms of dysfunction in Lapps in the north of Finland. *Proc Finn Dent Soc* 1974;70:37-49.
- Helkimo M. Studies on function and dysfunction of the masticatory system. II. Index for anamnestic and clinical dysfunction and occlusal state. *Svensk Tandlak Tidskr* 1974;67:101-21.
- Pancherz H. The mechanism of Class II correction in Herbst appliance treatment. A cephalometric investigation. *Am J Orthod* 1982;82:104-13.
- Forsberg CM, Eliasson S, Westergren H. Face height and tooth eruption in adults—a 20-year follow-up investigation. *Eur J Orthod* 1991;13:249-54.
- Tegelberg A, Wilhelmsson B, Walker-Engstrom ML, Ringqvist M, Andersson L, Krekmanov L, et al. Effects and adverse events of a dental appliance for treatment of obstructive sleep apnoea. *Swed Dent J* 1999;23:117-26.
- Lowe AA, Sjöholm TT, Ryan CF, Fleetham JA, Ferguson KA, Remmers JE. Treatment, airway and compliance effects of a titratable oral appliance. *Sleep* 2000;23(Suppl 4):S172-8.
- Marklund M, Franklin K, Persson M. Orthodontic side effects of mandibular advancement devices during treatment of snoring and sleep apnoea. *Eur J Orthod* 2001;23:135-44.
- Pancer J, Al-Faifi S, Al-Faifi M, Hoffstein V. Evaluation of variable mandibular advancement appliance for treatment of snoring and sleep apnea. *Chest* 1999;116:1511-8.
- 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;52:362-8.
- Ohayon MM, Li KK, Guilleminault C. Risk factors for sleep bruxism in the general population. *Chest* 2001;119:53-61.
- McNamara JA Jr. Dentofacial adaptations in adult patients following functional regulator therapy. *Am J Orthod* 1984;85:57-71.
- Bondemark L. Does 2 years' nocturnal treatment with a mandibular advancement splint in adult patients with snoring and OSAS cause a change in the posture of the mandible? *Am J Orthod Dentofacial Orthop* 1999;116:621-8.
- Helkimo M. Studies on function and dysfunction of the masticatory system. IV. Age and sex distribution of symptoms of dysfunction of the masticatory system in Lapps in the north of Finland. *Acta Odontol Scand* 1974;32:255-67.
- Portier F, Portmann A, Czernichow P, Vascaut L, Devin E, Benhamou D, et al. Evaluation of home versus laboratory polysomnography in the diagnosis of sleep apnea syndrome. *Am J Respir Crit Care Med* 2000;162:814-8.
- 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;109:1269-75.