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Dental and occlusal changes during mandibular advancement splint therapy in sleep disordered patients

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SUMMARY The aims of this longitudinal, observational study were two-fold: first, to determine in adults with sleep disorders the extent of dental and occlusal changes following the use of a mandibular advancement splint (MAS) and, second, to determine the time course of these changes.

One hundred adult subjects (87 males, 13 females) diagnosed with obstructive sleep apnoea (OSA) and/or asymptomatic snoring were treated with non-adjustable MAS. At the outset each subject was randomly assigned to a group and reviewed 6, 12, 18, 24 or 30 months after placement of a splint. There were 20 subjects in each group. Craniofacial changes were measured on lateral cephalometric radiographs taken at the initial and review appointments.

When the changes in all subjects were examined, the SNA, ANB angles, ANS–PNS length and face height increased, and the mandibular first molars and the maxillary first premolars significantly over-erupted. Significant retroclination of the maxillary incisors and proclination of the mandibular incisors were accompanied by reductions in maxillary arch length, overbite and overjet. When the changes over time were determined, the mandibular symphysis was significantly lower at all review periods. An increase in face height and reductions in overbite and overjet were evident at 6 months, and over-eruption of the maxillary first premolars and mandibular first molars, and proclination of the lower incisors were found at 24 months. Significant positive correlations were also found between the amount of anterior opening by the appliances and changes in overbite at 24 and 30 months.

The appliance used produced small, unpredictable changes in the occlusion that tended to occur after 24 months' wear. It is postulated that the changes in overbite might be lessened by keeping the bite opening to a minimum.

Introduction

Oral appliances, such as mandibular advancement splints (MAS), are an accepted method for the treatment of mild to moderate obstructive sleep apnoea (OSA) and snoring (American Sleep Disorders Association Standards of Practice Committee, 1995; Schmidt-Nowara, 1999). The aim of these appliances is to enlarge the oropharyngeal airway by repositioning the mandible downwards and forwards.

Recent studies of patients with moderate sleep disorders have reported that long-term wear of MAS was accompanied by small changes in the position of the mandible, reductions in both overbite and overjet, and a forward shift of the mandibular molars (Bondemark, 1999; Pantin *et al.*, 1999; Fritsch *et al.*, 2001; Marklund *et al.*, 2001). Significant dental side-effects in individual cases have also been reported (Panula and Keski-Nisula, 2000; Rose *et al.*, 2001). The molar changes can be questioned because some of the observations were derived from study casts and, consequently, may be confounded by a downward and forward posturing of the mandible. While there may be some disagreement about the site(s) of the dental and occlusal changes due to MAS, there is less information about their onset.

The aims of this cephalometric study were two-fold: first, to determine the extent of dental and occlusal changes following the use of a non-adjustable MAS for the treatment of sleep disorders, and, second, to determine these changes over time.

Subjects and methods

From 114 consecutive adult patients with OSA and/or habitual snoring medically referred to an orthodontic practice for a MAS, 100 subjects (87 men, 13 women) agreed to participate in this study. Of the 114 patients, one subject declined to participate and 13 subjects were excluded because, on questioning, they were found to be wearing the appliance less than 5–6 hours per night. The mean age of the men was 49.0 years (standard deviation 8.3 years) and for the women 51.0 years (standard deviation 10.2 years). Further details of the subjects and methods are given in Robertson (2002).

The appliance used in this study was a non-adjustable rigid splint (Robertson, 1997) which covered the occlusal surfaces of the maxillary and mandibular teeth (Figure 1). The splints were constructed to advance the mandible 75 per cent of the maximum protrusion obtained by each subject. In this sample, maximum protrusion ranged

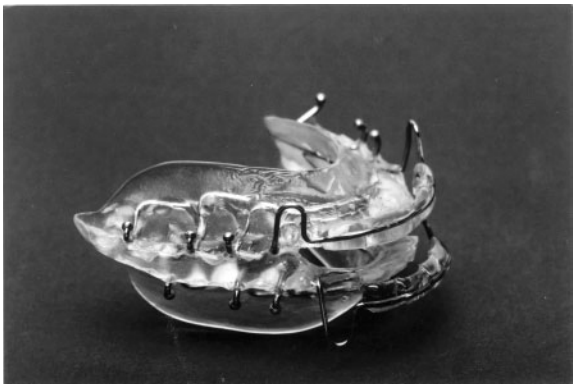

Figure 1 The mandibular advancement splint used in this study.

from 3 to 14 mm. For appliance construction, mandibular advancement was measured clinically with a George gauge to the nearest millimetre (George, 1992).

Assessment of dental and occlusal changes

At the outset all subjects had two lateral cephalometric radiographs taken: one with the teeth in the intercuspal position and with the head in the so-called natural head position (NHP), and a second film with the appliance *in situ*. This latter film was used to confirm the amount of mandibular advancement and opening obtained with each appliance. At this visit each subject was randomly assigned to a group to be reviewed either 6, 12, 18, 24 or 30 months later. There were 20 subjects in each group, with no more than three women in any one group. The subjects received their appliances 1 week later. At the review appointment a third lateral cephalometric radiograph with the teeth in the intercuspal position and the head in the NHP was obtained. The subjects were seated for all radiographs which were taken in the afternoon by the same operator.

The reference points and planes given in Figure 2 were transferred to mylar film, digitized twice with a reflex metrograph (Scott, 1981), and converted to linear and angular measurements (Table 1). The positions of the first molars, maxillary first premolars, and maxillary and mandibular central incisors, relative to anatomically stable reference lines in the maxilla and mandible, were measured on the initial and review films. The position of the mandible was measured relative to an anatomically stable reference line in the cranial base (Johnston, 1996). The differences between each subject's review and initial film, taken with the teeth in the intercuspal position, were used to determine the skeletal, dental and occlusal changes.

To determine the errors in the radiographic method, 10 randomly selected films were retraced and remeasured by the same operator (CR) and compared with the *t*-test for paired data and the errors calculated using Dahlberg's formula (1940). There were no statistically significant

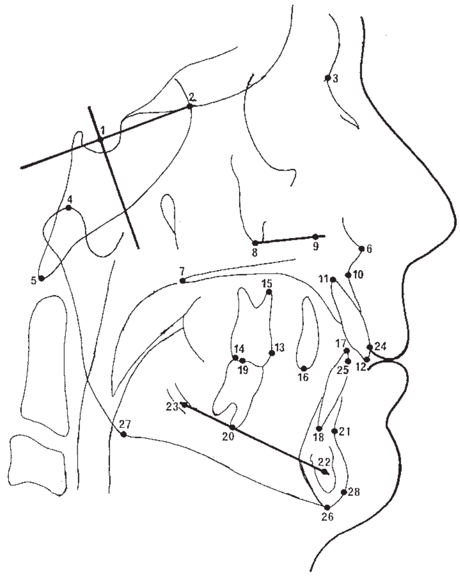

Figure 2 Cephalometric reference points. (1) S, sella; (2) SE, spheno-ethmoidal junction; (3) N, nasion; (4) Cd, condylion; (5) Ba, basion; (6) ANS, anterior nasal spine; (7) PNS, posterior nasal spine; (8) IZ_1, inferior zygoma (1). The lower most point on the average of the right and left outlines of the zygoma; (9) IZ_2, inferior zygoma (2). The constructed point 2 cm rostral to IZ_1 along the line parallel to the floor of the nose through IZ_1; (10) A, point A; (11) UIA, upper central incisor apex; (12) UIE, upper central incisor edge; (13) U6MCpt, upper first molar mesial contact point; (14) U6DCT, upper first molar distal cusp tip; (15) U6MRA, upper first molar mesial root apex; (16) UPMCT, upper first premolar cusp tip; (17) LIE, lower incisor edge; (18) LIA, lower incisor apex; (19) L6DCT, lower first molar distal cusp tip; (20) L6MRA, lower first molar mesial root apex; (21) B, point B; (22) Fid_1, fiducial point 1. A point on a natural structure within the mandibular symphysis; (23) Fid_2, fiducial point 2. A point on a natural structure of the posterior body of the mandible; (24) overbite point. The point of intersection between the perpendicular through UIE and a line drawn parallel to the functional occlusal plane through the point LIE; (25) overjet point. The point of intersection of the line drawn parallel to the functional occlusal plane through UIE and the labial surface of the most prominent mandibular incisor; (26) Me, menton; (27) Go, gonion; (28) Pg, pogonion. Cephalometric measurements and planes: S–SE, cranial base reference line, joining 1 and 2; IZ_1–IZ_2, maxillary reference plane, line joining 8 and 9; Fid_1–Fid_2, mandibular reference plane, line joining 22 and 23; FOP, functional occlusal plane. The average occlusal plane of the buccal teeth including the first molars and premolars. This plane is used to determine overbite and overjet points; Cd vert, the vertical distance between the condylion and an extension of the line S–SE; Cd horiz, the horizontal distance between the condylion to a line perpendicular to the line S–SE through S.

differences between the duplicate measurements. The errors, which fell within the ranges of 0.17–0.50 mm and 0.20–0.95 degrees, are comparable with those reported in a similar study (Coltman *et al.*, 2000). Associations between the amount of mandibular advancement and opening measured cephalometrically and the antero-posterior skeletal relationship (ANB angle) at the outset were investigated with Pearson product-moment correlation coefficients. Differences between the groups at the outset were investigated with a one-way ANOVA and Duncan's new multiple range test. Unpaired *t*-tests

Table 1 Changes in sleep disordered subjects (n = 100) during mandibular advancement splint therapy.

Skeletal variables	Initial Mean	Initial SD	Review Mean	Review SD	Mean difference	P
SNA	81.38	3.74	81.7	3.53	–0.32	**0.023**
SNB	78.41	3.8	78.42	3.59	–0.01	0.927
ANB	3.22	2.1	3.5	2.09	–0.29	**0.013**
N–Me	130.89	7.81	131.66	7.72	–0.76	**0.0001**
N/ANS–PNS	56.94	3.52	57.05	3.56	–0.11	0.356
Me/ANS–PNS	72.96	5.93	73.62	5.9	–0.66	**0.0001**
S–Go	87.2	7.42	87.7	7.41	–0.5	**0.0001**
S/ANS–PNS	47.99	3.76	47.94	3.84	0.05	0.56
Go/ANS–PNS	38.75	6.24	39.31	6.29	–0.56	**0.001**
ANS–PNS	54.4	4.09	55.36	3.81	–0.95	**0.002**
Ba–PNS	45.1	4.53	45.04	4.18	0.06	0.763
Cd–Pg	125.35	7.19	125.18	7.01	0.17	0.362
Cd–Go	67.04	6.32	66.74	6.15	0.31	0.116
Go–Pg	80.68	5.14	80.6	5.19	0.08	0.606
Mandibular position						
Cd vert	17.61	4.05	18.42	3.86	–0.81	**0.0001**
Cd horiz	14.77	3.58	14.84	3.53	–0.07	0.666
Fid_1 vert	118.46	7.69	119.45	7.69	–0.99	**0.0001**
Fid_1 horiz	39.68	12.63	39.49	12.63	0.19	0.471
Dentoalveolar variables						
U6DCT vert	28.81	3.52	29	3.28	–0.2	0.259
U6DCT horiz	7.29	4.39	7.17	4.44	0.12	0.577
U6/IZ_1–IZ_2	67.68	8.4	67.03	8.77	0.65	0.264
L6DCT vert	21.54	2.27	21.91	2.33	–0.37	**0.021**
L6DCT horiz	34.94	4.86	34.86	4.71	0.07	0.668
L6/Fid_1–Fid_2	103.28	21.28	103.6	20.74	–0.32	0.852
Pm vert	32.63	3.56	33.02	3.45	–0.39	**0.002**
Pm horiz	11.43	4.37	11.58	4.76	–0.15	0.505
UIE vert	37.41	3.59	37.33	3.73	0.08	0.604
UIE horiz	29.31	5.3	28.95	5.26	0.36	0.153
UI/IZ_1–IZ_2	104.75	8.79	103.14	9.1	1.58	**0.001**
LIE vert	34.05	3.15	34.15	3.37	–0.1	0.398
LIE horiz	7.34	4.88	6.87	4.71	0.47	**0.002**
LI/Fid_1–Fid_2	83.81	10.87	86.53	8.21	–2.71	**0.001**
Overbite	4.09	2.62	3.07	2.1	1.02	**0.0001**
Overjet	4.25	2.23	3.19	1.76	1.06	**0.0001**
MaxAL	37.54	4.68	37.07	4.29	0.47	**0.006**
MandAL	30.48	4.17	30.71	4.19	–0.23	0.23

Significant differences at the 5 per cent level are shown in bold.
SD, standard deviation.

were used to test for gender differences at the outset and t-tests for paired data were used to determine if there were any statistically significant differences between the initial (T1) and review (T2, T3, T4, T5, T6) measurements. Associations between the changes in the mandibular molars, overbite and overjet, the maxillary and mandibular incisors, and the amount of mandibular opening and advancement were investigated with Pearson product-moment correlation coefficients.

Mandibular advancement

Initial mandibular advancement was established clinically with the George gauge (George, 1992). The amount of advancement and anterior (opposite the incisors) and posterior (opposite the first molars) vertical opening by the appliances was determined by comparing the measurements taken from the two initial cephalometric radiographs (with and without the appliance *in situ*). Mandibular advancement was measured as the horizontal movement of the lower incisors reference point (LIE), along a line parallel to the functional occlusal plane (FOP). Anterior opening was measured as the vertical distance between the upper and lower incisal edges (UIE–LIE) along a line perpendicular to the FOP. The FOP was the line passing through points 14 and 16 (Johnston, 1996). The degree of posterior vertical opening was determined as the perpendicular distance between the lower first molar distal cusp tip (L6DCT) to the FOP.

Results

At the outset the mean mandibular advancement by the appliances was 6.83 mm [standard deviation (SD) 1.78 mm], the mean incisal opening was 5.64 mm (SD 1.86 mm), and the mean opening opposite the first molars was 2.61 mm (SD 1.36 mm). There were no significant cephalometric differences between the groups or between the male and female subjects.

Changes in the combined group

When all the subjects were combined into a single group to determine the extent of the dental and occlusal changes, 12 small but statistically significant increases and five significant reductions were found between the initial and review films (Table 1). A small increase in SNA was accompanied by a similar increase in ANB. The total anterior face height (N–Me), lower face height (Me/ANS–PNS), and posterior face height (S–Go, Go/ANS–PNS) also increased significantly. Approximately 86 per cent of the increase in total anterior face height occurred in the lower face. Maxillary length (ANS–PNS) increased significantly and the mandible was displaced significantly downward (Cd vert, Fid_1 vert), but not forward. Both the mandibular first molar and the maxillary first premolar (L6DCT vert, Pm vert) over-erupted slightly. Significant retroclination of the maxillary incisors ($UI/IZ_1–IZ_2$) and proclination of the mandibular incisors ($LI/Fid_1–Fid_2$) were accompanied by reductions in maxillary arch length, overbite, and overjet. There was a statistically significant positive association between the amount of advancement obtained with each appliance and the ANB angle ($n = 100$, $r = 0.302$, $P = 0.002$).

Changes over time

The significant changes over time are given in Table 2. A conspicuous finding is that only one variable (Fid_1 vert) was common to all periods. At the first review period (T2, 6 months), small but statistically significant increases in face height (N–Me, S–Go, Go/ANS–PNS) were accompanied by a significant downward position of the mandible (Cd vert, Fid_1 vert) and significant reductions in overbite and overjet. Only one significant increase (Fid_1 vert) occurred at 12 months. Significant increases in both the total and lower anterior face heights (N–Me, Me/ANS–PNS) and the vertical position of the mandible relative to the cranial base (Cd vert, Fid_1 vert) were found after 18 months' splint wear. The overbite and overjet were also reduced in this group. By the second year of wear, SNA and face height (N–Me, Me/ANS–PNS) had increased. The mandible continued to be further (Cd vert, Fid_1 vert) down the articular eminence than at the outset. Both the mandibular first molars (L6DCT vert) and the maxillary first premolars (Pm vert) had over-erupted and the mandibular incisors had been proclined ($LI/Fid_1–Fid_2$). At the final review period the mandibular incisors were proclined, on average, 4 degrees and the overbite and overjet reduced. Lower face height, although still increased, was less at 30 months than at 18 and 24 months. There were no significant changes in the positions of the first molars or in arch length. Statistically significant positive correlations were also found between the amount of anterior opening obtained with each appliance and the changes in overbite at 24 and 30 months (Table 3).

Discussion

There is good evidence that in untreated individuals small dental and occlusal changes occur throughout life (Behrents, 1985). For this reason, reference planes were used based on anatomically stable landmarks (Johnston, 1996) to detect any changes in the positions of the teeth and mandible. Mandibular advancement appliances, used in the treatment of OSA, widen the oropharyngeal airway by repositioning the mandible downwards and forwards during sleep. Therefore, it was not surprising that they produced similar changes to functional appliances (Aelbers and Dermaut, 1996; Collett, 2000). In agreement with Bondemark (1999), a small but statistically significant increase was found in face height, the mandible was lower relative to the cranial base, the maxillary first premolar and mandibular first molar had over-erupted, the overbite and overjet were reduced, and the mandibular incisors were proclined. No significant changes were found in the positions of the maxillary first molars with the appliance used.

The findings from this study show that the so-called skeletal and mandibular positional changes can be mainly attributed to appliance-induced dental changes, although initial facial growth may have contributed (Behrents, 1985). For example, the increases in SNA and ANB, which some might argue are evidence of 'skeletal' change, are more likely to be due to remodelling of point A following retroclination of the upper incisors. This conclusion is supported by a failure to find significant changes in the positions of the anatomically stable reference points in the maxilla relative to the cranial base. The increase in palatal length is somewhat more problematic: it may be due to the difficulty in locating either ANS, PNS or both points, remodelling of ANS secondary to retroclination of the upper incisors, or a chance finding. The latter should not be dismissed because the probability of one or more tests being significant by chance alone at the 5 per cent level out of 36 tests is high ($P = 0.84$). Downward positioning of the mandible by the appliance increases face height which allows the mandibular molars and maxillary premolars to slightly over-erupt. The significant maxillary incisor

Table 2 Significant changes during mandibular advancement splint therapy, by length of treatment.

Variables	Initial		Review		Mean difference	*P*
	Mean	SD	Mean	SD		
6 months (n = 20)						
N–Me	131.02	5.06	132.05	4.93	–1.03	**0.0001**
S–Go	86.88	7.46	87.89	7.47	–1.01	**0.001**
Go/ANS–PNS	38.59	6.12	39.84	5.86	–1.25	**0.001**
Cd vert	16.83	3.46	17.837	3.6	–1.01	**0.022**
Fid_1 vert	119.11	6.4	119.96	7.14	–0.85	**0.012**
Overbite	3.35	1.98	2.74	1.95	0.61	**0.037**
Overjet	3.67	1.45	2.8	1.61	0.87	**0.001**
12 months (n = 20)						
Fid_1 vert	118.58	9.57	119.78	9.22	–1.2	**0.011**
18 months (n = 20)						
N–Me	131.63	5.36	132.23	5.43	–0.7	**0.033**
Me/ANS–PNS	74.1	4.04	74.66	4.06	–0.56	**0.048**
Cd vert	17.48	3.47	18.41	3.64	–0.93	**0.043**
Fid_1 vert	119.81	5.73	120.46	5.93	–0.66	**0.031**
Overbite	3.83	2.45	2.93	1.74	0.9	**0.008**
Overjet	4.36	1.97	3.3	1.62	1.06	**0.0001**
24 months (n = 20)						
SNA	81.25	4.48	81.95	4.09	–0.7	**0.024**
N–Me	130.47	8.36	131.75	8.64	–1.28	**0.0001**
Me/ANS–PNS	72	5.57	73.05	5.65	–1.05	**0.007**
Cd vert	18.05	3.58	19.07	3.24	–1.02	**0.007**
Fid_1 vert	117	8	118.4	7.93	–1.4	**0.0001**
L6DCT vert	20.69	2.51	21.87	1.83	–1.17	**0.025**
Pm vert	32.29	3.47	33.02	3.8	–0.73	**0.025**
LIE horiz	7.48	5.9	6.83	5.94	0.65	**0.02**
LI/Fid_1–Fid_2	84.56	10.66	86.71	9.87	–2.15	**0.002**
Overbite	4.5	2.31	3.14	2.21	1.36	**0.0001**
Overjet	4.79	3.49	3.53	2.52	1.26	**0.001**
30 months (n = 20)						
Me/ANS–PNS	71.84	6.24	72.68	6.37	–0.84	**0.015**
Fid_1 vert	117.82	8.61	118.66	8.4	–0.84	**0.023**
UIE vert	37.21	3.75	36.52	3.98	0.69	**0.029**
LIE horiz	9.2	5.58	8.14	4.94	1.06	**0.012**
LI/Fid_1–Fid_2	82.04	9.7	86.34	9.36	–4.3	**0.0001**
Overbite	4.43	2.6	2.61	2.27	1.82	**0.005**
Overjet	3.84	1.71	2.63	1.27	1.21	**0.005**

Significant differences at the 5 per cent level are shown in bold.
SD, standard deviation.

Table 3 Associations between anterior opening by the appliance and change in overbite.

Duration (months)	*n*	*r*	*P*
6	20	0.103	0.667
12	20	–0.036	0.879
18	20	0.019	0.936
24	20	0.611	**0.004**
30	20	0.573	**0.008**

Significant differences at the 5 per cent level are shown in bold.

retroclination, which was only found in the larger combined sample, can be attributed to the appliance acting directly on the incisors. However, increased pressure from the lips due to the altered mandibular posture may also play a part. Although the changes in the positions of the maxillary incisors were small and highly variable, a precision metal casting enclosing the teeth may prevent their movement and the consequent reductions in overbite, overjet and the length of the maxillary arch that were found.

When the changes over time were examined there was considerable variation both within and between groups. Only downward displacement of the mandibular symphysis was found at all review periods. While an increase in face height and reductions in overbite and overjet were evident at 6 months, over-eruption of the maxillary first premolars and mandibular first molars, and proclination of the lower incisors were not detected until 24 months. Significant positive correlations were also found between the amount of anterior opening due to each appliance and the changes in overbite at 24 and 30 months. The appliances used in this study were, on average, 2.6 mm thick (SD 1.3 mm) posteriorly and 5.6 mm thick (SD 1.8 mm) anteriorly. This finding could indicate that the thickness of these appliances should be kept to the minimum consistent with the depth of the overbite and the use of screws to advance the mandible. At present there is no convincing evidence that this is the case, because if a causal relationship does exists between anterior opening by an appliance and a change in overbite it would be reasonable to expect it to be more obvious with time. No significant association was found between the amount of bite opening and the change in overjet. The only consistent finding in the smaller groups was a downward positioning of the mandibular symphysis.

As a non-adjustable appliance was used in this study, it can be argued that these results are not comparable with those where fully adjustable appliances were used. Pantin *et al.* (1999), however, considered that dental side-effects were largely generic to mandibular advancement and tended not to be device specific. In a review article, Schmidt-Nowara (1999) concluded that the newer titratable appliances created the potential of a greater degree of mandibular advancement, but also a greater likelihood of complications. Overall, very few of the occlusal changes found in this study were of concern to the patients, with treatment discontinued in only one patient due to adverse dental side-effects. Unfortunately, cephalometric predictors for patients who may be at risk from adverse occlusal changes with mandibular advancement treatment have yet to be established. Further investigation in this area is needed, especially for those patients who are at present undergoing treatment with fully titratable appliances as, to-date, no data of the long-term effects of these appliances on the occlusion have been forthcoming.

Conclusion

The present study provides data on the extent, and time course, of dental and occlusal changes occurring during mandibular splint therapy in sleep disordered patients. Although the response by the subjects in this study was extremely variable, changes in face height, the position of the mandible, overjet, and overbite occurred as early as 6 months. Over-eruption of the maxillary first premolars and mandibular first molars and proclination of the mandibular incisors were not evident for at least 2 years. These preliminary results suggest that overbite changes might be lessened by keeping the bite opening to a minimum.

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References

Aelbers C, Dermaut L 1996 Orthopedics in orthodontics: Part 1, fiction or reality—a review of the literature. American Journal of Orthodontics and Dentofacial Orthopedics 110: 667–671

American Sleep Disorders Association Standards of Practice Committee 1995 Practice parameters for the treatment of snoring and obstructive sleep apnea with oral appliances. Sleep 18: 511–513

Behrents R G 1985 Growth in the aging craniofacial skeleton. Monograph No. 17, Craniofacial Growth Series. Center for Human Growth and Development, University of Michigan, Ann Arbor, pp. 102–114

Bondemark L 1999 Does 2 years' nocturnal treatment with a mandibular advancement splint in adult patients with snoring and OSAS cause a change in posture of the mandible? American Journal of Orthodontics and Dentofacial Orthopedics 116: 621–628

Collett A 2000 Current concepts on functional appliances and mandibular growth stimulation. Australian Dental Journal 45: 173–178

Coltman R, Taylor D, Whyte K, Harkness M 2000 Craniofacial form and obstructive sleep apnea in Polynesian and Caucasian men. Sleep and Breathing 23: 943–950

Dahlberg G 1940 Statistical methods for medical and biological students. Interscience Publications, New York

Fritsch K M, Iseli A, Russi E W, Bloch K E 2001 Side effects of mandibular advancement devices for sleep apnea treatment. American Journal of Respiratory Critical Care Medicine 164: 813–818

George P 1992 A new instrument for functional appliance bite registration. Journal of Clinical Orthodontics 26: 721–723

Johnston L 1996 Balancing the books on orthodontic treatment: an integrated analysis of change. British Journal of Orthodontics 23: 93–102

Marklund M, Franklin K, Persson M 2001 Orthodontic side-effects of mandibular advancement devices during treatment of snoring and sleep apnoea. European Journal of Orthodontics 23: 135–144

Pantin C, Hillman D, Tennant M 1999 Dental side effects of an oral device to treat snoring and obstructive sleep apnea. Sleep 22: 237–240

Panula K, Keski-Nisula K 2000 Irreversible alteration in occlusion caused by a mandibular advancement appliance: an unexpected complication of sleep apnea treatment. International Journal of Adult Orthodontics and Orthognathic Surgery 15: 192–196

Robertson C 1997 Obstructive sleep apnoea. Part II. Treatment with a customised dental appliance. New Zealand Dental Journal 83: 4–9

Robertson C 2002 Cranial base considerations between apnoeics and non-apnoeic snorers, and associated effects of long-term mandibular advancement on condylar and natural head position. European Journal of Orthodontics 24: 353–361

Rose E C, Schnegelsberg C, Staats R, Jonas I E 2001 Occlusal side effects caused by a mandibular advancement appliance in patients with obstructive sleep apnea. Angle Orthodontist 71: 452–460

Schmidt-Nowara W 1999 Recent developments in oral appliance therapy of sleep disordered breathing. Sleep and Breathing 3: 103–106

Scott P 1981 The reflex plotters: measurement without photographs. Photogrammetric Record 10: 435–446