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Orthodontic side-effects of mandibular advancement devices during treatment of snoring and sleep apnoea

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SUMMARY The aims of this study were to investigate possible orthodontic side-effects following the use of mandibular advancement devices (MAD) in adults with snoring and sleep apnoea. A second objective was to analyse the effect of the appliance design. Seventy-five patients treated with MAD and 17 reference patients were studied at follow-up after 2.5 ± 0.5 years. In the test group, 47 patients were provided with soft elastomeric devices, while the remaining 28 patients received hard acrylic devices.

The treatment induced a change in overjet of –0.4 ± 0.8 mm (mean ± SD) and a change in overbite of –0.4 ± 0.7 mm (mean ± SD). These changes were larger than those found in the reference group ($P < 0.01$). The odds ratio (OR) for the largest quartile of reduction in overjet was 3.8 in patients using hard acrylic devices compared with those using soft elastomeric devices ($P < 0.05$). A large reduction in overjet in patients using the hard acrylic devices was unrelated to the degree of mandibular protrusion by the device. The OR for a large reduction in overjet in patients using the soft elastomeric devices with a protrusion of 6 mm or above was 6.8 compared with smaller mandibular protrusions ($P < 0.05$).

The results indicate that the orthodontic side-effects are small during the treatment of adult subjects with MAD for snoring and sleep apnoea, especially in patients using soft elastomeric devices with mandibular protrusions of less than 6 mm. The follow-up of patients treated with MAD is recommended, as individual patients may experience marked orthodontic side-effects.

Introduction

Mandibular advancement devices (MAD) are becoming an accepted form of treatment for snoring and milder forms of sleep apnoea (Bonham *et al*., 1988; Clark *et al*., 1993, 1996; O'Sullivan *et al*., 1995; Schmidt-Nowara *et al*., 1995; Ferguson *et al*., 1996; Marklund and Franklin, 1996; Marklund *et al*., 1998a,b). It is especially beneficial for patients who suffer from supine-dependent sleep apnoeas (Marklund *et al*., 1998c). The treatment aims to widen the oropharyngeal airway by repositioning the mandible in a forward and downward direction during sleep. The device shares similarities with functional appliances used for the correction of distal occlusion in actively growing patients (Rakosi, 1997a).

Functional appliances move the mandible forward and induce intermittent muscle forces on the jaws and teeth (Rakosi, 1997b; Katsavrias and Halazonetis, 1999). In addition to orthopaedic effects, the applied forces are designed to move the upper teeth in a distal direction, the lower teeth in an anterior direction and to induce vertical effects on the teeth (Rakosi, 1997a; Katsavrias and Halazonetis, 1999). Previous studies of orthodontic tooth movements during treatment with functional appliances have demonstrated a change in molar relationship and a reduction in overjet and overbite, particularly during tooth eruption (Pancherz, 1984; Johnston, 1986; Jakobsson and Paulin, 1990; Cura *et al*., 1996).

Tooth movements are undesirable in adults treated for snoring and sleep apnoea with

MAD. A MAD for sleep apnoea is, however, only used during the night, while functional appliances used for the correction of distal occlusion are also recommended for daytime use. A Herbst appliance, which advances the mandible continuously has a more pronounced effect on overjet than a functional appliance used on a part-time basis (Pancherz *et al.*, 1989).

Mandibular protrusions of 3 mm or more by functional appliances in actively growing patients induce orthodontic tooth movements earlier than mandibular protrusions of 1 mm (DeVincenzo and Winn, 1989). It is possible that some adults will experience tooth movements when treated for snoring and sleep apnoea with MADs (Pantin *et al.*, 1999). The recommended protrusion induced by the device is 50–75 per cent of maximum protrusion, which is similar to 3 and 9 mm (Clark *et al.*, 1993, 1996; O'Sullivan *et al.*, 1995).

The aim of the present study was to investigate side-effects on dental occlusion, and arch widths in adults treated for snoring and sleep apnoea with MADs. A second objective was to analyse whether a device made of hard acrylic anchored mainly to the dentition differed in terms of orthodontic side-effects compared with a device made of soft elastomer.

Subjects and methods

Subjects

One-hundred-and-fifty-five patients who consecutively received treatment for snoring and sleep apnoea with MADs were asked about the frequency with which they had used their devices at a follow-up after 2.5 ± 0.5 years (mean ± SD). Seventy-five patients who had used their devices for more than 50 per cent of the nights made up the test group (Table 1). Forty-seven of these patients used devices made of soft elastomer and 28 patients used appliances made of hard acrylic (Table 1, Figures 1 and 2). Seventeen patients who had been given MADs, but stated that they were unable to tolerate the treatment formed the reference group (Table 1).

Thirty-six patients who used their devices for less than 50 per cent of the nights were excluded from further evaluations. Another 27 patients from the original 155 were not included as 10 of them refused to participate in the study, nine had initial plaster casts of insufficient quality, seven had moved and one had died.

The age of all 92 patients (75 patients in the test group and 17 patients in the reference group) was 53 ± 8.3 years (mean ± SD) (Table 1) and there were 78 men and 14 women. Age and sex distribution did not differ between the reference

Table 1 Patient characteristics and mandibular movement with the mandibular advancement devices.

	Treatment group								
	Soft elastomeric device group (n = 47)			Hard acrylic device group (n = 28)			Reference group (n = 17)		
	Median	Range	x ± SD	Median	Range	x ± SD	Median	Range	x ± SD
Age at the start	54	36–70	55 ± 7.7	52	25–69	51 ± 9.4	49	42–66	52 ± 7.3
Observation period (years)	2.2	1.9–4.2	2.3 ± 0.4	2.5	1.9–3.3	2.6 ± 0.3	2.9	2.1–4.0	3.0 ± 0.6
Initial occlusion:									
Overjet (mm)	3.4	0.0–13	3.9 ± 2.2	4.1	1.5–9.4	4.5 ± 2.4	2.4	1.0–5.5	2.9 ± 1.4
Overbite (mm)	3.0	0.0–8.4	3.2 ± 1.8	3.7	0.5–8.0	3.8 ± 2.0	2.6	–3.5–7.7	2.4 ± 2.4
Mandibular movement:									
Protrusion (mm)	5.5	2.0–10	5.7 ± 1.7	5.5*	2.5–9.0	5.8 ± 1.6*	4.5	2.5–7.0	4.5 ± 1.2
Opening (mm)	9.5	5.0–14	9.6 ± 1.7	10*	7.0–14	10 ± 1.9*	9.5	7.0–13	9.7 ± 1.7

*n = 27.

group and the two treatment groups. All the patients had normal or distal occlusion and a sufficient number of teeth for at least one premolar occlusal contact in each quadrant. Eighteen of the 92 patients had an apnoea-hypopnoea index (AHI) of below 5 according to full-night sleep apnoea recordings before the start of treatment. Forty-six patients had an AHI of between 5 and 20 and 28 patients had an AHI of above 20.

Approval for the study was obtained from the Medical Ethics Committee at Umeå University.

The mandibular advancement devices

The MADs were made from either hard acrylic, SR-Ivocap (Ivoclar, Schaan/Liechtenstein), or soft SR-Ivocap Elastomer. Both types of device covered all the teeth in order to minimize adverse tooth movement. The devices made of soft elastomer were kept in place by approximal interdigitations and extensions that covered the buccal and lingual gingiva (Figure 1). The devices made of hard acrylic had four metal clasps and a labial bow to aid retention (Figure 2).

The MADs were made to hold the mandible forward by 4–6 mm and downward by a minimum of 5 mm at the start of treatment in order to prevent upper airway obstruction (Table 1). The mandibular protrusion was later increased in patients who still snored with the device in place or had remaining apnoeas during treatment, and reduced in patients who experienced craniomandibular pain. The degree of mandibular repositioning with the device in position at the time of the follow-up was recorded on initial plaster casts according to wax construction bites taken before the start of treatment or at the time of the last adjustment of the device. The mandibular protrusion by the device was measured in the premolar area along an occlusal plane, defined by the mesial cusp of the upper right first molar or a premolar and the edge of the right upper central incisor (Figure 3). The mandibular opening was measured on the right central incisor.

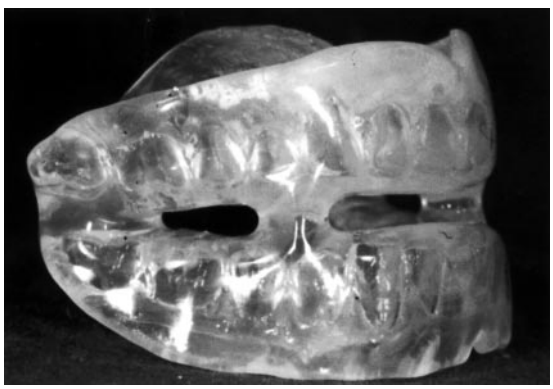

Figure 1 Mandibular advancement device made of soft elastomer.

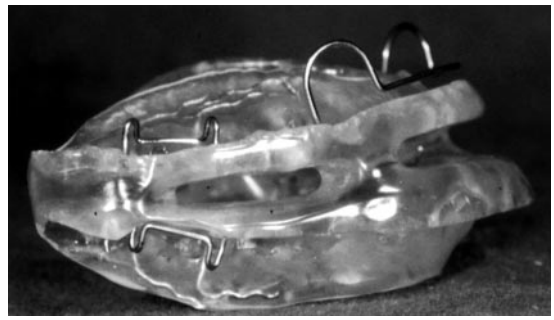

Figure 2 Mandibular advancement device made of hard acrylic.

With the device *in situ*, the mandibular protrusion was 5.7 ± 1.6 mm (mean ± SD) and the mandibular opening was 9.9 ± 1.8 mm (mean ± SD) at follow-up in the 75 patients of the study group (Table 1). The degree of mandibular repositioning was similar for both types of MAD.

Measurements of tooth movements

Plaster casts in centric occlusion taken 9 ± 9 days (mean ± SD) before the start of treatment

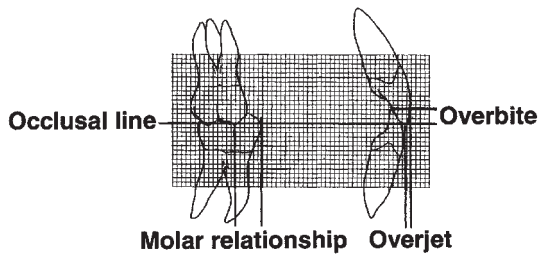

Figure 3 Measurements of overjet, overbite and shift in occlusion on posterior teeth.

and after a treatment time of 2.5 ± 0.5 years (mean ± SD) were used to measure tooth movement. Centric occlusion, defined as the mandibular contact position with maximum contact between the teeth (Ramfjord and Ash, 1995), was registered using a wax index (Alminax, Kemdent) taken in the supine position. Centric relation was defined as the most distal mandibular contact position (Ramfjord and Ash, 1995). The distance between centric occlusion and centric relation was measured intraorally as a change in position between marks on premolar teeth. A sliding calliper to the nearest 0.05 mm or transparent graph paper to the nearest 0.5 mm were used for measurements on casts of each jaw separately, casts in centric occlusion (Figure 3) or directly on the patient's teeth.

Sagittal occlusal side-effects induced by the device were recorded as a change in overjet and a change in the relationship between the posterior teeth along the occlusal plane. Overjet was measured from the most mesial point of the right upper incisor edge to the perpendicular projection on the buccal surface of a lower incisor (Figure 3). The shift in occlusion along the occlusal plane was recorded at the mesial surfaces of the first molars and first premolars. The mean change between the left and right sides was used in the evaluations. Negative values indicated a mesial shift in the lower dentition in relation to the upper dentition.

Vertical occlusal side-effects were recorded as a change in overbite at the same location as the recording of overjet. Overbite was measured buccally on a lower incisor, from the incisor edge to the projected point of the mesial edge of the right upper incisor (Figure 3). A negative value indicated a decrease in overbite.

Transverse side-effects induced by the device were recorded as changes in the inter-molar and inter-canine widths in each jaw separately. Bilateral points that were easily identified on the pre-treatment and follow-up casts at the first molars and canines were used in these measurements.

All the measurements were repeated on 46 randomly-selected patients. The random errors were calculated according to the formula: $S_e = \sqrt{S_d^2/2}$, where S_e is the random error and S_d is the standard deviation of the differences between replicates (Houston, 1983). The random errors for overjet, overbite, and transverse relations were within ±0.4 mm, and those for the lateral shift of the occlusion and anterior movement and opening by the device were within ±0.6 mm.

The patients were asked to estimate the subjective orthodontic side-effects of the MAD in a questionnaire in terms of: 'No observed effect on the dentition', 'The occlusion changes in the morning after a night of using a MAD, but the occlusion becomes normal during the day', 'Permanent change in occlusion', or 'I don't know'.

Statistical methods

Wilcoxon's matched-pairs signed-rank test was used for evaluations of tooth movements and the Mann–Whitney test for independent observations to analyse differences in tooth movements between the treatment and the reference groups. The χ^2-test and Kruskal–Wallis *H*-test were used to evaluate any differences in sex and age between the treatment and reference groups. Spearman's rank correlation was used to analyse the association between mandibular protrusion and mandibular opening by the device. The influence of sex, age, treatment time, type of appliance, and mandibular repositioning with the device in position on the orthodontic side-effects was estimated in logistic regression models using odds ratios (OR; Kleinbaum, 1996). The calculations were performed using the SPSS 9.0 Statistical Package. A *P*-value of less than 0.05 was considered significant.

Results

Sagittal occlusal side-effects of the device

The MAD induced a change in overjet of –0.4 ± 0.8 mm (mean ± SD) and a mesial shift in occlusion at the first molars of –0.4 ± 0.6 mm (mean ± SD; Figure 4, Table 2). These effects were more pronounced than those found in the reference group ($P < 0.01$; Table 2).

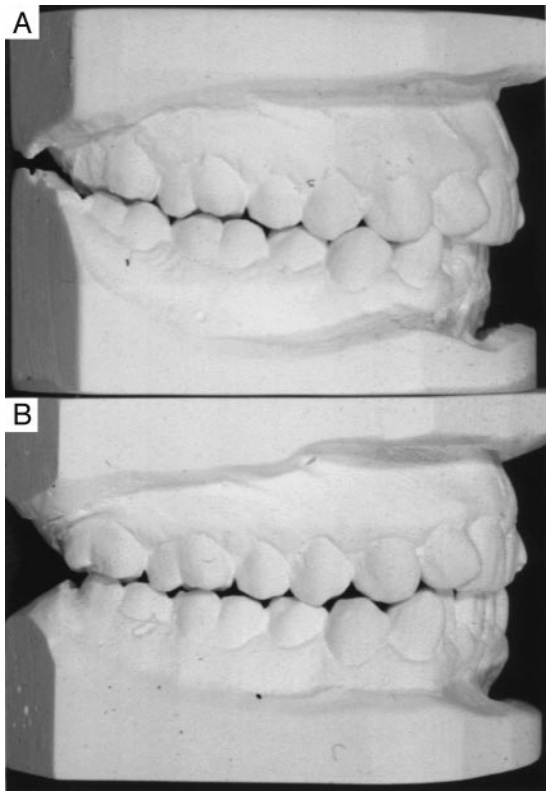

Figure 4 Mesial shift in occlusion induced by the device. Initial plaster casts (A) and at follow-up (B).

Vertical occlusal side-effects of the device

Overbite changed during treatment by –0.4 ± 0.7 mm (mean ± SD), which was a more pronounced effect than that found in the reference group ($P < 0.01$; Figure 5, Table 2).

Transverse side-effects of the device

In patients who had used the soft elastomeric devices, maxillary arch width at the first molars increased by 0.3 ± 0.7 mm (mean ± SD; $P < 0.05$) and mandibular arch width at the first molars by 0.3 ± 0.6 mm (mean ± SD; $P < 0.05$; Table 3).

In patients who used the hard acrylic devices, maxillary arch width at the canines changed by –0.2 ± 0.3 mm (mean ± SD; $P < 0.01$ and mandibular arch width at the first molars increased by 0.2 ± 0.3 mm (mean ± SD; $P < 0.01$; Table 3).

Side-effects on occlusion in relation to appliance design

The 18 patients with the largest quartile reduction in overjet experienced a change ranging from –2.8 to –0.8 mm (Table 2). The OR for this largest quartile reduction in overjet was 3.8 in patients using hard acrylic devices compared

Table 2 Mesial shift in occlusion and change in arch width in the treatment group compared with the reference group.

	Treatment group						Reference group						Difference
		percentile						percentile					
	n	25	50	75	Range	*x* ± SD	*n*	25	50	75	Range	*x* ± SD	*P*-value
Occlusion													
Mesial shift at:													
First molars (mm)	53	–0.9	–0.3	0.0	–2.0–1.0	–0.4 ± 0.6	15	–0.3	0.0	0.3	–0.5–0.5	0.0 ± 0.3	<0.01
First premolars (mm)	71	–0.8	–0.3	0.0	–2.5–0.5	–0.5 ± 0.6	17	0.0	0.0	0.3	–0.5–0.5	0.0 ± 0.3	<0.001
Change in overjet (mm)	75	–0.8	–0.2	0.2	–2.8–1.2	–0.4 ± 0.8	17	–0.1	0.2	0.5	–0.5–0.6	0.2 ± 0.4	<0.01
Change in overbite (mm)	75	–0.9	–0.4	0.0	–2.0–1.1	–0.4 ± 0.7	17	–0.2	0.0	0.4	–0.5–1.4	0.2 ± 0.5	<0.01
Arch width													
Change at:													
Maxillary first molars (mm)	50	–0.2	0.3	0.6	–2.0–2.1	0.2 ± 0.7	12	–0.3	0.1	0.1	–1.1–0.6	0.0 ± 0.4	NS
Maxillary canines (mm)	68	–0.4	–0.1	0.2	–1.0–1.0	–0.1 ± 0.4	15	–0.2	0.2	0.5	–0.5–0.7	0.2 ± 0.4	<0.05
Mandibular first molars (mm)	42	0.1	0.2	0.6	–1.1–1.7	0.3 ± 0.5	11	–0.2	0.1	0.6	–1.0–1.1	0.2 ± 0.6	NS
Mandibular canines (mm)	70	–0.4	–0.1	0.4	–1.8–1.2	0.0 ± 0.5	14	–0.3	0.0	0.2	–0.5–0.6	0.0 ± 0.3	NS

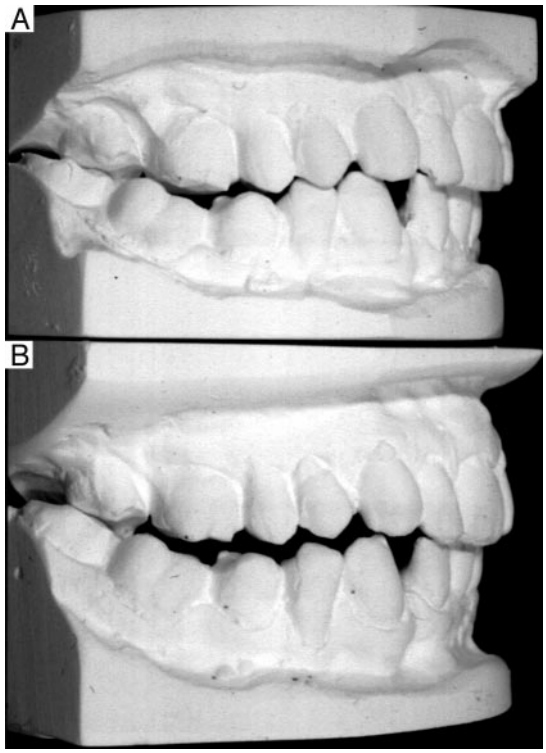

Figure 5 Reduction in overbite bite raising induced by the device. Initial plaster casts (A) and at follow-up (B).

with patients using soft elastomeric devices according to a logistic regression model adjusted for age, sex, treatment time, and mandibular repositioning ($P < 0.05$; Tables 3 and 4, Figure 6A).

A soft elastomeric device had an OR of 6.8 to induce a large reduction in overjet when the protrusion was 6 mm or more ($P < 0.05$; Table 4, Figure 6B). The degree of mandibular opening in the soft elastomeric device was unrelated to a large reduction in overjet. Patients aged 60 and above had an OR of 5.8 when associated with a large reduction in overjet ($P < 0.05$).

A hard acrylic device had an OR of 8.0 when linked with a large reduction in overjet when the mandibular opening was less than 11 mm ($P < 0.07$; Table 4, Figure 6C). The degree of mandibular protrusion with the hard acrylic device was unrelated to a large reduction in overjet. The correlation between mandibular protrusion and mandibular opening was $r_s = 0.4$ ($P < 0.05$) in the whole treatment group (Figure 6A) and $r_s = 0.3$ ($P < 0.05$) in the hard acrylic group (Figure 6C). These associations had no interactive effects on any OR.

No relationship was found between the change in overbite and age, sex, mandibular protrusion, mandibular opening, treatment period, or type of appliance.

Centric relation

The median distance between centric occlusion and centric relation was 0 mm (range 0 to 2 mm) before treatment and remained unchanged at follow-up.

Table 3 Orthodontic side-effects with respect to appliance design**.**

	Soft elastomeric device group					Hard acrylic device group				
	n	Median	Range	*x* ± SD	*P*-value	*n*	Median	Range	*x* ± SD	*P*-value
Occlusion										
Mesial shift at:										
First molars (mm)	30	–0.1	–1.8–1.0	–0.3 ± 0.6	<0.01	23	–0.5	–2.0–0.5	–0.6 ± 0.6	<0.001
First premolars (mm)	43	–0.3	–2.0–0.5	–0.4 ± 0.6	<0.001	28	–0.5	–2.5–0.5	–0.5 ± 0.6	<0.001
Change in overjet (mm)	47	–0.2	–2.4–1.1	–0.3 ± 0.7	<0.05	28	–0.6	–2.8–1.2	–0.6 ± 0.9	<0.01
Change in overbite (mm)	47	–0.3	–2.0–1.1	–0.4 ± 0.7	<0.01	28	–0.5	–2.0–0.6	–0.5 ± 0.7	<0.01
Arch width										
Change at:										
Maxillary first molars (mm)	29	0.3	–0.9–2.1	0.3 ± 0.7	<0.05	21	0.1	–2.0–0.8	0.0 ± 0.7	NS
Maxillary canines (mm)	43	0.1	–1.0–1.0	0.0 ± 0.4	NS	25	–0.3	–1.0–0.5	–0.2 ± 0.3	<0.01
Mandibular first molars (mm)	25	0.2	–1.1–1.7	0.3 ± 0.6	<0.05	17	0.2	–0.2–0.8	0.2 ± 0.3	<0.01
Mandibular canines (mm)	44	–0.1	–1.8–1.2	0.0 ± 0.6	NS	26	0.0	–1.0–0.8	0.0 ± 0.5	NS

Table 4 Odds ratios for the quartile with the largest reduction in overjet controlling for sex and treatment time.

	Whole treatment group (n = 75)			Soft elastomeric device group (n = 47)			Hard acrylic device group (n = 28)		
	OR	95% CI	*P*-value	OR	95% CI	*P*-value	OR	95% CI	*P*-value
Hard acrylic device	3.8	1.1–13	0.04						
Protrusion of ≥ 6 mm	3.7	1.1–12	0.04	6.8	1.1–44	0.04	2.5	0.3–19	0.37
Opening of < 11 mm	6.9	1.2–40	0.03	3.1	0.2–55	0.44	8.0	0.8–78	0.07
Age > 60 years	2.8	0.7–12	0.15	5.8	1.1–44	0.04	0.6	0.0–13	0.77

Subjective effects

Sixty-nine of the 75 patients in the treatment group (92 per cent) replied to the questionnaire. Thirty-seven patients reported 'No observed effect on the dentition', 28 patients that 'The occlusion changes in the morning after a night of using a MAD, but the occlusion becomes normal during the day', and three patients that there was 'Permanent change in occlusion' and one patient answered 'I don't know'. One patient reported that his left upper central incisor had become markedly elongated during the treatment period (Figure 7). There was no difference in subjective

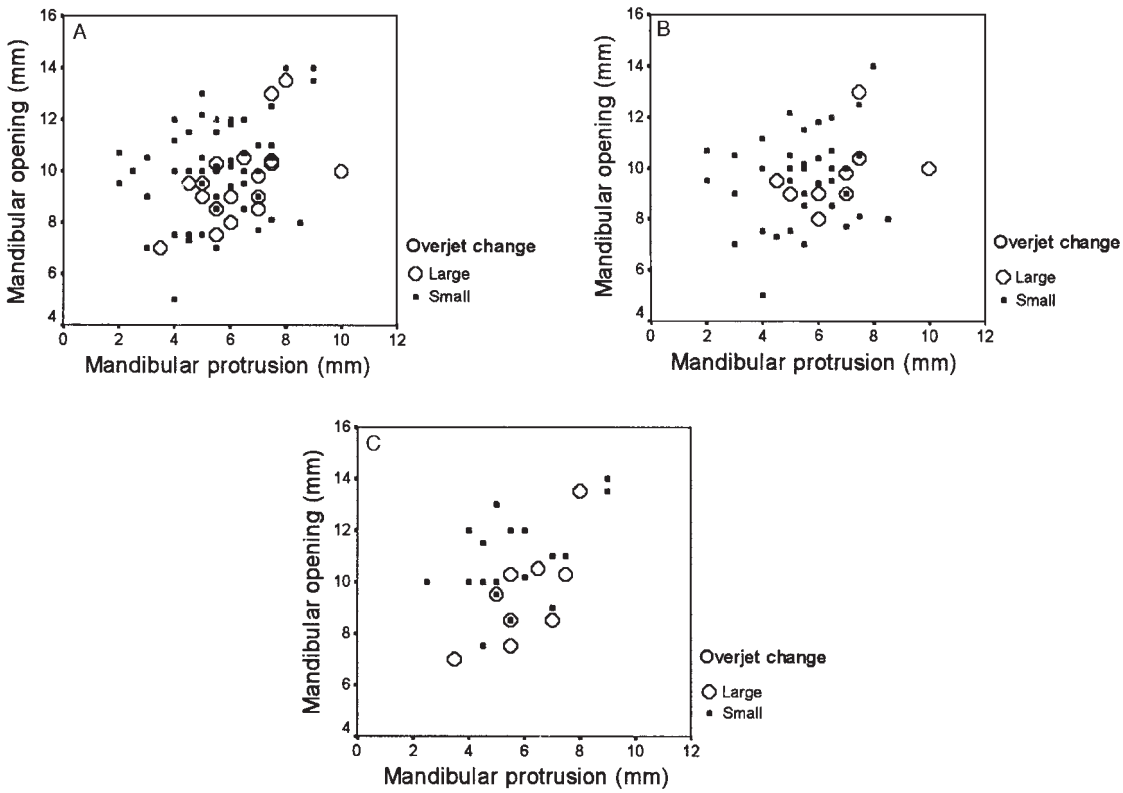

Figure 6 Mandibular protrusion and opening in relation to a large reduction in overjet during treatment. (A) Treatment group. (B) Soft elastomeric device group. (C) Hard acrylic device group.

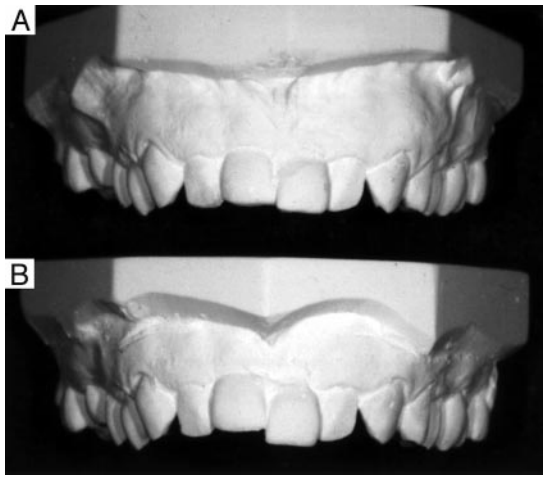

Figure 7 Change in position between upper incisors induced by the device. Initial plaster cast (A) and at follow-up (B).

reports of occlusal change between the two types of device.

Discussion

Minor orthodontic side-effects on occlusion and arch widths were observed after 1.9–4.2 years of treatment in adults with MADs for snoring and sleep apnoea in the present study. The side-effects were, however, more pronounced in subjects using devices made of hard acrylic and in patients treated with soft elastomeric devices with a large mandibular protrusion.

Centric occlusion is commonly used to evaluate the effects of orthodontic devices (Proffit, 1993). This contact position has a surface reproducibility of approximately 0.12 mm^2, which represents a circle with a radius of 0.2 mm (Tripodakis *et al*., 1995). The average mesial shift in occlusion as a result of MAD in the present study was thus only slightly larger than the surface reproducibility for centric occlusion. The random error of the measurement for overjet was ±0.4 mm among the present patients. The subjects with the largest quartile reduction in overjet experienced a change ranging from –2.8 to –0.8 mm, which exceeded the measurement error. These patients were therefore chosen to analyse factors related to orthodontic side-effects during treatment using logistic regression models.

The OR for a large reduction in overjet was 3.8 in patients using devices made of hard acrylic. The orthodontic side-effect produced by the hard acrylic type of device was unrelated to the degree of mandibular protrusion by the device. It is possible that the specific design of the hard acrylic device diminished the effect of other factors related to orthodontic tooth movement, such as the degree of mandibular protrusion. Treatment with the soft elastomeric type of device with mandibular protrusions of below 6 mm was, however, related to a markedly lower risk of orthodontic tooth movement than treatment with soft elastomeric devices with larger protrusions. A minimum amount of mandibular protrusion by the device is probably needed to obtain a successful effect on snoring and sleep apnoea (Clark *et al*., 1993; Marklund *et al*., 1998a,b). A smaller amount of protrusion may, however, be required in subjects with mild sleep apnoea compared with those who suffer from more severe sleep apnoea (Marklund *et al*., 1998a). Less than 5 mm of mandibular protrusion is usually sufficient in subjects with milder forms of sleep apnoea and orthodontic side-effects are therefore avoided in most patients (Marklund *et al*., 1998a).

The MADs were individually adjusted in order to reduce snoring and sleep apnoeas. Individual patients needed both a large protrusion and a large opening, while smaller advancements and openings were adequate in others. This is probably the explanation for the positive correlation between the actual mandibular protrusion and mandibular advancement in the present study.

There are indications that increasing the mandibular opening above a specific level is related to a reduction in pharyngeal airway space with a possible impaired apnoea reduction (L'Estrange *et al*., 1996). This makes recommendations based on the degree of mandibular opening in order to reduce orthodontic side-effects uncertain. In the present study, a large mandibular opening was related to small orthodontic side-effects (Table 4). Side-effects produced by the soft elastomeric device were, however, unrelated to the degree of mandibular opening. Consequently, the present results

indicate that using a soft elastomeric device reduces the orthodontic side-effects during the treatment of snoring and sleep apnoea. The results of this investigation show that follow-up is important during treatment with a MAD, as patients are generally unaware of any changes in occlusion during treatment.

The mesial shift in occlusion induced by the MADs in the present sample of adults was small compared with that found in children and adolescents treated full-time or only during the night with functional appliances to correct distal occlusion. In children or adolescents, a mean change in overjet of approximately –5 mm has been reported during a similar treatment period (Pancherz, 1984; Cura *et al*., 1996). About half this change in overjet can be attributed to dentoalveolar effects and may thus be achieved during treatment with functional appliances in subjects with no remaining growth potential (McNamara, 1984; Pancherz, 1984; Johnston, 1986). Orthodontically untreated adults have stable occlusion in terms of overjet and overbite (Carter and McNamara, 1998).

Functional appliances are designed to produce specific tooth movements. Individualized effects may be obtained by changing the degree of mandibular repositioning and the contact areas between the device and the teeth (Rakosi, 1997a). Both types of MAD used in the present study were designed to prevent adverse tooth movements, mainly by increasing the contact areas between the appliance, the teeth, and the alveolar processes. The MAD made of soft elastomer was extended over larger areas of the alveolar processes compared with the device made of hard acrylic, as a result of which a change in the distribution of forces may have influenced the teeth. This may explain the smaller mesial shift in occlusion in patients using a device made of soft elastomer than in those with a device made of hard acrylic. In addition, differences in physical properties between the soft elastomer and hard acrylic may explain the variability in side-effects. Slightly different effects on dental arch width were observed with the two appliances. These changes in arch width were small, however, compared with those found when functional appliances are used for orthodontic purposes in children and adolescents (Gibbs and Hunt, 1992).

Conclusions

Orthodontic side-effects are small during treatment for snoring and sleep apnoea with a MAD, especially in patients using devices made of soft elastomer with mandibular protrusions below 6 mm. A follow-up after 2 years is recommended as individual patients may experience marked orthodontic side-effects.

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