ORIGINAL ARTICLE

Long-term sequellae of oral appliance therapy in obstructive sleep apnea patients: Part 2. Study-model analysis

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Introduction: Side effects observed in the occlusion and dental arches of patients using an oral appliance (OA) to treat snoring or sleep apnea for more than 5 years have not yet been investigated. **Methods:** Stone casts trimmed in centric occlusion before appliance placement and after an average of 7.4 ± 2.2 years of OA use in 70 patients were compared visually by 5 orthodontists. **Results:** Of these patients, 14.3% had no occlusal changes, 41.4% had favorable changes, and 44.3% had unfavorable changes. Significant changes in many variables were found. Patients with greater initial overbites and Class II Division 1 and Class II Division 2 malocclusions were more likely to have favorable or no changes. More favorable changes in overbite occurred in subjects with large baseline overbites. A greater baseline overjet and more distal mandibular canine relationship were correlated to favorable changes. A greater initial overjet was correlated to a more favorable change, a decrease in mandibular crowding, a smaller change in anterior crossbite, and a greater change in overjet. **Conclusions:** OA wear after a mean of 7.4 years induces clinically relevant changes in the dental arch and the occlusion. (Am J Orthod Dentofacial Orthop 2006;129:205-13)

Obstructive sleep apnea (OSA) is a life-threatening disease that demands treatment. Many patients receive continuous positive airway pressure treatment, but the acceptability of this type of therapy is compromised because of related side effects and its intrusive nature. Oral appliance (OA) therapy is the first treatment choice for patients with primary snoring and mild apnea and for moderate-to-severe OSA patients who are intolerant of or refuse treatment with continuous positive airway pressure.[1] OAs protrude the mandible and hold it in forward and downward position. As a consequence, the upper airway enlarges anteroposteriorly[2] and laterally,[3,4] improving its stability.[5] The efficacy of an OA is related to adequate retention and the amount of mandibular protrusion.[6,7]

Recent studies have evaluated cephalometric side effects related to long-term use of OAs.[8-16] Most craniofacial side effects were classified as orthodontic changes, interpreted mainly as tooth movements. In the analysis of study models, some authors[9,12,14] confirmed the decrease in overjet (OJ) and overbite (OB) found in the cephalometric analysis; there was also a significant mesial shift of the mandible. Marklund et al[12] found different changes in arch width depending on the appliance used, but the mandibular intermolar distance increased with both appliances. Rose et al[14] found a significant increase in mandibular arch length. All study-model changes were considered minor and clinically irrelevant during the period evaluated.

OA therapy is considered a lifelong treatment, and an understanding of the possible side effects and their clinical consequences is important for the follow-up protocol. Currently, side effects have been evaluated only over relatively short times, and a long-term clin-

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The Klearway appliance was invented by Alan A. Lowe. International patents have been obtained by the University of British Columbia; specific licensees are assigned the rights to manufacture and distribute it worldwide. This study was supported by CNPq, an entity of the Brazilian Government for scientific and technological development, as a scholarship to the first author.
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ical approach to evaluate the changes from study models might be relevant. We postulate that longer use of an OA will cause greater changes in a patient's dentition. Therefore, the purpose of this study was to evaluate, with study-model analysis, occlusal changes induced by OA therapy after more than 5 years.

MATERIAL AND METHODS

Patients were invited to participate in this study if they had been using an OA for at least 5 years. They were recruited by telephone after being identified in a previous study,[17] or as they came to the Dental Sleep Apnea Clinic at the University of British Columbia or to an author's (A.A.L.) private practice for regular follow-ups of their OAs. All subjects were currently using the appliance for 4 or more days a week and had been doing so consistently for more than 5 years. Patients who had been treated with an appliance other than a mandibular advancement device (eg, tongue-retaining device) for snoring or OSA were excluded. Even though some patients started with a different appliance, all were currently using Klearway as described previously[18] and in Part 1 of this study.[19] Patients were excluded if diagnostic study models were missing or of poor quality. The University of British Columbia Ethics Committee approved the design of this study.

The study sample included 70 subjects, 7 women and 63 men, mean age 50.0 ± 9.7 years, with pretreatment respiratory disturbance index values of 28.0 ± 14.9 per hour and body mass index values of 29.3 ± 5.8 kg/m^2. Baseline and treatment follow-up study models in centric occlusion were obtained for all patients. Initial study models, demographic data, and sleep studies were also used to evaluate possible correlations and changes in dental structures and occlusion. Respiratory disturbance index was defined as the apnea and hypopnea index from a full-night polysomnography or an oxygen desaturation index greater than 4% per hour from the overnight oximetry. Demographic data used in the correlations were collected before OA placement. The period of OA use was calculated as the interval between the date of the first appliance placement and the date that the new study models were collected. All measurements on the study models were made by an orthodontist (M.F.) and reviewed by another (S.F.).

Angle classification[20] of malocclusion was used to identify the anteroposterior relationship of the maxillary and mandibular first molars and canines. For statistical purposes, to follow the linearity of positions, Class II (canine and molar) was coded as 1, Class I (canine and molar) as 0, and Class III (canine and molar) as –1. Mesial shifts of the mandibular molars and canines were expressed with negative values. A sliding caliper to the nearest 0.05 mm was used to measure OJ, OB, arch length, and intermolar and intercanine distances. OJ and OB were measured for each anterior tooth (left and right central incisors, lateral incisors, and canines). Anterior OJ and OB were calculated as the mean of OJ or OB between the maxillary central incisors. The sample was divided into shallow OB (<1 mm), normal OB (1-4 mm), and deep OB (>4 mm).

Arch length was measured in millimeters, through the general alignment of contact points, from the mesial contact surface of a permanent first molar to the mesial contact surface of the contralateral permanent first molar. If the first permanent molars were missing, the second molars were used. Intermolar distance was the width between the mesiolingual cusp of the first permanent molar to the mesiolingual cusp of the contralateral molar; it was measured for the maxillary and mandibular molars. If the first permanent molars were missing, the second molars were used. Intercanine distance was measured as the width between the center of the permanent canine to the contralateral canine. If the canine was missing, this was considered missing data unless the first premolar was in the space of the canine and functioned as a canine before and after treatment. Other assessments of tooth movements and occlusion were made visually. Changes in crowding, appearance of interproximal open spaces in the arches, tipping and rotations, occlusal contacts, size of occlusal contacts, and anterior and posterior crossbites were evaluated. Crowding was defined as an altered tooth position caused by inadequate space in the alveolar arch and classified as increased, decreased, or no change after treatment. Evaluation of interproximal open spaces was done for both arches by examining the study models and looking at the anteroposterior contact surfaces of the teeth before and after treatment. Only open spaces created after treatment were counted; tipping was recorded as tooth movement, either spontaneous or therapeutic. Tipping was recorded as mesial, distal, buccal/labial, or lingual for each tooth after treatment. Rotation (torsiversion) was interpreted as a malposition in which the tooth became rotated around its long axis, making the contact point with the proximal tooth different from the optimal anatomic contact point. Rotations that occurred after treatment were recorded as mesiolingual and distobuccal rotations.

Occlusal contacts (the relationship of maxillary and mandibular teeth as they were brought into functional contact) were recorded before and after treatment, by using articulating paper directly on the models, and the number of teeth in contact was determined. The sizes of the occlusal contacts were classified as increased, decreased, or no change with the articulating paper. Crossbite or edge-to-edge was an abnormal relationship of a tooth or teeth to the opposing teeth in which normal buccolingual relationships were either in an edge-to-edge or a reversed relationship, with the mandibular teeth more buccally positioned than the maxillary teeth. Both anterior (33 to 43) and posterior (38 to 34 and 44 to 48) evaluations were done separately, and, if at least 1 tooth was in crossbite, the number of mandibular teeth in crossbite was recorded. In the posterior open bite assessment, the number of maxillary teeth that lost contact with the mandibular teeth was counted.

Five orthodontists evaluated the malocclusions (Class I, Class II Division 1, Class II Division 2, and Class III), and, with all baseline and follow-up study models, they (blinded to study-model measurements) determined whether there was no change, whether the change was favorable or unfavorable, and how much change there was (small, intermediate, or large). For this assessment, the following definitions were used: *no change:* if there was no or a very small movement that was not clinically relevant; *a favorable change:* if there was correction of Class II molar or canine relationship, reduced OJ or OB, or reduced palatal impingement or mandibular incisor crowding; *an unfavorable change:* if there were changes to edge-to-edge incisors, reverse OJ or OB, or vertical openbite, reduced interarch contacts, or a posterior crossbite. Method errors were calculated by Dahlberg statistics.[21] The mean differences of successive measurements ranged from 0.069 to 0.126 mm, and the mean discrepancy did not exceed 0.120 mm.

Data analysis

The results of the study-model analysis were evaluated with a statistical package (SPSS software, Chicago, Ill). Data are presented as percentage or means ± standard deviations. To assess the statistical significance of changes in the measurements before OA treatment and at follow-up, paired Student *t* tests were used for parametric variables, and nonparametric changes (molar relationship, canine relationship, type of change, size of contact area, and crowding) were analyzed with the Wilcoxon Matched Pairs Signed Ranks Test or the Yates correction. Differences between subgroups of patients were first tested with analyses of variance (ANOVA) followed by the post-hoc Tukey test. Correlations were carried out with Pearson correlation tests for parametric variables or Spearman tests for nonparametric variables. A *P* value of <.05 was considered significant.

Table I. Occlusal changes according to skeletal subtype

	Class I	*Class II Div 1*	*Class II Div 2*	*Class III*	*Total*
No change (14.3%)	6	1	2	1	10
Favorable change (41.4%)					
Small	6	5	2	0	13
Intermediate	6	1	6	0	13
Large	0	3	0	0	3
Unfavorable change (44.3%)					
Small	8	0	0	0	8
Intermediate	14	0	0	1	15
Large	8	0	0	0	8
Total	48	10	10	2	70
%	69%	14%	14%	3%	100%

RESULTS

After the use of an OA for a mean of 7.4 ± 2.2 years, a study-model evaluation was completed in 70 patients. As shown in Table I, 5 orthodontists found that 48 patients were initially Class I, 10 were Class II Division 1, 10 were Class II Division 2, and 2 were Class III. A dental or an occlusion change was verified visually in 85.7% of the patients. In assessing the changes induced by OAs, the orthodontists found no clinical change in 10 patients (14.3%), favorable changes in 29 patients (41.4%), and unfavorable changes in 31 patients (44.3%). Favorable and unfavorable changes were further subdivided into small, intermediate, and large, and separated according to skeletal subtype. The unfavorable group included more Class I subjects, and the favorable group included more Class II subjects at the pretreatment evaluation.

For the mandible-to-maxilla relationship, there was a significant mesial shift of the mandibular canines and molars. On the right side, 5 Class II molar relationships became Class I, 7 Class I relationships became Class III, and 1 Class II relationship became Class III. On the left side, 7 Class II molar relationships became Class I, 10 Class I relationships became Class III, and 2 Class II relationships became Class III.

Differences between the skeletal subtypes according to type of change showed several differences in pretreatment craniofacial structures, follow-up evaluations, and amounts of change (Table II). In the pretreatment evaluation, the unfavorable group included more Class I patients, and the favorable group included more Class II subjects. The pretreatment left mandibular canine was more mesially positioned in the unfavorable group than in the favorable group; on the right side, a similar significant difference was found between the

Table II. Differences between skeletal subgroups according to type of change

	Unfavorable *n = 31*	*No change* *n = 10*	*Favorable* *n = 29*
Pretreatment			
Molar type[a]	0.97	1.40	1.86
Canine relation R[b]	0.29	0.00	0.62
Canine relation L[b]	0.29	0.60	0.79
OB (mm)	2.70	4.46	4.47
OJ (mm)	2.12	2.75	3.95
Posttreatment			
Canine relation R[b]	–0.34	–0.10	0.31
Canine relation L[b]	–0.33	0.50	0.62
OB (mm)	0.46	3.87	2.52
OJ (mm)	0.45	2.90	2.72
Changes			
Canine relation R[b]	–0.65	–0.10	–0.31
Canine relation L[b]	–0.67	–0.10	–0.17
Anterior crossbite[c]	3.57	0.00	0.66
Posterior crossbite[c]	2.53	0.40	0.80
Posterior openbite[d]	0.20	0.10	0.04
OB (mm)	–2.29	–0.58	–1.90
OJ (mm)	–1.75	0.17	–1.20

All values expressed as means.
*$P < .05$; **$P < .01$; *R*, Right; *L*, left.
[a]Class I = 1, Class II Div 1 = 2, Class II Div 2 = 3, Class III = 0.
[b]Class I = 0, Class II = 1, Class III = –1. Negative changes are related to mesial shift of mandible.
[c]Number of teeth per patient in edge-to-edge or crossbite.
[d]Number of teeth per patient in that condition.

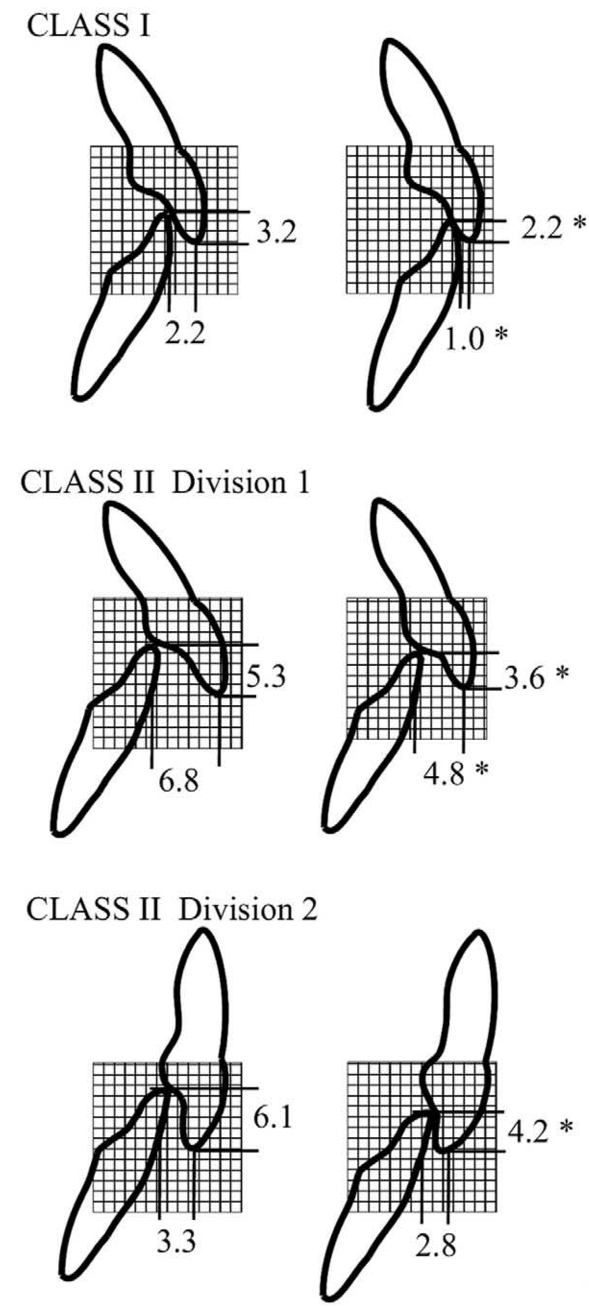

Fig 1. Schematic representation of mean changes in OB and OJ according to type of maloclusion. *Significant changes ($P < .05$).

no-change and favorable subgroups. Initial OB and OJ were significantly smaller at pretreatment in the unfavorable group compared with the favorable one. In the posttreatment measurements, the unfavorable group was statistically different from the favorable and the no-change groups, showing a more mesial and Class III

Table III. Study model measurements, expressed values are follow-up minus initial measurement

	Total sample (n = 70)			Class I (n = 48)			Class II Div 1 (n = 10)			Class II Div 2 (n = 10)		
Variables	*Mean*	*SD*	P	*Mean*	*SD*	P	*Mean*	*SD*	P	*Mean*	*SD*	P
Maxilla												
Intercanine, mm	–0.09	0.59	NS	–0.17	0.62	NS	–0.07	0.34	NS	0.28	0.59	NS
Intermolar, mm	0.16	0.79	NS	0.14	0.83	NS	0.01	0.79	NS	0.46	0.69	NS
Arch length, mm	0.07	1.19	NS	0.07	1.32	NS	–0.05	1.04	NS	0.18	0.88	NS
Interprox. open spaces[a]	0.43	0.94	*	0.48	0.92	*	0.40	0.70	NS	0.10	1.20	NS
Crowding[b]	0.03	0.38	NS	0.08	0.35	NS	0.00	0.47	NS	–0.20	0.42	NS
Mandible												
Intercanine, mm	0.40	0.66	*	0.42	0.66	*	0.59	0.76	NS	0.18	0.66	NS
Intermolar, mm	0.57	0.78	*	0.65	0.75	*	0.44	0.87	NS	0.41	0.56	NS
Arch length, mm	0.50	0.93	*	0.52	0.94	*	0.75	1.15	NS	0.25	0.73	NS
Interprox. open spaces[a]	0.77	0.36	*	0.88	1.33	*	0.60	1.26	NS	0.60	1.78	NS
Crowding[b]	–0.03	0.59	NS	0.04	0.62	NS	–0.30	0.48	NS	–0.20	0.42	NS
Interarch relation												
Overbite, mm	–1.91	1.53	*	–2.03	1.71	*	–1.67	1.31	*	–1.87	0.44	*
Overjet, mm	–1.24	1.52	*	–1.23	1.50	*	–1.97	1.56	*	–0.48	1.21	NS
OB 13, mm	–2.00	1.82	*	–2.16	2.01	*	–1.93	1.53	*	–1.52	0.86	*
OB 12, mm	–1.99	1.78	*	–2.21	2.00	*	–1.47	1.25	*	–1.83	0.70	*
OB 11, mm	–1.93	1.59	*	–2.08	1.79	*	–1.56	1.22	*	–1.94	0.54	*
OB 21, mm	–1.88	1.53	*	–1.99	1.66	*	–1.79	1.53	*	–1.79	0.56	*
OB 22, mm	–1.81	1.41	*	–1.99	1.53	*	–1.50	1.14	*	–1.51	1.06	*
OB 23, mm	–1.96	1.83	*	–2.28	2.02	*	–1.25	1.14	*	–1.49	1.03	*
OJ 13, mm	–1.07	1.24	*	–1.23	1.42	*	–0.61	0.41	*	–0.70	0.52	*
OJ 12, mm	–1.45	1.51	*	–1.34	1.36	*	–1.96	1.99	NS	–1.04	1.41	NS
OJ 11, mm	–1.28	1.57	*	–1.23	1.54	*	–2.05	1.81	*	–0.63	1.16	NS
OJ 21, mm	–1.20	1.54	*	–1.21	1.52	*	–1.88	1.46	*	–0.32	1.29	NS
OJ 22, mm	–1.39	1.51	*	–1.31	1.42	*	–2.35	1.90	*‡	–0.69	1.10	NS
OJ 23, mm	–1.27	1.56	*	–1.17	1.18	*	–2.65	2.57	NS‡	–0.23	0.80	NS
Molar relation R[c]	–0.26	0.49	*	–0.34	0.54	*	–0.11	0.33	NS	–0.14	0.38	NS
Molar relation L[c]	–0.39	0.56	*	–0.47	0.61	*	–0.20	0.42	NS	–0.17	0.41	NS
Canine relation R[c]	–0.43	0.58	*	–0.50	0.55	*†	–0.30	0.67	NS	–0.30	0.67	NS
Canine relation L[c]	–0.38	0.57	*	–0.47	0.58	*†	–0.20	0.63	NS	–0.10	0.32	NS
Size of contact area[b]	–0.47	0.74	*	–0.48	0.77	*	–0.40	0.70	NS	–0.40	0.70	NS
Tooth in contact[a]	–3.01	4.60	*	–3.58	5.00	*	–1.80	3.19	NS	–1.20	2.66	NS
Anterior crossbite[a]	1.81	2.36	*	2.46	2.46	*†	0.20	0.42	NS	0.10	0.32	NS
Posterior crossbite[a]	1.49	2.06	*	1.69	2.20	*	1.00	1.76	NS	0.60	1.58	NS

*$P < .01$; *ns*, not significant; *R*, right; *L*, left; variables shown as mean changes and SD.
†Changes significantly different from other groups (Class II Division 1 and Class II Division 2).
‡Changes significantly different from Class II Division 2.
[a]Number of teeth per patient in that condition.
[b]Means calculated from scores: decrease = –1, no change = 0, increase = +1.
[c]Means calculated from scores: Class I = 0, Class II = 1, Class III = –1. Negative changes are related to mesial shift of mandible.

canine relationship, and smaller OB and OJ. The no-change group was statistically different from the unfavorable group in canine relationship (right and left), anterior and posterior crossbite, OB, and OJ. The no-change group was different from the favorable group in OB and OJ. These calculations showed a significant difference between the unfavorable and favorable groups for canine mesialization, number of teeth per patient that changed into edge-to-edge or crossbite in the anterior and posterior segments, and number of teeth per patient that changed into an edge-to-edge or posterior open-bite relationship (Table II).

The interarch relationship showed a decrease in OB and OJ in the entire anterior segment (Fig 1). An OB decrease of more than 1 mm occurred in 68.6% of the patients, and an OJ decrease of more than 1 mm occurred in 50% of the patients. A schematic of OB and OJ changes in the craniofacial subgroups is given in Figure 1. The Class I and Class II Division 1 patients showed significantly smaller OBs and OJs in the posttreatment measurements, whereas the Class II Division 2 subjects had differences in OB but not in OJ.

All mean changes and standard deviations for the study model variables divided according to skeletal

Table IV. Frequency and percentages of total number of teeth per patient that changed into edge-to-edge or crossbite relationship

	Anterior (13–23)		*Posterior (18–14, 24–28)*	
	Frequency	*%*	*Frequency*	*%*
0	39	55.7	35	50.0
1	4	5.7	11	15.7
2	3	4.3	6	8.6
3	2	2.9	5	7.1
4	9	12.9	6	8.6
5	3	4.3	2	2.9
6	10	14.3	2	2.9
7	n/a	n/a	3	4.3
8	n/a	n/a	0	0.0

n/a, Not applicable.

type are shown in Table III. In evaluating all patients combined, we found significant changes in the number of interproximal open spaces in the maxilla and the mandible, and significant increases in intercanine, intermolar, and arch length distances as well as in the number of interproximal open spaces. For the assessment of interarch relationships, there were changes in OB and OJ measured in each anterior tooth, more mesial molar and canine relationships on the right and left sides, decreases in the numbers of teeth per patient in contact with the opposing teeth, and increases in the numbers of teeth per patient in anterior and posterior crossbites. After we evaluated the Class I craniofacial subgroup separately, the same variables described above changed significantly. Class II Division 1 subjects had significant changes in almost all anterior teeth, OB, and OJ, with the exception of OJ measured on teeth 12 and 23. The Class II Division 2 subjects showed significant alterations in OB and in OB of each anterior tooth, but OJ changed significantly only on tooth 13. Class I subjects, compared with Class II Division 1 and Class II Division 2 subjects, demonstrated greater changes in canine mesialization (left and right) and in the number of teeth per patient in anterior crossbite. Class II Division 1 patients differed from Class II Division 2 patients, showing a greater decrease in OJ measured on teeth 22 and 23.

As to the number of teeth that had lost contact with the opposite arch, there was a mean decrease of 3 teeth per patient. This change varied from 13 teeth (worst) that lost contact to 6 teeth (best) that gained contact. The contact area increased in 10 patients, did not change in 17 patients, and decreased in 43 patients. In the estimate of anterior and posterior OB, most patients had a combination of 2 or more teeth in edge-to-edge or open-bite relationships. After we calculated the percentages of patients with teeth changing into edge-to-edge and open-bite relationships, the premolars were most common (over 14%). The buccolingual relationships changing into edge-to-edge relationship or crossbite varied depending on the number of teeth that came into this relationship. For the anterior segment, 39 patients (55.7%) had no change, and 10 patients (14.3%) showed all 6 anterior teeth with abnormal labiolingual relationships. For the posterior segment, 35 patients (50%) showed no change; no one had all 8 posterior teeth with abnormal buccolingual relationships. Percentages of patients with 0 to 8 teeth under such conditions are shown in Table IV.

With regard to tooth tipping and rotation, 7 patients did not have such changes. There were mesial tipping in 19 patients, affecting 1 to 6 teeth per patient, mostly in the mandibular arch, and distal tipping in the maxillary arch of only 3 patients (1 or 2 teeth). Buccal/labial tipping occurred in 73.9% of the patients, affecting 1 to 12 teeth, mostly mandibular anterior teeth. Lingual tipping appeared in 21.1% of the patients, mainly in the maxillary anterior incisors. Mesiolingual and distobuccal rotations were predominant in the mandibular arch in 27.1% and 35.7% of the patients, respectively.

In the initial OB subgroups, the deep OB group had a significantly greater change in OB when compared with the shallow OB group ($P = .008$). Analyzed with Pearson or Spearman correlations, the following variables showed significant correlations. Longer use of the OA correlated with more interproximal open spaces in the maxilla ($r = 0.267$) and less change in mandibular intermolar distance ($r = -0.302$). The older the patient at the beginning of treatment, the greater the change in OB ($r = -0.270$). An initial deep OB correlated with a more favorable change ($r = 0.362$), less anterior crossbite ($r = -0.351$) and greater reduction in the OB ($r = -0.321$). A greater initial OJ correlated with a more favorable change ($r = 0.397$), with less anterior crossbite ($r = -0.276$) and greater decrease in OJ ($r = -0.306$).

DISCUSSION

Even though OAs have been used to treat snoring and sleep apnea for the past 15 years, their side effects over periods longer than 5 years are still uncertain. This study is the first to demonstrate that OA use for a mean period of 7.4 years affects occlusal and dental structures, such as increased mandibular arch length, mesial shift of the mandibular teeth, decreased OB, and decreased OJ. In contrast to previous studies, we found significant orthodontic side effects in 85.7% of the patients and suggest that tooth movement increases with longer use of OAs.

OA mechanisms of action on the dentition might be similar to functional appliances, such as the Herbst or Twin-block, but OAs are used in nongrowing adults and for only 6 to 8 hours a day. Unlike an orthodontic setting, the treatment plan for snoring and OSA does not attempt tooth movement. Although some tooth movement was expected, we found that, in 41.4% of the patients, these changes were actually favorable for the patient's occlusion; this is the first study to acknowledge that not all tooth movements are clinically undesirable. Important findings in the difference between unfavorable (44.3%) and favorable (41.4%) changes are relevant to the initial clinical assessment of patients referred for OA treatment. The patients with favorable occlusal changes, as determined by the initial dental evaluation, were more likely to be Class II Division 1 or Class II Division 2, with more distal mandibular canine positions and greater initial OB and OJ. Most patients who had unfavorable changes were Class I at the beginning of treatment. The unfavorable patients significantly changed their occlusion more into an edge-to-edge or anterior and posterior crossbite as well as open-bite positions. In previous articles, the authors pointed out that the side effects induced by OAs were small[12] and clinically irrelevant.[14] However, minimal or no changes were found in only 14.3% of our patients, the no-change group. This group had only 1 characteristic that significantly differed from the favorable group in the initial evaluation—the right canine relationship. The differentiation between the groups was done blinded to all measurements, and, after the study-model analysis, we found some measurement changes in the no-change group, but, because they were minor, they were probably not detected clinically. The type of change had no correlation with the period of OA use, but patient compliance was not objectively measured.

It appears that the maxilla is more stable during adulthood than the mandible[22] and might be less prone to changes over time. Our study and that of Rose et al[14] found changes in the maxilla that did not achieve statistical significance. In contrast, Marklund et al[12] found a decrease in the maxillary intercanine distance (0.3 mm) with a hard acrylic device and an increase in the mandibular molar width (0.2 mm) with an elastomeric device. In our results, we did not find statistical differences in maxillary intercanine and intermolar distances, arch length, or crowding. In a small section of our sample, the Class II Division 2, the maxillary canine and molar widths increased by 0.28 and 0.46 mm, respectively. Although it was not specified by Marklund et al,[12] the different skeletal subgroups' characteristics might explain the differences in the results. The differences between our study and others[12,14] might be related to design, material, or amount of mandibular advancement of the Klearway appliance used by most patients in this sample. However, most of the changes we found have been seen previously, although on a smaller scale.[12,14] Therefore, we believe that these changes are not restricted to Klearway but are mostly related to long-term use of OAs.

Interestingly, the mandible showed increases in canine and molar widths, arch lengths, and the numbers of interproximal open spaces. It has been shown that the mandibular incisors are proclined with the use of OAs,[10] possibly causing an enlargement of mandibular arch length. Increases in arch length and anterior spaces[14] or in intermolar distance[12] were previously found. This is the first study that could determine whether all of these measurements, as well as intercanine distance, changed significantly. Although the mandibular arches can change over the years in adults, the tooth movements identified in this study are in the opposite direction of the changes found in untreated patients.[20] Therefore, we believe that the changes in our patients are mainly related to OA wear. In snoring and OSA patients, changes occur in the same direction as those observed with functional appliances.[23] The time period of OA use in our study was longer than in previous studies, and so we hypothesize that some tooth movements do continue with longer use of the appliance. The forces induced by the appliance in an artificial forward mandibular position and the mandibular anterior incisor proclination might explain the increase in intermolar distance. We hypothesize that there might be a tongue posture change during the day as a consequence of mandibular incisor proclination. There might also be a buccal force component on the molar induced by the appliance during the night. With a posterior open bite,[19] there is less occlusal contact. Without the cusp fossa relationship, and after the extrusion movement, the molar might be more susceptible to buccal tipping, thus widening the mandibular arch in this new position.

OB and OJ changed significantly in our sample, in accordance with previous reports of a similar and regular pattern of tooth movement induced by OA use.[8-15] Although there was no significant difference between malocclusion groups for OB and OJ, there were significant differences between Class II Division 1 and Class II Division 2 subjects for the OJ change of teeth 22 and 23. OJ changed significantly except in Class II Division 2 subjects; this was expected orthodontically, because Class II Division 2 patients have deeper initial OB associated with retroclination of the maxillary incisors, greater muscle activity, and more hypertonic lower lips, and therefore appear to be more

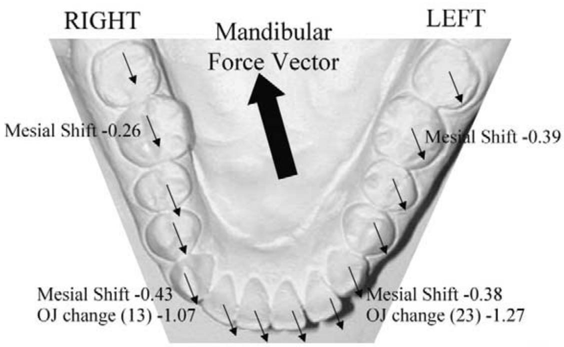

Fig 2. Hypothetical forces of mandible in right-sided chewer and forces (*small arrows*) that OA might apply to each tooth.

difficult to treat orthodontically.[24] The amount of change in OB and OJ was not significantly different between the favorable and unfavorable groups; this finding is important in the interpretation that OAs change the anterior tooth relationship, but, depending on initial tooth position, the changes might or might not be favorable.

There were some differences between right and left changes. The forces imposed on the teeth by the OA are reciprocal to the forces of the muscles that try to bring the mandible to a centric relationship. The OA used in this study has a full-arch occlusal coverage, and the bite registration midline was obtained at two thirds of full protrusion according to the patient's repeatable path of comfortable protrusion. Therefore, the mechanical loading was applied to all teeth in protrusion. We hypothesize that the forces of the mandible during chewing, speech, and bruxism do not follow a centered straight line but, instead, are directed to the preferred chewing side or to the side with the greater condyle displacement. The distribution of chewing-side preference in the population seems to be related to hemispheric laterality and does not change because of missing teeth, implants, or restorations; the right side is predominantly used for chewing, in 73.3% to 85% of subjects.[25] The right and left condyle displacement with the OA in place was described as equal or with the right side in a more forward position.[6] Based on chewing-side preference and condyle position, the forces of the mandible would be backward and to the right, and consequently the force applied by the appliance on the teeth would be forward and angulated to the left (Fig 2). Because of the arch shape, the force vectors in each tooth are different. Our findings support this angled force theory because, on the right side, the forces on the canine have a greater mesial vector direction, and we found a greater change in the canine relationship on the right side (mesial movement); on the opposite side, the force vector had a labial (buccal) direction, which would explain the smaller mesial movement and the greater decrease in OJ. Also, the forces on the right molar are mesial, toward the premolar. Once resistance in the arch is encountered, fewer molar relationship changes on the right side were produced; on the left side, the forces were mesial and buccal, and hence the left molars would be more prone to move buccally and mesially; this explains the greater change in molar relationship on this side (Table III, Fig 2).

This is the first study to quantify the frequency of tooth rotation and tipping movements after long-term OA use. Even though the OA used in this study has full occlusal coverage, we should not exclude such analysis, because OAs appear to move teeth in an uncontrolled environment. All anterior and posterior open bites of our patients changed significantly, similar to a prior study,[14] and we found that the premolars appeared in edge-to-edge or open-bite relationships in up to 14% of our patients, whereas the molars had a slightly lower frequency of up to 11% (Fig 2). Once a patient has this kind of change, there is often a combination of more than 1 tooth in an edge-to-edge or open-bite condition.

From a clinical perspective, it is important to determine useful predictors of OA side effects in snoring and OSA patients. We have found some correlations, none of which were very strong, but we hypothesize that several characteristics are involved, each with a different weight of influence. A deeper OB correlated with a greater reduction in the OB, and the greater the initial OJ, the greater the reduction in OJ. There is also a correlation between greater OB and OJ and more favorable change and lower incidence of anterior crossbite. There was a correlation between older age and a decrease in OB; Marklund et al[12] also found more movement in older patients. These results might be related to periodontal health in elderly people, because the severity of sleep apnea tends to increase with age. This group is increasing in the dental setting, and more careful assessment and further research regarding these issues are needed.

A particular strength of this study was the duration of OA use. This was the first study to evaluate long-term side effects for more than 5 years. Nonetheless, our study had several limitations. Patient compliance was not objectively measured because there is no commercially available compliance monitor. Molar and canine relationships were evaluated only in categories instead of actual millimeters. The classification of favorable or unfavorable, although based on objective standards, was subjective, and, for the minimum bias, we used the evaluations of 5 orthodontists at 1 setting for all study models. Further studies with computerized superimposition of 3-dimensional coordinates of the maxilla, the mandible, and the dentition, before treatment and in a follow-up assessment, are required to better quantify these side effects and eliminate part of the subjectivity of the follow-up evaluation.

CONCLUSIONS

The use of a mandibular advancement appliance over a mean duration of 7.4 years induced significant occlusal changes in 85.7% of the patients in this study. Interestingly, for almost half of them, tooth movement was considered favorable. The group with unfavorable changes had significantly smaller OB and OJ in the pretreatment measurements, and unfavorable changes were more likely in the Class I craniofacial subgroup. The mandible showed significant changes in arch length and intercanine and intermolar distances; the maxilla was more stable. OA therapy is a lifelong treatment of a disease that tends to worsen with age, and careful monitoring of the common side effects elucidated in this study is mandatory, not only by cephalometric evaluation, but also with study models. Additional studies are required to assess the forces imposed by the appliance on each tooth with various mandibular advancements, among patients with right and left chewing preferences, and to analyze temporomandibular joint displacement with the appliance in place.

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