ORIGINAL ARTICLE

Long-term sequellae of oral appliance therapy in obstructive sleep apnea patients: Part 1. Cephalometric analysis

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Introduction: Oral appliances (OAs) have been widely used to treat snoring and sleep apnea, but their effects on craniofacial structures in patients after 5 years or more of wear have not yet been quantified. **Methods:** Seventy-one patients who had worn adjustable mandibular repositioners to treat snoring or sleep apnea were evaluated. Upright lateral cephalometric radiographs in centric occlusion taken before treatment and after a mean of 7.3 ± 2.1 years of OA use were compared. Baseline sleep studies and patient demographic data were included in the analysis. **Results:** Cephalometric analyses after long term OA use showed significant ($P <$ .01) changes in many variables, including increases in mandibular plane and ANB angles; decreases in overbite and overjet; retroclined maxillary incisors; proclined mandibular incisors; increased lower facial height; and distally tipped maxillary molars with mesially tipped and erupted mandibular molars. The initial deep overbite group had a significantly greater decrease in overbite. Duration of OA use correlated positively with variables such as decreased overbite and increased mandibular plane angle; changes in the dentition appeared to be progressive over time. **Conclusions:** After long-term use, OAs appear to cause changes in tooth positions that also might affect mandibular posture. (Am J Orthod Dentofacial Orthop 2006;129:195-204)

Obstructive sleep apnea (OSA) symptoms such as snoring and daytime somnolence are common. Snoring appears to affect 35% to 40% of adults and is related to OSA, which has a prevalence of 4% to 19%, depending on the definition used.[1,2] The treatment of OSA has a great impact on a patient's quality of life.[3-5] Oral appliance (OA) use as a therapy for OSA has proven over the past 10 years to be effective for treating sleep apnea patients, reducing the apnea and hypopnea index,[4-10] improving oxygen saturation during sleep, reducing snoring, and, more recently, reducing arterial blood pressure.[11,12] Many imaging techniques have been used to investigate the etiology of OSA, including cephalometrics, videofluoroscopy, tomography, and magnetic resonance imaging.[13-15] The cephalometric method (2-dimensional, simple and widely established in dentistry) has been used to assess craniofacial and upper airway characteristics and predictors of sleep apnea.[16,17] Important recent findings correlate cephalometric characteristics and OA treatment outcomes.[7,18-21] The Academy of Dental Sleep Medicine suggested the use of cephalograms as a diagnostic aid at the initial dental examination of every patient receiving OA treatment.[14,22]

Side effects of OA use include dry mouth, excessive salivation, tooth and jaw discomfort, myofascial pain, tooth grinding, and stiffness of the jaw, but these are frequently reported as mild, acceptable, and transient.[7,23-27] In a short-term analysis of adverse events during the first year of OA use, Tegelberg et al[28] found that neither mandibular movements nor occlusion had changed in patients with a mean age of 49 years. Almeida et al[29] evaluated the temporomandibular joint (TMJ) with magnetic resonance imaging over a mean period of 11.5 months in a sample of patients (mean age, 46) and found no changes in the TMJ related to OA use. Otsuka et al[30] showed that, over an average period of 6.5 months, occlusal contact area and bite

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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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force decreased with an OA. Subjective changes in the dental occlusion were reported in 12% to 19.2% of patients.[26,27,31] Using cephalometric analysis, various authors evaluated craniofacial changes induced by OA use for an average of 2 to 3 years. Significant changes were reported: more downward[32] and forward[32,33] mandibular positions, decreased overbite (OB) and overjet (OJ),[24,27,32-34] retroclination of the maxillary incisors,[24,33,34] proclination of the mandibular incisors,[33-35] increased lower facial height,[32,33,35] and changes in molar relationship.[24] OA use also changes the upper airway configuration; decreases in palatal length and increases in pharyngeal area, probably related to loss of edema caused by snoring and repetitive apneas, have been reported.[33,35]

OA therapy might be a lifelong treatment. Hence, a better understanding of the possible side effects and consequences are important in the follow-up protocol. We postulate that longer use of OAs could cause greater changes in a patient's craniofacial structures. The purpose of this study was to evaluate, by using cephalometric data in a sample of OSA patients, the skeletal, dental, and occlusal changes from OA therapy after 5 or more years of wear.

Fig 1. Titratable oral appliance (Klearway). Palatal screw enables 44 advancements of mandible in 0.25 mm increments.

MATERIAL AND METHODS

Patients who had worn OAs for at least 5 years were recruited to participate in this study.[25] They came to the Sleep Apnea Dental Clinic at the University of British Columbia or to an author's (A.A.L.) private practice for regular follow-up of their OAs and were currently using their OAs for 4 or more days a week and had been doing so for more than 5 years. All patients had been treated with a mandibular advancement device for snoring or OSA. Even though some patients started with a different appliance, all were using Klearway (Fig 1), and all were titrated until the optimal anteroposterior mandibular position was achieved as described previously.[36] The vertical opening was kept to a minimum to prevent downward rotation of the mandible. Patients were excluded if they had missing or poor-quality diagnostic upright cephalometric films. The study was approved by the University of British Columbia Ethics Committee.

The sample consisted of 71 OSA subjects, 8 women and 63 men, mean age 49.7 $\pm$ 9.7 years, with pretreatment respiratory disturbance index values of 28.9 $\pm$ 17.0 per hour and body mass index values of 29.3 $\pm$ 5.9 kg/m^2. A posttreatment upright cephalogram in centric occlusion was taken for each patient. Initial cephalograms in the upright centric occlusion, demographic data, and sleep studies were also used to evaluate possible correlations and changes in skeletal and dental structures. The 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 an overnight oximetry study. Demographic data used in the correlations were collected before OA placement. The period of OA use was calculated as the interval between appliance placement and the date of the new cephalogram. All lateral cephalometric radiographs were taken with the same cephalostat (Counterbalance Cephalometer Model W-105, BF Wehmer, Ill), with the patient in the upright position, with natural head posture, in centric occlusion, and at the end of tidal expiration. Tracings were constructed for each lateral headfilm; landmarks and traditional contours of the anatomic structures were digitized.[14,37,38] The positions of teeth, maxilla, and mandible were examined, including measurements of the angulations of incisors and molars, molar heights, relationship between maxillary and mandibular incisors, relationship between maxillary and mandibular molars, relationship between maxilla and mandible, size and position of the maxilla, size and position of the mandible, and facial height. In addition, we evaluated upper airway size with tongue height and area, soft palate length and area, nasopharynx area, oropharynx area, hypopharynx area, and vertical airway length. The points, lines, angles, distances, and areas are shown in Figures 2 and 3. Condylion position was measured as previously described.[33] The same orthodontist (J.O.S.) traced and digitized each cephalometric radiograph.

Data analysis

After digitization, the results of the cephalometric analysis were transferred to a statistical package (SPSS,

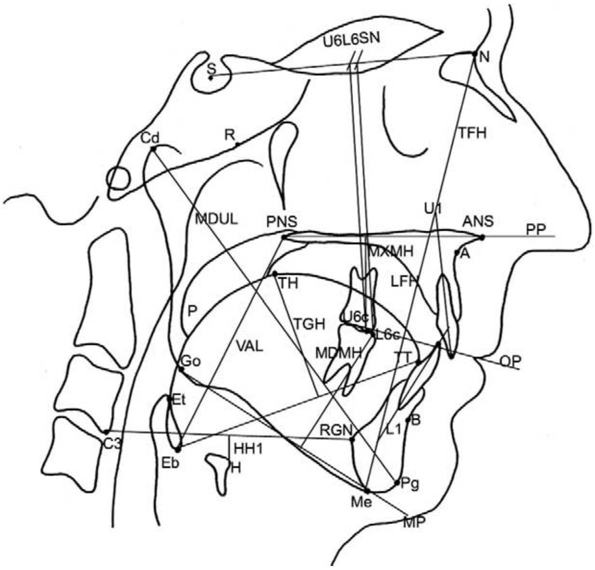

Fig 2. Diagrammatic representation of landmarks and variables. Points: *S,* sella; *N,* nasion; *ANS,* anterior nasal spine; *PNS,* posterior nasal spine; *A,* Point A; *B,* Point B; *Pg,* pogonion; *Me,* menton; *RGN,* retrognathion; *Go,* gonion; *Cd,* condylion; *U1i,* upper incisor edge; *U6c,* upper molar mesial cusp tip; *L1i,* lower incisor edge; *L6c,* lower molar mesial cusp tip; *Eb,* base of epiglottis; *Et,* tip of epiglottis; *H1,* hyoid point; *C3,* third vertebra point; *TT,* tongue tip; *TH,* superior tongue curve point; *P,* tip of soft palate; *R,* roof of pharynx as point on posterior pharyngeal wall constructed by line PNS to cross-sectional point of cranial base and lateral pterygoid plate. Planes: *SN,* anterior cranial base; *MP,* mandibular plane (Me-Go); *PP,* palatal plane (ANS-PNS); *OP,* occlusal plane (midpoint between maxillary and mandibular incisor edges to midpoint between maxillary and mandibular molar mesial cusps); *U1,* upper incisor (connects incisor edge to root apex); *L1,* lower incisor (connects incisor edge to root apex); *U6,* upper molar (connects U6c to its mesial root apex); *L6,* lower molar (connects L6c to its mesial root apex). Linear measurements (in millimeters): *MXMH,* maxillary molar height (U6c ⊥ PP); *MDMH,* mandibular molar height (L6c ⊥ MP); *OB,* overbite (maxillary incisal edge to mandibular incisal edge on occlusal plane); *OJ,* overjet (maxillary incisal edge to mandibular incisal edge on line ⊥ to occlusal plane); *U6L6SN,* maxillary molar (U6c) distance to mandibular molar (L6c) projected on S-N plane; *MDUL,* mandibular length (Cd-Pg); *LFH,* lower facial height (Me-PP on N-Me line); *TFH,* total facial height (N-Me); *HH1,* vertical position of hyoid (H1 ⊥ C3-RGN); *TGH,* tongue height (TH ⊥ TT-Eb); *VAL,* vertical airway length (PNS-Eb). Angular measurements: maxillary incisor angle (U1 to SN, U1 to PP); maxillary molar angle (U6 to SN, U6 to PP); mandibular incisor angle (L1 to MP); mandibular molar angle (L6 to MP); interincisor angle (IIA); anteroposterior position of the maxilla (SNA angle); anteroposterior position of mandible (SNB angle); palatal plane angle (SNPP); mandibular plane angle to base of cranium (SNMP angle); mandibular plane angle to palatal plane (PPMP angle); chin position relative to cranium (SNPg angle).

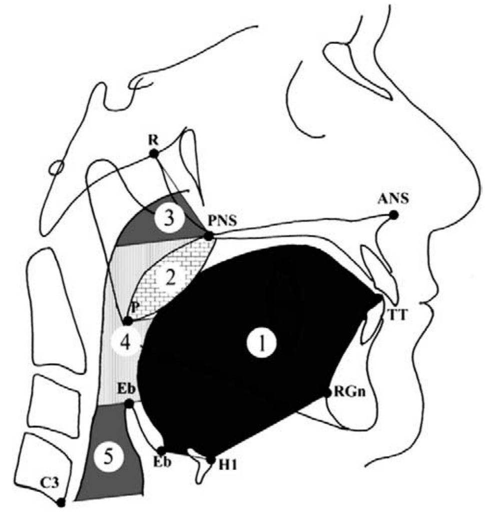

Fig 3. Diagrammatic representation of landmarks and contours used to identify tongue, soft palate, upper airway, and cross-sectional areas. *1,* tongue cross-sectional area; *2,* soft palate cross-sectional area; *3,* nasopharynx cross-sectional area; *4,* oropharynx cross-sectional area; *5,* hypopharynx cross-sectional area. *R,* roof of pharynx; *P,* tip of soft palate; *Eb,* base of epiglottis; *Et,* tip of epiglottis; *H1*, hyoid point; *C3*, third vertebra point; *TT*, tongue tip; *PNS,* posterior nasal spine; *ANS,* anterior nasal spine; *RGn,* retrognathion.

Chicago, Ill). Data are presented as means ± standard deviation. To assess statistically significant changes in the measurements before and during OA treatment, a paired Student *t* test was used. The Bonferroni inequality correction for significance levels was used for multiple comparisons. Differences between subgroups of patients were first tested with analysis of variance (ANOVA) followed by the post-hoc Tukey test. Correlations were carried out with Pearson correlation tests for parametric variables. Linear regression analysis was used to determine the relationship between the change in OB and baseline craniofacial variables, apnea severity, and duration of OA use. A *P* value less than .05 was considered significant.

Table I. Cephalometric variables that changed significantly after use of OA

	Total sample			*Class I*			*Class II Div 1*			*Class II Div 2*		
	Mean	*SD*		*Mean*	*SD*		*Mean*	*SD*		*Mean*	*SD*	
Maxilla												
U1 to SN (°)	−3.1	4.8	*	−3.6	4.8	*	−4.3	5.6	ns	−0.1	3.5	ns
U1PP (°)	−3.5	4.7	*	−4.1	4.3	*	−3.9	6.8	ns	−0.7	3.8	ns
U6 to SN (°)	−2.3	4.4	*	−2.5	4.7	*	−1.2	4.7	ns	−3.0	2.7	*
U6PP (°)	−2.6	4.7	*	−3.0	4.8	*	−0.8	5.5	ns	−3.4	3.3	ns
MXMH (mm)	0.5	1.5	*	0.6	1.6	ns	0.6	1.2	ns	0.5	1.2	ns
Mandible												
SNMP (°)	0.7	1.9	*	0.8	2.0	*	0.7	2.1	ns	−0.1	1.8	ns
PPMP (°)	1.0	0.8	*	1.2	1.8	*	−0.1	1.9	ns	0.5	2.0	ns
SNPg (°)	−0.4	1.4	ns	−0.5	1.5	ns	−0.5	1.1	ns	0.2	1.2	ns
MDUL (mm)	0.5	2.3	ns	0.3	2.2	ns	0.6	2.5	ns	1.7	1.3	ns
L1 to MP (°)	6.6	5.2	*	7.3	5.0	*	7.0	6.2	*	3.7	4.8	ns
L6 to MP (°)	3.4	6.2	*	3.3	5.7	*	4.5	9.8	ns	2.4	4.9	ns
MDMH (mm)	0.7	1.5	*	0.8	1.6	*	0.8	1.5	ns	0.7	1.6	ns
Intermaxillary relationships												
OB (mm)	−2.8	2.5	*	−3.3	2.5	*	−1.6	1.7	ns	−1.9	2.1	ns
OJ (mm)	−2.6	1.9	*	−2.9	1.9	*	−2.4	1.8	*	−1.5	1.6	ns
IIA (°)	−4.1	6.3	*	−4.4	6.2	*	−3.5	8.3	ns	−3.6	5.6	ns
ANB (°)	0.5	1.2	*	0.4	1.3	ns	0.8	1.4	ns	0.4	0.9	ns
U6L6SN (mm)	−1.8	2.2	*	−1.8	2.4	*	−2.1	1.8	*	−1.5	1.6	ns
TFH (mm)	1.8	2.4	*	2.1	2.5	*	1.4	1.7	ns	1.5	2.4	ns
LFH (mm)	1.8	1.9	*	2.1	1.7	*	1.5	1.9	ns	1.6	1.5	ns
UFHLFH %	−1.9	2.8	*	−2.2	2.7	*	−1.7	2.8	ns	−1.8	2.6	ns
Upper airway												
VAL (mm)	1.8	4.1	*	1.9	4.3	*	0.5	3.9	ns	2.6	2.7	ns
TGH (mm)	1.5	3.6	*	2.0	3.8	*	0.0	2.9	ns	0.6	3.1	ns
TNGXA (mm^2)	119.4	233	*	132.2	246	*	60.8	179.9	ns	150.5	129	*

Variables that showed statistical significance $*P < .01$ *SD,* standard deviation; *ns,* not significant; *Div,* division. Changes expressed as posttreatment minus pretreatment values. See Fig 2 for abbreviations.

RESULTS

The 71 patients had been wearing OAs for a minimum of 4 nights a week. Most wore this appliance every night because, without regular wear, morning headaches and excessive daytime sleepiness were reported. These patients had been using OAs for 7.3 ± 2.1 years when the follow-up evaluation was completed. A team of 5 orthodontists evaluated pretreatment and posttreatment models and reached consensus on the Angle classification[39] of each patient. The mean cephalometric changes according to craniofacial type before treatment and after long-term use of the OA for the whole sample are shown in Table I. Of the 71 patients, molar relationships were 49 Class I, 10 Class II Division 1, 10 Class II Division 2, and 2 Class III.

In the total sample, the maxilla showed a significant retroclination of the incisors (ΔU1 to SN angle and ΔU1 to PP angle equal to −3.1° and −3.5°, respectively), the molars tipped distally (ΔU6ΔSN angle and ΔU6PP angle equal to −2.3° and −2.6°, respectively) and extruded (0.5 mm). In the mandible, there was a significant downward rotation (ΔSNMP angle and ΔPPMP angle equal to 0.7° and 1.0°, respectively), proclination of the lower incisors (ΔL1 to MP angle = 6.6°), the molars tipped mesially (ΔL6 to MP angle = 3.4°) and also extruded (0.7 mm). There were no significant differences in chin position relative to the cranium (SNPg angle), mandibular length, or condylion vertical and horizontal positions. The relationship between maxillary and mandibular incisors significantly changed, with decreases in OB (−2.8 mm), OJ (−2.6 mm), interincisor angle (−4.1°), and an increase in basal bone relationship (0.5°). There was a mesial tendency in the follow-up molar relationship (ΔU6L6SN = −1.8 mm). There were significant increases in total facial height (1.8 mm) and lower facial height (1.8 mm), with more changes in lower facial height because of a decrease in the proportion of upper facial height to lower facial height (ΔUFHLFH% = −1.9%). In the analysis of the upper airway, there were increases in vertical airway length (1.8 mm), tongue height (1.5 mm), and tongue cross-sectional area (119.4 mm^2). For the Class I subgroup, the only variables that were not statistically significant, in comparison with the

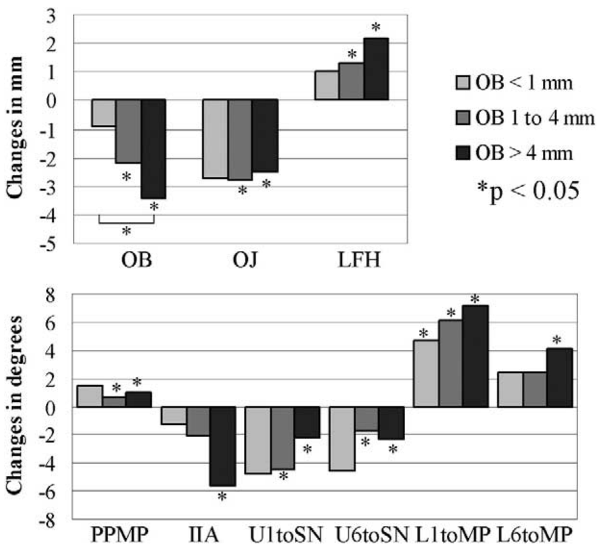

Fig 4. Cephalometric changes divided by initial OB measurements.

whole sample, were maxillary molar height and basal bone relationship (ANB angle). In the Class II Division 1 subgroup, significant changes were observed: proclination of the lower incisors (ΔL1 to MP angle = 7.0°), decrease in OJ (−2.4 mm), and mesial tendency in the molar relationship (ΔU6L6SN = −2.1 mm). In the Class II Division 2 subgroup, only the maxillary incisors (−3.0°) and the tongue cross-sectional area (150.5 mm^2) changed significantly. Although different variables became significant for the different intermaxillary relation groups, there was no statistical difference within the craniofacial types. The 2 patients with Class III malocclusions were excluded from the statistics because of the small sample size (see Fig 2 for definitions).

In relation to the initial OB, as shown in Figure 4, the sample was divided into shallow OB (<1 mm), normal OB (1-4 mm), and deep overbite (>4 mm). The deep OB group had statistically significant changes in OB, OJ, lower facial height, and PPMP, IIA, U1 to SN, U6SN, L1MP, and L6MP angles. The normal OB group showed significant changes similar to the deep OB group with the exception of the IIA and L6 to MP angles. Mandibular incisor angulation was the only variable that changed significantly in the shallow OB group. There was a significant difference between the shallow and deep groups for OB changes. Subjects with deep OBs before OA use tended to have greater changes in bite depth over time (Fig 4).

For duration of OA use, the sample was divided into 3 subgroups: <6 years, 6-8 years, and > 8 years of OA use, and further subdivided according to skeletal type (Table II). In the entire sample, there were significant differences between subgroups 6-8 years and >8 years: less extrusion of the maxillary molars, less proclination of the mandibular incisors, and smaller decreases in the interincisor angle in the 6-8 years group. The hyoid progressively increased its vertical position, showing a significant difference between the subgroups <6 years and >8 years. In the Class I subgroup, there were significant changes between the subgroups <6 years and >8 years, showing progressive decreases in SNA angle, increases in mandibular plane angle, backward position of pogonion, and increases in total facial height. The OB change increased significantly between the subgroups <6 years and 6-8 years. In the Class II subgroup, the hyoid progressively increased its vertical position, and there was less extrusion of the mandibular molars (Table II).

Several variables showed significant correlations when analyzed with Pearson correlation. An initial deep OB correlated with a greater reduction in OB (R2 = 0.13) and a greater increase in lower facial height (R2 = 0.08). An initial proclined maxillary incisor correlated with a greater increase in ANB angle (R2 = 0.08) and a greater decrease in U1 to SN angle (R2 = 0.08). An initial steep mandibular plane correlates with more retroclination of the maxillary incisors (R2 = 0.09). Longer use of an OA and increasing patient age correlated with a more retropositioned pogonion (R2 = 0.07 and R2 = 0.07, respectively). Longer use of an OA also correlated with a more vertical position of the hyoid bone (R2 = 0.14). A more severe baseline apnea and hypopnea index correlated with a greater decrease in ANB angle (R2 = 0.13).

DISCUSSION

This study demonstrates that OAs used for a mean period of 7.3 years have a significant impact on occlusal and dental structures, eg, a 2.8 mm decrease in OB and a 2.6 mm decrease in OJ. Changes observed in craniofacial structures were mainly related to significant tooth movements. Although some changes might be undesirable in certain patients, we believe that the effective treatment of a life-threatening disease such as OSA supersedes the maintenance of baseline occlusion. Even if major tooth movements are seen, the discontinuation of OA treatment should occur only if the patient accepts another treatment modality, such as continuous positive airway pressure. Because the greatest changes are in the anterior teeth, studies of OA designs with less force or pressure on the labial surfaces of the maxillary incisors and on the lingual surfaces of the mandibular incisors are indicated to evaluate whether these changes could be reduced.

Table II. Duration of oral appliance use and amount of change

	All (n = 71)			*Class I (n = 49)*			*Class II (n = 20)*		
	< *6y*	*6-8y*	> *8y*	< *6y*	*6-8y*	> *8y*	< *6y*	*6-8y*	> *8y*
# of patients	25	21	25	18	15	16	7	6	7
Maxilla									
SNA (°)	0.8	0.0	−0.3	0.9	−0.1	−0.8	0.4	0.1	0.9
MXMH (mm)	0.7	1.1	0.0	0.94	0.89	−0.1	0.0	1.7	0.2
Mandible									
SNMP (°)	0.3	0.4	1.2	−0.1	0.7	1.9	1.2	−0.3	−0.2
SNPg (°)	0.1	−0.5	−0.8	0.2	−0.6	−1.2	−0.4	−0.4	0.3
L1 to MP (°)	6.3	8.9	5.0	6.5	9.3	6.2	5.8	7.7	2.8
MDMH (mm)	0.3	0.7	1.1	0.1	0.8	1.5	1.0	0.4	0.8
HH1 (mm)	−0.5	1.3	2.5	0.3	1.5	2.7	−2.4	0.7	2.7
Intermaxillary relationships									
OB (mm)	−2.0	−3.7	−2.8	−2.1	−4.4	−3.8	−1.8	−2.0	−1.5
IIA (°)	−3.6	−6.9	−2.4	−3.0	−7.1	−3.5	−5.0	−6.5	0.6
TFH (mm)	1.3	2.1	2.0	1.0	2.2	3.2	2.0	1.9	0.5

*$P < .05$. Changes expressed as posttreatment minus pretreatment values. See Fig 2 for abbreviations.

This is the first study of the side effects of OAs used for more than 5 years. In previous studies, only 12% to 19.2% of patients were reported to have occlusal changes,[26,27,31] but, as demonstrated by previous authors,[27,31,34] their perceptions do not correlate with objective measurements unless those changes were brought to the patient's attention by a general dentist. One study evaluated the general untreated population and found small, although sometimes significant, dental arch changes, and OB and OJ were reported to be stable during adulthood.[40] In the literature on OAs, their side effects are similar, are not influenced by type of appliance, and are of greater magnitude than in the general population. OAs do impose a significant pressure on dental structures, having to hold the mandible and subsequently the tongue in a forward position. Our findings were expected, although not of this magnitude, as a result of these forces. In a review article, Aelbers and Dermaut[41] concluded that most orthopedic appliances move teeth, but not craniofacial structures, and only Herbst appliances showed significant decreases in ANB angle and increases in SNB angles and mandibular length (condylion-pogonion) distance in children. In the orthodontic literature, it is common clinical conjecture that removable orthopedic appliances have minor effects on the adult dentition but seldom apply such jaw displacement forces as those seen in OSA patients.

According to our results, OAs induced tooth movements but not craniofacial skeletal changes. The changes we found are opposite to the findings with a Herbst appliance in growing children.[42] We found an increase in ANB angle, a tendency for SNB angle to decrease, and no change in mandibular length (condylion-pogonion) in children; these could be interpreted as downward rotation of the mandible, seen as an increase in SNMP angle related to the decrease in OB and OJ without mandibular growth. Downward rotation of the mandible without forward displacement, the absence of mandibular growth, and changes in dental positions in this study confirm previous findings[24,27,33,35,43] with the exception of Bondemark,[32] who found increases in mandibular length and forward rotation of the mandible. Still, these findings challenge a paradigm in orthodontics because significant amounts of tooth movement were achieved with OAs in adults. Although it was not measured in our study, Marklund et al[34] and Bondemark[32] reported no change between centric relation and centric occlusion before and after OA use; this also suggests that the occlusal changes we found are related to tooth movement and not to a neuromuscular adaptation.

As a consequence of the proclination of the mandibular incisors, the retroclination of the maxillary incisors, and the molar extrusion, rotation of the mandible and increases in interincisal angle and lower facial height were observed. But these were not the only statistically significant measurements in our study; the mandibular molar extruded and tipped forward as the maxillary molar rotated distally and extruded. This was confirmed by the mesial tendency in the molar relationship, indicating a more forward position of the mandibular arch, also reported by Fritsch et al[24] and Marklund et al.[34] We believe that these tooth movements are movements of the entire arch. OAs have full-arch occlusal coverage, and therefore the mechanical loading force is applied to all teeth; this could explain the mesial movement of the mandibular molar and the distal movement of the maxillary molar. If the incisors move, all supporting dental structures might move in response to this change; perhaps transceptal fibers also have an important role in this phenomenon. A healthy periodontium is continuously remodeling to maintain equilibrium and function.[44] Molar extrusion findings have not been described previously. In contrast, Rose et al[31] hypothesized that intrusion of the molars (increase in the posterior open bite) is related to vertical openings greater than 8 to 12 mm induced by the OA. However, no cephalometric measurements of molar height confirmed molar intrusion in that report.

With objective cephalometric measurements, decreases in OB and OJ agree with previous studies,[24,27,31-34] except for that of Ringqvist et al,[43] who found decreases that did not reach statistical significance. Although our study was cross-sectional, including different patients in each duration-of-use subgroup, we found that changes in OB tended to continue as long as OAs were used. This could explain why we found greater changes than previous shorter studies. Changes in OB and OJ seem to be related to incisor angulation changes, which have been described as smaller but similar in other articles.[24,27,31-35,43]

Although studies in children show that changes related to orthodontic treatment can be predicted in part by the characteristics of the initial malocclusion, we found no statistical difference between the amounts of dental and occlusal changes and the different malocclusion groups; this confirms previous findings.[27,31,34] Although significant levels were not achieved, we observed differences among Class I, Class II Division 1, and Class II Division 2 subjects (Table I). The OB changes were −3.3 mm in Class I, and −1.6 and −1.9 mm, respectively, in Class II Division 1 and Class II Division 2. Another interesting finding was a much smaller proclination of the mandibular incisors and retroclination of the maxillary incisors in the Class II Division 2 subjects. Even though these changes were smaller and did not achieve statistical significance, because of the intermaxillary relationships in the Class II Division 2 subjects, they might have clinical relevance, producing an anterior edge-to-edge bite. This peculiarity might be related to our traditional concept of significant vertical muscle forces in Class II Division 2 patients. However, our sample might have been too small to find significant differences between these skeletal subgroups.

For the amount of mandibular advancement, most patients in this study had used 1 to 6 appliances during the period that the side effects occurred, and so the amount of advancement might have varied during treatment. Over time, OSA worsens, and further advancements of the mandible might be required. As a clinical protocol for treatment with the Klearway appliance, mandibular advancement starts at two-thirds of maximum protrusion (6-10 mm), and further advancement is required for persistent snoring or sleep apnea symptoms. Almeida et al[29] reported that an increase in mandibular advancement was correlated with a decrease in the respiratory disturbance index. Marklund et al[34] also found greater efficacy with appliances with 75% advancement compared with 50% advancement. Although we could not ascertain the amount of advancement from the patient records, it was always more than 6 mm. The accurate measurement of the amount of advancement and the subsequent side effects over 5 years are still necessary to understand the mechanisms involved. Several authors reported that orthodontic changes were not related to OA design or mandibular advancement.[24,27,31] Robertson et al[33] postulated that changes in OB could be reduced with a smaller vertical opening of the appliance. Marklund et al[34] reported no relationships between the amount of vertical opening and OJ change and between mandibular advancement and OB change, but that, with a mandibular advancement greater than 6 mm, a soft elastomeric appliance had a greater risk of causing OJ changes than a hard acrylic appliance. However, the patients who used the hard acrylic appliances had greater changes in OB and OJ. The Klearway appliance is a titratable appliance made of thermo-sensitive acrylic. We believe that the orthodontic side effects found in our study and most similar studies are related to mandibular advancement and not to differences in appliance design or material. Nonetheless, a prospective random study with 2 groups with different appliances is needed, including a cephalometric study in centric occlusion before treatment followed by a study with the appliance in the titrated position more than 5 years later, to confirm the possible differences.

A particular strength of this study was the duration of OA use. This was the first study to evaluate long-term side effects over a mean period of 7.3 years, but there were some potential limitations. Patient compliance was not objectively measured. There is no commercially available compliance monitor because the appliance must function intraorally, without a power supply.[36] As a cross-sectional study, findings over a period of time are verified in different patients, and not in the same patient over time, and this could result in error. A cephalometric prospective study over a determined period is required. Some patients changed the type of OA used during the study period. Almeida et al[29] reported no TMJ changes with an OA, but we did not assess the TMJ in the long term in our study. For the measurements of condylion position, there was no significant difference in either its vertical or horizontal position, in contrast to an earlier study in which a significant downward displacement was seen.[33] Condylion measurements should be interpreted with caution because only a careful TMJ assessment, based on tomography or magnetic resonance imaging, can properly evaluate the position of the TMJ and possible changes related to OA usage. Patients needing OAs are usually older than 40 years, when periodontal disease tends to increase, and a prospective study with a detailed periodontal assessment is required to evaluate this possible important predictor of tooth movement. Sleep apnea is more prevalent in men, and, in our clinic, over 80% of the patients are men. In a previous study, women experienced more side effects and showed a greater tendency to abandon treatment than men.[25]

Dividing our sample into groups with various durations of OA use, we found that most changes tended to continue over time. These results are especially important because OAs might be a lifelong therapy, and changes in the alveolar bone over time could affect tooth movements. When the apical surface of a tooth impinges on cortical bone, the remodeling process is no longer possible, and there is a risk of root resorption or bone fenestration.[45,46] Measurements of alveolar bone width and shape of the incisors were not evaluated; further studies are required. The consequences of OA use over 20 or 30 years is unknown, and careful follow-ups of these patients are imperative.

From a clinical perspective, it would be useful to find good predictors of OA side effects. This study found that patients with a baseline OB greater than 4 mm had greater changes in OB than those with an initial OB smaller than 1 mm. The greater the initial OB, the greater the decrease in OB. We found other correlations, none of which were strong, but we hypothesize that several characteristics are involved, each with a different amount of influence. A more proclined maxillary incisor at baseline was correlated with a greater decrease in the U1 to SN angle. Another interesting finding was that the older the patient, the greater the retroposition of the mandible. Marklund et al[34] found similar results, and this might be related to diminished periodontal health in elderly patients that would favor the decrease in OJ and consequent increase in SNPg angle. OSA tends to worsen with age, and, as life expectancy increases, there might be more demand in the geriatric population for OA therapy.[2] A lower hyoid position is a characteristic of OSA severity,[37] and obesity is another.[47] Although we could not find a statistical difference in hyoid position before and after treatment, we determined that the longer a patient used an OA, the greater the hyoid's vertical distance. Increases were found by Robertson et al[33] after 1 year of treatment and by Fransson et al[35] after 2 years of treatment. We hypothesize that a greater inferior hyoid displacement could be age related. Nelson et al,[48] in a longitudinal study, identified increases in hyoid position and vertical airway length. These factors might be related to the tendency of patients to worsen with age and suggest the need for greater mandibular advancements over time. A larger tongue is related to more severe apnea and to a greater body mass index.[37,47] Although it was not measured, the patients studied might have gained weight, or their OSA might have been exacerbated during OA use.

CONCLUSIONS

Our results showed that craniofacial side effects occur after long-term OA use, and this might have clinical implications. With the use of mandibular advancement appliances over a mean duration of 7.3 years, we found significant and progressive changes in the dentition. Because OAs are a lifelong treatment approach for OSA, and the changes appeared to continue over time, the collection of cephalometric radiographs, study models, and intraoral photographs before and during treatment should be encouraged in all clinical OA protocols.

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