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Scientific Investigations

Obstructive Sleep Apnea and Mandibular Advancement Splints: Occlusal Effects and Progression of Changes Associated with a Decade of Treatment

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Study Objectives: To evaluate the magnitude and progression of dental changes associated with long-term mandibular advancement splint (MAS) treatment of obstructive sleep apnea (OSA).

Methods: Retrospective study of adults treated for primary snoring or mild to severe OSA with MAS for a minimum of 8 years. The series of dental casts of patients were analyzed with a digital caliper for changes in overbite, overjet, dental arch crowding and width, and inter-arch relationships. The progression of these changes over time was determined and initial patient and dental characteristics were evaluated as predictors of the observed dental side effects of treatment.

Results: A total of 77 patients (average age at start of treatment: 47.5 ± 10.2 years, 62 males) were included in this study. The average treatment length was 11.1 ± 2.8 years. Over the total treatment interval evaluated there was a significant ($p < 0.001$) reduction in the overbite (2.3 ± 1.6 mm), overjet (1.9 ± 1.9 mm), and mandibular crowding (1.3 ± 1.8 mm). A corresponding significant ($p < 0.001$) increase of mandibular intercanine (0.7 ± 1.5 mm) and intermolar (1.1 ± 1.4 mm) width as well as incidence of anterior crossbite and posterior open bite was observed. Overbite and mandibular intermolar distance were observed to decrease less with time, while overjet, mandibular intercanine distance, and lower arch crowding all decreased continuously at a constant rate.

Conclusions: After an average observation period of over 11 years, clinically significant changes in occlusion were observed and were progressive in nature. Rather than reaching a discernible end-point, the dental side effects of MAS therapy continue with ongoing MAS use.

Commentary: A commentary on this article appears in this issue on page 1293.

Keywords: obstructive sleep apnea, sleep apnea therapy, sleep apnea complications, removable orthodontic appliances, orthodontic appliances adverse effects, time factors, treatment outcome

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Obstructive sleep apnea (OSA) often leads to poor sleep quality, daytime sleepiness, and an increased risk of motor vehicle accidents, hypertension, and stroke.[1] Oral appliances, which function to hold the mandible in a forward position and enlarge the airway during sleep, are indicated as a primary treatment option for snoring and mild to moderate OSA. These appliances are also being implemented as a alternative for patients with severe OSA who are unwilling or unable to tolerate continuous positive airway pressure for the management of their disease.[1] To this end a number of recent studies have documented the efficacy of mandibular advancement splints (MAS) in improvements in daytime sleepiness, AHI, and mean arterial blood pressure and/or cardiovascular health.[2-10]

The MAS is the main type of oral appliance currently used, and though well tolerated, has identified short-term and long-term side effects. Initial transient effects may include excess salivation or mouth dryness, temporomandibular joint and dental discomfort and irritation of intra-oral tissues.[11] The skeletal and dental changes that occur after prolonged MAS treatment have been previously described in terms of appliance design, amount of mandibular protrusion, and duration of wear.[12-15]

BRIEF SUMMARY

Current Knowledge/Study Rationale: Mandibular advancement splints are an effective treatment option for OSA patients, with changes to the dental occlusion as a common side effect. Due to the indefinite nature of OSA treatment a clear understanding of the magnitude and progression of long-term occlusal changes is needed.

Study Impact: With the longest observation period yet to be reported, the results from this study confirm that long-term MAS treatment leads to significant changes in occlusion for the majority of patients. These dental changes were found to be progressive in nature, and continue with ongoing MAS use.

However, some of these studies are limited by a relatively short observation period, considering that MAS treatment may continue indefinitely through a patient's lifetime.

Previous studies examining effects over at least a 5-year treatment period have shown significant decreases in overbite (OB)—the vertical overlap of the anterior teeth, and overjet (OJ)—the horizontal overlap of the anterior teeth, ranging from 0.6-1.91 mm and 0.6-1.24 mm, respectively, after long-term appliance use.[16-18] These studies also report various

Table 1—Baseline patient characteristics.

N	77
Males	62
Age (years)	47.5 ± 10.2 (26–70)
Years in treatment	11.1 ± 2.8 (8.0–19.3)
BMI	29.4 ± 7.2 (18.7–63.6)
AHI (N = 54)	29.8 ± 16.9 (2.4–77.4)

Values presented as mean ± standard deviation (range).

degrees of changes in mandibular crowding, posterior occlusal contacts and in mandibular arch width. The progression at which these changes occur is still unclear. It has been proposed that dental changes may decrease with time,[16,19] while others[20] have found that changes tend to be progressive in nature. Interestingly, Battagel, in a study of 30 patients averaging 3.64 years of MAS use, found no statistically significant correlation between the duration of MAS wear and the change in OB and OJ.[15] However these previous attempts to classify the time course of occlusal changes with MAS use may have been over too short an observation period to appreciate their progression.

Though MAS adherence rates vary, potential reasons for discontinuing treatment are occlusal side effects and complications.[21] It is hoped that an improved understanding of the progression of these dental changes may help in designing optimal treatment protocols that allow for maximum adherence to prescribed MAS treatment. The present study characterizes the dental changes associated with MAS therapy over the longest observation period published to date, as well as an examination of the progression of these side effects over time.

The specific aims of this study are to report on the magnitude and progression of dental changes associated with long-term MAS treatment, as well as to investigate the relationship between the observed changes, the initial occlusion, and the BMI.

METHODS

De-identified demographic data and dental study casts of patients (**Table 1**) who were treated a minimum of 8 years with a MAS for snoring or OSA were retrieved from the Sleep Apnea Dental Clinic at the University of British Columbia and the private practice of a co-author. In these clinics it is typical protocol to produce dental casts for any follow-up appointment requiring major repair or replacement of the MAS. Thus patients had a variable number of intermediate records available; however, all had ≥ 8 years between their initial and most recent set of records. Patients were excluded if they had missing dental study casts from either their initial or most recent set of records, and most patients reported wearing the appliance nightly. The total period of MAS use was calculated as the interval between initial appliance placement and the date of the most recent study casts. Initial severity of OSA for treated patients ranged from primary snoring to severe OSA. The Clinical Research Ethics Board of the University of British Columbia approved this study.

MAS Treatment

All patients were treated with a custom made, titratable, biblock mandibular advancement appliance (Klearway; Space Maintainers Laboratories Canada Ltd., Calgary, Canada), made of thermoplastic material with embedded metal clasps. The upper and lower members of the appliance are connected via an adjustable screw assembly, which fits in the area of the palatal vault and allows for titration in 0.25-mm increments. The initial mandibular advancement was set at two-thirds of maximum mandibular protrusion, and then further advancements were prescribed by 0.25-mm increments until self-reported resolution of snoring and daytime sleepiness symptoms, or until uncomfortable for the patient. Improvement in OSA was then often verified by a follow-up overnight sleep study with the appliance in place.

Data Collection and Statistical Analysis

The dental study casts were measured with a digital caliper with a resolution of 0.1 mm by a single investigator. Characteristics assessed included OJ and OB (mean values for the central incisors were used), dental crowding, intermolar and intercanine distances, as well as the number of posterior teeth with open occlusal contacts and anterior teeth in crossbite.[18] Fifteen sets of models were measured a second time after a 2-week interval to assess method error. Descriptive measures and paired t-tests were used to report changes over the entire observation period (final – initial records), while method errors were calculated using Dahlberg's formula. Spearman and Pearson correlation coefficients were used to determine the influence of initial patient characteristics on the magnitude of occlusal changes. In an examination of all available data points, a mixed-effect polynomial regression analysis was used to analyze the data for the rate at which changes occur over the course of treatment. To determine the influence of initial occlusion on the rate of change, patients were also further subdivided into groups of normal or excessive initial OJ and OB for this analysis. Statistical significance was determined at $p < 0.05$.

RESULTS

Overall Occlusal Changes

The records of a total of 77 patients with an average treatment time of 11.1 years were included for analysis in this study. Twenty-six patients presented with mild and moderate OSA, while 28 had severe OSA prior to initiation of treatment. The remaining 23 patients were either snorers or had only baseline oximetry performed. They were predominantly male and mildly obese (mean BMI 29 kg/m^2). Further description of the patient's baseline characteristics can be seen in **Table 1**. The assessed method error for the dental measurements ranged from 0.13 to 0.64 mm.

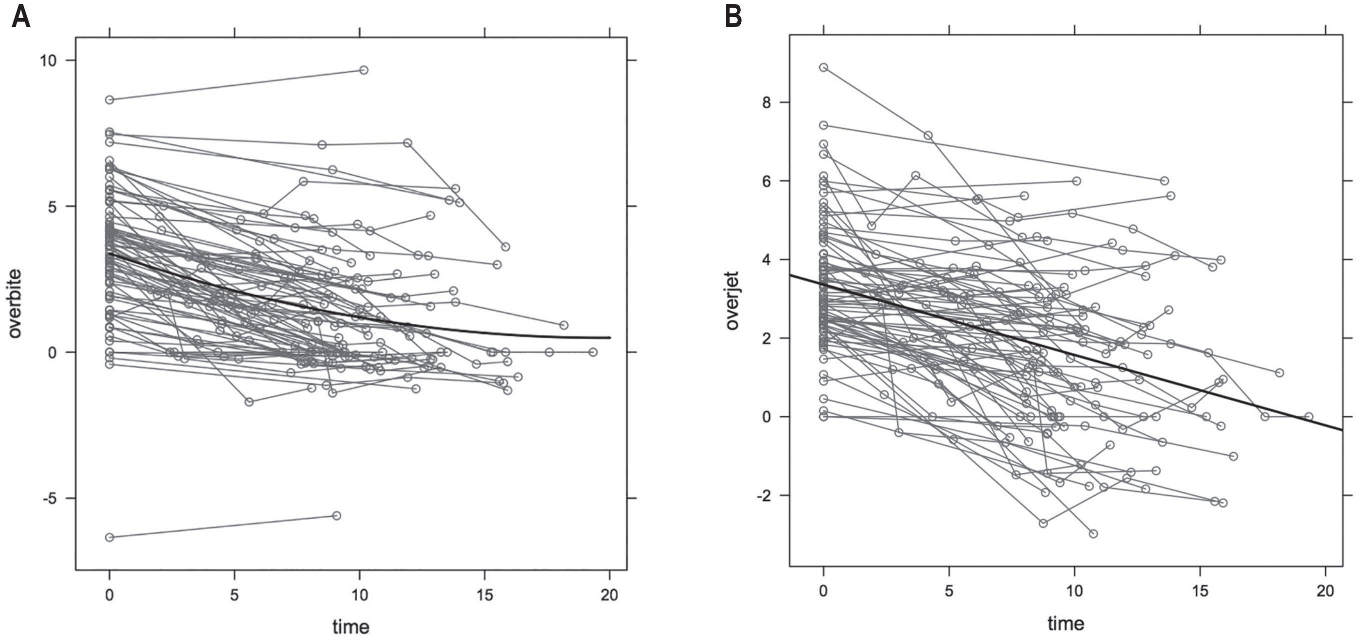
Over the total treatment interval evaluated there was a significant change in the relationship between the upper and lower arches where a decrease in the OJ and OB was observed. Additionally the lower arch was found to have expanded significantly, as measured by increases in mandibular intercanine and intermolar distances, as well as a decrease in mandibular arch

Table 2—Overall occlusal changes during treatment (n = 77).

	Initial	Final	Final – Initial	p value
Overbite (mm)	3.4 ± 2.3	1.1 ± 2.1	-2.3 ± 1.6	< 0.001
Overjet (mm)	3.3 ± 1.7	1.4 ± 2.1	-1.9 ± 1.9	< 0.001
Mandibular crowding (mm) *	0.6 ± 2.5	-0.6 ± 2.7	-1.3 ± 1.8	< 0.001
Maxillary crowding (mm)	2.0 ± 2.9	1.8 ± 2.9	+0.2 ± 1.3	0.31
Mandibular intercanine width (mm)	26.2 ± 2.3	26.9 ± 2.2	+0.7 ± 1.5	< 0.001
Maxillary intercanine width (mm)	34.6 ± 2.8	34.4 ± 2.9	-0.2 ± 1.2	0.11
Mandibular intermolar width (mm)	34.8 ± 3.5	35.9 ± 3.6	+1.1 ± 1.4	< 0.001
Maxillary intermolar width (mm)	39.5 ± 4.0	39.8 ± 4.4	+0.4 ± 1.4	0.02
Mandibular posterior teeth out of occlusion	0.7 ± 2.0	2.6 ± 2.6	+1.9 ± 2.1	< 0.001

Values presented as mean ± standard deviation. * A negative number denotes spacing.

Figure 1—All data points for the entire sample population for overbite **(A)** and overjet **(B)** in millimeters, as a function of number of years in treatment.



The data for each individual patient is connected by a gray line. The overall relationship of all data is represented by the black line, demonstrating the decreasing but leveling off, and linear rate of changes for overbite and overjet respectively.

crowding (**Table 2**). No significant changes were observed in maxillary variables.

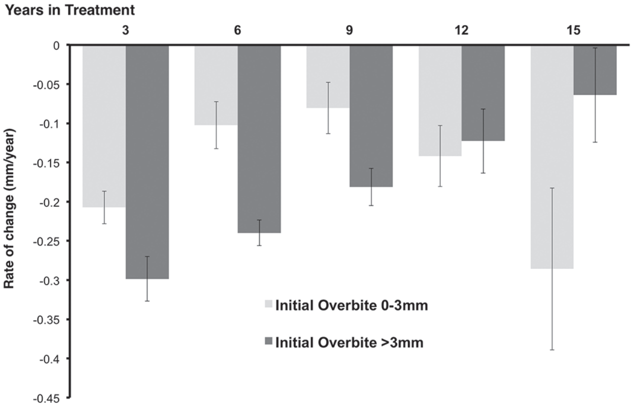
Two important characteristics that anecdotally weigh heavily in a patient's perception of the quality of occlusion, posterior openbite and anterior crossbite, both demonstrated significant changes in the sample population. A posterior openbite, which for the purposes of this study is defined by the loss of occlusal contact on at least 2 posterior teeth, developed in 51% (39/77) of the sample. Similarly 62% (48/77) of the sample developed an anterior crossbite of at least one tooth—defined as a lack of positive horizontal overlap of the upper anterior teeth over the lower anterior teeth. However of those patients that developed a crossbite, an average of 4 teeth were involved.

Progression of Occlusal Changes

Of the occlusal parameters that changed significantly during treatment ($p < 0.001$), additional analysis was performed to characterize how these changes progressed with time. Mixed effects polynomial regression analyses were performed to determine the relationship of these variables to time in treatment. The scope of the population data for both OJ and OB are illustrated in **Figure 1**. Once this relationship was established the rate of change per year could be calculated, demonstrating significant differences in how these changes progressed over time. Looking at the entire sample population, OB was observed to decrease less with time, while OJ decreased continuously at a constant rate.

The progression in OB and OJ changes were further examined in terms of initial occlusal characteristics (**Figures 2** and **3**, respectively), which revealed that the initial amount of OJ had no effect on the progression of change. However the initial amount of OB did alter the pattern of future changes, as patients with a small initial OB were found to have the rate of change first decrease, and then later increase in magnitude as treatment time was extended beyond 9 years. Conversely, patients with

Figure 2—Rate of change in overbite based on baseline bite characteristic of deep (N = 48) or normal (N = 26).



Patients with no initial vertical overlap (N = 3) were excluded from the analysis.

Figure 3—Rate of change in overjet based on baseline bite characteristic of excess (N = 39) or normal (N = 38) horizontal overlap of the anterior teeth.

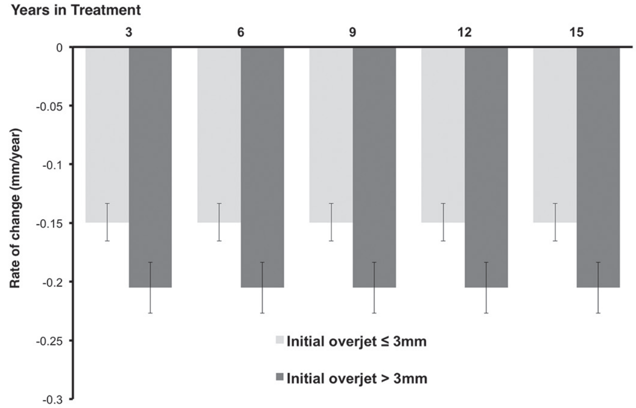


Figure 4—Rate of change in mandibular intercanine distance.

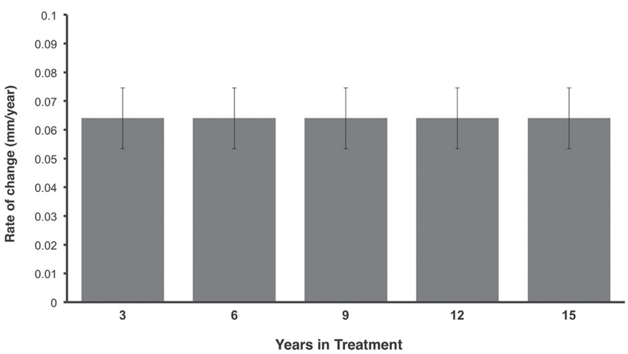


Figure 5—Rate of change in mandibular intermolar distance.

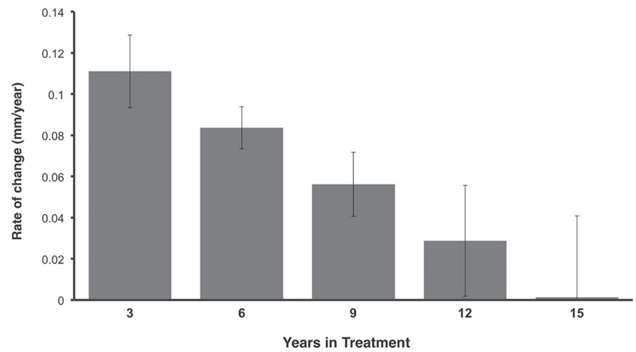
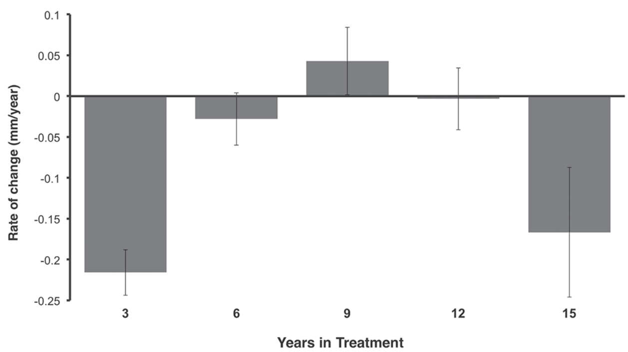


Figure 6—Rate of change in mandibular arch crowding.



deep bite at pre-treatment saw the rate at which their overbite lessened, gradually decrease with time.

Examining the mandibular arch characteristics, we found significant change over time in the intercanine width, which continuously increased at a constant rate, while mandibular intermolar distance was found to increase most rapidly initially and then taper off with small increases occurring after 12 years of treatment time (**Figures 4** and **5**) The changes in the rate at which mandibular arch crowding decreases appears to be more complex, with early rapid decrease followed by small changes until after 12 years of treatment when the rate rises again (**Figure 6**).

Patient Characteristics as Predictors of Occlusal Changes

In assessing initial patient characteristics for predictors of occlusal changes, we found that patient age, sex, and pretreatment BMI were unrelated to the amount of both OJ and OB reduction, as well as the occurrence of anterior crossbite or posterior openbite. The amount of total change in overjet was significantly correlated to initial AHI (r = 0.28), though no other relationships with occlusal variables were found.

Initial OJ was not significantly related to the occurrence of anterior crossbite or posterior openbite. Initial OJ was positively correlated to the total observed change in both OB (r = 0.28) and OJ (r = 0.33). Initial overbite was significantly negatively correlated (r = -0.37) to anterior crossbite and positively correlated (r = 0.44) to total observed change in overbite caused by MAS treatment.

DISCUSSION

The present results demonstrate the dental changes associated with MAS treatment of OSA over the longest observation period published to date. After an average of over 11 years of treatment, clinically significant reductions of 2.3 mm and 1.9 mm in OB and OJ, respectively, are seen. Also, it is clear that the changes in occlusion are progressive in nature. Rather than reaching a discernible end-point, the reductions in OB and OJ and widening of the lower dental arch continue with ongoing MAS use.

The magnitude of the changes presently reported are slightly greater than those previously described for long-term (> 5 years) studies. Martinez et al. found a mean OB reduction of 0.81 mm and OJ reduction of 1.1 mm from 15 OSA patients with 4.8 years of MAS use.[16] Similarly, Marklund found reductions in both OB and OJ of 0.6 mm from a 5-year follow-up of 187 OSA patients.[18] Almeida and colleagues[18] in an examination of 70 patients over a 7-year period recorded reductions of 1.91 mm and 1.24 mm in overbite and overjet, respectively. These minor differences may be due in part to varying observation periods and smaller sample sizes. The smaller amounts of change reported by Marklund[17] maybe further influenced by her use of monoblock, non-adjustable appliances.

Importantly, the dental changes occurring from MAS use are not limited to decreases in OB and OJ, but rather include a number of parameters of the dentition (**Table 2**). Mandibular crowding decreases, just as mandibular intercanine and intermolar width increase over the course of treatment. We also found on average that an openbite developed on more than two lower posterior teeth. These findings are in line with those previously reported by other long-term studies.[16,18,22] The physiology of biologic tooth movement has been well characterized,[23] and it is understood that even very low applied forces, if applied for a sustained amount of time (such as for several hours during nighttime wear of an appliance) will result in tooth movement. All MAS appliances position the mandible forward and retain it in place by contacting the dentition. The force required to suspended the mandible and associated soft tissues thus is transmitted to the dental arches and likely results in the occlusal changes reported.[24] It should be understood then that the dental side effects of MAS treatment are a product of protruding the mandible to achieve a therapeutic effect rather than specific appliance design.[25] This is likely why studies examining side effects comparing different appliance designs have found very little difference in terms of magnitude of these secondary effects of dental movement.[12,13] Indeed, by extension into the orthodontic literature, one can see that attempts to provide more or less tooth-appliance contact or even rigidly splinting the mandibular teeth together with a cast metal framework does little to mitigate the dental movement.[26] All but one of the 77 patients examined experienced greater than 0.2 mm of occlusal change in terms of overjet and overbite, which speaks to the confidence at which one can expect to see dental movement with this type of therapy.

The development of posterior open bite and anterior teeth in crossbite were also common among the patients of this study. A posterior openbite may occur as the lower arch, and in particular the lower incisors are protruded forward as a result of prolonged MAS treatment. Commonly observed in the orthodontic treatment of retrognathic malocclusions with functional appliances,[27] this type of tooth movement causes an occlusal interference as the patient is now unable to close the posterior teeth down together completely due to the premature contact of the anterior teeth. Similarly, crossbites of anterior teeth will occur as the lower arch moves forward and the overjet and overbite are reduced to the point where the lower teeth protrude beyond the upper anterior teeth. These two facets of occlusion have also been previously reported in the literature. Vezina et al. reported both anterior and posterior openbite in a small proportion of patients who had been treated with MAS for an average of over 3.5 years, though no openbites were found in patients treated for 6 months or less.[12] Rose and colleagues, after a treatment period of at least two years in 34 patients, found a posterior openbite had developed in 26% of the patients studied.[25]

Upon examining the time frame at which occlusal changes occur with MAS treatment, we found that the reduction in overjet is progressive and continues at a constant rate so as long as the MAS treatment continues. This is a logical finding considering that the main mechanism of action with a MAS appears to be the protrusion of the mandible and associated soft tissues, improving the caliber of the upper airway.[28] As long as this continues to occur, forces will also continue to be applied to the teeth resulting in tooth movement. Overbite however was found to decrease less with time in our sample population. This may be explained by the inseparable relationship of overjet and overbite. As the mandible and lower arch are protruded forward, the overbite will decrease less and less until eventually there is no longer any further vertical overlap of the anterior teeth. At this point the lower arch can continue to be protruded forward without any further interference from the upper anterior teeth. Our results align with those of Marklund, who reported on the progression of occlusal changes in a subset of 51 patients treated for at least 5 years with a mono-block style of MAS.[17] Marklund found overall that dental side effects increased with treatment time as well as more frequent use of the device. She also stated that overjet decreased continuously during the observed 5-year treatment period, whereas overbite changes diminished with time in the sample population studied.

Conflicting results were previously reported by Pantin et al. in a retrospective survey of 106 patients recalled and examined following an average duration of MAS treatment of 31 ± 18 months.[19] They found that the proportion of patients with occlusal change increased with length of use of the mandibular advancement splint up to 2 years. Beyond 2 years, the proportion remained relatively constant. The authors further stated that this implies that a patient's period of greatest vulnerability to these complications is within the first 2 years of treatment. This key difference with the present study may be partially explained by differences in study design. Unlike our longitudinal examination of patients, Pantin et al. performed a cross-sectional analysis, where patients were examined only once at a particular point in time. Additionally very few (n = 27) of these patients were in MAS treatment longer than 48 months.

Pre-treatment BMI was found to be unrelated to any observed occlusal changes. This may not be surprising considering the extended observation period, throughout which patients may see their BMI vary widely, masking any direct relationship that may exist between these variables. We found that the initial AHI was positively related to the magnitude of observed reduction in overjet. The influence of AHI on change in overjet may be explained by the fact that patients with more severe OSA could be more likely to have their mandibles advanced a greater amount to see a relief in symptoms compared to patients with a milder degree of the disease.[29] It has been previously shown that the relationship between the force applied to the arches and amount of mandibular advancement is almost linear, with the force increasing with increasing mandibular advancement.[24]

In the present study, patients with a greater amount of initial overjet tended to see larger total reductions to both overjet and overbite. This may be due to the greater amount of clearance for the forward movement of the lower dentition that occurs in these patients, before the lower anterior teeth would contact the corresponding upper anterior teeth. We also found that patients with minimal amounts of initial overbite were more likely to experience crossbite of the anterior teeth with prolonged MAS treatment, while those with greater amounts of initial overbite saw greater amounts of overbite reduction as the result of treatment. These results lead to the notion that the specific expected occlusal changes associated with MAS treatment may be predicated on the presentation of patient's dentition, with the vast majority seeing marked reductions in both overbite and overjet.

This study has some limitations, including that only one particular MAS was investigated and the risk of selection bias due to the retrospective study design. While great care was used to include all available records that met the treatment time (> 8 years) criteria, the patients who discontinued treatment for any reason over this period were not included in the analysis. Also, the compliance and reporting of the exact amount of time the appliance was used was subjective and based on patient self-reporting to routine follow-up questions. However the majority of patients in this study all were successfully treated with their MAS appliance based on follow-up PSG, and over the course of the observation period most had their MAS remade or replaced at their own cost—an unlikely occurrence if the appliance was rarely used. Future studies involving multiple appliance designs and incorporating newly developed compliance monitors embedded within the MAS should help determine a minimum threshold of use that will result in the dental changes reported here. The strength of this study is the observed period of MAS treatment at 11.1 years, which is the longest to date, described in the literature. This long-term treatment with several intervening data time points allowed for the novel reporting of a longitudinal analysis of the progression of occlusal changes associated with MAS treatment.

Mandibular advancement splints are an effective, noninvasive treatment option for snoring and obstructive sleep apnea. The present findings make it clear that many of the significant dental changes that occur will continue to progress over the duration of treatment, and as MAS treatment of OSA will continue indefinitely, the prudent clinician will be aware of these changes and discuss them openly with patients in their care.

REFERENCES

1. Kushida CA, Morgenthaler TI, Littner MR, et al. Practice parameters for the treatment of snoring and obstructive sleep apnea with oral appliances: an update for 2005. *Sleep* 2006;29:240-3.
2. Holley AB, Lettieri CJ, Shah AA. Efficacy of an adjustable oral appliance and comparison with continuous positive airway pressure for the treatment of obstructive sleep apnea syndrome. *Chest* 2011;140:1511-6.
3. Gotsopoulos H, Kelly JJ, Cistulli PA. Oral appliance therapy reduces blood pressure in obstructive sleep apnea: a randomized, controlled trial. *Sleep* 2004;27:934-41.
4. Barnes M, McEvoy RD, Banks S, et al. Efficacy of positive airway pressure and oral appliance in mild to moderate obstructive sleep apnea. *Am J Respir Crit Care Med* 2004;170:656-64.
5. Aarab G, Lobbezoo F, Heymans MW, Hamburger HL, Naeije M. Long-term follow-up of a randomized controlled trial of oral appliance therapy in obstructive sleep apnea. *Respiration* 2011;82:162-8.
6. Gagnadoux F, Fleury B, Vielle B, et al. Titrated mandibular advancement versus positive airway pressure for sleep apnoea. *Eur Respir J* 2009;34:914-20.
7. Hoekema A, Stegenga B, Bakker M, et al. Simulated driving in obstructive sleep apnoea-hypopnoea; effects of oral appliances and continuous positive airway pressure. *Sleep Breath* 2007;11:129-38.
8. Aarab G, Lobbezoo F, Hamburger HL, Naeije M. Oral appliance therapy versus nasal continuous positive airway pressure in obstructive sleep apnea: a randomized, placebo-controlled trial. *Respiration* 2011;81:411-9.
9. Andrén A, Hedberg P, Walker-Engström ML, Wahlén P, Tegelberg Å. Effects of treatment with oral appliance on 24-h blood pressure in patients with obstructive sleep apnea and hypertension: a randomized clinical trial. *Sleep Breath* 2013;17:705-12.
10. Dieltjens M, Vanderveken OM, Hamans E, et al. Treatment of obstructive sleep apnea using a custom-made titratable duobloc oral appliance: a prospective clinical study. *Sleep Breath* 2013;17:565-72.
11. Chan AS, Cistulli PA. Oral appliance treatment of obstructive sleep apnea: an update. *Curr Opin Pulm Med* 2009;15:591-6.
12. Vezina JP, Blumen MB, Buchet I, Hausser-Hauw C, Chabolle F. Does propulsion mechanism influence the long-term side effects of oral appliances in the treatment of sleep-disordered breathing? *Chest* 2011;140:1184-91.
13. Lawton HM. A comparison of the Twin Block and Herbst mandibular advancement splints in the treatment of patients with obstructive sleep apnoea: a prospective study. *Eur J Orthod* 2005;27:82-90.
14. Doff MHJ, Finnema KJ, Hoekema A, Wijkstra PJ, de Bont LGM, Stegenga B. Long-term oral appliance therapy in obstructive sleep apnea syndrome: a controlled study on dental side effects. *Clin Oral Investig* 2013;17:475-82.
15. Battagel JM, Kotecha B. Dental side-effects of mandibular advancement splint wear in patients who snore. *Clin Otolaryngol* 2005;30:149-56.
16. Martínez-Gomis J, Willaert E, Nogues L, Pascual M, Somoza M, Monasterio C. Five years of sleep apnea treatment with a mandibular advancement device. Side effects and technical complications. *Angle Orthod* 2010;80:30-36.
17. Marklund M. Predictors of long-term orthodontic side effects from mandibular advancement devices in patients with snoring and obstructive sleep apnea. *Am J Orthod Dentofacial Orthop* 2006;129:214-21.
18. Almeida FR de, Lowe AA, Otsuka R, Fastlicht S, Farbood M, Tsuiki S. Long-term sequellae of oral appliance therapy in obstructive sleep apnea patients: Part 2. Study-model analysis. *Am J Orthod Dentofacial Orthop* 2006;129:205-13.
19. Pantin CC, Hillman DR, Tennant M. Dental side effects of an oral device to treat snoring and obstructive sleep apnea. *Sleep* 1999;22:237-40.
20. Robertson C, Herbison P, Harkness M. Dental and occlusal changes during mandibular advancement splint therapy in sleep disordered patients. *Eur J Orthod* 2003;25:371-6.
21. Ferguson KA, Cartwright R, Rogers R, Schmidt-Nowara W. Oral appliances for snoring and obstructive sleep apnea: a review. *Sleep* 2006;29:244-62.
22. Ueda H, Almeida FR, Lowe AA, Ruse ND. Changes in occlusal contact area during oral appliance therapy assessed on study models. *Angle Orthod* 2008;78:866-72.
23. Proffit WR, Fields HW Jr, Sarver DM. Contemporary orthodontics. 5 ed. St. Louis: Elsevier, 2013.
24. Cohen-Levy J, Petelle B, Pinguet J, Limerat E, Fleury B. Forces created by mandibular advancement devices in OSAS patients. *Sleep Breath* 2012;17:781-9.
25. Rose EC, Staats R, Virchow C, Jonas IE. Occlusal and skeletal effects of an oral appliance in the treatment of obstructive sleep apnea. *Chest* 2002;122:871-7.
26. Weschler D, Pancherz H. Efficiency of three mandibular anchorage forms in Herbst treatment: a cephalometric investigation. *Angle Orthod* 2005;75:23-7.
27. DeVincenzo JP. Changes in mandibular length before, during, and after successful orthopedic correction of Class II malocclusions, using a functional appliance. *Am J Orthod Dentofacial Orthop* 1991;99:241-57.
28. Chan ASL, Sutherland K, Schwab RJ, et al. The effect of mandibular advancement on upper airway structure in obstructive sleep apnoea. *Thorax* 2010;65:726-32.
29. Marklund M, Franklin KA, Sahlin C, Lundgren R. The effect of a mandibular advancement device on apneas and sleep in patients with obstructive sleep apnea. *Chest* 1998;113:707-13.

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DISCLOSURE STATEMENT

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