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Original

# Short-term effects of oral appliances with equal bite-raising distance but with varying protrusions on occlusal force, contact area and load center

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**Abstract: The purpose of this study was to demonstrate how short-term wearing of an oral appliance (OA) with equal bite-raising distance but with varying protrusions affects occlusal force, contact area and load center. Twelve young healthy volunteers participated. With the appliance, the mandible was protruded 0%, 45%, 60% and 75% of maximum protrusion capacity, with 10 mm bite-raising between the first molars. The occlusal force, contact area and load center at maximum voluntary clenching were measured before wearing the OA, at 1 h, 3 h and 6 h during wearing, and 1 h after removal. When compared to the values before wearing the OA, occlusal force was significantly lower at 1 h, 3 h and 6 h during wearing in the case of no mandibular protrusion, and at 3 h and 6 h after for 45%, 60% and 75% of maximum mandibular protrusion ($P < 0.05$). Occlusal contact area was significantly smaller at 1 h and 6 h during wearing in the case of no protrusion, and at 6 h during wearing in the case of 45% of maximum protrusion ($P < 0.05$). There was a tendency for anterior shift in the location of the occlusal load center at 3 h and 6 h during wearing of the OA with any level of maximum protrusion. No significant change in these three measurements was found at 1 h after removal of the OA. The present study demonstrated that wearing an OA had only a marginal and transient influence on oral functions when their changes were compared before and after wearing the OA. (J. Oral Sci. 50, 253-258, 2008)**

Keywords: oral appliance; mandibular protrusive distance; occlusal force; occlusal contact area; occlusal load center.

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## Introduction

Repositioning of the mandible forward and downward by wearing an oral appliance (OA) has become widely used for the treatment of obstructive sleep apnea syndrome (OSAS) (1). The use of an OA including a mandibular advancement appliance is aimed at preventing obstruction of the upper airway caused by the tongue and soft palate. The efficacy of this approach has been reported in numerous clinical studies (2-6).

However, long-term sustained repositioning of the mandible forward and downward increases the likelihood of adverse effects on occlusal functions involving the jaw muscles (7,8) and temporomandibular joints (3,7), and the morphology of the maxillofacial area (9). Up to now, studies examining the influence of an OA in terms of the raised bite distance and mandibular protrusive distance on these elements of occlusal function have been limited (8,10-12). In order to improve the design of an OA, more knowledge of its effects is required. As an initial study to investigate this issue, we selected young healthy volunteers and tested whether short-term wearing (1 h, 3h and 6 h)

of an OA with equal bite-raising distance (10 mm) but with varying protrusion (0%, 45%, 60% and 75% of maximum protrusion capacity) affected occlusal force, occlusal contact area and the occlusal load center.

## Materials and Methods

This study was approved by the Ethics Committee at Nihon University School of Dentistry (approval No: 2005-25), and written informed consent was obtained from all subjects.

### Subjects

We studied 12 subjects (healthy volunteers: 6 male and 6 female) aged 26-29 (mean ± SD: 27.7 ± 1.1) years, who were scheduled for dental treatment at Nihon University Dental Hospital. Exclusion criteria included mal-dentition and a history of oral and maxillofacial dysfunction.

### Fabrication of the OA

Maxillary and mandibular master casts were attached to a semi-adjustable arcon articulator (Hanau Wide-VUE II, Teredyne Hanau) in the intercuspal position. To reproduce the sagittal condylar path angles, we measured and traced the condylar path of protrusive excursion using a 6-degrees-of-freedom jaw-movement tracking device (Gnatho Hexagraph II, GC, Tokyo, Japan). Then, we drew a straight line from the intercuspal and protrusive positions, and measured the angle between it and the Frankfort horizontal (FH) plane. The bite-raising distance of the OA was set at 10 mm. Specifically, the intersecting distance between the cervical line and the line passing through the mid-point of the mesiodistal width of the crown of the maxillary and mandibular right first molars that intersects perpendicular to the occlusal plane was 10 mm more than the distance at the intercuspal position. Resin blocks made from self-curing acrylic resin were placed in the condylar guide of the articulator to adjust the mandibular protrusive distance to 0%, 45%, 60% and 75% of the maximum protrusion capacity of the subjects, which was measured and calculated using a Gnatho Hexagraph II.

The OA was made from a thermoplastic resin sheet 1.0 mm thick (Erkodur, Erkodent Erich Kopp GmbH). The resin sheet, placed on the mandible, was formed by using a maxillary and mandibular master cast followed by heating and pressuring. It was then cut at the level of contour, but at slightly more incisal level in the case of anterior teeth. The divided thermoplastic resin sheets corresponding to the maxilla and mandible were coupled with quick self-curing acrylic resin (Unifast II, GC) on an articulator.

Using this method, four types of OAs were constructed: 10-mm bite-raising with no protrusive distance; and 10-mm bite-raising with protrusive distances of 45%, 60% and 75% of maximum protrusion capacity.

### Measurement of occlusal force, occlusal contact area, and occlusal load center

Measurements of occlusal force, occlusal contact area and occlusal load center were conducted before wearing the OA, at 1 h, 3 h and 6 h during wearing of each OA, and at 1 h after OA removal. Each subject was instructed to sit with the FH plane parallel to the floor, and then maximum voluntary clenching for five seconds on a commercially available detector (DENTAL PRESCALE®: 50H, R type, Fujifilm, Tokyo, Japan) was conducted 3 times with 1-min intervals during each measurement session. A 1-week interval was allowed between the wearing of each type of OA.

### Analyses of occlusal force, occlusal contact area and occlusal load center

Occlusal force and occlusal contact area were analyzed using a commercially available apparatus (OCCLUZER®: FPD-707, Fujifilm) specially designed for the detector, DENTAL PRESCALE®.

Occlusal load center was analyzed according to the method reported by Shinogaya and Matsumoto (13). In brief, images of the occlusal view of a maxillary diagnostic cast taken perpendicular to the occlusal plane with a digital camera (FinePix: S2 Pro, Fujifilm) were used as standard images. Occlusal contact point and occlusal load center collected from the Occluzer were superimposed on the standard images using a personal computer (LaVie LL900/9, NEC, Tokyo, Japan) wirh image treatment software (Adobe Photoshop CS3 Extended, Adobe Systems, California, USA). The relative position of the occlusal load center within the dentition was calculated as a coordinate value (%). For the coordinate axes, the line passing through the contact point of the right and left central incisors and crossing perpendicular to the median palatine suture was defined as the X axis, whereas the line passing through the distobuccal cusp of the left second molar and parallel to the median palatine suture was defined as the Y axis. Defining the intersection of the two axes as the origin and the distobuccal cusp of the right second molar as X = 100% and Y = 100%, antero-posterior and right-left coordinates of the occlusal load center were represented two-dimensionally.

The highest value of three measurements for each of occlusal force, occlusal contact area and occlusal load center was used as a representative value for individual subjects. The obtained data were subsequently subjected to statistical analysis.

### Statistical analysis

The data were expressed as means ± SEM. To evaluate how differences in protrusive distance affect occlusal force, occlusal contact area and occlusal load center, comparisons with the values before wearing the OA were made by analysis of valiance (ANOVA) followed by post hoc Dunnett's test. Differences at $P < 0.05$ were considered statistically significant. All analyses were conducted using SPSS software (v. 11.0.1 J, SPSS Science, Inc.).

## Results

### Occlusal force

Figure 1 shows the values of occlusal force relative to the values before wearing the OA set as 100%. When compared to the values before wearing OA, occlusal force in the case of no mandibular protrusion was significantly lower at 1 h, 3 h and 6 h during wearing of the OA ($P < 0.05$). In the cases of 45%, 60% and 75% of maximum mandibular protrusion, occlusal force was significantly lower at 3 h and 6 h during wearing of the OA ($P < 0.05$). However, 1 h after removal of the OA, no significant change was found in any cases of mandibular protrusion.

### Occlusal contact area

Figure 2 shows values of occlusal contact area relative to the values before wearing the OA set as 100%. When compared to the values before wearing the OA, occlusal contact area in the case of no protrusion was significantly smaller at 1 h and 6 h during wearing of the OA ($P < 0.05$). In the case of 45% of maximum protrusion, occlusal contact area was significantly smaller only at 6 h during wearing of the OA ($P < 0.05$). However, 1 h after removal of the OA, no significant change was evident in any cases of mandibular protrusion.

### Occlusal load center

Figures 3A and 3B show values of antero-posterior and right-left location of the occlusal load center. When compared to the values before wearing the OA, there was a tendency for an anterior shift in the location of the occlusal load center at 3 h and 6 h during wearing of the OA at maximum protrusion. However, no lateral shift in the occlusal load center was found at any level of mandibular protrusion.

## Discussion

The present study evaluated whether short-term wearing (1-6 h) of an OA with a constant bite-raising distance (10 mm) but with varying degrees of protrusion (0%, 45%, 60% and 75% of maximum protrusion capacity) affected occlusal force, occlusal contact area, and occlusal load center. For the experimental design, a relatively short wearing period (6 h) was selected by assuming an overnight wearing period, with shorter periods (1 h and 3 h) selected as references. Recovery of occlusal function parameters was also tested at 1 h after OA removal. A relatively large bite-raising distance (10 mm at the maxillary and mandibular right first molar and approximately 15-17 cm at the maxillary and mandibular central incisor) was determined based on the report by Taga et al. (14), which indicated that wearing a template approximately 12 mm thick at the second molar improved SAS. Protrusive distance was set at 45%, 60% and 75% of maximum protrusion capacity, considering previous studies that had used values of 50-80% (5,9-12): 0% was selected to evaluate the influence of bite-raising alone. Thus, the range of protrusive distances selected in this study was considered to be within the normal clinical range.

In this study, it was necessary to measure occlusal force and occlusal contact area repeatedly. For this purpose, DENTAL PRESCALE® and its analytic apparatus, OCCLUZER®, were employed because of their applicability and high reliability. In fact, previous reports have indicated that this system is easy to operate and highly reliable, as well as having good reproducibility for measurement of analytical parameters such as occlusal force and occlusal contact area, thus allowing us to conduct measurements under conditions similar to the intercuspal position (15,16).

In the case of no mandibular protrusion, when compared to the values before wearing the OA, occlusal force was significantly lower at 1 h, 3 h and 6 h during wearing of the OA. A significant reduction in occlusal contact area was also seen at 1 h and 6 h. In this situation, the 10-mm bite-raising alone induced by wearing the OA created enforced mandibular rotation without condylar excursion. However, in the usual open-close movement, the condyle performs both excursion and rotation to produce a 10-mm opening, which is considered to keep the mandibular position outside the habitual path of open-close movement (17). Consequently, this may induce fatigue in the masticatory muscles and cause a reduction of both occlusal force and occlusal contact area by extension of the jaw-closing muscle due to bite-raising.

For 45%, 60% and 75% of maximum mandibular protrusion, occlusal force was significantly reduced at 3 h and 6 h during wearing of the OA. A significant reduction in occlusal contact area was also seen at 6 h. It was reported previously that rotation of the condyle toward the opening direction and persistence of the opening position inhibit masseteric $\alpha$ motor neurons (18). Two sources of trigeminal inputs are thought to be involved in the inhibitory

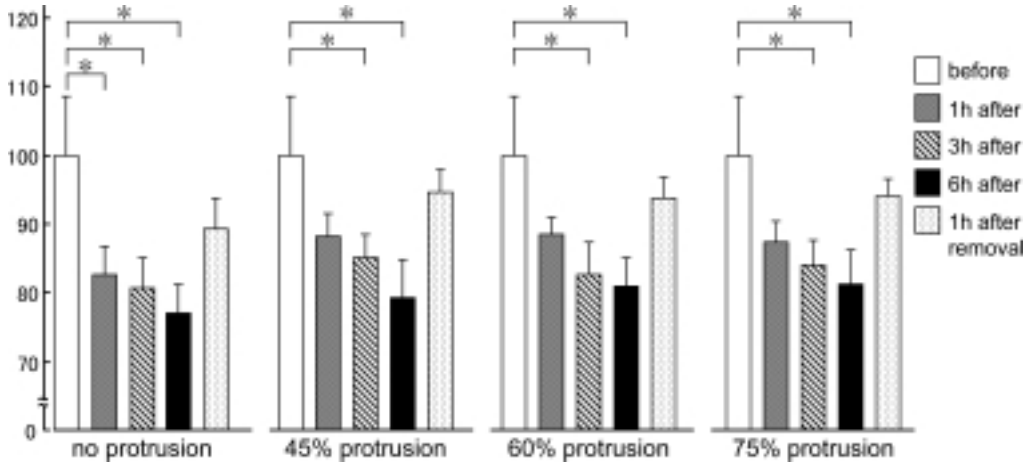


Fig. 1 Effects of wearing OA on occlusal force.
Mean ± SEM
n = 12
*: $P < 0.05$

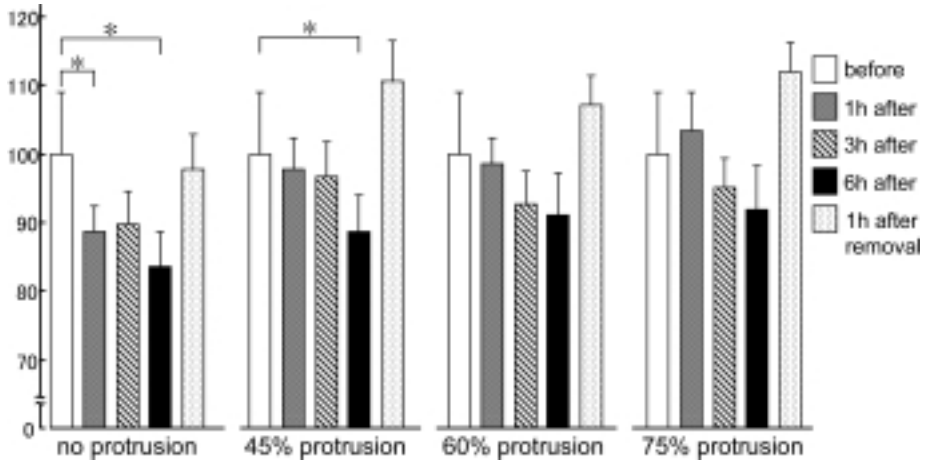


Fig. 2 Effects of wearing OA on occlusal contact area.
Mean ± SEM
n = 12
*: $P < 0.05$

mechanism of jaw-closing motor neuron activity following extensive jaw opening. One is the tendon organ receptors in the jaw closing muscles and the other is noxious afferents from the temporomandibular joint capsule. Together with previous results, our findings suggest that the occusal force may be reduced by inhibition of jaw-closing motor neurons, as a consequence of long-term maintenance of the condyle in a forward and downward position, accompanied by rotation and excursion induced by wearing the OA.

For the antero-posterior location of the occlusal load center there was a tendency for an anterior shift in the location of the occlusal load center at 3 h and 6 h during wearing of the OA at any level of maximum protrusion. However, no lateral shift of the occlusal load center was found at any level of mandibular protrusion, suggesting that the main area of occlusal contact shifted from the molar to the premolar by the large protrusive distance keeping the mandible in a forward and downward position. This would also be a possible cause of the significant reduction in occlusal force.

More importantly, at 1 h after removal of the OA, no significant change was evident in occlusal force, occlusal contact area or occlusal load center at any degree of

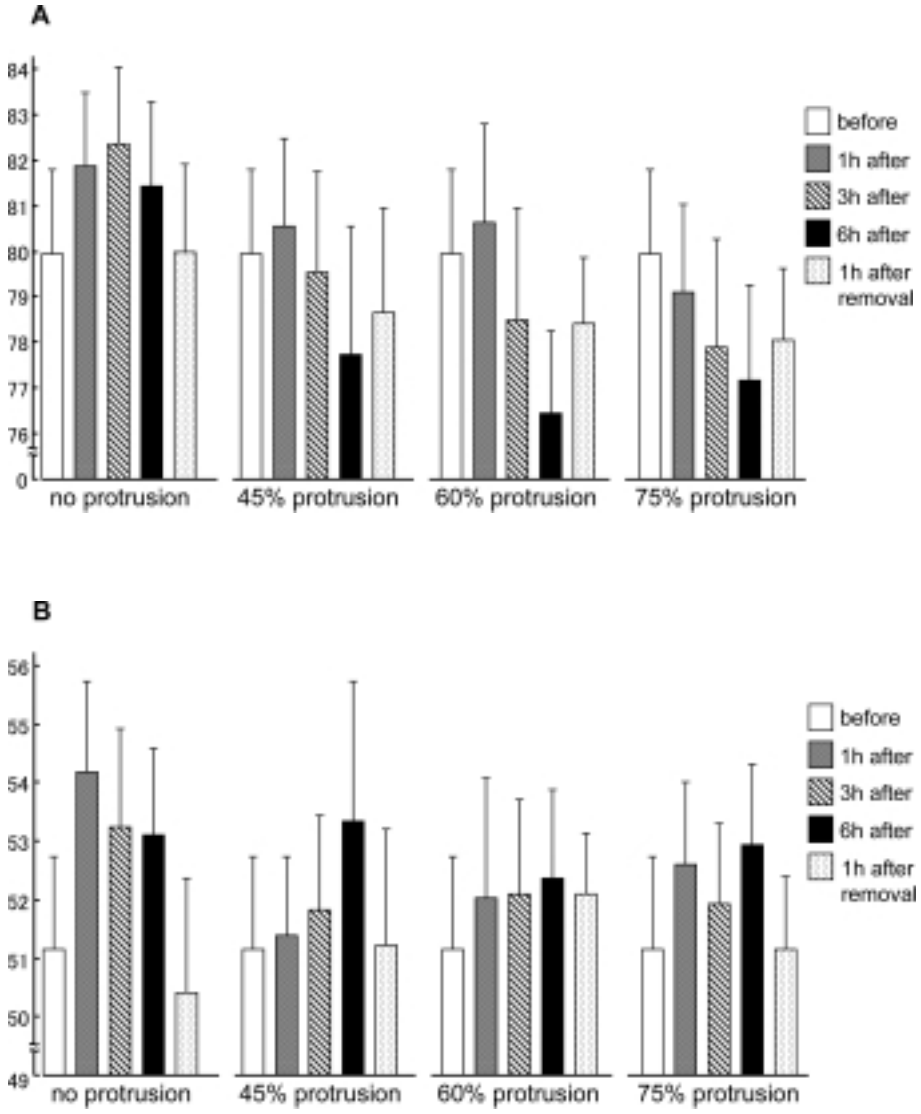


Fig. 3 Effects of wearing OA on occlusal load center.
A, antero-posterior location of the occlusal load center; B, right-left location of the occlusal load center.
Mean ± SEM
n = 12
*: $P < 0.05$

mandibular protrusion, indicating that the effects of wearing an OA are transient.

Although this study focused on short-term wearing of an OA, future studies are needed to evaluate the influence of long-term continuous OA use, as patients must wear these devices on consecutive nights for treatment purposes. In fact, some morphological (9,19) and functional (7) alterations have already been reported. For instance, for OAs worn in the maxillofacial area, posterior rotation of the mandible (9), and reductions in overjet and overbite and alterations in the horizontal relationship of the maxillary and mandibular first molars (19) have been found. From a functional viewpoint, a survey of snorers and OSAS patients who wore OAs with full coverage of the maxillary and mandibular molars continuously for more than 5 years reported the occurrence of side effects such as relatively mild temporomandibular joint pain and myofacial pain, as well as changes in occlusion (7).

In summary, the present study has demonstrated that wearing our specially manufactured OA for 6 h had only a marginal and transient influence on oral functions when changes in these parameters were compared before and after wearing the OA.

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## References

1. Lindman R, Bondemark L (2001) A review of oral devices in the treatment of habitual snoring and obstructive sleep apnea. Swed Dent J 25, 39-51
2. Liu Y, Zeng X, Fu M, Huang X, Lowe AA (2000) Effects of a mandibular repositioner on obstructive sleep apnea. Am J Orthod Dentofacial Orthop 118, 248-256
3. Tegelberg A, Wilhelmsson B, Walker-Engström ML, Ringqvist M, Andersson L, Krekmanov L, Ringqvist I (1999) Effects and adverse events of a dental appliance for treatment of obstructive sleep apnoea. Swed Dent J 23, 117-126
4. Bondemark L (1999) Does 2 years' nocturnal treatment with a mandibular advancement splint in adult patients with snoring and OSAS cause a change in the posture of the mandible? Am J Orthod Dentofacial Orthop 116, 621-628
5. O'Sullivan RA, Hillman DR, Mateljan R, Pantin C, Finucane KE (1995) Mandibular advancement splint: an appliance to treat snoring and obstructive sleep apnea. Am J Respir Crit Care Med 151, 194-198
6. Rose EC, Schnegelsberg C, Staats R, Jonas IE (2001) Occlusal side effects caused by a mandibular advancement appliance in patients with obstructive sleep apnea. Angle Orthod 71, 452-460
7. Pantin CC, Hillman DR, Tennant M (1999) Dental side effects of an oral device to treat snoring and obstructive sleep apnea. Sleep 22, 237-240
8. Rose E, Staats R, Virchow C, Jonas IE (2002) A comparative study of two mandibular advancement appliances for the treatment of obstructive sleep apnoea. Eur J Orthod 24, 191-198
9. Ringqvist M, Walker-Engström M-L, Tegelberg Å, Ringqvist I (2003) Dental and skeletal changes after 4 years of obstructive sleep apnea treatment with a mandibular advancement device: a prospective, randomized study. Am J Orthod Dentofacial Orthop 124, 53-60
10. Marklund M, Franklin KA, Persson M (2001) Orthodontic side-effects of mandibular advancement devices during treatment of snoring and sleep apnoea. Eur J Orthod 23, 135-144
11. Pitsis AJ, Darendeliler MA, Gotsopoulos H, Petocz P, Cistulli PA (2002) Effect of vertical dimension on efficacy of oral appliance therapy in obstructive sleep apnea. Am J Respir Crit Care Med 166, 860-864
12. Walker-Engström ML, Ringqvist I, Vestling O, Wilhelmsson B, Tegelberg A (2003) A prospective randomized study comparing two different degrees of mandibular advancement with a dental appliance in treatment of severe obstructive sleep apnea. Sleep Breath 7, 119-130
13. Sinogaya T, Matsumoto M (1998) Evaluation of prosthodontic treatment by occlusal force distribution: a methodological study. Eur J Prosthodont Restor Dent 6, 121-125
14. Taga H, Tomaru T, Naitoh S, Maehara S, Taga M, Maehara K, Serada K (2004) Effect of template therapy on sleep apnea syndrome. Showa Igakkai Zasshi 64, 114-119 (in Japanese)
15. Hattori Y, Okugawa H, Watanabe M (1994) Occlusal force measurement using dental prescale. Nihon Hotetsu Shikagakkai Zasshi 38, 835-841 (in Japanese)
16. Shiono H, Chiba SH, Watanabe S, Igarashi T, Nakajima K, Takeda T, Ishigami K, Ohki K (1995) Basic study on "Dental Prescale System" Part I. The range of fluctuation in occlusal contact area and the influence of applying bite-silicone material on "Dental Prescale". Nihon Hotetsu Shikagakkai Zasshi 39, 710-716 (in Japanese)
17. Ulrich J (1959) The human temporomandibular joint: kinematics and actions of the masticatory muscles. J Prosthet Dent 9, 399-408
18. Kawamura Y, Abe K (1974) Role of sensory information from temporomandibular joint. Bull Tokyo Med Dent Univ 21 Suppl, 78-82
19. Bondemark L, Lindman R (2000) Craniomandibular status and function in patients with habitual snoring and obstructive sleep apnoea after nocturnal treatment with a mandibular advancement splint: a 2-year follow-up. Eur J Orthod 22, 53-60