Effect of Occlusal Appliances and Clenching on the Internally Deranged TMJ Space

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Aims: *Stabilization appliances and mandibular anterior repositioning appliances have been used to treat patients with internal derangement of the temporomandibular joint (TMJ) based on the assumption that these appliances work by decompressing the TMJ. The purpose of this study was to indirectly test this assumption.* **Methods:** *Bilateral TMJ tomograms of 7 subjects with unilateral anterior disc displacement without reduction (ADDwor) were taken during comfortable closure and during maximum clenching in maximum intercuspation; tomograms were also taken with the 2 types of occlusal appliances in use. Outlines of the condyle and the temporal fossa were automatically determined by an edge-detection protocol, and the minimum joint space dimension of the joints with and without ADDwor was automatically measured for each experimental condition as the outcome variable.* **Results:** *Upon comfortable closure and maximum clenching, the minimum joint space dimensions of the ipsilateral and contralateral joints with the use of stabilization appliances and mandibular anterior repositioning appliances were not significantly different from those seen in maximum intercuspation.* **Conclusion:** *These findings do not indicate that these appliances induce an increase in joint space during closing and clenching in joints with ADDwor.*
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Key words: temporomandibular disorders, stabilization appliance, mandibular anterior repositioning appliance, tomogram, image-analyzing procedure

Stabilization appliances (SA) and mandibular anterior repositioning appliances (MARA) have been widely used for management of temporomandibular disorders (TMD) such as internal derangement and degenerative arthritis. Although these appliances have been assumed to reduce interarticular surface compression in the temporomandibular joint (TMJ) during closing or clenching,[1–4] no scientifically supportive data have been reported about the surface-to-surface decompressive effects on the TMJ structures.

In a previous study,[5] a helical blurring-motion tomogram that was enhanced by a computerized image-analysis system was used to directly measure changes in condylar position and joint space dimension during comfortable closure (CC) and maximum clenching in the intercuspal position (ICP) and when 2 different occlusal appliances (SA and MARA) were used in normal, asymptomatic TMJ subjects. It was found that in normal, asymptomatic subjects, the minimum joint space dimension during maximum clenching with the SA was equivalent to maximum clenching in ICP, while maximum clenching with the MARA was significantly less. These findings did not support the hypothesis that these appliances induce an increase in joint space during clenching.

Since the sample that was used in the previous study consisted of normal, asymptomatic TMJ subjects, extrapolation of the results to the TMJ internal derangement and/or osteoarthritic subjects who are treated with these appliances is easily challenged. Therefore, a homogeneous sample of subjects who had been diagnosed with unilateral anterior disc displacement without reduction (ADDwor) was recruited in the current study to clarify the effect of these appliances and clenching on the minimum TMJ space of affected and nonaffected joints. The null hypothesis that was tested in this study is that there is no increase in the minimum TMJ space of patients with unilateral ADDwor while the patients are using the appliances.

Materials and Methods

Subjects

Seven subjects (4 females and 3 males, mean age 36.5 ± 12.6 years) with unilateral ADDwor (6 right cases and 1 left case) were recruited from patients who sought treatment at the TMD clinic of Okayama University Dental School. The inclusion criteria were: *(1)* clinical history of unilateral TMJ pain and locking during opening and/or difficulty in jaw opening for less than 6 months, *(2)* presence of all teeth except for third molars, and *(3)* magnetic resonance image (MRI) evidence of unilateral ADDwor, which was defined according to previously described criteria.[6] The exclusion criterion was clear radiographic evidence of osseous changes in the TMJ. Mean and standard deviation (SD) of the voluntary maximum jaw opening dimension between the maxillary and mandibular right central incisors was 38.6 ± 8.6 mm. This study protocol was approved by an appropriate committee in the authors' department, and informed consent was obtained from each subject prior to the commencement of the study.

Experimental Procedure

The SA and MARA were fabricated for each subject prior to the experiment. Dental impressions of the maxillary and mandibular arches were used to make the stone casts. The SA that was used in this experiment was a maxillary complete appliance with a flat occlusal table. This device was adjusted to provide uniform simultaneous occlusal contact of all teeth except the third molars. The MARA that was used was a maxillary complete appliance with indentations and guiding ramps that kept the mandible in an anterior position. The SA was designed to open the jaw vertically 3 mm from ICP in the anterior region; the MARA was designed to hold the jaw in a straight, forward position 2 mm from ICP, with the mandibular and maxillary anterior teeth in an edge-to-edge relationship. The subjects were instructed to close their jaws comfortably without biting. The interjaw relationship for SA and MARA was registered intraorally with a silicone impression material (Exabite, GC) by the use of a jaw-tracking system (mandibular kinesiograph K6-I, Myotronics) to monitor the position of the mandible. The mandibular position was monitored to instruct the subjects on where to position their jaws during the occlusal registration and to check the postadjustment position of the jaws after completion of the appliances. The appliances were made of a polymethylmethacrylate resin (Acron MC, Shofu) and were preadjusted on an articulator. Prior to the experiment, both appliances were carefully adjusted by the use of articulating paper to obtain a stable position, with even contact on all posterior teeth subjectively and objectively. The final interjaw relationship that was achieved with the appliances was reconfirmed with the jaw-tracking system in a fashion blind to the subjects. The subjects were then trained to clench maximally in ICP and with the SA and MARA.

For the radiographic assessment, each subject was seated with his or her head tightly fixed by a head positioner with individualized bilateral ear rods and pointers on his or her forehead and under his or her nose so that Camper's plane was parallel to the floor. Beam angles were corrected 15 degrees laterally so that tomographic slices were perpendicular to the long axes of the mandibular condyle. Serial sagittal tomograms of the TMJs were obtained with the Optiplanimat (Siemens) having a spiral 45-degree pattern that provided at least 3 slices of 2-mm thickness at intervals of 5 mm (160 mAs, 66 kVp; Fuji G-4 screen, Fuji Photo Film). The tomogram with the slice level that was nearest to the central part of the condyle was selected. Joint images were obtained at this slice depth with the subjects closing comfortably and clenching maximally in the maximum ICP. This procedure was repeated for both appliances for each of the 7 subjects. Six images were taken for each joint: 1 baseline condition (CC in ICP) and 5 experimental conditions (CC with the SA and with the MARA, and maximum clenching in ICP with both the SA and the MARA). The sequence for acquiring each of these 6 images was randomly assigned for each joint. Three-minute

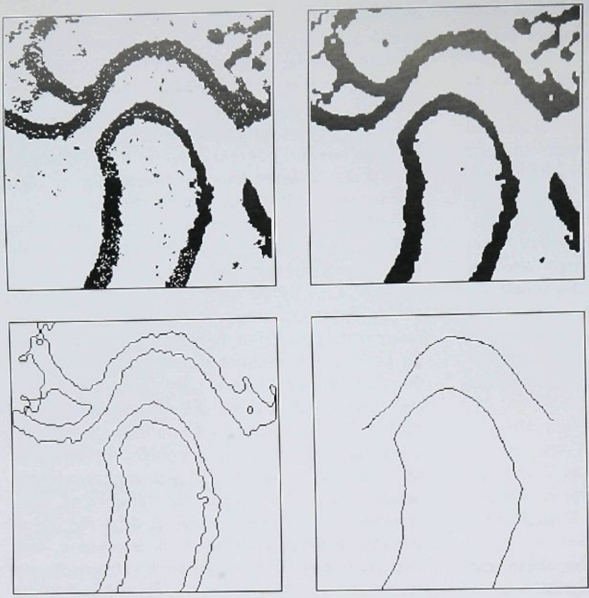

Fig 1a *(left)* Edge detection and discrimination analysis produced a binarized image of the tomogram.

Fig 1b *(right)* Fusion of the binarized image and labeling of the condyle and the temporal fossa outlines eliminated noise and resulted in a much clearer binarized image.

Fig 1c *(left)* To create outlines for measurement, the borders of the labeled images were traced. Outermost dots were connected to make a closed image.

Fig 1d *(right)* Outer outline of the condyle and inner outline of the glenoid fossa, which are the closest to the joint space, were selected from the border image.

intervals were allowed between the imaging procedures. The radiologic technician was given no information on the specific aim of this study.

Image-Analyzing Procedures

All tomograms were numbered sequentially and 2-dimensional joint space measurements were performed in a blinded fashion by one of the authors. Tomograms were digitized with a charge-coupled device (CCD) camera (TK-1070, Victor). Outlines of the condyle and the temporal fossa were then automatically determined by means of the following steps (Fig 1).

First, after digitizing, imaging data were smoothed by median filtering, which easily removed noise without deteriorating the signal data. Second, to binarize the smoothed image, edge detecting was performed with the following formula, which contains spatial differentiation procedures:

$$e = \sqrt{[\Delta x f(i, j)]^2 + [\Delta y f(i, j)]^2}$$

where e is the edge strength; $f(i, j)$ is the gray level in the coordinates (i, j); $\Delta x f(i, j)$ is $(f[i + 19, j] - f[i, j] - (f[i, j] - f[i - 19, j])$; and $\Delta y f(i, j)$ is $(f[i, j + 19] - f[i, j]) - (f[i, j] - f[i, j - 19])$. Briefly, the edge detection protocol that was used in this study was a modified Laplacian method[7] that was newly designed for this analysis. Discrimination analysis[8] was used for thresholding (Fig 1a).

Third, the binarization routine included user-interactive identification of the outlines simultaneously on the original and the binarized images. If 1 threshold in an entire imaging area was not enough to clearly delineate the outlines of the condyle and the articular eminence simultaneously, then the threshold was partially changed and a map of several different thresholds was manually composed. Once the thresholds were determined for each joint, no change was made during the whole measurement course for the same joint.

Fourth, after fusion and labeling the condyle and the temporal fossa (Fig 1b), their outlines were processed by tracing the borders (Fig 1c). The image that was formed by the superior line of the condyle and the inferior line of the temporal fossa was selected as the original image and used to measure changes in joint space dimension (Fig 1d).

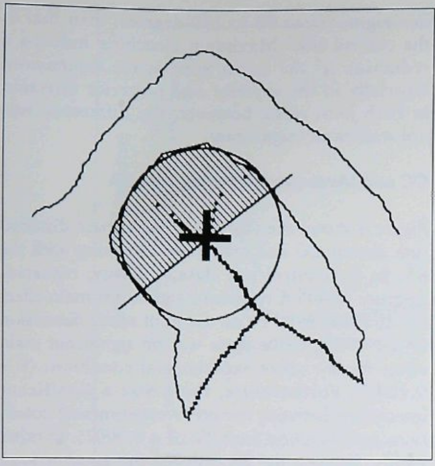

Fig 2a After each condyle was skeletonized, a semicircle with its center situated on a condyle skeleton line (its distance transformation value was used for the radius of the semicircle) was moved to locate the position in which its area most closely approximated the condyle (indicated by shading). The center of the circle was used as the reference point of the condyle (Pc).

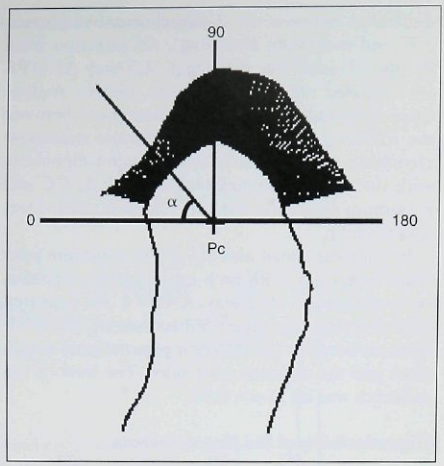

Fig 2b Minimum joint space dimension, which was defined as the shortest distance between the condyle and fossa outlines, was determined automatically. A line that started at the reference point of the condyle (Pc) and formed angle α with a line perpendicular to Camper's plane was drawn radially. The intersections between the radial line and the outline of the condyle and the temporal fossa were determined. Intersections were measured as the joint space dimension in angle α.

Outcome Measurement and Data Reduction

To measure joint space dimension, a reference point in the condyle (Pc) was determined and overplotted onto the images (Fig 2). After each condyle was skeletonized,[9] a semicircle with its center situated on a condyle skeleton line was moved to locate the position in which it most closely approximated the condyle outline[10]; the center of the circle was used as Pc (Fig 2a).

Joint space dimensions were measured every 2 degrees from Pc. A vertical reference line that connected Pc with the temporal fossa divided the joint space into anterior (linear measurements from 0 to 90 degrees) and posterior (linear measurements from 90 to 180 degrees) joint spaces (Fig 2b). Since Pc was determined in each tomogram, the vertical reference line was also drawn in each tomogram.

The minimum joint space for each experimental condition was individually determined for each subject. It was defined as the shortest distance between the condyle and the fossa outlines. Measurements were corrected with the following formula because the tomograms were magnified according to the table-to-subject distance.

$$L = a/(1{,}150[1{,}150 - (97 + b)])$$

where L is the actual dimension (mm); b is the table-to-subject distance (mm); a is the dimension measured on the tomogram; 1,150 is the film focus distance (mm); and 97 is the table-to-film distance (mm).

All radiographic landmarks were digitized, and calculations were performed with a computer system (NEC PC-9801 RA21) by means of a special program that was created by one of the authors.

Statistical Analysis

A 3-way analysis of variance (ANOVA) for repeated measurements was employed in the ICP data to analyze mean differences in joint space dimension between: *(1)* 2 experimental conditions (CC and maximum clenching), *(2)* direction from Pc, and *(3)* joint side difference. A 2-way ANOVA for repeated measurements was used to analyze mean differences in joint space dimension between the following experimental conditions: maximum clenching in ICP, CC and maximum clenching with the SA, maximum clenching in ICP, CC and maximum clenching with the MARA, and direction from Pc.

In addition, mean and SD of the minimum joint space dimension with each experimental condition were computed. A 2-way ANOVA for repeated measurements was employed to analyze mean differences between the different experimental conditions and the different joint sides. The level of significance was set at $\alpha = 0.05$.

Reproducibility of the Measurements

A test for reproducibility of the above measurement method was performed with a 22-year-old man.[11,12] Six tomograms were obtained at 3-minute intervals during CC in ICP. The minimum joint space was measured in the 6 tomograms as described. The minimum joint space (mean ± SD) and its relative direction (vector) from Pc was determined as 1.27 ± 0.07 mm and 35.06 ± 5.62 degrees, respectively. The SD was less than the pixel size resolution (0.10 mm) of the initial digitizing procedure of the tomograms.

Results

CC and Maximum Clenching in ICP

Figure 3 shows changes in the joint space distribution during maximal clenching in ICP. A 3-way, repeated-measure ANOVA revealed no significant main effects for joint side difference ($P = 0.4933$) or for clenching ($P = 0.2167$) on the joint space dimension. On the other hand, a significant main effect for direction from Pc on the joint space dimension was observed ($P < 0.0001$). There were no significant interactions between joint side difference and clenching ($P = 0.7376$), or between clenching and direction from Pc ($P = 0.3618$). However, there was a statistically significant interaction between angle difference from Pc and joint side difference ($P = 0.0008$). In other words, mean joint space dimension during CC was almost identical in the ADDwor and the normal sides. However, joint space dimension in the ADDwor side had larger variability in the posterior region (from 90 to 130 degrees) than that in the control side. Maximum clenching induced a reduction of the mean joint space dimension, especially in the superior and posterior direction in both joint sides; however, the difference was not statistically significant.

CC and Maximum Clenching with SA

Figure 4 shows the changes in joint space distribution during CC and maximum clenching with the SA. In the control side data, a 2-way, repeated-measure ANOVA revealed a significant main effect for direction from Pc on the joint space dimension ($P < 0.0005$), while there was no significant main effect for the other experimental conditions ($P = 0.1087$). Furthermore, there was a significant interaction between the other experimental conditions and direction from Pc ($P < 0.0001$). In other words, wearing the SA reduced the anterior joint space and expanded the posterior joint space in relation to those seen during maximum clenching in ICP. Mean joint space dimension was reduced during maximum clenching with the SA in relation to that seen during CC with the SA; however, the effect was not significant.

In the ADDwor side data, a 2-way, repeated-measure ANOVA revealed a significant main effect for direction from Pc on the joint space dimension ($P < 0.0001$), while there was no significant main effect for the other experimental conditions ($P = 0.4582$). There were no significant interactions between the other experimental conditions and direction from Pc ($P = 0.9473$). In other words, wearing the SA induced an increase in the posterior joint space dimension in relation to that seen during maximum clenching in ICP; however, the effect was not statistically significant. Furthermore, joint space dimension was evenly reduced in any angular direction from Pc during maximum clenching with the SA, although the effect was not significant. Interestingly, the anterior joint space dimension on the ADDwor side was almost identical during all of the experimental conditions.

CC and Maximum Clenching with MARA

Figure 5 shows the changes in joint space distribution during CC and maximum clenching with the MARA. In the control side data, a 2-way, repeated-measure ANOVA revealed a significant main effect for direction from Pc ($P < 0.0001$) and for the other experimental conditions ($P < 0.0001$) on the joint space dimension. There was also a

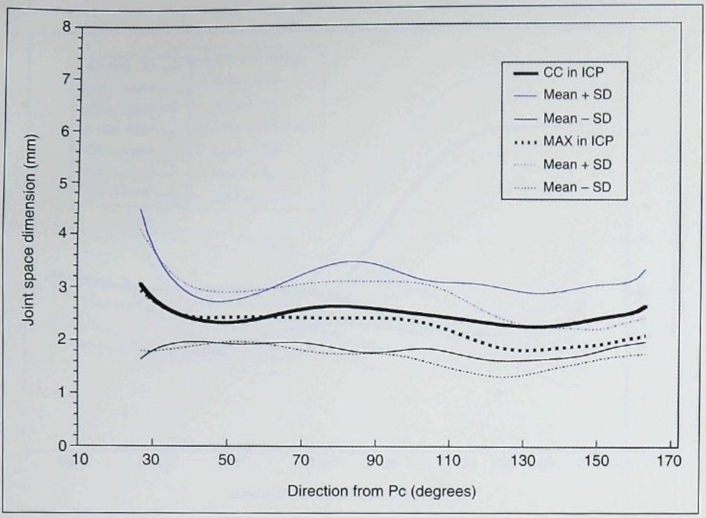

Fig 3a Changes in joint space distribution during maximum clenching in ICP on the control side. CC in ICP = comfortable closure in the intercuspal position; MAX in ICP = maximum clenching in the intercuspal position; Pc = reference point in the condyle; SD = standard deviation.

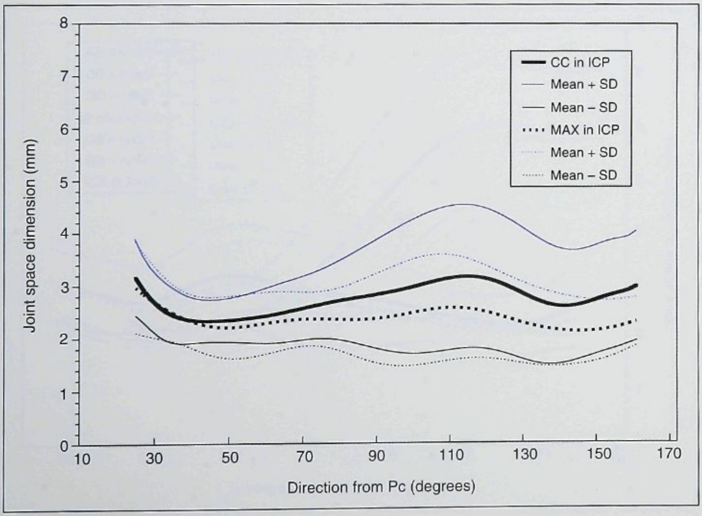

Fig 3b Changes in joint space distribution during maximum clenching in ICP on the ADDwor side. CC in ICP = comfortable closure in the intercuspal position; MAX in ICP = maximum clenching in the intercuspal position; Pc = reference point in the condyle; SD = standard deviation.

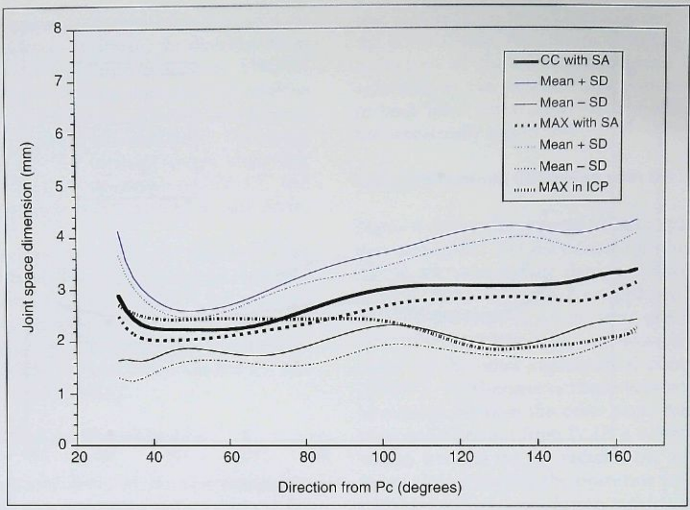

Fig 4a Changes in joint space distribution during CC and maximum clenching on the SA on the control side. CC with SA = comfortable closure onto stabilization appliance; MAX with SA = maximum clenching onto stabilization appliance; Pc = reference point in the condyle; SD = standard deviation.

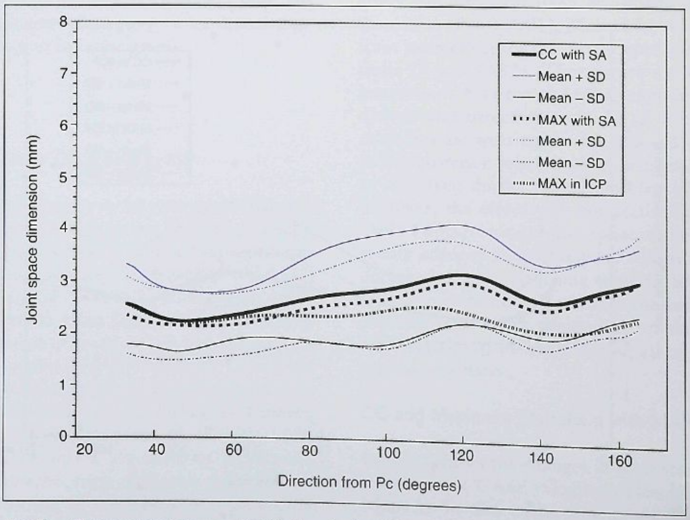

Fig 4b Changes in joint space distribution during CC and maximum clenching on the SA on the ADDwor side. CC with SA = comfortable closure onto stabilization appliance; MAX with SA = maximum clenching onto stabilization appliance; Pc = reference point in the condyle; SD = standard deviation.

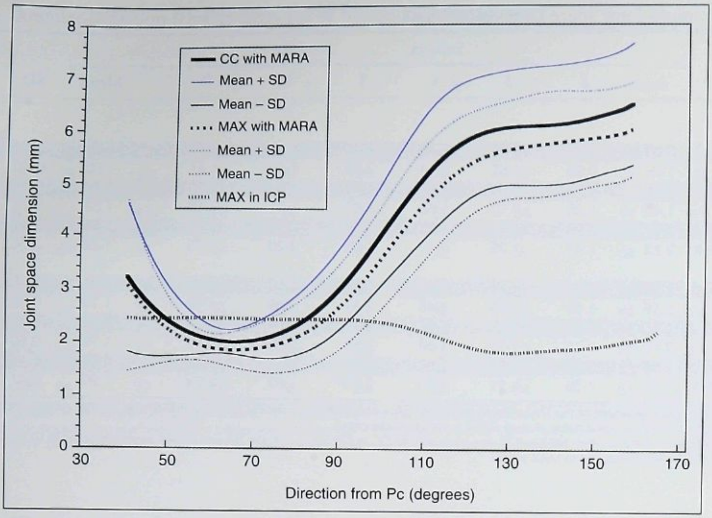

Fig 5a Changes in joint space distribution during CC and maximum clenching on the MARA on the control side. CC with MARA = comfortable closure onto mandibular anterior repositioning appliance; MAX with MARA = maximum clenching onto mandibular anterior repositioning appliance; Pc = reference point in the condyle; SD = standard deviation.

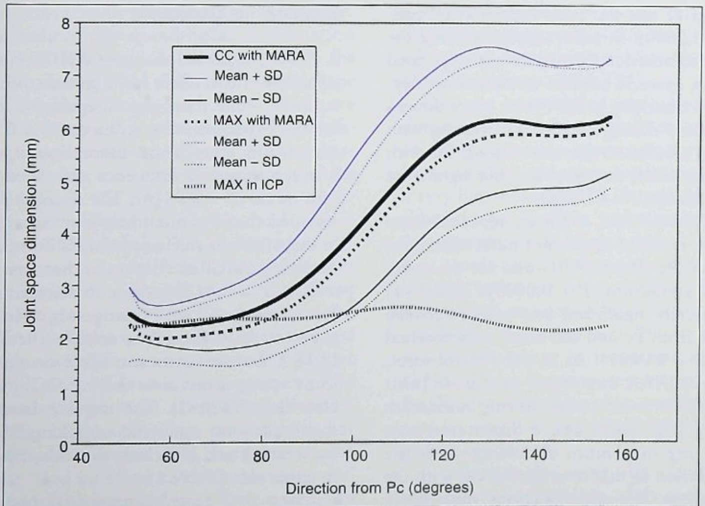

Fig 5b Changes in joint space distribution during CC and maximum clenching on the MARA on the ADDwor side. CC with MARA = comfortable closure onto mandibular anterior repositioning appliance; MAX with MARA = maximum clenching onto mandibular anterior repositioning appliance; Pc = reference point in the condyle; SD = standard deviation.

Table 1 Minimum Joint Space Dimension (mm)

	Subject 1	2	3	4	5	6	7	Mean	SD	P value*
Control side										
CC in ICP	2.00	1.12	1.60	2.09	2.08	1.41	2.32	1.80	0.43	—
MAX in ICP	1.69	0.95	1.55	2.14	2.02	1.46	1.41	1.60	0.40	0.1672
CC with SA	1.65	1.63	1.54	1.91	1.77	1.61	2.20	1.76	0.23	0.7074
MAX with SA	1.46	1.25	1.15	1.63	1.62	1.41	2.13	1.52	0.32	0.6388
CC with MARA	2.07	1.98	1.47	1.73	1.59	2.26	1.82	1.85	0.28	0.8485
MAX with MARA	2.12	1.44	1.25	1.49	1.89	2.20	1.75	1.74	0.36	0.5103
ADDwor side										
CC in ICP	2.38	1.80	1.44	1.53	2.64	1.60	1.97	1.91	0.45	—
MAX in ICP	2.18	1.66	1.35	1.45	2.31	1.49	1.44	1.70	0.39	0.0132
CC with SA	2.33	1.35	1.65	1.97	2.77	1.54	2.01	1.95	0.49	0.7336
MAX with SA	2.17	1.18	1.34	1.69	2.55	1.52	2.10	1.79	0.50	0.4912
CC with MARA	1.84	1.79	1.90	1.97	2.67	1.69	2.65	2.07	0.41	0.3223
MAX with MARA	1.70	1.36	1.71	1.89	2.59	1.62	2.34	1.89	0.43	0.3198

ADDwor = anterior disc displacement of the TMJ without reduction; SA = stabilization appliance; MARA = mandibular anterior repositioning appliance; ICP = intercuspal position; CC = comfortable closure; MAX = maximum clenching.
*Based on a 2-tailed paired t test in which MAX in ICP was compared to CC in ICP; CCs with the SA and MARA were compared to CC in ICP; and MAXs with the SA and MARA were compared to MAX in ICP.

statistically significant interaction between the direction from Pc and the other experimental conditions ($P < 0.0001$). In other words, wearing the MARA reduced anterior joint space and expanded posterior joint space in relation to those seen during maximum clenching in ICP. Joint space dimension was reduced during maximum clenching with the MARA in relation to that seen during CC with the MARA; however, the effect was not significant (least square means, $P = 0.3326$).

On the ADDwor side, a 2-way, repeated-measure ANOVA revealed significant main effects for direction from Pc ($P < 0.0001$) and for the other experimental conditions ($P < 0.0005$). There was also a statistically significant interaction between the direction from Pc and the other experimental conditions ($P < 0.0001$). As in the control joint, wearing the MARA expanded posterior joint space in relation to that seen during maximum clenching in ICP. Joint space dimension was reduced during maximum clenching with the MARA in relation to that seen during CC with the MARA; however, the effect was not statistically significant (least square means, $P = 0.5459$). Interestingly, the anterior joint space dimension in the ADDwor side was almost the same in all of the experimental conditions.

Minimum Joint Space Dimensions in Experimental Conditions

A 2-way, repeated-measure ANOVA showed no significant main effect for joint side difference ($P = 0.3265$), while there was a significant main effect for the experimental conditions ($P = 0.0171$). No statistically significant interaction was observed between joint side difference and the experimental conditions ($P = 0.9416$). The 2-tailed paired t-test revealed that the minimum joint space dimension in the ADDwor side was reduced during maximum clenching in ICP in relation to that seen during CC in ICP ($P = 0.0132$), while in the normal side the joint space did not change significantly ($P = 0.1672$). In both sides, neither the SA nor the MARA had a significant effect on the minimum joint space dimension during CC or maximum clenching (Table 1). The angular direction of the minimum joint space did not change significantly by wearing and clenching onto the SA or MARA in either side (Table 2).

Table 2 Angular Direction (Degree from Pc) of Minimum Joint Space

	Subject									
	1	2	3	4	5	6	7	Mean	SD	*P* value*
Control side										
CC in ICP	42	104	84	150	160	122	26	98	51	—
MAX in ICP	126	110	78	146	160	128	126	125	26	0.1706
CC with SA	136	62	78	38	40	124	32	73	42	0.3999
MAX with SA	144	42	78	36	32	128	34	71	48	0.3946
CC with MARA	66	62	74	80	56	70	50	65	10	0.1207
MAX with MARA	64	54	74	78	62	72	52	65	10	0.1125
ADDwor side										
CC in ICP	24	34	140	136	64	92	132	89	49	—
MAX in ICP	18	34	54	150	152	92	124	89	55	0.9886
CC with SA	30	40	48	46	148	84	132	75	47	0.5829
MAX with SA	26	44	66	48	60	78	132	65	34	0.1617
CC with MARA	64	44	62	88	62	70	42	62	16	0.1811
MAX with MARA	54	72	64	56	60	56	34	57	12	0.1713

Pc = reference position in the condyle; ADDwor = anterior disc displacement of the TMJ without reduction; SA = stabilization appliance; MARA = mandibular anterior repositioning appliance; ICP = intercuspal position; CC = comfortable closure; MAX= maximum clenching.
*Based on a 2-tailed paired *t* test in which CC in ICP was used as a reference for other experimental conditions.

Discussion

This study has several advantages over prior studies. First, it was based on direct measurements using TMJ imaging of joint position. Therefore, our data include any mandibular deformation effects during clenching. On the other hand, the method for assessing joint distractive effects of the appliances involved the prediction of minute condylar movements that were induced by clenching tasks from remote mandibular point movements, which were measured with a jaw-tracking system. Based on the predicted condyle movements, Ito et al[3] assessed the direction and relative magnitude of TMJ loading. They compared condylar movements during clenching with different occlusal splints and concluded that no significant condylar shift was induced by clenching onto the SA and MARA. Based on these data, they assumed that decompressive effects were induced by the use of such appliances. However, the examiners could only measure movement of a hypothetical condylar point that might not reflect the interarticular surface relationship in the TMJ. Furthermore, the data might have inherent errors in the measurement of condylar movement since their system did not reflect the effect of the deformation of the mandible during clenching on the condylar movement data. It is well known that a decrease in mandibular arch width can be measured at open and protruded jaw positions.[13] Moreover, deformation of the human mandible during clenching has been estimated by finite element analysis to range from 0.46 to 1.06 mm.[14] Those findings demonstrate that deformation levels of the mandible during normal function are too large to permit the assessment of the relationship of the articular surfaces of the TMJ.

Changes in condylar position and joint space dimension were automatically measured on a helical blurring-motion tomogram that was enhanced by a computerized image-analyzing procedure with a very high resolution (0.10 mm). Considering that other digital imaging techniques (eg, computed tomography or MRI) provide no more than 0.5 mm resolution, this computer-aided analogue imaging technique has a relatively high capability of detecting minute changes in condylar position and joint space dimension. This system also has a special advantage in being automatic and thus avoiding bias in measurements of the outcome. Finally, measurements were performed by a separate investigator who was blinded to the experimental conditions.

In accordance with the results that were obtained in our previous study with asymptomatic subjects, overall data in this study show that upon maximum clenching by the subject, the minimum joint space dimension with the SA and the MARA was equivalent to that seen in ICP. These data show that neither appliance increases joint space, even in unilateral ADDwor cases. If the analogy between joint space and joint loading is correct, then these appliances do not decompress joint articular tissues. It is likely that the transfer of loading to a slightly (SA) to moderately (MARA) different zone of joint articular tissues results from the use of an occlusal appliance. It is also likely that wearing the MARA induces slight anterior joint space compression and dramatic posterior joint space distraction.

In contrast to the results that were obtained in normal, asymptomatic subjects, neither the SA nor the MARA induced reduction of the anterior joint space in the ADDwor subjects on the ADDwor side. This might be the result of the displaced disc acting as an obstacle to the translatory movement of the condyle. This assumption is also supported by the fact that the mean anterior joint space dimension for the SA and for the MARA was slightly less than that seen during maximum clenching in ICP on the control side, while the mean joint space was similar for all of the experimental conditions on the ADDwor side. Joint space data should be carefully interpreted, especially in anterior disc displacement cases.

In our opinion, the hypothesis that these appliances automatically induce an increase in joint space and therefore decompress TMJ articular tissues cannot be accepted. Such appliances might, however, have a beneficial effect on patients' clinical symptoms because of their tendency to change clenching behavior. Clark et al[15] emphasized this aspect of the appliance therapy as an explanation for their efficacy.

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