Original article

Changes in joint space dimension after the correction of Class II division 1 malocclusion

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Summary

Objective: The aim of this prospective longitudinal investigation was to compare the relationship between the temporomandibular joint (TMJ) condyles and the temporal fossae by means of tomography before and after the orthodontic correction of Class II, division 1 malocclusion using the activator appliance.

Materials and methods: The final sample consisted of 26 consecutively treated Class II, division 1 patients (19 boys and 7 girls with an average pre-treatment age of 11 years) who underwent orthodontic treatment by means of an activator appliance. Before treatment all patients were free of signs and symptoms associated to TMJ disorders. Bilateral tomographic records before and after treatment were taken and analyzed. Outlines of the condyle and temporal fossa were automatically determined by an edge-detection protocol, and the minimum joint space dimension was automatically measured every 2 degrees. For further analysis, the joint space was divided into anterior, superior, and posterior joint spaces.

Results: The average treatment time with the activator appliance was 366 days. In all subjects, activator treatment resulted in a Class I dental arch relationship. After activator treatment, no differences were found in the joint space measurements in any direction. Comparisons between the right and left condyles were not significantly different.

Conclusions: Joint space dimension in Class II division I children was similar before and after treatment in both TMJs.

Introduction

The activator appliance has been successfully used for early treatment of Class II, division 1 malocclusions for many years. Effects on dentofacial structures have been sufficiently studied and reported (1). However, the possible effect of this appliance on the temporomandibular joints (TMJ) is not clear (2–5), with recent interest focusing on this area. The use of functional appliances could promote a change in TMJ morphology, which could result from a remodelling process of the glenoid fossa and the condyle, affecting the position of both the condyle and the articular disc.

The main secondary effects classically reported in the correction of Class II malocclusions with functional appliances include maxillary growth restriction, alterations in the growth of the condyle and its displacement within the fossa, and remodelling of the glenoid fossa. These three factors contribute approximately to 50 per cent of the changes that occur parallel to the occlusal plane (6). When a patient wears a functional appliance, the mandible is advanced to a protrusive position whenever the patient bites, forcing the condyles to move out from the glenoid fossa. This protrusive position of the condyle may contribute to the correction of the Class II, division 1 by stimulating its growth or by remodelling the glenoid fossa into a new position and thus changing the position of the condyle in the fossa. The remodelling of the glenoid fossa has been demonstrated on TMJ roentgenograms by a double contouring
of the anterior surface of the post-glenoid spine (7–9). Bone apposition has also been described after the use of the Herbst appliance, being more intense at the inferior part of the glenoid spine and less pronounced towards the top of the spine (10) although Katsavrias (11, 12) reported that it was possible that glenoid fossa remodelling is not altered by mandibular protrusive appliances during treatment of skeletal Class II problems.

Nevertheless, the effects of condylar anterior displacement are not clear. Several studies have evaluated TMJs before and after treatment (7, 13, 14) and have reported that altered condyle/fossa relationships may be present at the end of the Herbst treatment but restored during the retention period. On the other hand, Croft et al. (15) found no significant changes in the joint space during treatment and even observed a significant post-treatment decrease in the posterior joint space. Most of the previous studies are based on the Herbst appliance and it may not have the same consequences on TMJs as the activator.

In order to properly assess changes in the condylar position induced by the orthodontic appliance, several authors have measured in tomograms the anterior and posterior joint spaces in the sagittal plane following geometric methods (16, 17). These methods assess the anterior and posterior TMJ space using two linear measurements. However, these measurements may not be representative of the total joint space. Recently (18, 19), a helical blurring motion tomogram enhanced by a computerized image analysis system has been used to measure directly the changes in the condylar position and joint space dimensions. This method allows the measurement of the joint space dimension every 2 degrees from the centre of the condyle for the assessment of the anterior, superior, and posterior joint space, providing more information than the previously reported two linear measurement method.

The purpose of this prospective study was to evaluate the effects of the activator therapy on the position of the mandibular condyles using a new tomographic technology that allows an accurate measurement of the articular space.

Materials and methods

A total of 29 consecutive patients (19 boys and 10 girls) with Angle Class II division I malocclusion were recruited from referrals to the orthodontic clinic at the school of dentistry where the study took place, and selected to receive orthodontic therapy using an activator appliance.

Patients were included if they fulfilled the following criteria: bilateral Class II molar of at least half cusp and hand-wrist radiographic stage before the peak of pubertal growth spurt. Subjects were excluded if they presented skeletal asymmetries, unilateral posterior crossbite, articular noises at clinical examination (opening-closing), capsular or muscle pain, previous trauma of the orofacial region, articular systematic pathology, previous orthodontic treatment, and if they were medicated with steroids. Ethical approval of the study was obtained from the Institutional Review Board (IRB) for protection of human subjects at our University. All subjects received full explanations of the aim and the design of the study before its start and agreed to participate by signing an IRB-approved informed consent.

All efforts were made throughout the study to minimize radiation exposure of our patients, as required by the Radiation Safety Division, taking into account the ALARA principle. According to this principle (‘as low as reasonably achievable’), radiation dose was reduced to the lowest possible level following a paediatric protocol (considering age, weight and height, and customized shielding) consistent with sound diagnostic imaging.

Routine diagnostic orthodontic records were taken, including: medical and dental histories, oral clinical examination, centric occlusion bite registration, dental casts mounted in articulator, intra and extraoral photographs, lateral cephalometric, panoramic, tomographic, and hand-wrist radiographs. The slide from the intercuspal position to the retruded contact position was assessed before and after treatment.

The tomographic X-rays were taken 2 months before treatment and 20 days after treatment on average.

Orthodontic therapy comprised the use of the Teuscher activator combined with an extraoral high-pull headgear. To obtain the bite registration for the constructive bite, patients were asked to protrude the mandible as far as possible; 4mm were then subtracted from this position. This record was not taken in an edge to edge position in all patients, since this evokes different forward movements of mandible for each patient, depending on the initial overjet. The constructive bite was standardized using the George gauge (Great Lakes Orthodontics, Tonawanda, New York, USA), which automates the bite registration procedure for functional orthodontic appliances in an accurate manner. At the beginning of treatment, all patients were instructed to wear the activator at least 14 hours daily.

A cephalostatic device was used to hold the patient’s head in a stable position. This procedure also allowed precise patient positioning.

All tomograms were numbered sequentially and two-dimensional joint space measurements were made in a blinded fashion by one of the authors using an image analyzer. Tomograms were digitized with a charge-coupled device camera (TK-1070; Victor), then the outlines of the condyle and the temporal fossa were automatically determined using the following methodology (Figure 1):

Once the image was digitized, it was smoothed by median filtering, which easily removed noise without deteriorating the signal data. Then the edge detection was attained by binarization of the smoothed image using the following formula:

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

where $e$ is the edge strength; $f(i,j)$ is the gray level in the co-ordinates $(i,j)$; $\Delta x f(i,j)$ is $[f(i + 19, j) - f(i,j)] - [f(i,j) - f(i - 19, j)]$; and $\Delta y f(i,j)$ is $[f(i + 19, j) - f(i,j)] - [f(i,j) - f(i, j - 19)]$. This edge-detection protocol is a modification of the Laplacian method that has been re-designed for this analysis. For thresholding, we used discrimination analysis (20) (Figure 1a). The binarization routine included identification of the outlines simultaneously on the original and the binarized images. If the threshold in an entire imaging area was not enough to clearly delineate the outlines of the condyle and 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 (Figure 1b).

After fusion and labelling of the condyle and the temporal fossa, their outlines were processed by tracing the borders (Figure 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 the changes in the joint space dimension (Figure 1d). After each condyle was skeletonized, a semicircle was overlapped onto the images and moved to locate the position in which it most closely approximated the condyle outline (20); the centre of the circle was used as reference point of condyle (Pc) (Figure 2a). Joint space dimensions were measured every 2 degrees from Pc (Figure 2b) being the first measurement at 10 degrees in the posterior joint space and the last at 160 degrees in the anterior joint space. For further analysis, two reference lines connecting Pc with the temporal fossa divided the joint space into anterior (linear measurements from 160 to 110 degrees), superior (linear measurements from 110 to 60 degrees), and posterior (linear measurements from 60 to 10 degrees) joint spaces.

All radiographic landmarks were digitized, and calculations were performed using a computer system [NEC PC-9801 RA21; NEC Corporation, Minato (Tokio), Japan] by means of a custom-made program. An independent investigator who was blinded to the experimental conditions made all measurements.

Sample size determination
To determine the sample size needed in our study, we selected a minimum detectable difference of 0.5 mm in the joint space dimension, based on the study by Dalili et al. (21). After performing a power analysis for paired samples to produce 80 per cent power at the 0.05 per cent level of significance, the required sample size was 25 patients.

Statistical analysis
The evaluation of the data was performed using SPSS Statistics version 19 (SPSS Inc., Chicago Illinois, USA). First, the normal distribution of the data was assessed using the Shapiro–Wilk and Kolmogorov–Smirnov tests. A two-way analysis of variance (ANOVA) for repeated measurements (Bonferroni test for multiple comparisons) was used to analyze mean differences in joint space dimensions between: (1) the direction from Pc (joint space dimensions every 2 degrees) and (2) two time points (before and after therapy). In addition, means and standard deviations of the minimum joint space dimension were calculated for the posterior, superior, and anterior joint space. Student’s t-test for paired samples was used to test for joint side differences. Statistical significance was set at \( P \leq 0.05 \).

Reproducibility of the measurements
A test for reproducibility of the above measurement method was performed with a 22-year-old volunteer. Six tomograms were obtained at 3-minute intervals. The minimum joint space was measured in the six tomograms as described. The minimum joint space (mean ± standard deviation) and its relative direction (vector) from Pc was determined as 1.27 ± 0.07 mm and 35.06 ± 5.62 degrees, respectively. The standard deviation was less than the pixel size resolution (0.10 mm) of the initial digitizing procedure of the tomograms (18, 19).

Results
The final sample consisted of 26 patients (19 boys and 7 girls). The average pre-treatment age was 11 years and 2 months. Out of the 29 initially selected patients (19 boys and 10 girls), two dropped out of the study because they were not willing to wear the appliance. The post-treatment left tomographic data of one patient were not adequate. Therefore, the study was confined to 26 patients.

The average treatment time was 366 days. The end point of therapy was the attainment Class I occlusion. The slide from the intercuspal position to the retruded contact position was clinically irrelevant (<1 mm) in all cases. No patient suffered face or jaw trauma during the observation period.

Tomographic results
All the data showed a normal distribution. The unit of measurement of the articular space was calculated in ‘dots’ by the software and then converted to mm.

Two-way repeated-measure ANOVA revealed no significant differences for the direction from Pc or for pre- and post-treatment data on the right joint space dimension \( (P = 0.7039) \) (Figure 3). No significant differences were found for the left joint space dimension either \( (P = 0.8762) \) (Figure 4). The curves of both joints showed the same trend. Posterior joint spaces tended to be smaller before

Figure 1. Determination of the outlines of the condyle and the temporal fossa. (a) Digitized and smoothed image. (b) Fusion of the binarized image and labelling of the condyle and temporal fossa outlines eliminated noise and resulted in a much clearer binarized image. (c) To create outlines for the measurements, the borders of the labelled images were traced. Outermost dots were connected to make a closed image. (d) 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.

Figure 2. Measurement of joint space dimension. (a) Determination of Pc (reference point of the condyle). (b) Reference lines used to divide the joint space into 2 degrees intervals. 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 Pc and formed angle \( \alpha \) 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 \( \alpha \).
treatment than after treatment. Anterior joint spaces showed the opposite tendency. This fact was more evident in the right joint (Figure 3) than in the left joint (Figure 4). Nevertheless, differences were not significant.

The average descriptive data of the posterior (from 10 to 60 degrees), superior (from 60 to 110 degrees), and anterior (from 110 to 160 degrees) right and left joint spaces before and after treatment are shown in Table 1. Figure 5 shows the box plots of these measurements. Comparisons between right and left TMJs did not show any significant differences before or after treatment (Table 2).

The joint space analysis demonstrated only small and non-significant changes throughout the entire observation period.

Before treatment, the mean right posterior joint space tended to be smaller than the anterior joint space (2.64 versus 2.93 mm, \(P = 0.191\)). In the left side, the same trend was found (2.96 versus 3.13 mm, \(P = 0.510\)). Although these differences were not statistically significant, they showed that before treatment both condyles tended to be placed slightly back in the fossa.

After treatment, both condyles showed a tendency to move forward in the fossa although differences were again not statistically different. In the right side, the anterior joint space tended to be smaller than the posterior space (2.67 versus 2.87 mm, \(P = 0.306\)). The left condyle tended to show a more neutral position within the fossa since the anterior and posterior articular spaces were nearly the same (2.97 versus 2.92 mm, \(P = 0.837\)) at the end of treatment.

**Discussion**

This paper evaluates the changes of the condyle position within the fossa after using a functional appliance (activator) from a new perspective: the measurement of the articular space by means of multiple linear measures. The articular space is a volume between the head of the condyle and the mandibular fossa in the cranial base. In a two-dimensional film an area represents this space. To measure this area, it may not be appropriate to use only one single linear value as representation of the total anterior or posterior articular space. Therefore, we have used a method that allows taking many linear measures every 2 degrees to provide more information about this area.

![Figure 3](image_url). Right TMJ mean space distribution (mm) measured every 2 degrees, before and after treatment. Error bar: ± 1 SD. Two-way repeated-measures ANOVA (Bonferroni) \(P = 0.7039\). ANOVA, analysis of variance; TMJ, temporomandibular joint.

![Figure 4](image_url). Left TMJ mean space distribution (mm) measured every 2 degrees, before and after treatment. Error bar: ± 1 SD. Two-way repeated-measures ANOVA (Bonferroni) \(P = 0.8762\). ANOVA, analysis of variance; TMJ, temporomandibular joint.

**Table 1.** Descriptive data of the posterior, superior, and anterior joint spaces for the right and left joint before and after treatment. 10–60 = posterior joint space; 60–110 = superior joint space; 110–160 = anterior joint space. (1 mm = 12.15 dots).

<table>
<thead>
<tr>
<th></th>
<th>Mean in dots (mm)</th>
<th>Lower</th>
<th>Upper</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Right (IR) 10–60</td>
<td>32.02 (2.64)</td>
<td>29.14</td>
<td>34.91</td>
<td>7.14</td>
</tr>
<tr>
<td>Initial Right (IR) 60–110</td>
<td>36.11 (2.97)</td>
<td>32.86</td>
<td>39.37</td>
<td>8.06</td>
</tr>
<tr>
<td>Initial Right (IR)110–160</td>
<td>35.56 (2.93)</td>
<td>30.88</td>
<td>40.24</td>
<td>11.39</td>
</tr>
<tr>
<td>Initial Left (IL) 10–60</td>
<td>35.96 (2.96)</td>
<td>31.59</td>
<td>40.33</td>
<td>10.83</td>
</tr>
<tr>
<td>Initial Left (IL)60–110</td>
<td>40.36 (3.32)</td>
<td>35.92</td>
<td>44.79</td>
<td>10.97</td>
</tr>
<tr>
<td>Initial Left (IL)110–160</td>
<td>38.08 (3.13)</td>
<td>33.16</td>
<td>43.00</td>
<td>12.17</td>
</tr>
<tr>
<td>Final Right (FR) 10–60</td>
<td>34.82 (2.87)</td>
<td>31.45</td>
<td>38.19</td>
<td>8.35</td>
</tr>
<tr>
<td>Final Right (FR) 60–110</td>
<td>36.24 (2.98)</td>
<td>33.34</td>
<td>39.15</td>
<td>7.19</td>
</tr>
<tr>
<td>Final Right (FR)110–160</td>
<td>32.46 (2.67)</td>
<td>29.18</td>
<td>35.74</td>
<td>8.11</td>
</tr>
<tr>
<td>Final Left (FL) 10–60</td>
<td>35.50 (2.92)</td>
<td>31.24</td>
<td>39.76</td>
<td>10.55</td>
</tr>
<tr>
<td>Final Left (FL) 60–110</td>
<td>39.93 (3.29)</td>
<td>36.08</td>
<td>43.78</td>
<td>9.54</td>
</tr>
<tr>
<td>Final Left (FL) 110–160</td>
<td>36.11 (2.97)</td>
<td>31.80</td>
<td>40.41</td>
<td>10.66</td>
</tr>
</tbody>
</table>
For this purpose we used tomographic data since we aimed to assess changes in the articular space and were not interested in soft tissue changes, which might have required the use of magnetic resonance images (MRI). It has been claimed that lateral tomography represents a more accurate image of the osseous anatomy when compared with MRI (22). The use of panoramic or cephalometric images was discarded since they do not offer a clear view of the TMJs.

The use of tomographic or MRI to demonstrate TMJ adaptation during functional appliance therapy has been previously reported (2–5, 10, 15, 23). Three adaptive processes in the TMJ have been postulated for the correction of the Class II malocclusions: 1) increased condylar growth, 2) anterior glenoid fossa displacement due to fossa remodelling, and 3) changes in the fossa–condyle relationship (24). Traditionally, three measures were taken to assess the articular space. But this method involves a subjective election of three points that are geometrically determined without anatomic references. In longitudinal studies, after treatment, the articular space is measured again in the same way but growth and remodeling might have changed the shape of the condyle and the fossa. Condylar growth, especially in the posterior direction, has been histologically verified in animals as a response to mandibular advancement appliances (25–28). Similar radiographical findings have been described in humans (4, 10, 29). Morphologic changes in the external shape of the condyle have been found in all three planes of space, with the axial plane showing the greatest degree of change (30, 31). Therefore, if the condylar shape changes, the points used before treatment could not be related to the points used after treatment to measure the joint space.

Previous studies have assessed condylar position and morphology with conventional tomography. However, in some cases, margins of the joint structures were unclear due to large slice thicknesses ranging between 1.0 and 3.0 mm. In our study, changes in condylar position and joint space dimension were measured on a helical blurring motion tomogram enhanced by a computerized image analyzing procedure with a very high resolution (0.1 mm). Other digital imaging techniques provide no more than 0.5 mm resolution. Thus our computed-aided analogue imaging technique has a relatively high capability of detecting small changes in condylar position and joint space dimensions. Another advantage was the automated process that avoided bias in measuring the outcome.

The descriptive data of the anterior, posterior, and superior joint space before and after activator treatment revealed that, on average, all measured variables were within the physiologic range. No differences were found between the right and the left condyle before and after treatment. Also, there were no significant differences in the superior, posterior, and anterior articular space before and after treatment within each condyle.

Several authors (32, 33) have suggested that forward posturing of the mandible after treatment exaggerates the orthopaedic effects attained with the functional therapy. Considering the pooled data of the left and right joint, our results showed that there were no significant differences in joint space before and shortly after appliance removal. There was a tendency for the condyle to be positioned slightly forward in the fossa at the end of treatment, but differences were not significant. These results are similar to those reported for the Herbst (4, 15) and Fränkel (23) appliance. The small changes observed in the joint space suggest that treatment effects cannot be attributed to a forward mandibular posture (15). According to Ruf and Pancherz (4), the MRIs of the Herbst patients taken at 6–12 weeks of treatment showed an area of increased signal intensity at the posterior–superior aspect of the condyle that reflected the condylar remodelling. Moreover, fossa remodelling could be visualized as a bright area at the anterior aspect of the post-glenoid spine. After an extended use of the appliance, the combined remodelling of the condyle and the fossa would try to preserve the condyle–fossa relationship after the treatment. This hypothesis could justify the absence of changes observed in our study. However, Ruf and Pancherz (4) and Wadhawan et al. (35) reported that the condyle was significantly more anteriorly positioned in the immediately post-treatment MRIs, but 1 year later the condyle had returned to its original position. The reposition to the original position could be due to the displacement of the condyle within the fossa or to the completion of

![Box plot of the posterior (10–60), superior (60–110), and anterior (110–160) joint spaces for the right (R) and left (L) joint before (Initial = I) and after (Final = F) treatment, measured in dots (1 mm = 12.15 dots).](image)

**Table 2.** Paired *t*-test comparing the right and left joint space distribution, before (initial) and after (final) treatment. 10–60 = posterior joint space; 60–110 = superior joint space; 110–160 = anterior joint space. (1 mm = 12.15 dots).

<table>
<thead>
<tr>
<th>Joint space</th>
<th>t</th>
<th>P value</th>
<th>Difference of means in dots (mm)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial right to left 10–60</td>
<td>-1.511</td>
<td>0.137</td>
<td>-3.87 (-0.32)</td>
<td>-9.00, 1.27</td>
</tr>
<tr>
<td>Initial right to left 60–110</td>
<td>-1.596</td>
<td>0.117</td>
<td>-4.22 (-0.35)</td>
<td>-9.54, 1.09</td>
</tr>
<tr>
<td>Initial right to left 110–160</td>
<td>-0.754</td>
<td>0.454</td>
<td>-2.47 (-0.2)</td>
<td>-9.06, 4.11</td>
</tr>
<tr>
<td>Final right to left 10–60</td>
<td>-0.364</td>
<td>0.717</td>
<td>-0.95 (-0.05)</td>
<td>-6.17, 4.28</td>
</tr>
<tr>
<td>Final right to left 60–110</td>
<td>-1.706</td>
<td>0.094</td>
<td>-3.95 (-0.31)</td>
<td>-8.59, 0.70</td>
</tr>
<tr>
<td>Final right to left 110–160</td>
<td>-1.483</td>
<td>0.144</td>
<td>-3.83 (-0.3)</td>
<td>-9.02, 1.36</td>
</tr>
</tbody>
</table>

CI, confidence interval.
the condyle–fossa remodelling process. Also, Kinzinger et al. (36) reached similar conclusions in a similar study using fixed functional appliances.

Most of the previous studies are based on the Herbst appliance and there are very few studies where an activator has been used. Therefore, comparisons with our results should be done carefully.

Different studies have shown that non-concentric condylar position may be a component of Class II malocclusions (37). Pullinger et al. (38) reported that non-concentric condylar positioning was a feature of Class II, division 1 malocclusions where the condyles were more anteriorly placed than in Class I patients. Ruf and Pancherz (4) and Chintakanon et al. (3) also found anteriorly positioned condyles in the majority of children with Class II malocclusion. The same trend was described by Logsdon and Chaconas (39), Vitral et al. (40), and Prabhata et al. (41). Gianella et al. (42), on the other hand, stated that condyles in Class II were essentially centred, whereas Bacon et al. (43) found that the condyle was in a more retrusive position represented by an increased distance from nasion to the condylar neck. Asymmetry of TMJ space has been confirmed in different studies (44, 45). Previous reports (2, 44–48) accept a range of –12 to +12 per cent of the complete articular space to consider a concentrically positioned condyle. In our study, Class II division 1 patients showed a centred condylar position before and after treatment since TMJ space dimension was not different in any direction.

Although a larger sample would be necessary to further investigate these findings, in our opinion and in agreement with the results, condylar positioning in Class II division I is essentially centred. In spite of the condyle being located anteriorly by activator, this position is not maintained shortly after treatment and it seems that the TMJ remodelling is involved in the preservation of the initially centred condyle position.

Conclusions
Considering the results of this study, we can conclude:

1. The joint space measurements indicate no differences in any direction in condyle position before and after activator treatment.
2. There were no significant differences in the superior, posterior, and anterior articular space before and after treatment between the right and left condyle.
3. There is a trend to neutral position of the condyles within the fossa before and after treatment.
4. The small changes observed in joint space suggest that treatment effects should not be attributed to a forward mandibular position.

References

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