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The relationship between temporomandibular joint disc morphology and stress angulation in skeletal Class III patients

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SUMMARY The aim of this study was to examine the relationship between disc position and stress direction on the condyle by means of stress analysis using the rigid body spring model (RBSM) theory. The material consisted of 88 joints of 44 Class III dentofacial deformity patients, divided into symmetry and asymmetry groups on the basis of the Mx–Md midline position. The asymmetry group was identified by comparison with a reference midline vertical plane passing through a plane from ANS to Me. Asymmetry was diagnosed when the angle between these two planes was greater than 3 degrees. The geometry of the stress analysis model was based on sagittal tomography of the subject. The first molar, gonial angle, and the most anterior, superior, and posterior points on the condyle were plotted on a computer display, and stress angulation on the condyles was calculated with the RBSM program.

In addition to anterior displacement with or without reduction, three types of disc position could be identified using magnetic resonance imaging (MRI): anterior, fully covered and posterior. In the asymmetric group, stress angulation was significantly higher ($P < 0.05$) at the deviation side compared with the non-deviation side. There was also a significant correlation between disc position and stress angulation ($P < 0.05$). In the asymmetry group, regression analysis indicated a significant correlation ($P < 0.001$) between the difference in stress angulation (between the deviation side and the non-deviation side) and the degree of asymmetry (measured by the angle of asymmetry). This study demonstrated that temporomandibular joint (TMJ) stress was associated with TMJ morphology in Class III patients whether or not they were asymmetric.

Introduction

Previous magnetic resonance imaging (MRI) investigations of temporomandibular joints (TMJs) examined a large number of healthy controls (Kircos *et al.*, 1987; Silverstein *et al.*, 1988; Drace and Enzmann, 1990; Hans *et al.*, 1992; Davant *et al.*, 1993). Some of these studies, involving quantitative measurements of disc position, used a sagittal image to define the disc position (Kircos *et al.*, 1987; Hans *et al.*, 1992). Disc displacement is the most common abnormality seen on images of the TMJ. Usually the displacement is anterior, anterior lateral, or anterior medial. In the normal joint, the posterior band of the biconcave disc is located superior to the condyle in the closed mouth position (Westesson, 1983; Westesson *et al.*, 1985; Katzberg *et al.*, 1988; Paesani *et al.*, 1992; Tasaki *et al.*, 1996). Normal disc position had been defined in previous studies without including a description regarding skeletal pattern and occlusion (Silverstein *et al.*, 1988; Drace and Enzmann, 1990).

However, images different from those for normal joint categories were recognized in Class III subjects. The MRIs of TMJ disc tissue differed from the normal images previously reported, and a classification of the disc position in skeletal Class III patients has been reported (Ueki *et al.*, 2000). Three types of disc position could be identified by means of MRI in addition to anterior displacement with or without reduction: anterior, fully covered and posterior. Although the anterior type is the typical image of a normal joint, the fully covered and posterior types are found in Class III subjects. It was assumed that these differences in disc position were associated with mandibular morphology and stress distribution.

Most studies agree that the external and internal morphology of a given bone and/or joint in the adult is determined by the biomechanical loads placed upon it during growth (Hylander, 1985; Korioth *et al.*, 1992; Hylander and Johnson, 1997); these loads arise from function of the associated musculature. It was therefore assumed that the difference in stress distribution in the TMJ was associated with jaw deformity and the disc position in skeletal Class III patients. The aim of this study was, therefore, to examine the relationship between TMJ morphology and stress angulation in skeletal Class III patients.

Several theoretical approaches have been used in an attempt to understand various aspects of TMJ biomechanics (Koolstra *et al.*, 1988; Kang *et al.*, 1990; Korioth and Hannam, 1990; Chen and Xu, 1994; Tanaka *et al.*, 1994; DeVocht *et al.*, 1996; Tanne *et al.*, 1996). Some finite element models (FEM) of the TMJ have been developed to simulate condyle motion or stress change. However, the geometry of the FEM was based on only one typical image of a TMJ, while in fact data on many material properties were needed. For this reason, FEM was inadequate as a technique for investigation. A stress distribution analysis method using the rigid body spring model (RBSM) was employed because many individual images had to be analysed to provide a more comprehensive biomechanical description of the loading and the results had to be suitable for statistical analysis. Finally, the amount of data collected was potentially rather large and a simple analysis was required.

Subjects and methods

Subjects

The material consisted of 88 joints of 44 patients (38 female, six male) with an average age of 22.0 ± 6.1 years from the Department of Maxillofacial Surgery, Graduate School of Medicine, Kanazawa University, who were diagnosed as having a skeletal Class III dentofacial deformity (ANB less than 2 degrees) to undergo mandibular setback surgery. No patients had TMJ symptoms that indicated degenerative change. However, some had sounds (clicking, crepitus). Two cephalograms (frontal and lateral), a bilateral sagittal tomography and bilateral MRI were obtained for all subjects. Informed consent was obtained from the patients and the study was approved by Kanazawa University Hospital.

Methods

The subjects were diagnosed as skeletal Class III on the basis of lateral cephalometric analysis. The degree of asymmetry was determined from antero-posterior (AP) cephalograms.

On the AP cephalogram, the angle formed by the ANS–menton plane and a line perpendicular with the bilateral zygomatic frontal suture plane was defined as the angle of asymmetry. The patients were divided into two groups on the basis of the Mx–Md midline position. The asymmetry group consisted of subjects whose Mx–Md midline was more than 3 degrees from the perpendicular, and the symmetry group whose Mx–Md midline deviated less than 3 degrees (Figure 1). These reference lines were used in a previous study (Ueki *et al.*, 2000). One observer performed all digitizations so that the cephalometric method errors were small and acceptable.

A detailed assessment of each pair of TMJs was performed with a 1.5 tesla MRI system (Signa Scanner, General Electric Medical Systems, Milwaukee, Wisconsin, USA), using bilateral 3 inch dual surface coils with the jaw first in the closed (intercuspal) resting position and then at the maximal opening position. In order to identify and confirm the exact discal tissue, an open and closed position was required. Exact midcondylar sections of the mandibular condyles were determined, after the condylar long axis was identified on a horizontal plane image using an initial axial

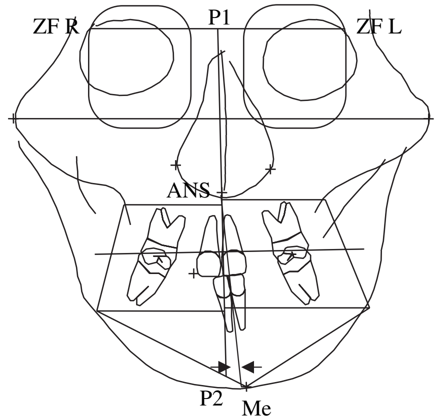

Figure 1 Antero-posterior cephalogram for assessment of mandibular asymmetry. ZFR, zygomatic bilateral points on the medial margin of the zygomatic frontal suture, representing the intersection of the orbital rims; ZFL, zygomatic frontal suture at the intersection of the left orbit; ANS, tip of the anterior nasal spine just below the nasal cavity and above the hard palate; Me, point on the inferior border of the symphysis directly inferior to the mental protuberance and below the centre of the trigonium mentali. The angle of the ANS–menton plane and a line perpendicular (P1–P2) with the bilateral zygomatic frontal suture plane (ZFR–ZFL) was defined as the angle of asymmetry.

localizer. These images, which fulfil the experimental protocol of bilateral orthogonal sagittal planes of both TMJs in the closed jaw position, were obtained by using a repetition pulse (TR) of 2000 milliseconds, echo times (TEs) of 20 milliseconds, 3 mm image slice thickness, and a field of view of 10 cm. These were followed by bilateral sagittal plane open jaw images with a TR of 1000 milliseconds and TEs of 20 milliseconds.

Sagittal tomographs (60 kV, 20 mA, 8 seconds and spiral) of the TMJ were obtained at the cross-sectional plane to the condylar long axis in the intercuspal position with a 2 mm slice thickness. The midcondylar slices were scanned into a computer (GT9500 scanner, Epson, Tokyo, Japan). The first molar, gonial angle, and the most anterior, superior, and posterior points on the condyle on the computer display (Figure 2) and the mandibular two-dimensional RBSM were analysed with the Fortran program (Takeuchi *et al.*, 2002)(Figure 3).

The values of the direction vector (stress angulation) and the degree of the resultant force vector on the condyle to the mandibular body were calculated. The stress angulation was defined as the angle between the resultant force vector on the condyle and a line perpendicular to the Frankfort horizontal plane.

The mathematical knowledge necessary to understand the concept of the RBSM program, as well as the FEM, have been published previously (Takeuchi *et al.*, 2002).

All joint discs were classified according to the following definitions of their position (Figure 4)(Ueki *et al.*, 2000): anterior displacement with or without reduction: the entire disc is antero-inferior to the most anterior point on the contour of the condyle; anterior: the centre of the intermediate

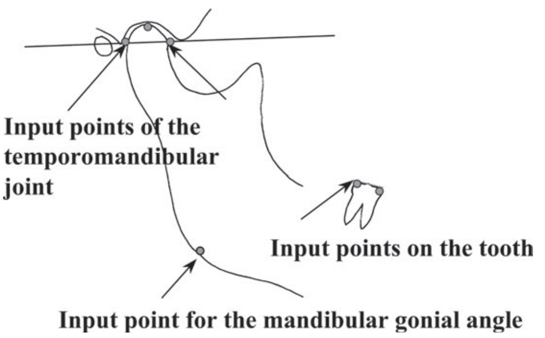

Figure 2 Input points on the mandible.

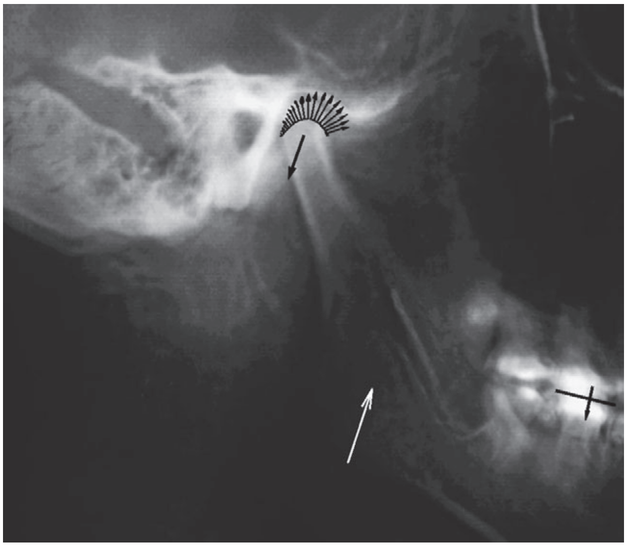

Figure 3 Visualization of the results with the rigid body spring model analysis. The short arrows on the condylar surface indicate stress distribution on the integral points. The long arrow on the condylar surface indicates the direction of the resultant force vector (stress angulation).

zone is between 0 and 90 degrees and the most posterior point of the posterior band is postero-superior to the most anterior point on the contour of the condyle but less than 180 degrees; fully covered: the most anterior point of the anterior band is less than 0 degrees and the most posterior point of the posterior band is greater than 180 degrees; posterior: the most anterior point of the anterior band is more than 0 degrees and the most posterior point of the posterior band is greater than 180 degrees.

Stress angulation between joints with an anterior displaced disc and other disc types was compared. Eighty-eight joints were divided into the following subgroups and stress angulation was examined with the Mann–Whitney *U*-test:

1. Anterior displacement with symmetry ($n = 8$)
2. No anterior displacement with symmetry ($n = 36$)
3. Anterior displacement on the deviation side with asymmetry ($n = 14$)
4. No anterior displacement on the deviation side with asymmetry ($n = 11$)
5. Anterior displacement on the non-deviation side with asymmetry ($n = 8$)
6. No anterior displacement on the non-deviation side with asymmetry ($n = 11$).

Stress angulation between the deviation and non-deviation sides was compared. The joints were divided into four subgroups ($n = 22$ each) and stress angulation examined with the Wilcoxon signed-ranks test:

7. Right side with symmetry
8. Left side with symmetry
9. Deviation side with asymmetry
10. Non-deviation side with asymmetry.

Data were statistically analysed with Stat View 4.5 (Abacus Concepts, Berkeley, California, USA). As the frequency distribution of the data was unknown, a non-parametric test was used. The statistical significance of the differences between the right and left sides within the same group was analysed by paired comparison using the Wilcoxon signed-ranks test. Differences between groups were analysed by non-paired comparison using the Mann–Whitney *U*-test. A chi-squared test was used to compare the frequency of TMJ symptoms.

A simple regression analysis using Stat View 4.5 was also performed. The differences were considered significant at $P < 0.05$.

Results

TMJ symptoms (clicking, crepitus) were diagnosed in 12/22 subjects (54.5 per cent) in the symmetry group and 15/55 subjects (68.2 per cent) in the asymmetry group, a total of 27/44 patients (61.4 per cent). However, the symptoms were not severe and degenerative changes in the TMJ were not found. Patients with fully covered or posterior type joints reported a significantly lower frequency of TMJ symptoms than those with an anterior displacement joint with or without reduction or anterior type joints ($P < 0.05$; Table 1).

The results indicated that the stress angulation in group 3 was significantly higher than in group 4 ($P < 0.05$). Likewise, the stress angulation in group 5 was significantly higher than in group 6 ($P < 0.05$) (Table 2). The stress angulation in group 9 was seen to be significantly higher than the stress angulation in group 10 ($P < 0.05$; Table 3).

The correlation between the position of the disc and the stress angle was investigated. It was found that joints with posterior positioned discs (type D, Figure 4) had a significantly lower stress angle than any other type, and that there was a significant correlation between disc position and stress angulation [$n = 88$, $R = 0.369$, adjusted $R^2 = 0.126$, root mean squared (RMS) residual = 4.454; $P = 0.0004$](Figure 5).

Furthermore, in the asymmetry group, the difference in bilateral stress angulation (deviation side – non-deviation

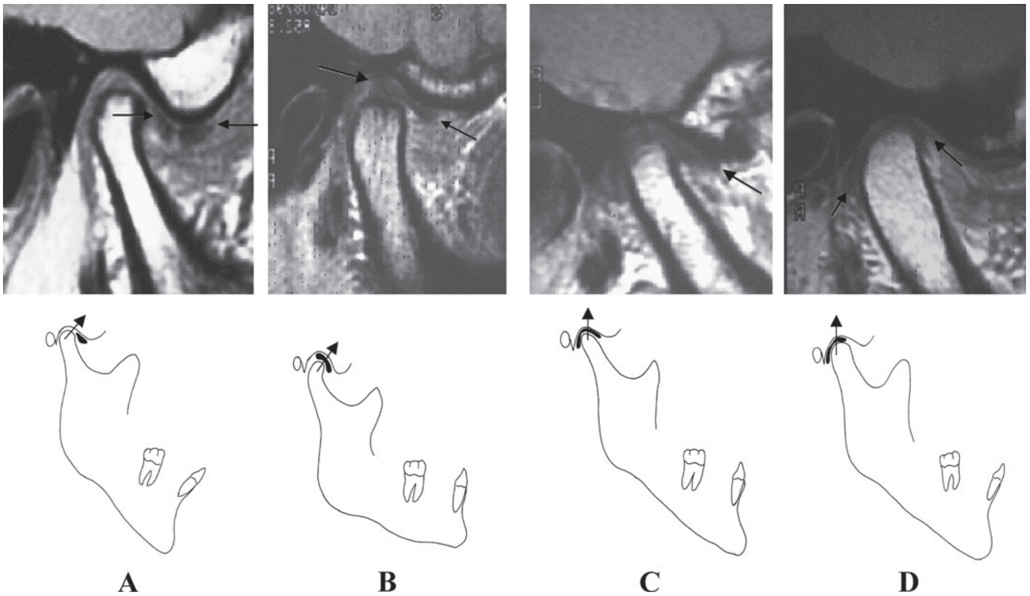

Figure 4 Classification of disc tissue on the sagittal magnetic resonance images and schematic drawings of the four disc positions. The arrow on the condylar surface indicates the average direction of the resultant force vector. (A) Anterior displacement with or without reduction, (B) anterior, (C) fully covered, (D) posterior.

Table 1 Number of temporomandibular joints with symptoms.

	Symmetry group (n = 44)	Asymmetry group (n = 44)	Total
Anterior displacement	6/8 ⎤	18/25 ⎤	24/33 ⎤
Anterior type	7/11 ⎥ *	5/9 ⎥ *	12/20 ⎥ *
Fully covered type	3/11 ⎥	0/3 ⎥	3/14 ⎥
Posterior type	1/14 ⎦	1/7 ⎦	2/21 ⎦

*$P < 0.05$ (chi-squared test).

side) and the Mx–Md midline was positively correlated. This was statistically significant (n = 22, R = 0.825, adjusted R^2 = 0.664, RMS residual = 1.889; P < 0.0001)(Figure 6).

Discussion

O'Ryan and Epker (1984) demonstrated different loading characteristics of the TMJ on the basis of different skeletal patterns. Through examination of the trabecular patterns of condyles from Class I, Class II open bite, and Class II deep bite skeletal patterns, they deduced the vectors of condylar loading in the functioning joint, which suggested that the functional loading patterns in each of these groups were significantly different. If the structure of the condyle of the TMJ is different in different skeletal patterns, it is likely that the anatomical relationship of the condyle/disc/fossa may also be. These may be different patterns of movement of the condyle, disc and fossa in these different skeletal types. However, their study examined only the trabecular pattern of the condyle, and not the joint disc tissue. Furthermore, no dynamic analysis was performed. In the present study, stress analysis of the TMJ using two-dimensional RBSM was carried out for 88 TMJs, and an objective evaluation based on the data was performed both dynamically and statistically.

The RBSM theory was incorporated into a model devised as a discrete method for analysing R–R type (the two bodies bonded by an interface are both rigid) interface problems. This theory assumes that an element itself is a rigid body, and the model represents a calculation method to measure the concentration of energy by the force exerted on a bundle of springs distributed along the boundary of the element. Compared with the FEM, which is commonly used in the field of dentistry (Chen and Xu, 1994; Tanaka *et al.*, 1994; DeVocht *et al.*, 1996; Tanne *et al.*, 1996), the RBSM theory is superior because the calculation can be carried out easily and rapidly with only a small amount of information compared with FEM. The FEM is suitable for calculating stress within elements, while the RBSM theory is used for calculating the surface force between elements. This theory has been used to analyse stress on the knee, hip, and wrist in the field of orthopaedic surgery (Genda *et al.*, 1995; Schuind *et al.*, 1995). These studies prove that RBSM can provide reliable results. On the other hand, the structure of the TMJ is significantly different from that of the knee or hip joint and its characteristic anatomy and movement make it difficult to manage the data. In this study, both tomography and MRI were used to assess the TMJ structure as accurately as possible.

When the six subgroups were compared, anteriorly displaced joints showed significantly higher stress angulation on both the deviated and non-deviated sides in the asymmetry group. However, there was no significant

Table 2 Comparison of stress angulation between joints with an anteriorly displaced disc and other disc types.

	Symmetry group		Asymmetry group			
			Deviated side		Non-deviated side	
	Anterior displacement		Anterior displacement		Anterior displacement	
	+	–	+	–	+	–
Stress angulation (degrees)	15.38 ± 3.93	15.12 ± 4.12	20.44 ± 4.69*	15.85 ± 4.64*	17.08 ± 4.04*	13.06 ± 4.40*

*$P < 0.05$ (Mann–Whitney U-test).

Table 3 Comparison of stress angulation between the deviation and non-deviation sides.

	Symmetry group		Asymmetry group	
	Right side	Left side	Deviation side	Non-deviation side
Stress angulation (degrees)	15.59 ± 3.50	14.74 ± 4.56	19.32 ± 4.52*	14.25 ± 4.89*

*$P < 0.05$ (Wilcoxon signed-ranks test).

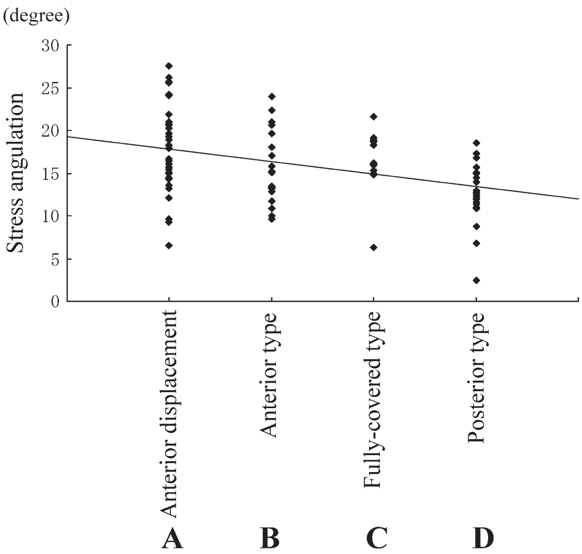

Figure 5 Correlation between stress angulation and the four disc types.

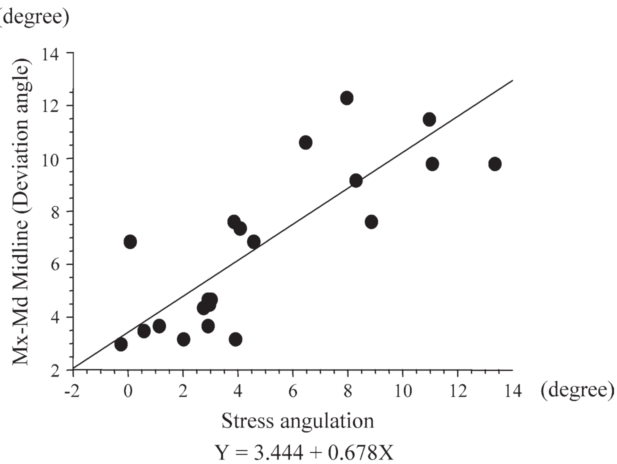

Figure 6 The result of a simple regression analysis of the difference in bilateral stress angulation (deviation side – non-deviation side) and Mx–Md midline (deviation angle) in the asymmetry group. Y, stress angulation; X, Mx–Md midline.

difference between anteriorly displaced joints and other joints. These results suggest that an anterior displaced disc is associated with asymmetrical mandibular morphology and stress of the TMJ. Schellhas *et al.* (1992) concluded that TMJ internal derangement could lead to mandibular retrusion and asymmetry. The relationship between TMJ internal derangement and dentofacial deformity has not yet been clarified, but it is suggested that stress in the TMJ may constitute an important factor for solving this problem.

When the deviated and non-deviated sides were compared, it was found that in Class III asymmetry cases the stress on the deviated side was positioned more anteriorly and on the non-deviated side more superiorly. Furthermore, the correlation between stress angulation and the Mx–Md midline in the asymmetric group suggests that mandibular asymmetry is strongly associated with the difference in stress distribution on bilateral TMJs.

The correlation between classification and stress angulation indicated that the stress direction of the anterior displaced or anterior type disc was more anterior to the condyle. On the other hand, the stress directions of the fully covered and posterior types had a tendency to be more superior to the condyle. In other words, disc position and morphology were related to stress distribution. The four relationships between disc tissue and mandibular are illustrated in Figure 4.

The incidence of TMJ symptoms in fully covered and posterior type joints was very low, so these can be considered to be a normal function.

Conclusion

The results of this study suggest that disc tissue is positioned so as to relieve stress, and that the TMJ is adapted to skeletal morphology in Class III subjects. Furthermore, the difference in stress distribution in bilateral TMJs may be one of the factors that induce the development of mandibular asymmetry. The findings also demonstrated that TMJ disc morphology in Class III subjects is associated with stress on the condyle and skeletal pattern. However, a further examination of this association in skeletal Class I and II subjects is required.

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