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Original Article

Articular disc displacement in mandibular asymmetry patients

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Mechanisms of disc displacement in temporomandibular joint (TMJ) internal derangement (ID) in mandibular asymmetry have not been clearly defined. This study examines the degree and direction of disc displacement and their relationship with vertical asymmetry in terms of both clinical and biomechanical aspects. A retrospective study of disc displacement was performed in 31 mandibular asymmetry patients using MR imaging. The degree and direction of disc displacements on the shifted side and contralateral side TMJ were investigated with the degree of vertical asymmetry. Furthermore, three-dimensional finite element models of entire mandible include TMJ and maxillary teeth in occlusion were created to simulate displacement of the articular disc during clenching condition. The direction of displacement on the shifted side and contralateral side were significantly different. Articular disc has tendencies to displace more on the shifted side even in mild degree of vertical asymmetry. The degree of displacement was correlated with the amount of asymmetry. The MR results were consistent with the tendencies of disc displacement predicted from the finite element models. We suggest that disturbance in the *direction* of stress distribution through asymmetry of the mandible is one of the mechanisms related to disc displacement.

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Introduction

Temporomandibular joint (TMJ) internal derangement (ID) is a common problem faced by dentists treating patients with asymmetry. A high incidence of articular disc displacement, the most concern characteristic of TMJ ID, has been reported in patients with asymmetry[1-3]. Articular disc displacement has been recognized as possessing a cause-and-effect relationship with facial morphology and growth[4,5]: the side with symptoms is directly related to the amount of vertical asymmetry[6]. Moreover, the mandible appears to be shorter on the side with more advanced disc displacement[2]. Articular disc displacement is more common in the anterior direction, but medial and lateral disc displacement[7-9] — which significantly limit mouth opening[10,11] — is also observed.

Many studies have investigated the mechanism of articular-disc displacement. In general, an increase in friction has been claimed as a major causative factor in displacement of the articular disc[12,13]. The generation of harmful reactive oxidative species that destroy important molecules, such as hyaluronic acid, collagens, and proteoglycans, impairs the integrity of the articular TMJ components and is also claimed to predispose subjects to disc displacement[14].

Differences in bilateral TMJ morphology in patients with mandibular asymmetry[15-17] may represent anatomic disorders that predispose these patients to

TMJ problems. Biomechanically, vertical dental and skeletal asymmetries of the mandible, such as canting of occlusal and mandibular planes in the frontal dimension due to a difference in the height of the right-left ramus, have been considered as important contributors to disturbances in TMJ loading that are related to TMJ ID[18]. However, how an asymmetric load affects articulardisc displacement in mandibular asymmetry has not yet been explained. This study examined the *degree* and *direction* of disc displacement and their relationship with the degree of vertical asymmetry in mandibular-asymmetry patients, in terms of both clinical and biomechanical aspects.

Materials and Methods

In vivo Retrospective Study

Subjects

Consecutive adult patients with mandibular asymmetry associated with TMJ ID who visited the Orthodontic Clinic of Tokyo Medical and Dental Hospital during 1999-2002 and were referred for MR imaging for TMJ ID prior to the treatment were included in this retrospective study. The subjects comprised 20 female and 11 male patients with a mean age of 25 years (range 18-46 years).

The criteria for including a patient were (i) presence of disc displacement on at least one side of TMJ, (ii) diagnosis of mandibular asymmetry in the vertical dimension, and (iii) no obvious health problems, trauma, or growth disturbances. As this study was a retrospective analysis of existing data, written informed consent was not obtained from the participating subjects, and was performed in accordance with the guidelines of the Helsinki Declaration (as revised in 1996).

Magnetic resonance imaging

The MR imaging was carried out with a 1.5-T unit (Magnetom Vision, Siemens) possessing bilateral 3-inch-diameter surface coils. Sequential bilateral images were made at closed-mouth and maximum-mouth-opening positions. The MR images were taken perpendicular (sagittal images) and parallel (coronal images) to the horizontal long axis of the condyle. These images depicted the disc, condyle, articular eminence, and glenoid fossa, and were used to analyze the disc-condyle relationship.

Normal disc position was defined by the junction of the posterior band with the retrodiscal area of the disc at the superior or 12 o'clock position ($\pm 10^\circ$) relative to the condyle. In the coronal plane of imaging, the disc IDs were perfectly centered on the condylar head, without transgressing a line through the condylar poles. Anterior disc displacement was defined when the posterior band was located anterior to the superior part of the condyle in all sagittal sections. Medial disc displacement and lateral disc displacement were defined when the disc crossed over one of the lines through the condylar poles in the coronal plane.

The degree of displacement in each direction was classified into slight, moderate, and severe displacement according to the criteria of Takase *et al.*[19].

Cephalometric radiography

Posteroanterior cephalograms obtained prior to orthodontic treatment were traced, and landmarks were identified and used to quantify the cant of the frontal mandibular plane (FMP), the angle between the perpendicular line of the facial midline and the line passing through the plane running through the antigonial notch bilaterally, which represented the asymmetry in the vertical dimension. A positive value indicated that this plane was inclined superiorly toward the shifted side (Figure 1).

The value of FMP was divided into three grades[6]: (i) mild asymmetry (FMP$<4^\circ$), (ii) moderate asymmetry (FMP = 4°-7°), and (iii) severe asymmetry (FMP$>7^\circ$).

Analysis and statistics

The records of direction and degree of disc dis-

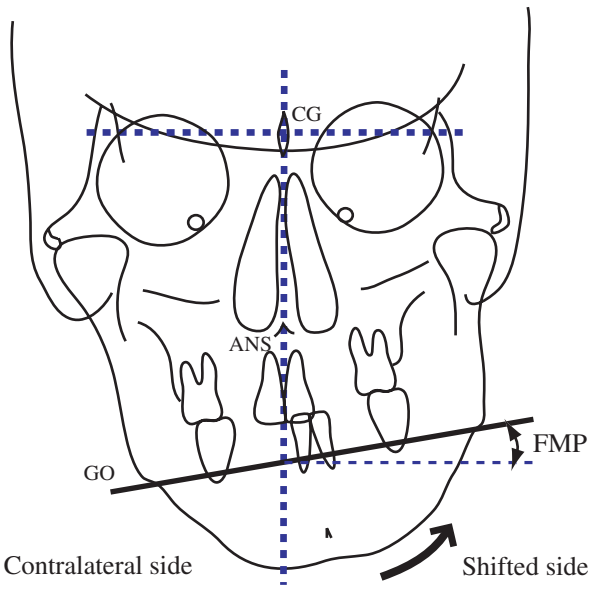

Fig. 1. The posteroanterior cephalometric landmarks, reference planes, and measurements of the frontal mandibular plane (FMP).

placement in each affected joint were performed separately in sagittal and coronal planes.

The FMP was evaluated with the degree and direction of disc displacement for each patient. Chi-square test was used to investigate the statistically significant difference of disc displacement between the shifted and contralateral side. A probability value of less than 0.05 was considered to indicate statistical significance.

Measurement error

All tracings and measurements on the posteroanterior cephalograms were performed twice; no significant differences were found between these measurements (the measurement error was 0.33%).

***In vitro* Mathematical Study**

The finite element model

Modeling

A previous developed three-dimensional finite element model of the standard human mandible with normal occlusion that includes a complete TMJ[18] was used in the present study. The material properties of each component were based on previous studies[20,21]. This model is referred as the standard model, and comprised 55,981 nodes and 47,643 solid elements.

To evaluate the effect of mandibular vertical asymmetry on the displacement of the articular disc, the ramus height, frontal occlusal plane (FOP; the plane combining the right and left mandibular first molars), and FMP of the standard model were modified. Based on our previous investigation[6] of adult mandibular-asymmetry patients, FOP and FMP can be considered as a single structure that moves in the same direction by the same amount. A difference of the right and left ramus is correlated with the inclination of the FMP, defined by the equation obtained from the regression analysis: Y=0.1587X+0.0696. According to these relations, 10 asymmetry models were created, in which FMP varied from 1° to 10° in 1° increments, ascending to the left side (Figure 2).

Loading and constraint conditions

For the loading conditions, the forces and lines of action of the masticatory muscles were determined. The models were then loaded with multiple force vectors to simulate the absolute moment of muscle forces during clenching over wide areas of attachment. The resultant force magnitude was determined on the assumption that the force is proportional to the area of the cross-section[22]. A resultant force of 500 N[23] was exerted by the lateral pterygoid muscle, the medial pterygoid muscle, the masseter muscle, and the temporal muscle in the ratio 1:2:2:4, respectively.

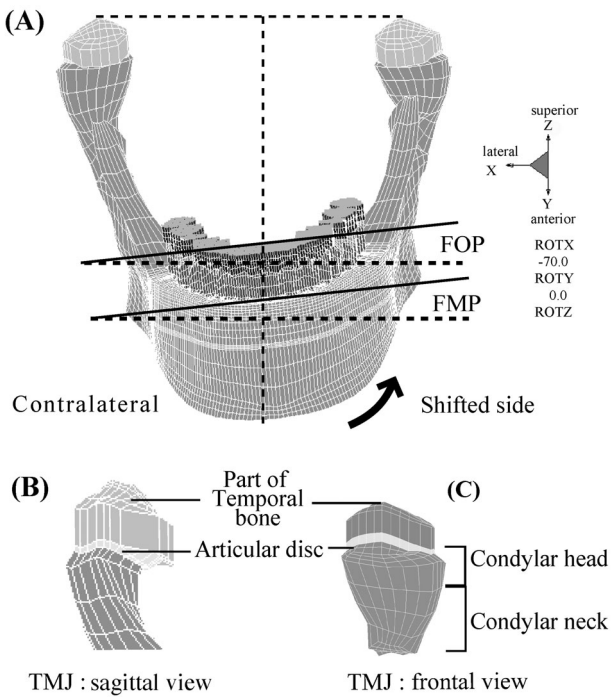

Fig. 2. Three-dimensional finite element model of the entire mandibular including occlusion and the temporomandibular joint (TMJ). (A) One of the asymmetry models with 6? of frontal occlusal and mandibular-plane inclination toward the left side. Sagittal (B) and frontal (C) views of the left TMJ, condyle, articular disc, and part of the temporal bone.

During loading, the upper surfaces of the glenoid fossa of the temporal bone and the base of the upper dentition were completely constrained.

Data analysis

Analyses of the finite element models were performed using commercially available finite element software (NISA II; EMRC, USA). All models were calculated using linear static analysis. To evaluate displacement analysis, the total displacement [$\sqrt{(x^2+y^2+z^2)}$] was calculated from displacement on the x-axis (displacement in mediolateral direction), y-axis (displacement in anteroposterior direction), and z-axis (displacement in inferosuperior direction).

The displacements of the articular disc from each model were compared between right and left sides of the asymmetric model and with those of the standard model.

Results

In vivo Retrospective Study

Relationship between vertical asymmetry and direction of displacement

Of 62 joints, anterior displacement was found in 22 joints, medial displacement was found in 13 joints, and lateral displacement was found in 11 joints.

In mild asymmetry group, disc displacement was found only on the shifted side in the anterior direction; no medial and lateral disc displacement was found in this group. In moderate and severe asymmetry groups, the disc was displaced remarkably in the anterior and lateral direction on the shifted side, and in the anterior and medial direction on the contralateral side, respectively (Figure 3A and B). The significant difference of the displacement direction was found between the shifted side and contralateral side ($p = 0.026$).

Relationship between vertical asymmetry and degree of displacement

The degree of displacement was directly related to the amount of asymmetry. Disc displacements associate with mild asymmetry were in slight-to-moderate degree. Patients with moderate asymmetry were affected with moderate-to-severe displacement on the shifted side and slight-to-moderate displacement on the contralateral side. In severe asymmetry group, the TMJs on both sides were affected, and the incidence of severe disc displacement was higher (Figure 3C and D).

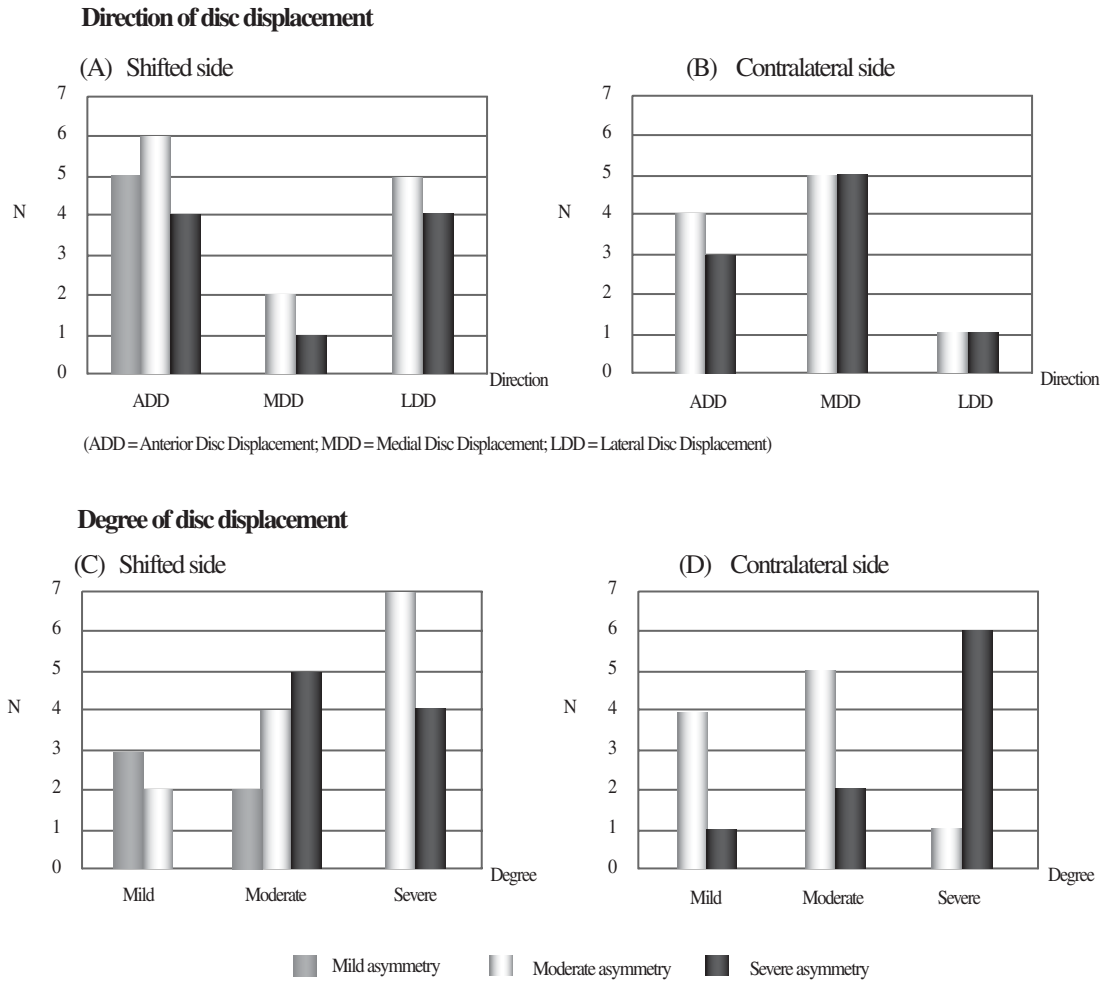

Fig. 3. Relationship between direction and degree of disc displacement and vertical asymmetry. Shifted-side discs were significantly displaced in the anterior and lateral direction, whereas contralateral-side discs were significantly displaced in the anterior and medial direction. The degree of displacement was more severe on the shift side than on the contralateral side when compared at the same degree of asymmetry

In vitro Mathematical Study

The displacements in asymmetric models were greater than those in the standard model and greater with larger vertical asymmetry. The discs on both sides tended to be displaced more in the anterior direction, in the range 0.009-0.024 μm. At the same time the shifted-side disc also tended to be displaced in the medial direction, whereas that on the contralateral side it tended to be displaced remarkably in lateral direction, in the range 0.095-0.100 μm. No additional changes for the displacement in the inferosuperior direction occurred relative to the standard model (Figure 4).

Discussion

The present results demonstrated that the direction and degree of disc displacement were related to the vertical asymmetry, both clinically and biomechanically. The degree of mandibular vertical asymmetry proportionally influenced the degree and direction of disc displacement both on the shifted and contralateral sides.

Relationship Between Vertical Asymmetry and Direction of Displacement

Vertical asymmetry affects disc displacement on the shifted- and contralateral-side TMJs in different ways. The analysis model showed the disturbance of direction of stress in the mandibular asymmetry both in coronal and sagittal plane. Though both sides articular discs have similar tendencies to displace more in the anterior direction, at the same time, the shifted-side disc also tended to be displaced more in lateral direction whereas it tended to displace more in medial direction on the contralateral side. Repetitive loading with unbalanced and inappropriate direction of stress may cause reactions of the lateral pterygoid muscle[24] and the accessory ligament around the TMJ[25], tending to increase the stability of the joint. These mechanical strains may cause fatigue and spasm to the muscles and ligaments that finally induce disc displacement

Disc displacement in the medial and lateral direction is less common in general TMJ ID patients[24], but the medial and lateral displacement in this group of patients was not an exception. On the other hand, we may conclude that mediolateral disc displacement is more common in mandibular-asymmetry patients

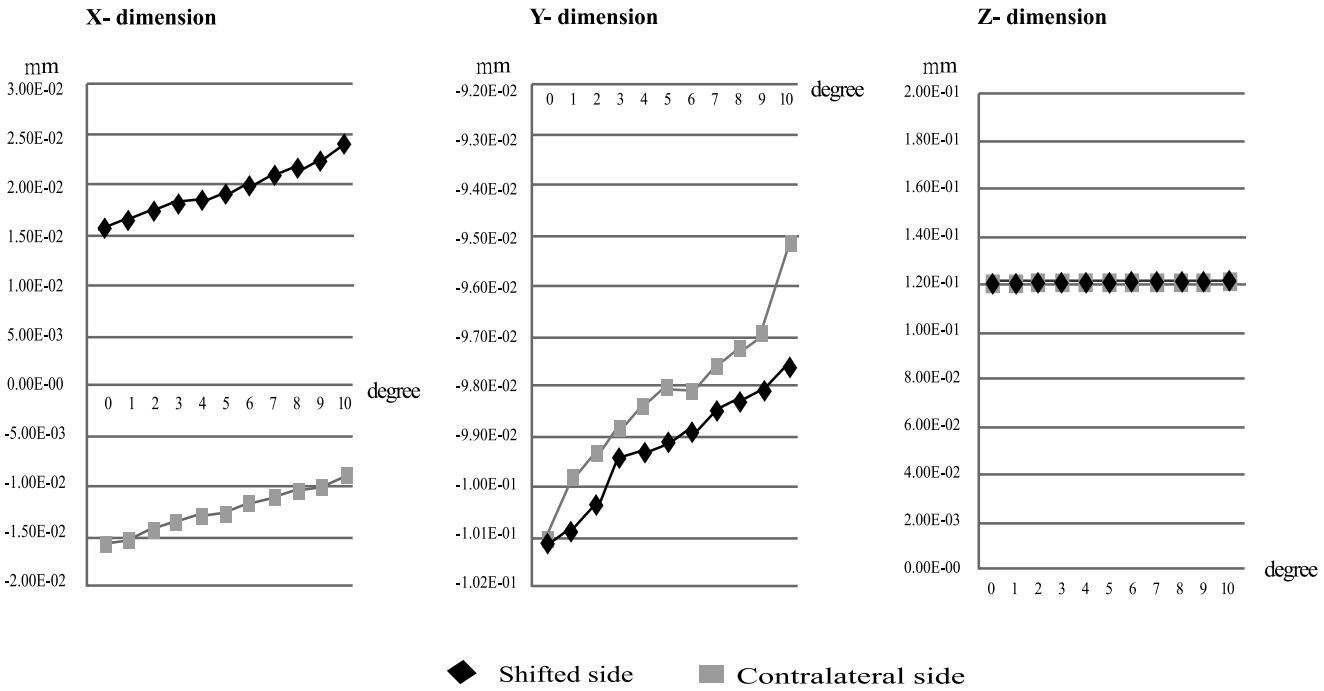

Fig. 4. Calculated results of disc displacement on the shifted- and contralateral-side TMJs, comparing between the standard model and each mandibular-asymmetry model. Shifted-side discs showed a greater tendency to be displaced more in the anterior and lateral direction as the asymmetry increased, whereas contralateral-side discs tended to be displaced in the anterior and medial direction.

than in those TMJ ID patients without asymmetry, even though the prevalence of anterior disc displacement was still higher.

Moreover, Kurita *et al*.[25] suggested that the discs for which the medial attachment is stretched would be displaced more anteriorly than those for which the lateral attachment is stretched. It is likely that disc displacement in a lateral direction enhances the anterior disc displacement. Medial and lateral disc displacement significantly limits mouth opening[10] and requires proper manipulation[11]. We suggest that intensive care of TMJ ID in these asymmetry patients is necessary to prevent the severe complications that may occur.

Relationship Between Vertical Asymmetry and Degree of Displacement

The degree of displacement is positively related to the degree of vertical asymmetry. This relationship has been widely discussed. Some suggested that disc displacement caused asymmetry, whereas others indicated that asymmetry caused TMJ problems. Many studies have been performed in adolescents to explain this relationship. Link and Nickerson[26] and Schellhas *et al*.[27] suggested the disc displacement had a cause-and-effect relationship with facial morphology and growth. Since this study was a cross-sectional study and all the subjects were adults, thus we had no information on the onset of the TMJ ID. From the clinical study, disc displacements were mainly observed on the shifted side even in the mild degree of asymmetry and as the degree of vertical asymmetry progress, in moderate asymmetry, disc displacements become more severe on the shifted side whereas displacements on the contralateral side were in mild to moderate degree. Therefore, it is conceivable that displacement starts from one side, the shifted side, and then furthers also to the contralateral side. Our findings are consistent with a previous study that found more severe disc displacement on the shorter side of the ramus[2].

Differences in bilateral TMJ morphology in patients with mandibular asymmetry have been widely reported. It has been claimed that the biomechanical characteristics of the joints change due to the differences in the shape of the eminence, and that a steep eminence plays a key role in the development of anterior disc displacement[28,29]. A steeper eminence on the shifted side has been also indicated. From our result of a tendency for displacement in the anterior direction, this may promote the displacement on the shifted side.

Mathematical study and disc displacement in mandibular asymmetry patients

The results of present mathematical study indicate a tendency for displacement of disc model in direction and degree, which helps to explain the actual disc displacement in patients due to the disturbances in the direction of TMJ loads. Moreover, it also supported the previous work that suggested a disturbance to the magnitude and distribution pattern of TMJ loads is an important contributing factor to TMJ ID in mandibular asymmetry[18]. However, the causes of TMJ ID are multifactorial, and include structural irregularities and mental tensions resulting from proprioceptive imbalances. Consequently, the displacement values obtained from the present analysis should be considered only from a comparative point of view. In addition, these models were simulated in a single clenching condition and at one point of time. Therefore, we may expect the greater value of displacement if the model is simulated and analyzed in dynamic condition as actual occur in the human being.

Several mechanisms may contribute to disc displacement in mandibular-asymmetry patients, such as disturbances of the bilateral TMJ structures, asymmetry of mandibular function, and friction. Disturbances in the direction of TMJ loads on the articular disc due to the vertical asymmetry is also one of the mechanism leading to disc displacement.

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