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Correlation between eminence steepness and condyle disc movements in temporomandibular joints with internal derangements on magnetic resonance imaging

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SUMMARY A steep articular eminence is reported to be a predisposing factor for the development of disc displacement. The purpose of this study was to evaluate the biomechanics of the temporomandibular joint (TMJ) in internal derangements and, additionally, to investigate whether a relationship exists between the steepness of the articular eminence and disc displacement, with (DDR) and without reduction (DDWR).

The material consisted of the sagittal TMJ magnetic resonance images (MRIs) of 39 joints (26 DDR and 13 DDWR). Sagittal and coronal TMJ MRIs were obtained at maximum intercuspation and in the maximum mouth-opening position. The steepness of the articular eminence, disc, and condyle rotation, and condyle translation were investigated. A Student's *t*-test was performed and correlation coefficients calculated.

The results revealed an increase in disc rotation in the DDR group and in condyle translation in the DDWR group ($P < 0.01$). Condyle rotation and the steepness of the articular eminence were similar in both groups. Disc rotation was positively correlated with condyle rotation and negatively correlated with condyle translation in the DDR group ($P < 0.05$, $r = 0.44$). Condyle translation was positively correlated with steepness of the articular eminence in the DDWR group ($P < 0.01$, $r = 0.74$). There was no correlation between movements of the disc-condyle assembly and the steepness of the articular eminence in the DDR group. Nevertheless, a relationship between condyle translation and the steepness of the articular eminence was found in the DDWR subjects.

Introduction

A pronounced steepness of the articular eminence in the temporomandibular joint (TMJ) has been proposed as an aetiological factor in the development of TMJ internal derangements (Atkinson and Bates, 1983; Hall *et al*., 1985; Kerstens *et al*., 1989a,b). It has been claimed that the biomechanical characteristics of the joints change due to differences in the shape of the eminence and that a steep eminence plays a key role in the development of anterior disc displacement. Atkinson and Bates (1983) have explained the biomechanical theory of TMJ disc displacement. According to this theory, the disc would have to rotate further forward on the condyle during mandibular movements to maintain the correct condyle-disc relationship in a TMJ with a steeper articular eminence. Hall *et al*. (1985) reported that the inclination of the posterior slope of the articular eminence was steeper in joints with anterior disc displacement than in asymptomatic joints. Kerstens *et al*. (1989a) evaluated the steepness of the articular eminence on radiographs and found a steeper slope in patients with anterior disc displacement than in subjects without TMJ dysfunction. They further reported an improvement in most patients who had undergone an eminectomy and surgical repositioning of the disc. These findings indicated that a flatter eminence may be more favourable (Kerstens *et al*., 1989b).

The disc and condyle rotation relative to the steepness of the articular eminence has not been studied together; probably because of the technical difficulties in radiographic visualization of soft

tissues during mandibular movement. Pseudo- and semi-dynamic magnetic resonance imaging (MRI) can be useful for this purpose as they depict soft tissues, and provide information with regard to TMJ movement during incremental mouth opening and closing (Ren *et al*., 1996; Eberhard *et al*., 2000). Since the correlation between the steepness of the articular eminence and the amount of disc rotation is unknown, the biomechanical theory of disc displacement cannot be sustained. Likewise, in opposition to the biomechanical theory of Atkinson and Bates (1983), Isberg and Westesson (1998) found that the degree of backward rotation of the disc was positively correlated with the steepness of the eminence in asymptomatic patients.

The aim of this study was to investigate the rotational characteristics of the disc-condyle complex against a determined steepness of the articular eminence of the TMJ in subjects with disc displacement with (DDR) and without reduction (DDWR). The null hypothesis to be tested was that the amount of disc and condyle movement in the glenoid fossa was related to the steepness of the articular eminence in internal derangements. The amounts of disc and condyle rotation, and condyle translation within the glenoid fossa were studied in association with the measurements of the steepness of the articular eminences in both the DDR and DDWR groups.

Materials and methods

Subjects

Thirty-nine subjects with symptomatic joints, consisting of 26 patients with DDR and 13 with DDWR. These symptomatic patients were selected from the Clinic of Orthodontics, Faculty of Dentistry, University of Ankara, Turkey. Their mean age was 24 years (range 10–36 years). Sagittal oblique and coronal MRIs were obtained in both maximum comfortable opening and intercuspation positions from the TMJ regions.

MRIs

Contiguous 3-mm sagittal oblique and coronal slices of the TMJ were taken with a 1.5 T (Tesla) superconductive MR scanner (GE Medical System, Milwaukee, MI, USA), using a 6×8-cm surface coil. Spin echo sequences were used with TR/TE, 500/21. The head was supported by a polyurethane foam head positioner, which also maintained the surface coil in contact with the skin overlying the joint. A laser guide was used to position the sagittal plane in the long axis of the magnet, with the Frankfort horizontal plane approximately vertical. Images were obtained in maximum intercuspation and at maximum comfortable mouth opening. The subjects lightly clenched during the imaging time to maintain the intercuspal position. Maximum comfortable opening was defined as the maximum symmetrical inter-incisal distance that could be maintained for 5 minutes, and the mandible was stabilized in this position by a rubber side-prop.

Coronal MRIs were used to diagnose whether rotational disc displacement existed or not. TMJs with sideway disc displacement were excluded from the present study.

Measurements of MRIs

Outlines of the fossa, eminence, condyle, and disc were traced on matte acetate sheets. Sufficient details of the temporal bone and mandible were included to permit accurate registration of the superimposed tracing. A reference line was drawn on the tracing in the closed mouth position and transferred to the open mouth tracing with the temporal bones superimposed (Price, 1990a).

The steepness of the eminence was measured on the MRIs. The highest point of the glenoid fossa (g) at a closed-mouth position was identified, and a horizontal reference line was established as the tangent to this point and parallel to the horizontal plane of the MRI; it thus corresponded to the Frankfort horizontal plane. A second line was drawn parallel from the top of the condyle to intersect with the posterior slope of the eminence. The intersecting point (e) was used as a reference point for the measurement of the steepness of the eminence. Another line (T) was then drawn from point (e) tangent to the posterior slope of the eminence. The angle (S) formed by reference lines T and Frankfort

horizontal indicated the inclination of the posterior slope of the eminence, thus representing the steepness of the eminence (Figure 1a).

Translation of the condyle was measured as the angle between the Frankfort horizontal plane and the axis of condyle translation. The axis of the condyle translation was drawn between uppermost articulating surfaces of the condyles at intercuspation and maximum mouth-opening positions (Figure 1a).

Rotation of the condyle was measured on the MRIs. The central condylar reference line passed through the uppermost extent of the condyle to the centre of its head. This reference line was transferred from the closed position tracing to the opened position tracing by superimposing the outlines of the mandible. Rotation of the condyle was measured as the angle between the central condylar reference lines at intercuspation and at maximum mouth-opening positions (Figure 1b).

To measure the amount of disc rotation, a line was drawn to represent the long axis of the sagittal contour of the disc. A line perpendicular to the long axis of the disc passed through the midpoint of the disc. The rotation was measured as the angle between the perpendicular lines to the long axis of the discs at intercuspation and at maximum mouth opening (Price, 1990b; Figure 1c).

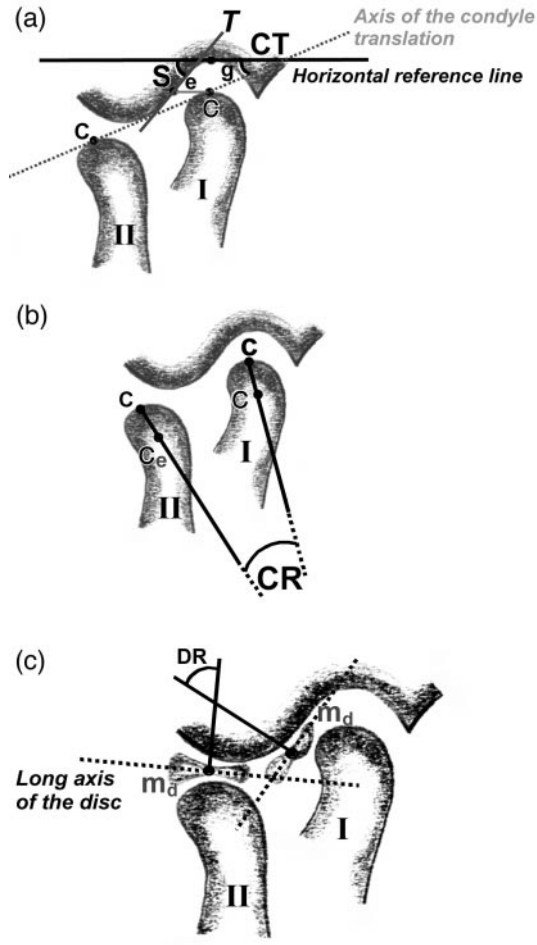

Figure 1 (a) Measurement of eminence steepness and translation of the condyle. g, the highest point of the glenoid fossa; c, top of the condyle; c', top of the condyle after mouth opening; e, intersecting point, which is drawn from the uppermost point of the condyle. Horizontal reference line represents Frankfort horizontal. T, tangential line is passed from point e to the posterior slope of the articular eminence. S angle corresponds to the steepness of the articular eminence. CT angle demonstrates translation of the condyle during mandibular function. I, closed-mouth position on MRI; II, at open-mouth position on MRI. (b) Measurement of condylar rotation. c_e, centre of the condyle head; c_e', centre of the condyle head after mouth opening. CR angle demonstrates rotation of the condyle during mandibular function. (c) Measurement of disc rotation. m_d, midpoint of the disc; m_d', midpoint of the disc after mouth opening. The long axis of the disc is passed from the anterior to the posterior band of the disc. DR angle demonstrates rotation of the disc during mandibular function.

Error of method

MRIs were traced on five separate days by the same investigator (HG) to determine repeatability of landmark identification and measurement technique. All angular MRI variables had a coefficient of intra-rater reliability ($r = \Sigma^2_{total}/\Sigma^2_{between}$) between 0.99 and 1.00. This means that if total variability is measured as 1, and between tracing variability was calculated to be 0.99, the remaining value (0.01) is due to tracing error or intra-rater error. This error was considered to be negligible.

Statistical method

The means, standard deviations, and ranges were calculated for each variable. Correlation coefficients were calculated between the steepness of the articular eminence, the degree of rotation

of the disc and the condyle, and the inclination of the condyle translation. A Student's *t*-test was used to compare the mean among the measurements of the disc rotation, condyle rotation, condyle translation, and the steepness of the eminence.

Results

The means, standard deviations, and ranges for each variable are shown in Table 1. The difference of disc rotation angle was statistically significant between the groups ($P < 0.01$), while condyle rotation and the steepness of the eminence were found to be similar in both groups. Condyle translation was more significant in the DDWR group than in the DDR group ($P < 0.01$).

Correlation coefficients were calculated for each of the variables in both groups. Correlation between condyle and disc rotation was statistically significant in the DDR group ($r = 0.44$, $P < 0.05$). However, a negative correlation coefficient was found between condyle translation and disc rotation ($r = –0.04$, $P < 0.05$; Table 2).

Neither disc/condyle rotation nor condyle translation within the glenoid fossa was correlated with the steepness of the articular eminence in the DDR group ($r < 0.39$, $P < 0.05$). Correlation between the steepness of the articular eminence and condylar translation was statistically significant in the DDWR group ($r = 0.74$, $P < 0.01$; Table 3).

Table 1 Data obtained in this study evaluated with a Student's *t*-test.

Measurements	DDR			DDWR			*P*
	Min	Max	$x \pm SD$	Min	Max	$x \pm SD$	
Disc rotation	4	87	44.90 ± 4.7	5	29	14.31 ± 2.4	**
Condyle rotation	1	28	14.06 ± 1.5	1	30	12.54 ± 2.5	NS
Condyle translation	3	46	27.10 ± 2.6	23	67	39.7 ± 3.9	**
Eminence steepness	34	77	54.81 ± 2.4	31	77	55.8 ± 4.5	NS

**$P < 0.01$, significant; NS, not significant.
DDR, disc displacement with reduction; DDWR, disc displacement without reduction.

Table 2 Correlation coefficients in subjects with disc displacement with reduction.

$n = 26$	Disc rotation	Condyle rotation	Condyle translation
Condyle rotation	0.44*		
Condyle translation	–0.44*	–0.53**	
Eminence steepness	0.26 NS	–0.11 NS	0.29 NS

*$r_{0.05} = 0.39$; **$r_{0.01} = 0.50$; NS, not significant.

Table 3 Correlation coefficients in subjects with disc displacement without reduction.

$n = 13$	Disc rotation	Condyle rotation	Condyle translation
Condyle rotation	0.14 NS		
Condyle translation	–0.03 NS	0.08 NS	
Eminence steepness	0.05 NS	–0.11 NS	0.75**

**$r_{0.01} = 0.68$; NS, not significant.

Discussion

Atkinson and Bates (1983) hypothesized that the biomechanics altered in joints with steep eminences. They suggested that the disc should rotate further forward on the condyle to maintain normal translation of the condyle-disc assembly, thus the disc would be predisposed to an anterior position at mouth closing. However, those authors emphasized that the bio-mechanical differences in joint anatomies were independent from other aetiological factors of TMJ dysfunctions such as muscle inco-ordination, trauma, joint laxity, or occlusal disharmony. When all other factors are eliminated, the only aetiological factor of TMJ internal derangement may be the anatomy of the eminence. This could be true on the basis of the presumption that the slope and thickness of the disc are the same in every joint regardless of the differences in the steepness of the eminence. The shape of the disc, however, is not clear in relation to the morphology of the eminence. The disc may serve as an important volumetric compensatory mechanism adapting to the shape of the articu-lating surfaces during condyle translation (Isberg and Westesson, 1998). The other important issue is the posterior disc attachments stretching the disc during mandibular functions. If the posterior disc attachments are over-stretched because of trauma to the jaw, luxation of the mandible, muscle hyperactivity, malocclusion, mandibular hypoplasia, loss of posterior teeth, distal deflective contacts, etc., the disc displaces permanently anterior of the condyle. It has been determined that disc rotation was decreased in the DDWR group in this present study. The disc may rotate backwards to accommodate to the condyle head at mouth opening. Thus, the correct relationship of the condyle, disc, and eminence are maintained. The morphological feature of the human disc is determined by its anatomical localization. Furthermore, the disc shape is biconcave due to the fact that the disc is positioned between the condylar head and the posterior slope of the articular eminence (Gökalp *et al*., 2000). The disc shape is distorted when the disc is gradually displaced forward related to the anterior of the condyle head. Consequently, the disc is folded due to pressure from the condylar movement (Murakami *et al*., 1993). Movement of the folded disc in the glenoid fossa is restricted, since accommodation between the condyle head and disc is disturbed.

Although a steep articular eminence is a predisposing factor for disc displacement, Ren *et al*. (1995) found that the articular eminence was steeper in asymptomatic volunteers with normal disc position than in patients with TMJ internal derangement. The steepness of the articular eminence decreased in the progressive internal derangement as a result of remodelling or degenerative changes of the bone. However, in this investigation the steepness of the articular eminence was found to be similar in both groups. Although the steepness of the eminence may be similar at the early stage of TMJ internal derangement, further development of the disease leads to gradual remodelling of the joint structure and flattening of the eminence.

The condyle displaces posteriorly due to the anteriorly displaced disc in the intercuspal position in subjects with DDR. The disc rotates further forward than the condyle within the glenoid fossa during mouth opening. The movement of the condyle is smaller than the movement of the disc, until the condyle recaptures the disc. When the disc is recaptured by the posteriorly positioned condyle during mouth opening, a click occurs, and the condyle-disc assembly slides forward together through the steepness of the posterior slope of the articular eminence. This relationship between the condyle and disc was found in the DDR group in this study.

Stretching of the retrodiscal attachments may be increased in DDWR subjects, due to the fact that the disc remains dislocated anteriorly, blocks the condyle into the intracuspal position, and limits protrusion of the mandible. This situation is called ‘locking’. When locking becomes more chronic, condylar translation gradually increases because of the condyle pushing the dislocated disc further (Farrar and McCarty, 1979). This may be the explanation for the increase in the amount of condylar translation in DDWR group found in this study.

Anterior disc displacement with and without reduction is usually treated by conservative

means (Moloney and Howard, 1986; Okeson, 1988; Lundh and Westesson, 1989; Gökalp and Türkkahraman, 2000). When conservative approaches fail, surgical repositioning of the disc may be considered. An arthroscopy technique has been developed to manipulate and hold the disc in a more favourable posterior and lateral position (Howard, 1989). Another treatment approach, which is used to prevent the disc dislocation, is eminectomy. Eminectomy has been applied to improve TMJ function in patients with a steep eminence (Kerstens *et al*., 1989b). However, the results could not verify that a steep eminence was an aetiological factor in the development of TMJ internal derangements.

Conclusions

According to the results of the present study, movement of the condyle-disc assembly not only depends directly upon the steepness of the articular eminence, but also relates to synchronization of the condyle-disc assembly during mandibular functions. Thus, the hypothesis that a steep articular eminence of the TMJ is a predisposing factor for disc displacement could not be verified.

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