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Osseous Morphology and Spatial Relationships of the Temporomandibular Joint: Comparisons of Normal and Anterior Disc Positions

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ABSTRACT

The objective of this study was to determine differences in spatial relationships and osseous morphology between temporomandibular joints with normal and anterior disc positions. Magnetic resonance imaging was employed to determine disc position in 335 temporomandibular joints in 175 subjects (106 female and 69 male) between the ages of 7.27 years and 20.0 years (mean age: 13.08 years). Twelve tomographic variables were measured from preorthodontic tomograms of the same individuals. Tomographic data were cross-referenced with MRI data for those with normal and full anterior disc displacement. Independent sample *t*-tests revealed significant differences for all measures of joint space, condylar position, and morphology of the articular eminence ($P < .05$) between joints with normal disc position and with full anterior disc displacement. This study indicated that measures of joint space and eminence morphology might provide diagnostic information for the assessment of joint status in the adolescent population.

KEY WORDS: Temporomandibular joint, Tomography, Magnetic resonance imaging, Internal derangement.

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INTRODUCTION Return to TOC

Several investigators have suggested that condylar position is related to internal derangements of the temporomandibular joint (TMJ). With respect to joint space analysis and the use of condylar position as a diagnostic tool, studies indicate that there are statistically significant differences in condylar position and absolute value of joint space between joints with altered disc position, verified with arthrography or magnetic resonance imaging (MRI), and joints with normal disc position.[1–3] Despite these findings, radiographically determined condylar retrusion or nonconcentric joint space does not necessarily predict internal derangement (ID). Research has suggested that measurement of joint space and determination of condylar position is of questionable value, given the high variability of condylar position within the fossa in the adult population.[3–6] Although the variability of condylar position in adults may minimize the diagnostic value of the measurement, there may be value in the assessment of joint space and condylar position in adolescents. The literature is deficient with respect to the assessment of joint space in relation to the position of the disc in adolescents. The data may provide information on normal anatomy of the developing TMJ and information about how the joint space in adolescents with normal and altered disc positions compares with that of their adult counterparts. The data might also provide other investigators with a baseline and give clues to differences in TMJ development in individuals with and without derangement.

Investigators often postulate that a cause-and-effect relationship exists between ID and osteoarthritis, but which of these entities precedes the other is yet to be established. Brand et al[1] found that 94% of patients with evidence of degenerative joint disease (DJD) had arthrographic evidence of ID, whereas only 47% of the joints with ID had evidence of DJD. Anderson and Katzberg[7] reported similar findings in their tomographic and arthrographic study of 141 TMD patients. Of the patients with reducing disc displacement, 9% showed signs of degeneration, but 39% and 60% of patients with nonreducing disc displacement and perforation, respectively, exhibited degenerative changes. De Leeuw et al[8] found that patients with reducing disc displacement showed less hard-tissue structural change than did patients with nonreducing disc displacement in a 30-year follow-up study of 55 joints. These authors support the observation that in most cases, degenerative changes are secondary to ID.

Displacement of the disc would necessitate alteration of loading conditions and the nutritional status in the TMJ.[9,10] The altered joint dynamics and increased shearing stresses associated with internal derangement may lead to physiologic remodeling, which would increase the congruity of the loading surfaces of the joint and reduce the force per unit area.[11] When the joint's capacity for remodeling has been exceeded, with or without disc displacement, remodeling may progress gradually into osteoarthritis.[12] Common radiographic changes include subchondral sclerosis, flattening of the condyle and articular eminence, osteophyte formation, lipping, erosions, or the formation of a cyst with the breakdown of subchondral bone.[13] Distinguishing between osteoarthritis and adaptive physiological remodeling is difficult radiographically and may only be possible histologically on the basis of the articular tissue integrity or synovial fluid markers.[14–16] Objective examination of radiologic osseous contours may provide clues about the distinction between physiologic remodeling and osteoarthritic changes.

Although tomography is inappropriate as a diagnostic test for ID,[17] several authors have demonstrated the validity of tomography for assessment of osseous contours and abnormalities.[18–22] The primary obstacle is defining a valid reference paradigm for condylar and eminence morphology to enable quantification between patients. Linear and angular measurements relative to constructed or arbitrary reference points,[23–26] as well as subjective evaluation of changes in the condylar and temporal components, have all been examined in radiographic images of the temporomandibular joint.

The purpose of this retrospective research study was to determine objectively whether temporomandibular disc position is associated with specific positional and morphological changes of the osseous components of the TMJ, as viewed in axially corrected tomographs of an adolescent population. By examining this relationship, the contribution of tomographic radiographs to the identification of joint abnormalities in an adolescent population can be assessed. In addition, information derived from this study may lead to better understanding of the factors contributing to and sequelae of ID in an adolescent population.

MATERIALS AND METHODS Return to TOC

Axially corrected tomographic radiographs and MRIs of 335 TMJs from 175 subjects (106 female and 69 male) between the ages of 7.27 years and 20.0 years (mean age 13.08 years) were used for this study. Mean male age was 13.02 years, and mean female age was 13.12 years. The study group consisted of individuals who presented sequentially to a private imaging facility for orthodontic records, regardless of TMJ status, and from whom consent was obtained for participation in the study.

Tomographic technique

All tomographic images were made at the same private imaging facility using a Tomax Ultra-scan (Incubation Industries, Inc, Warrington, Pa) with hypocycloidal motion. Exposure settings were 100 milliseconds, 5 mA, and 78 kilovolt (peak). Head positioning was established by alignment of the Frankfort plane parallel to the plane of the film, with the teeth in maximum intercuspation, using a polyvinylsiloxane (President Jet-Bite, Coltene/Whaledent Inc, Mahwah, NJ) centric occlusion bite registration. The polyvinylsiloxane material ensured that the bite was not opened with the registration.

All tomographic radiographs were viewed under standardized conditions and traced onto acetate overlays with a 0.3 mm lead pencil. Each tomographic radiograph was traced approximately 1 week apart by the principal investigator and involved the identification of the outline of the mandibular condyle and glenoid fossa. The central slice of the tomographic survey was used for this study. Each tracing was scanned at 600 dots per inch (dpi) by the same investigator using a UMAX 1200S scanner (UMAX, Taiwan, Taiwan). A computer program, written in Microsoft Visual Basic for Windows (Microsoft Corp, Redmond, Wash), interpreted the data and returned angular, curvature, and distance measurements. The curvature calculation was validated through the repeated measurement of known polynomial curves at known locations. The average curvature calculation was verified by repeated measurements of varying radii. For both measures, the calculated variance was less than 1% of actual values.

MRI data

Magnetic resonance imaging of the TMJs was performed without sedation, using a 1.0 T magnet (Shimadzu Corp 3, Tokyo, Japan) and a unilateral 3-inch surface receiver coil. Axial scout images were obtained to identify the condyles. Bilateral closed-mouth sagittal sections were obtained perpendicular to the long axis of the condyle, making use of the same polyvinylsiloxane centric occlusion bite registration used in the tomographic survey. T1-weighted 500/20 (time to repetition ms/time to echo ms) pulse sequences were performed on all subjects using a 3-mm slice thickness, 140-mm field of view, number of excitations of 2, and an image matrix of 204 × 204.

An experienced radiologist subjectively evaluated the most representative central sagittal slice of the joint to determine disc position. Of the joints evaluated, only joints that exhibited normal disc position and joints with full displacement of the articular disc were included in this study. Normal disc position was defined as that point in the closed-mouth position at which the intermediate zone of the disc was interposed between the head of the condyle and the posterior slope of the articular eminence, with the anterior and posterior bands equally spaced on either side of the condylar load point in a bow-tie appearance. Full displacement of the articular disc was defined as the point at which the articular disc was anteriorly displaced relative to the posterior slope of the articular eminence and the head of the condyle. The bilaminar zone of the disc was interposed between the osseous articular structures and occupied the narrowest joint space. Disc reduction, nonreduction, or perforation were not criteria for assessment in this classification scheme.

Determination of loading distance

Determination of the loading surfaces of the condyle and the posterior slope of the articular eminence was based on the biomechanical model of Smith et al.[27] It was assumed that condylar reaction forces during maximum intercuspation were directed essentially perpendicular to the posterior slope of the articular eminence[27–31] and that the condylar loading point corresponded with the closest joint space perpendicular to the posterior slope of the articular eminence.[30] Except in a few joints with extensive condylar and posterior slope flattening, visual identification of the anterior joint space was straightforward. In those problem cases, the centerpoint of the flat region was used.

Condylar reaction forces were assumed to act through an angle of 32.5° superior and 32.5° inferior, perpendicular to the posterior slope of the articular eminence through the condylar loading point during unilateral biting.[27] In order to develop a loading distance for the purposes of this study, 20 joints representative of normal disc position (10 from females and 10 from males) and 19 joints representative of disc displacement (10 from females and 9 from males) were randomly selected. Only TMJs from separate patients were considered. The closest anterior joint space was measured perpendicular to the posterior slope of the articular eminence. Two circles identified the posterior slope of the articular eminence with closest fit to the glenoid fossa and the articular tubercle, respectively. The inflection of the posterior slope of the eminence from the circle circumferences provided 2 points to include a single tangent to the circles, which was parallel to the articular eminence (Figure 1).[32]

The error of measurement was determined by selecting 10 tomographic images representative of normal disc position and 10 images representative of disc displacement. These 20 tomographic images were traced 5 times and scanned at 600 dpi; the closest anterior joint space was then measured twice on each image. The standard deviation of the linear measure was determined over the 5 tracings of each radiograph. Subsequently, the average SD for each angular and linear measure was determined by calculating the average SD value over all 20 radiographs (Table 1).

Independent *t*-tests comparing gender in the normal and abnormal groups indicated no significant differences with respect to anterior joint space ($P > .05$). Because the anterior joint space in the abnormal group was significantly greater than that of the normal group ($P < .05$), the abnormal group was used for determining the loading distance. Joints from 3 males and 17 females with anterior disc position were randomly selected from their respective populations. Since 10 of the 67 joints (15%) with anterior disc position were male, 3 of the 20 joints selected were from the male sample. Anterior joint space was measured twice on 2 separate scanned tracings for each of the 20 joints selected. The average anterior joint space (AJS) was 2.74 mm, with a standard deviation of 0.95 mm. Loading distance was then determined according to the following formula:

The addition of 2 standard deviations and 2 measures of error to the mean would yield a conservative boundary for the total error, so that at least 95% of the subjects with anterior disc position and virtually all of the subjects with normal disc position would fall into the calculated loading distance.

Reference lines were drawn 3.15 mm superior and 3.15 mm inferior to the eminence loading point, perpendicular to an individualized eminence reference; these delineated the superior and inferior borders of the eminence loading surface (Figure 2). The points where these 2 lines intersected the surface of the condyle served as the superior and inferior boundaries of the condylar-loading surface. In order to divide the loading surface into superior, central, and inferior sectors, 2 intermediate lines were drawn 1.05 mm superior and 1.05 mm inferior to the eminence loading point and perpendicular to the eminence reference plane (Figure 3).

Tomographic measurements

Determination of tomographic variables involved the digitization of 34 points on the condylar-loading surface and 34 points on the eminence-loading surface. The digitization of 6 additional points was required for joint space measures. For each tomograph, 12 variables were calculated, described as follows:

Anterior, superior, and posterior joint space. Joint space measurements (AJS, anterior joint space; SJS, superior joint space; and PJS, posterior joint space) were determined according to the method of Pullinger et al[6] (Figure 4).

Superior, central, inferior, and overall condylar-loading curvatures. A computer program was developed that used digitized information to determine the average curvature for each 2.1 mm sector of the loading surface as well as the overall curvature for the entire length of the arc embedded within the 6.3 mm loading distance. A value of zero indicated a straight line, a positive value indicated a concave surface (rounded in toward the center of the condyle), and a negative value indicated a convex surface (rounded outward toward the posterior slope of the eminence, Figure 3).

Superior, central, inferior, and overall eminence-loading curvatures. A computer program was developed that used digitized information to determine the average curvature for each 2.1 mm sector of the loading surface as well as the entire arc superimposed on the 6.3 mm linear distance. A value of zero would indicate a straight line, a positive value would indicate a convex surface (rounded outward toward the condyle) to the posterior slope of the eminence, and a negative value would indicate a concave surface (rounded inward and away from the condyle, Figure 3).

Condylar position. Condylar position was calculated according to the method of Pullinger and Hollender[33] using the following formula: (PJS − AJS)/(PJS + AJS) × 100. A zero value indicated a concentric location of the condyle within the fossa. A positive value indicated an anterior condylar position, and a negative value indicated a posterior position.

All tomographic tracings were repeated twice and measured twice. The means of each tomographic variable were used for subsequent statistical evaluation.

Analysis of data

Method error. To determine the error of measurement of angular, linear, and curvature tomographic values, 10 tomographic images representative of normal disc position and 10 tomographic images representative of disc displacement were randomly traced 5 times each, and then each tracing was subsequently scanned at 600 dpi and digitized twice by the principal investigator. The standard deviation (SD) of each angular and linear measure was determined over the 5 tracings of each radiograph. The mean SD was determined separately for the 10 joints with normal disc position and for the 10 joints with anterior disc position. Subsequently, the mean SD of each angular and linear measure was determined by calculating the mean SD value over all 20 radiographs (Table 1).

Statistical analysis. Of the 335 joints, 176 (106 female and 70 male) were used for statistical analysis. Only those joints that fell into the normal or fully anteriorly displaced disc categories were used, which resulted in the elimination of 159 joints from the study. Oblique displacements were not included in the study group. Each joint was considered as a separate case, with right- or left-joint MRI data matched with the corresponding tomographic angular, linear, and curvature data from the same side. For the purposes of statistical analysis, independence of joints was assumed.

Independent samples *t*-tests were used to assess whether or not differences in tomographic measurements existed between genders for images representative of normal disc position and those representative of disc displacement. Because the results of the independent sample *t*-tests indicated that there were significant differences between males and females in the normal disc-position grouping, males and females were evaluated both separately and together (Table 2).

Independent samples *t*-tests for males and females were conducted for the linear, angular, and curvature tomographic variables following removal of outliers. The Levene test for equality of variances was used in conjunction with the independent samples *t*-tests. Joints with normal disc position and joints with fully displaced discs were compared by mean. Significance levels of less than 5% were considered statistically significant.

RESULTS Return to TOC

Descriptive data for the overall, female, and male populations according to normal or anterior disc position, along with results of independent *t*-tests, are listed in Tables 3 through 5. The combined and female samples showed a statistically significant difference between joints with normal and anterior disc position for all joint-space measures ($P < .05$), condylar position ($P < .0001$), and all 4 measures of eminence curvature ($P < .0001$). In a similar fashion, male joints displayed significantly different values for AJS ($P < .05$), SJS ($P < .001$), condylar position ($P < .05$), and all 4 measures of eminence curvature ($P < .05$).

DISCUSSION Return to TOC

In this study, objective measurement was used to quantify changes that occur in osseous tissues with ID. Use of the slope of the articular eminence and the closest AJS prevented the use of cranial and dental reference planes, which must be superimposed onto the films or assumed to exist. Thus, the reference system becomes based upon functional rather than anatomic criteria. In addition, this study provides objective criteria for loading-surface boundaries that are repeatable and nonarbitrary in a cross-sectional study of this type.

The finding of significantly greater SJS values in males compared to females with normal disc position is in agreement with the findings of Cohlmia et al.[23] These authors also reported a statistically significant greater SJS in a preorthodontic male population than in a similar female population, although their classification criteria did not include a description of disc position. This larger SJS in males could possibly be explained by a greater soft tissue thickness in the male group. Lubsen et al[34] histologically examined changes in cartilage and subchondral bone during maturation in a small sample of 11 males and 10 females. They found no significant differences between mature condyles in males and females; however, males retained their “immature” status longer. The immature condyle is characterized by greater soft-tissue thickness, reduced bone quantity and thickness, and greater vascular spaces. Another possible explanation could be the difference in the overall size of the condyle and temporal fossa between males and females in general.[24,35,36]

The significant difference in the overall eminence curvature may be due solely to the positional relationships or anatomical differences between males and females in this area. Ren et al[37] found that females had a nonsignificant 4° to 5° reduction in the angle of the eminence. For positional relationships, the superior position of the condyle within the fossa in females relative to males may result in a difference in the eminence-loading surface. As the condylar loading point moves superiorly within the fossa, the curvature of the eminence will generally become less convex because of the anatomy of the posterior slope of the eminence.

In keeping with previous studies,[1–3] this study shows that anterior disc position results in increased AJS and a reduced superior and relative posterior positioning of the condyle within the fossa. In females, the PJS was also significantly reduced in the anterior disc position group. The significantly greater AJS could be explained under 3 different situations. First, compensatory resorption of the condylar and articular eminence-loading surface with anterior disc position could occur, and increased concavity of the eminence in the anterior disc position would support this theory. Second, the condyle may be retropositioned within the fossa, resulting in increased AJS. Anterior movement of the thick posterior band to become interposed between the anterosuperior surface of the condyle, or the potential deformation of the disc, may form the mechanical basis for this observation.[38] The statistical significance and observed reduction in PJS in females and males, respectively, lends support to this idea, although the observed reduction in PJS is only between one and two thirds of the observed increase in AJS. Finally, the increased AJS may be an anatomic variant that is a preexisting contributing factor to internal derangement.

The reduced SJS in the anterior disc position group for both males and females agrees with previous findings.[2] This could be explained through the loss of the posterior band interposed between the condyle and the height of the mandibular fossa.

The relative retrusion of the condyle within the fossa for the anterior disc position grouping was statistically significant for males and females. As discussed previously, this is a relative movement of the condyle; the increase in AJS is only 62% and 37% of the decrease in PJS for females and males, respectively. Our findings neither support nor refute the hypothesis that condylar retrusion is a risk factor through altered biomechanics or through impingement of the bilaminar zone that maintains blood flow and nutrition in the joint. The condylar retrusion here may well be only secondary to altered disc position or a result of increased condylar and eminence remodeling. It may also be due to rotation of the condyle posteriorly in the fossa, secondary to a fulcrum effect at the second molar, with loss of the posterior band of the disc from the height of the mandibular fossa and potential shortening of the mandibular ramus characteristic of these patients.[39] However, one would expect to see an increase in SJS if the fulcruming phenomenon were true.

Direct comparison of condylar curvature between joints with normal disc position and joints with anterior disc position indicated no significant difference between groups of males or females. This varies with the findings of investigators who suggest that osseous changes in the condyle are indicative of osteoarthritis associated with ID.[2,3,7,40,41] Possible explanations include the prospect that forces on the condyle are distributed over the entire condylar head and thus are not exceeded in comparison with the posterior slope of the eminence.[42] Alternatively, if one is to examine the reference system, the lack of change in the condyle may be due to the insensitivity of the condylar curvature measurement to alterations of the positional relationships of the condyle within the fossa. The condylar load point serves as a starting point for the reference system. Thus, if the condylar load point does not change on the condyle and remodeling does not occur, no change will be seen in condylar curvature, even with change in position. Finally, the reference and measurement system may have been deficient in including areas of peripheral remodeling, or osseous changes may be qualitative in nature (sclerosis, change in trabecular pattern, or formation of cysts), rather than quantitative (erosions or flattening).

All measures of osseous eminence curvature in males and females indicated a statistically significant reduction in convexity of the posterior slope of the loading surface of the eminence for joints with anterior disc displacement. Possible explanations for this include positional relationships of the condyle within the fossa or regressive remodeling. Regressive remodeling would agree with previous reports describing a flattening of the eminence in response to an anterior disc position.[37,43] This could be viewed as an adaptive response to altered disc position that acts to increase mobility of the condyle in the presence of a chronically anteriorly displaced disc and to alter nonphysiologic loading patterns.[44]

The observation that the condyle and temporal fossa have the potential to undergo significant change in shape during the period from early adolescence to adulthood may account for some of the variation in joint-space measurements and measures of morphology.[36,45–47]

In addition, variables of craniofacial morphology, growth direction, and malocclusion have been shown by various authors to play a role in positional and morphological relationships of the temporomandibular joint.[23,24,26,48,49]

Inherent limitations in the measurement of tomographic variables and application of the reference system were encountered, including the following:

1. The definition of subjective anterior disc position did not include a classification of reducing or nonreducing disc, or a description of perforation. Nonreducing discs and discs with perforation are associated with an increased frequency of structural and hard-tissue changes in comparison to discs in subjects diagnosed with anterior disc displacement with reduction.[1,7,8,50]

2. The same investigator made all measurements.

3. Loading distance was defined in an attempt to develop an objective measure of condylar and temporal morphology under static loading conditions.[27] The actual area of loading varies with type of movement, muscle direction, craniofacial morphology, point of bite application, and through the medial, lateral, anterior, and posterior components of the joint in vivo.[29,51–53]

Challenges encountered in the application of the design of this study include the following:

1. The use of condylar load point and an associated reference system may prevent further use of the data in longitudinal studies because they are based on function rather than on anatomy.

2. Application of this design to the medial and lateral components of the joint may be presumptuous since loading in those components of the joint may not mimic loading of the central component.[52]

CONCLUSIONS Return to TOC

Evaluation of an adolescent group with normal and anterior disc positions revealed the following characteristics:

1. There are significant differences in joint space and curvature of the eminence-loading surface between male and female adolescents with normal disc position.

2. Adolescent males with anterior disc position have reduced SJS, increased AJS, relative condylar retropositioning, and reduced convexity of the eminence-loading surface (relative to adolescents with normal disc position).

3. Adolescent females with anterior disc position have reduced SJS and PJS, increased AJS, relative condylar retropositioning, and reduced convexity of the eminence-loading surface (relative to adolescents with normal disc position).

The results of this study suggest that joint space and information on the osseous architecture derived from axially corrected tomographic images may provide diagnostic information for the assessment of joint status in an adolescent population.

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TABLE 1. Method Error as Determined by a Pilot Study of 10 Joints Representative of Normal Disc Position and 10 Joints Representative of Disc Displacement. Mean, Maximum, and minimum SD Values for minimum Tomographic Variables

TABLE 2. Variables of Significance for Independent *t*-tests Between Male and Female Joints with Normal Disc Position (n = 109)

TABLE 3. Descriptives, Difference Between Means, and Results of Independent *t*-tests for Male and Female Joints with Normal and Anterior Disc Position (n = 176)

TABLE 4. Descriptives, Difference Between Means, and Results of Independent *t*-tests for Female Joints with Normal and Anterior Disc Position (n = 106)

TABLE 5. Descriptives, Difference Between Means, and Results of Independent *t*-tests for Male Joints with Normal and Anterior Disc Position (n = 70)

FIGURES Return to TOC

Click on thumbnail for full-sized image.

FIGURE 1. Posterior slope of the articular eminence

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FIGURE 2. Geometrical relationships in calculating loading distance. CLP indicates condylar load point; AJS, anterior joint space

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FIGURE 3. Delineation of overall, superior, central, and inferior sectors of the loading surface

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FIGURE 4. Locations of measurements of closest anterior (A), posterior (P), and superior (S) interarticular spaces in temporomandibular joint tomograms

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