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Assessment of Optimal Condylar Position in the Coronal and Axial Planes with Limited Cone-Beam Computed Tomography

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Abstract

Purpose: No quantitative standards for the optimal position of the mandibular condyle in the glenoid fossa are yet available in the coronal and axial planes. We previously reported measurements of this position in the sagittal plane, using recently developed limited cone-beam computed tomography (LCBCT) capable of imaging the craniofacial structures with high accuracy. In this study, we assessed the optimal condylar position in the coronal and axial planes.
Materials and Methods: The study included 24 joints in 22 asymptomatic patients (10 male, 12 female; age range 12–25 years, mean age 18 years) who had no disc displacement as confirmed by magnetic resonance imaging. Their joints had optimum function with the starting and end points of all functional jaw movements coincident with maximum intercuspation. Joint-space distances between the condyle and glenoid fossa were measured at the medial, central, and lateral positions in the coronal plane, and medial and lateral positions in the axial plane.
Results: The mean coronal lateral space (CLS), coronal central space (CCS), and coronal medial space (CMS) were 1.8 $\pm$ 0.4 mm, 2.7 $\pm$ 0.5 mm, and 2.4 $\pm$ 0.5 mm, respectively. The ratio of CLS to CCS to CMS was 1.0 to 1.5 to 1.3. The mean axial medial space (AMS) and axial lateral space (ALS) were 2.1 $\pm$ 0.6 mm and 2.3 $\pm$ 0.6 mm, respectively. There were no significant sex differences in these measurements.
Conclusions: These coronal and axial data, along with previously reported sagittal data, might provide norms for 3D assessment of optimal condylar position with LCBCT.

Studies have shown that disc displacement can exist in the absence of symptoms.[1,2] With the increasing use of magnetic resonance imaging (MRI) in detecting abnormalities of the temporomandibular joint (TMJ), it has become clear that disc displacement is not a rare event, even in the pediatric age group.[3] Indeed, disc displacement was reported to occur in a majority of pre-orthodontic adolescents.[4]

An anatomical study with cryosections of the TMJ demonstrated the presence of mediolateral disc displacement.[5] Arthrographic data correlates to cryosectional morphology showing underdiagnosis of mediolateral disc displacements.[6] Mediolateral disc displacements and anterior disc displacements with a medial or lateral component accounted for more than 50% of all disc displacements identified on coronal magnetic resonance images.[7] Both tomographic and MRI studies showed that the condyles of patients with anterior disc displacement were displaced posteriorly.[8,9] Likewise, the condyle may be situated more medially or laterally within the glenoid fossa when the disc is displaced sideways. These changes in condylar position can be detected on coronal MR images.[10] Furthermore, the direction of disc displacement may be estimated from the direction of condylar displacement in the coronal plane. Increasing availability of limited cone-beam computed tomography (LCBCT) provides the clinician with the ability to detect changes in condylar position in the sagittal, coronal, and axial planes.[11,12]

To correctly interpret condylar displacement, the optimal position of the condyle must be clearly defined in healthy joints that function normally with normal disc status. The purpose of this study was to assess condylar position in the coronal and axial planes with the same materials used in our previous study[13] designed to establish a normal condylar position in the sagittal plane.

Materials and methods

The study involved LCBCT images from 22 asymptomatic patients with optimal joints from a private orthodontic office (10 male, 12 female; age 12–26 years, mean age 18 years), and consent for inclusion in the study was obtained from each patient. These LCBCT images were judiciously taken for diagnostic purposes at initial examination prior to this retrospective study due to the suspected internal derangement and possible hard-tissue changes in the contralateral joint. Hence, the imaging of normal joints and findings summarized in this study are incidental findings, and the ethical board did not require any approval for a study of this nature.

Twenty-four joints meeting the following criteria were assessed: (1) no history of TMD; (2) no TMD symptoms at chairside examination; (3) sagittal and transverse discrepancies between centric occlusion (CO) and centric relation (CR) of <1 mm and <0.5 mm,[14] respectively, measured at joint level with a condylar position indicator (Panadent, Grand Terrace, CA); (4) normal condylar border movements as recorded with an axiograph II (SAM, Munich, Germany), with immediate side shift of <1 mm, all jaw movements starting at the terminal hinge axis (THA), no reverse curved tracing near THA, and all sagittal tracings of protrusive, mediotrusive, and opening border movements coinciding for the first 8 mm from THA[15]; and (5) normal disc position confirmed by an experienced radiologist subjectively with coronal and sagittal MRI slices, with the disc between the condyle and eminence in the sagittal plane, the posterior band of the disc at 12 O'clock position, no mediolateral disc displacement in the coronal plane, no excessive effusion, and no hypertrophy of the disc.

LCBCT images were taken with the subjects in an upright sitting position with the back as perpendicular to the floor as possible. The head was stabilized with ear rods in the external auditory meatus. The subjects were instructed to look into their own eyes in a mirror 1 m in front to obtain natural head position. The true horizontal line (THL) obtained from the natural head position was used as a reference plane.[16] TMJs were scanned with a dental LCBCT machine (PSR9000N, Asahi Roentgen, Kyoto, Japan). The long axis of the condyle was determined on the reconstructed 3D image. The vertical plane that contains the long axis and is perpendicular to the THL was defined as the coronal section. The horizontal plane perpendicular to the vertical sagittal plane that bisects the long axis, parallels with the THL, and passes through the most anterior point of the condyle was defined as the axial plane (Fig 1). The scanning conditions used were slice thickness of 0.1 mm, window width of 4095, and window level of 1024. Figures 2 and 3 show coronal and axial LCBCT images of a study subject's TMJ.

Linear measurements of optimal joint space between the condyle and fossa were made on the coronal and axial LCBCT images by using the landmarks and variables defined as follows. In the coronal image, the mediolateral width of the condyle was divided into sextants (Fig 4). The mid-point of the total width was projected to the surface of the condyle along a line perpendicular to the THL and designated as the coronal central point (CC). Similarly, the points on the condylar surface derived from lines perpendicular to the THL extending from the junction of the medial first and second sextants and those of the lateral first and second sextants were designated as coronal medial point (CM) and coronal lateral point (CL), respectively. The shortest distances from CM, CC, and CL to the fossa were measured and termed as coronal medial space (CMS), coronal central space (CCS), and coronal lateral space (CLS). In the axial plane, the distances from the medial pole (axial medial point: AM) and lateral pole (axial lateral point: AL) were measured to the medial and lateral walls of the fossa along the imaginary line extending from the long axis of the condyle and named as axial medial space (AMS) and axial lateral space (ALS),

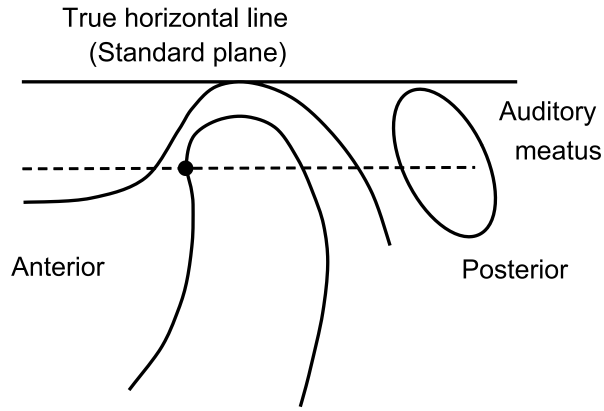

Figure 1 The dotted line shows the cut made to obtain the axial cross-sectional image of the TMJ used in this study. From the vertical cross-sectional image bisecting the long axis of the condyle, the horizontal slice parallel to the THL and passing through the most anterior point of the condyle was derived as the axial plane.

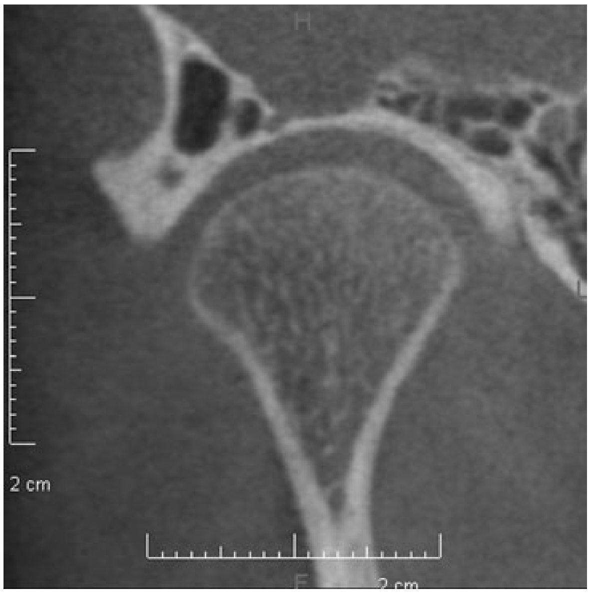

Figure 2 Coronal LCBCT image of the TMJ.

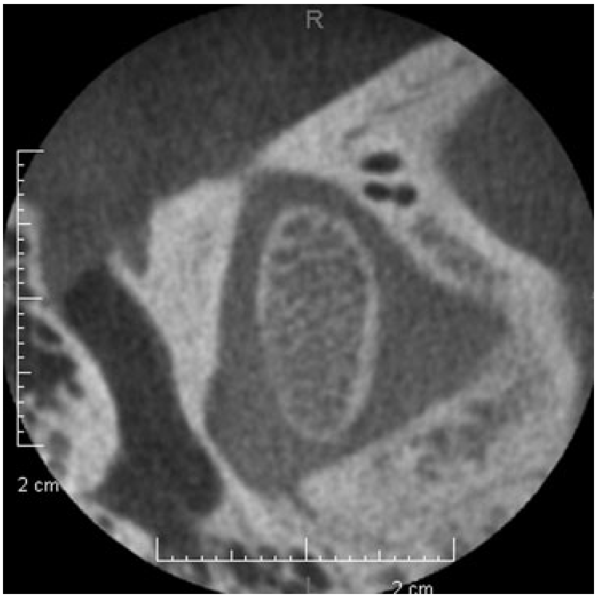

Figure 3 Axial LCBCT image of the TMJ.

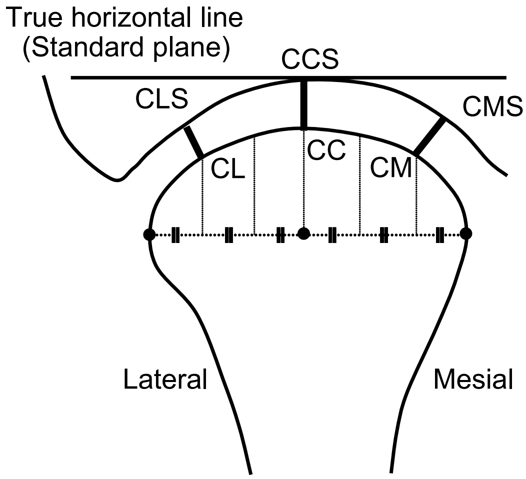

Figure 4 Landmarks and linear measurements of the space between the condyle and the glenoid fossa in the coronal plane. The THL was used as a standard plane. The mediolateral width of the condyle on the coronal cross-sectional image was divided into sextants. The mid-point of the total width was projected to the surface of the condyle along a line perpendicular to the THL and designated as coronal central point (CC). Similarly, the points on the condylar surface derived from lines perpendicular to the THL that extend from the junction of the medial first and second sextants and that of the lateral first and second sextants were designated as coronal medial point (CM) and coronal lateral point (CL). Linear measurements of joint space from CM, CC, and CL to the fossa were measured as the shortest distances from the respective points to the surface of the articular eminence and termed as coronal medial space (CMS), coronal central space (CCS), and coronal lateral space (CLS).

respectively (Fig 5). In the axial plane, the relative mediolateral position of the condyle in the fossa was expressed as percentages by dividing the medial and lateral joint-space values by their sum.

To assess the significance of any errors during measurement, 10 right and 10 left condyles of 10 subjects were reevaluated 3 months later. The mean difference between the first and second measurements was analyzed by the paired *t*-test. The error variance was calculated as a percentage of total variance (error%) using Dahlberg's double determination method. The mean differences were less than 0.08 mm (0.01–0.08 mm) with no significant difference for all measures. The error% was below 7.73% (1.10–7.73%).

Results

Statistical analysis with the *t*-test showed no significant sex differences in the CMS, CCS, or CLS values in the coronal plane, or the AMS or ALS values in the axial plane (Tables 1, 2). The mean CLS, CCS, and CMS measurements in the coronal plane were 1.8 ± 0.4 mm, 2.7 ± 0.5 mm, and 2.4 ± 0.5 mm, respectively. The ratio of CCS to CMS to CLS was 1.0 to 1.5 to 1.3 (Table 3). The mean AMS and ALS measurements and ratio of AMS to ALS are listed in Table 4.

Discussion

In our previous study,[13] the optimal condylar position was assessed by measuring the condyle-fossa distances on sagittal LCBCT images. Figure 6 shows sagittal MRI and CT images of the TMJ of a pre-orthodontic patient. The condyle-fossa relationship appears to be normal on the sagittal LCBCT image; however, the coronal images of the same joint (Fig 7) reveal a laterally displaced disc and a displaced condyle, respectively. The joint status may not be correctly represented when viewed

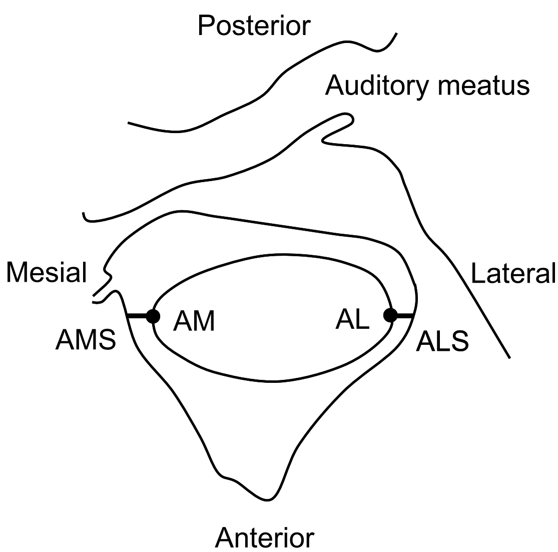

Figure 5 Landmarks and linear measurements of the space between the condyle and the glenoid fossa in the axial plane. The distances from the medial pole (axial medial point: AM) and the lateral pole (axial lateral point: AL) were measured to the medial and lateral walls of the glenoid fossa along the imaginary line extending from the long axis of the condyle and named as axial medial space (AMS) and axial lateral space (ALS), respectively.

Table 1 Statistical data of coronal sections for the subjects by sex

	Male (n = 11)			Female (n = 13)		
	Variables (mm)	Mean	SD	Mean	SD	T test
Coronal Medial Space	CMS	2.3	0.4	2.4	0.7	N.S.
Coronal Central Space	CCS	2.6	0.4	2.7	0.6	N.S.
Coronal Lateral Space	CLS	1.8	0.4	1.8	0.4	N.S.

N.S.: No Significant.

Table 2 Statistical data of axial sections for the subjects by sex

	Male (n = 11)			Female (n = 13)		
	Variables (mm)	Mean	SD	Mean	SD	T test
Axial Medial Space	AMS	2.1	0.6	2.2	0.6	N.S.
Axial Lateral Space	ALS	2.2	0.7	2.4	0.6	N.S.

N.S.: No Significant.

in one dimension, indicating the need to assess in multiple dimensions.

Solberg et al[17] found in their autopsied TMJs of young adults that the direction of disc displacement was mostly anteromedial. In an investigation with anteroposterior arthrography,[18] it was concluded that medial or lateral disc displacement cannot be diagnosed reliably with an anteroposterior projection. Results of an MRI study by Katzberg et al[19] and Haiter-Neto et al[20] suggested that the direction of disc displacement can vary three dimensionally. It is difficult to accurately assess the changes in condylar position or morphology in a single dimension, and this current study was carried out to assess condyle-fossa spatial relationships in the coronal and axial planes to add to sagittal information.

Many studies assess condylar position and morphology with conventional tomography.[21-23] However, margins of the joint structures were unclear due to large slice thicknesses ranging between 1.0 and 3.0 mm. To take coronal images by conventional tomography, the patient had to be positioned in the machine with the mouth open and the head tilted up, precluding the imaging of the joint in intercuspal position (Fig 8).

Christiansen et al[24] evaluated the morphology of the joint structures and joint-space distances in subjects with normal joints to find significant sex differences in the morphology but not in the joint-space distances. No significant sex differences were observed in any of the coronal or axial joint-space measurements in this study, either. The data for both sexes were thus combined for statistical analysis.

The absence of disc displacement, condylar displacement, or condylar deformity is a precondition for determination of the optimal condylar position. The normalcy of disc status was verified by examining the position and mobility of the disc on sagittal and coronal MR images in opening and closing.[25,26] Each subject's dental casts were mounted on an articulator in CR to measure CO-CR discrepancies with the condylar position indicator instrument[27] and confirm that CO-CR discrepancies were less than 1.0 mm in the sagittal plane and less than 0.5 mm in the transverse plane. It has been shown that a change in jaw movement can be a factor inducing a morphological change of the condyle.[28] A histological study by Thilander et al[29] suggested that excessive functional loading of the joint may lead to its morphological changes. In this study, the subject's mandibular movements were examined to confirm that the starting and end points are stable and coincident and that arcs of protrusive, rotational, and lateral movements coincide for the first few millimeters. Immediate side shift, an indicator of joint laxity, was also limited to less than 1 mm to ensure joint stability in the subjects. Solberg et al[17] observed an increased frequency of morphological deviation in the joints of autopsied subjects older than 20 years. Similar findings were reported by Thilander et al[29] and Oberg et al.[30] This study therefore included young patients aged between 12 and 25 years, with an average age of 18 years.

The linear joint space measurements made on the coronal LCBCT images in this study averaged 1.8 ± 0.4 mm for CLS, 2.7 ± 0.5 mm for CCS, and 2.4 ± 0.5 mm for CMS. Hansson

Table 3 Statistical data of coronal sections for the 24 subjects

	Variables (mm)	Mean	SD	Ratio
Coronal Medial Space	CMS	2.4	0.5	1.3
Coronal Central Space	CCS	2.7	0.5	1.5
Coronal Lateral Space	CLS	1.8	0.4	1.0

Table 4 Statistical data of axial sections for the 24 subjects

	Variables (mm)	Mean	SD	%
Axial Medial Space	AMS	2.1	0.6	48
Axial Lateral Space	ALS	2.3	0.6	52
Mean differences (mm)	0.01–0.08			
Error variance (%)	1.10–7.73			

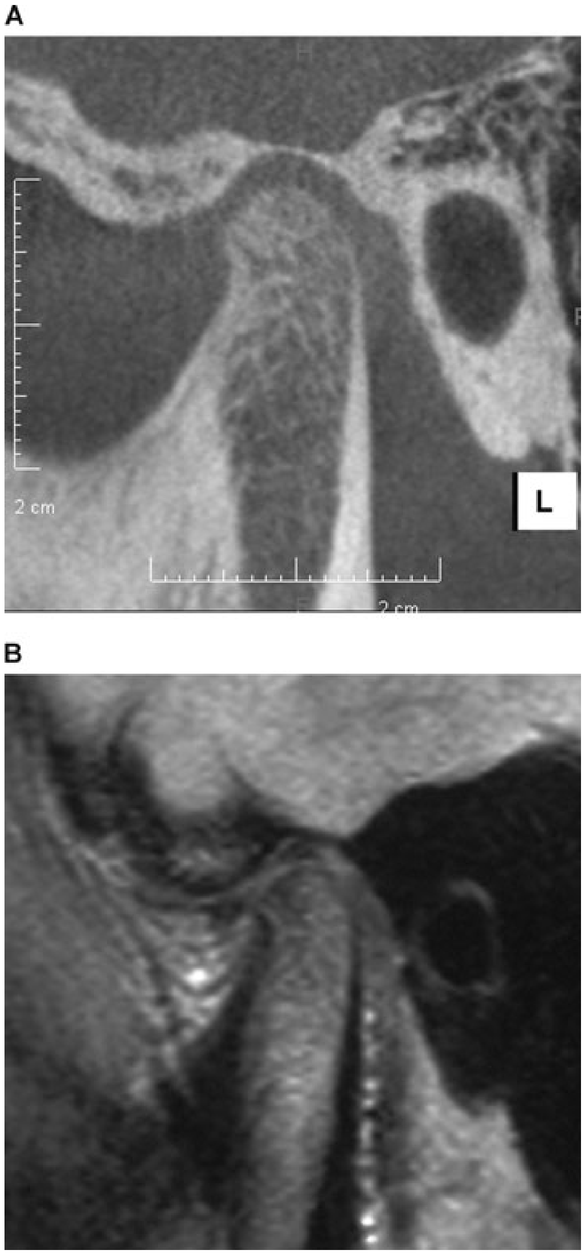

Figure 6 Initial sagittal LCBCT (A) and MRI (B) images of the TMJ of a pre-orthodontic 12-year-old patient.

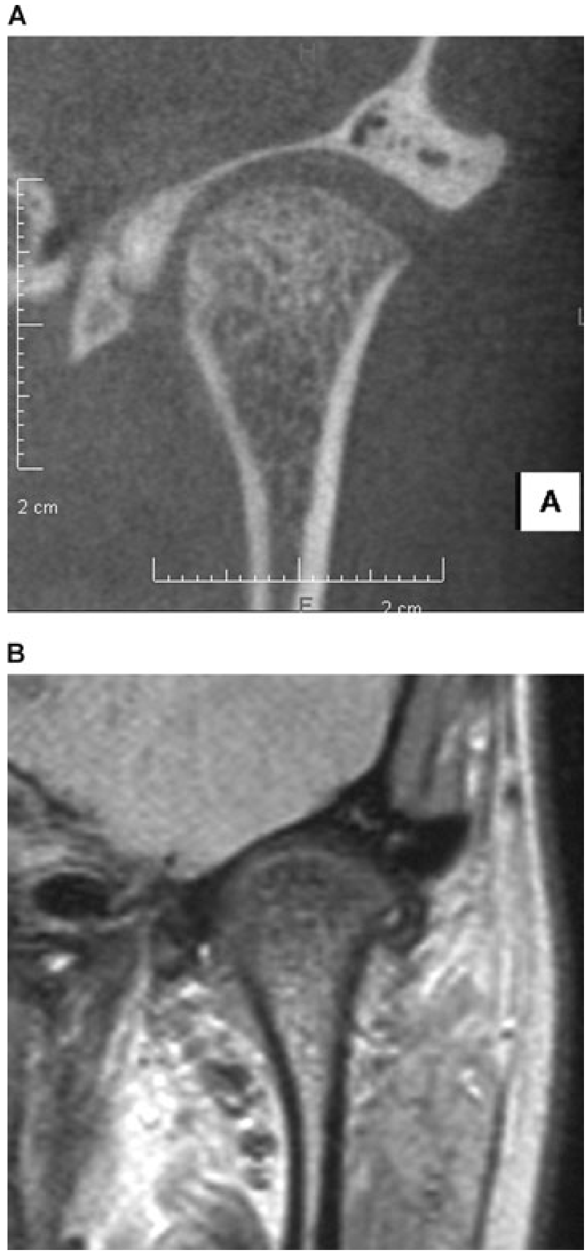

Figure 7 Initial coronal LCBCT (A) and MRI (B) images of the TMJ of the same 12-year-old patient.

et al[31] studied 48 joints obtained at autopsy from subjects aged 1 day to 93 years without gross signs of arthrosis. Their measurements in similar parts of the disc averaged 1.99 ± 0.68 mm for the lateral part, 2.84 ± 0.47 mm for the central part, and 2.31 ± 0.64 mm for the medial part. They also stated that the disc was relatively uniform in thickness mediolaterally in neonates but decreased laterally with age in the middle and posterior dense parts as a result of functional loading. The data from this study also showed that the joint space was smaller laterally than centrally or medially. The disc has uniform thickness in the sagittal plane at birth, but is transformed into a distinct bow–tie shape with the thinnest intermediate zone as it is subjected to functional load.[29] This indicates that the variation in disc thickness in a normal joint reflects the functional load to which the joint is exposed. It also suggests that functional disequilibrium resulting from disc displacement may lead to morphological changes in the osseous structures of the joint.

Medial and lateral joint spaces were also measured in the axial plane in this study. Mediolateral position of the condyle is assessable coronally but more clearly discernible in the axial plane. The average AMS and ALS measurements were 2.1 ± 0.6 mm and 2.3 ± 0.6 mm, respectively. The

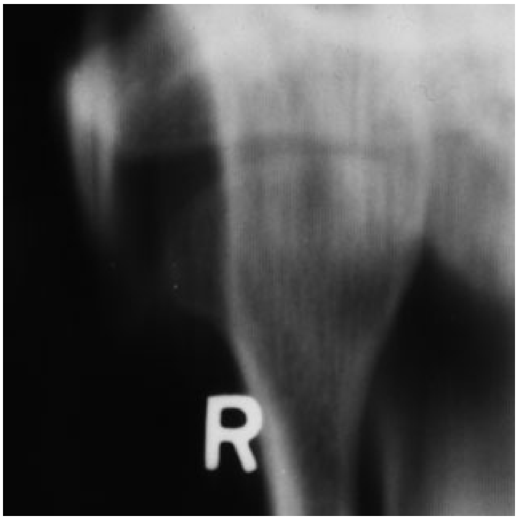

Figure 8 Coronal imaging of the TMJ by conventional tomography. The image was taken with the condyle positioned anteriorly to delineate its outline more clearly.

medial-to-lateral ratio was 48 to 52%, indicating the condyle is nearly centered within the fossa axially in a normal joint.

Conclusions

The mean coronal joint-space distances of functionally and morphologically optimal joints were 1.8 mm laterally, 2.7 mm centrally, and 2.4 mm medially with a ratio of 1.0 to 1.5 to 1.3, and their mean axial values were 2.1 mm medially and 2.3 mm laterally with a ratio of 48 to 52%. No sex difference was observed in any of the measurements. These results, along with the previously reported sagittal data, might serve as reference values for 3D assessment of optimal condylar position with LCBCT.

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