Assessment of optimal condylar position with limited cone-beam computed tomography

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Introduction: There are no quantitative standards for the optimal position of the mandibular condyle in the glenoid fossa. Recently developed limited cone-beam computed tomography (LCBCT) allows measurement of this position with high accuracy. **Methods:** LCBCT was used to assess 24 joints in 22 symptom-free subjects (10 male, 12 female; mean age, 18 years) who had no disc displacement as verified by magnetic resonance imaging. Their joints had optimum function with the starting and end points of all functional jaw movements coincident with maximum intercuspation. Linear measurements of anterior space (AS), superior space (SS), and posterior space (PS) were made to determine the position of the condyle for each joint. **Results:** The mean AS, SS, and PS values were 1.3 mm (SD ± 0.2 mm), 2.5 mm (SD ± 0.5 mm), and 2.1 mm (SD ± 0.3 mm), respectively. The ratio of AS to SS to PS was 1.0 to 1.9 to 1.6. No significant sex difference was noted in joint space distances. The results showed less variability of condylar position in the fossa than previously reported in normal subjects. **Conclusions:** These data from optimal joints might serve as norms for the clinical assessment of condylar position obtained by LCBCT. (Am J Orthod Dentofacial Orthop 2009;135:495-501)

A fundamental question in dentistry is what is the optimal position of the condyle in the glenoid fossa when the teeth are in maximum intercuspation. Although the way the teeth come together in occlusion can be observed directly in the mouth, condylar position in the fossa is inaccessible to the naked eye. Various radiographic modalities have been used to visualize this position.[1] Transcranial projection was first introduced. However, the images were difficult to interpret for anatomic reasons.[2] Research with laminography and tomography found that imaging accuracy could be improved by orienting the x-ray beam to the long axis of the condyle determined on a submentovertex image.[3-6] However, tomographic studies in normal samples showed great variability in condylar position and thus failed to provide clinically useful information that could help establish diagnostic criteria for optimal condylar position.[7,8]

Magnetic resonance imaging (MRI) has made it possible to view disc displacements in the coronal and sagittal planes.[9] MRI with the capability to depict changes in mediolateral disc position has replaced conventional arthrography. MRI can also show that there is no disc displacement. Research has suggested that normal samples in previous studies might have included joints with disc displacement.[10] MRI studies have shown disc displacement in volunteers who had no symptoms in the joint or related muscles.[11-13] When conducting a study on optimal condylar position, therefore, MRI examination of disc status is essential to exclude subjects with disc displacement.

Limited cone-beam computed tomography (LCBCT), a recently developed imaging technology, has been used for 3-dimensional (3D) imaging of the temporomandibular joint (TMJ) and has been shown to delineate the joint structures with high accuracy. According to Honda et al,[14] the thickness of the roof of the TMJ fossa, which is very thin, is 0.5 to 3.6 mm. Their LCBCT results showed no statistically significant difference with the actual measurements made with a micrometer. The combined use of LCBCT and MRI allows accurate measurement of condylar position with confirmed disc status.

Few studies on condylar position have carefully evaluated jaw function during screening of potential subjects. Optimum jaw function is a prerequisite for the health of the joint and should be considered in studying the relationship between stomatognathic dysfunction and occlusion. Studies on optimal condylar position should include subjects with normal jaw movement,[15,16] no evidence of loose ligaments or condylar

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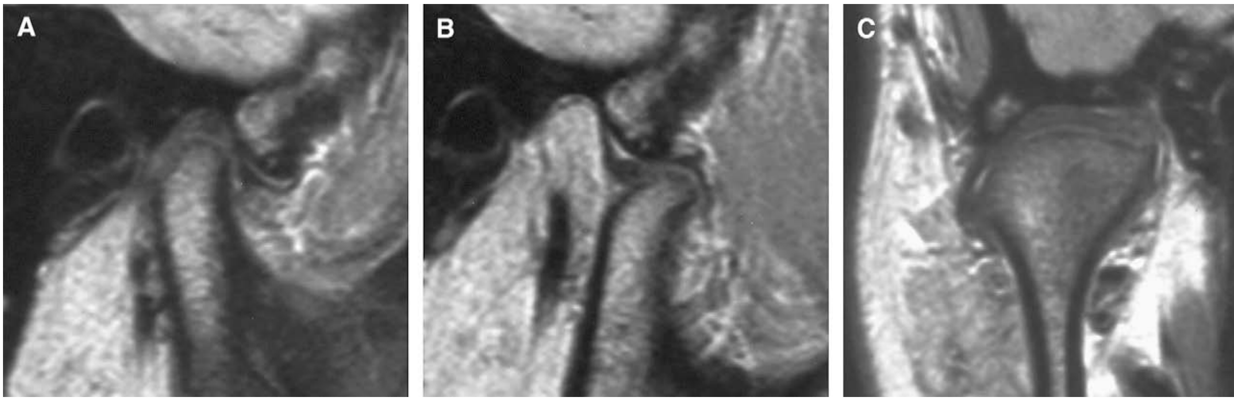

Fig 1. Normal MRIs of a TMJ, from a 1.5-T MR imaging system (Gyroscan ACS-NT Intera, Philips, The Netherland) with surface coils and 2.5-mm section thickness. Proton density-weighted images: FOV 12 cm, TR 2500 ms, TE 20 ms with a 256 × 256 matrix. Fat-suppressed (SPIR) T2-weighted images: TR 2500 ms, TE 100 ms. **A,** Sagittal closed-mouth image; **B,** sagittal open-mouth image; **C,** coronal closed-mouth image.

hypermobility,[17] and minimal occlusal interference.[18,19] When these criteria are met, the position of maximum intercuspation coincides with the starting and end points of all functional jaw movements.[20] Identification of stable and repeatable condylar position in functionally optimal joints will form a basis for future studies on the relationship between TMJ dysfunction (TMD) and condylar position.

Patients with disc displacement are a majority rather than a minority in clinical practice.[21] Research has shown that disc displacement is not rare even in children and adolescents, necessitating serious investigations of its impact on occlusal therapy.[22-26] This requires diagnostic criteria for the pretreatment assessment of disc status. The purpose of this study was to determine optimal condylar position in the fossa on sagittal LCBCT images in functionally optimal joints without disc displacement. Data derived from this study might provide a baseline for better understanding of the relationship between condylar position, disc displacement, and TMD.

MATERIAL AND METHODS

Twenty-two subjects with optimal joints were selected from patients at a private orthodontic office. They included 10 males and 12 females between 12 and 26 years of age, with an average age of 18 years. None had degenerative joint disease, disc displacement without reduction, or full disc displacement with reduction. Each subject had at least 1 joint that met the following criteria: (1) no history of TMD; (2) no TMD symptoms at chair-side examination; (3) centric occlusion and centric relationship discrepancies at joint level less than 1 mm in the sagittal plane and less than 0.5 mm in the transverse plane measured with a condylar position indicator (Panadent, Grand Terrace, Calif)[19]; (4) normal condylar border movements as recorded with an axiograph II (SAM, Munich, Germany), with immediate side shift of <1 mm, all jaw movements start at the terminal hinge axis (THA), and no reverse curved tracing near the THA[16]; (4) all sagittal tracings of protrusive, mediotrusive, and opening border movements coincided for the first 8 mm from the THA[15]; and (5) normal disc position confirmed by an experienced radiologist subjectively with coronal and sagittal MRI slices (Fig 1), with the disc between the condyle and the eminence in the sagittal plane, the posterior band of the disc at 12 o'clock position,[27] no mediolateral disc displacement in the coronal plane, no excessive effusion (Fig 2),[28] and no hypertrophy of the disc (Fig 3).

LCBCT images were taken with the subject 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 of them to obtain natural head position. The TMJs were scanned with a dental LCBCT machine (PSR9000N, Asahi Roentgen, Kyoto Japan) with a radiation field of 41 × 40 mm, voxel size of 0.1 mm, scan time of 13.3 seconds, tube voltage of 80kV, and tube current of 10 mA. These views were reconstructed into 3D images with volume-rendering software (Asahi Vision, Asahi Roentgen). The long axis of the condyle was determined on the reconstructed 3D image, and the vertical plane bisecting the long axis was defined as the sagittal section. The scanning conditions used were slice thickness of 0.1 mm, window width of 4095, and window level of 1024. Figure 4 shows an

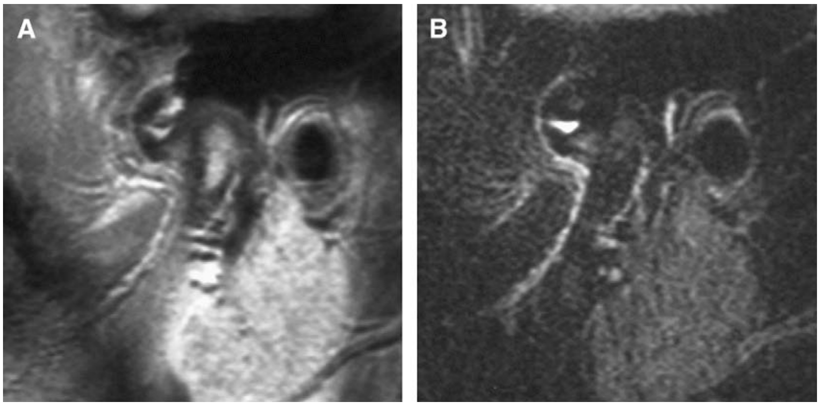

Fig 2. A sample of excessive effusion, with the same MRI setup as in Figure 1: **A,** sagittal closed-mouth image with partial disc displacement; **B,** SPIR T2 sagittal closed-mouth image of the same subject.

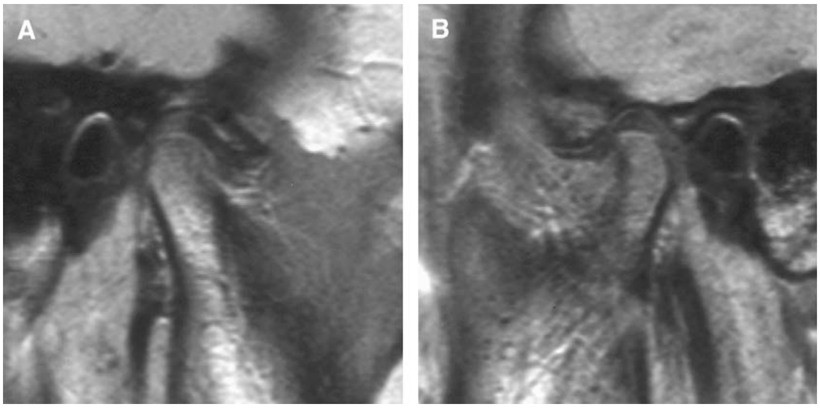

Fig 3. Hypertrophy of a disc, with the same MRI setup as in Figure 1: **A,** sagittal view of the right side showing a hypertrophic disc; **B,** sagittal view of the left side of same subject with a normal disc.

LCBCT image of the TMJ of the same subject as shown in Figure 1. The true horizontal line (THL) obtained from natural head position was used as the reference.[29] Linear measurements of optimal joint space between the condyle and the fossa were made on the sagittal LCBCT images by using the landmarks and variables defined in Figure 5. Spaces were measured on the printout by 3 experienced orthodontic specialists using a point caliper with 0.01-mm accuracy. Three linear measurements were made, and the mean value was used for statistical analysis.

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, the standard error of a single measure, and the relative contribution of errors to total observed variations were determined for each variable. The error variance (Ve) was calculated by using the following formula:

$$Ve = \sum (X1 - X2)^2/2n$$

where *X1* and *X2* represent the first and second measurements, and *n* is the sample size. The mean differences were less than 0.07 mm. In general, the contributions of errors to the total variance were small—from 0.01% to 0.07%.

RESULTS

Statistical analysis with the *t* test indicated no significant differences in the AS, SS, or PS values between the sexes (Table I). Mean AS, SS, and PS measurements were 1.3 mm (SD ± 0.2 mm), 2.5 mm (SD ± 0.5 mm), and 2.1 mm (SD ± 0.3 mm), respectively. The

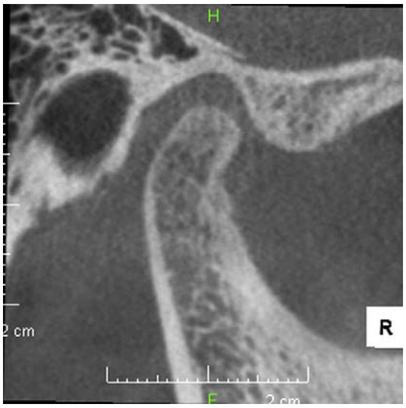

Fig 4. LCBCT image of the TMJ of the same subject as shown in Figure 1.

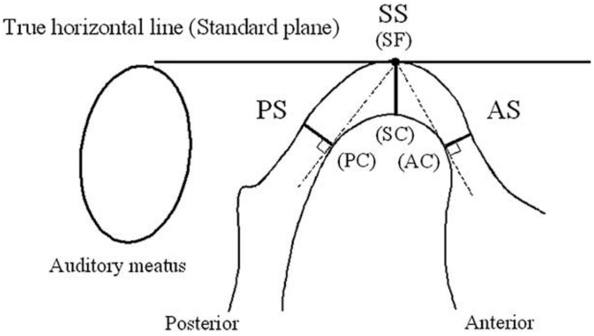

Fig 5. Landmarks and linear measurements of the space between the condyle and the glenoid fossa. The THL was used as the reference plane. The distance from the most superior condyle point (*SC*) to the most superior aspect of the glenoid fossa (*SF*) on the THL was measured as the superior joint space (*SS*). Lines tangent to the most prominent anterior and posterior aspects of the condyle were drawn from SF. Distances from the anterior (*AC*) and posterior (*PC*) tangent points to the glenoid fossa were measured as the anterior joint space (*AS*) and posterior joint space (*PS*).

ratios of SS and PS to AS, with AS set to 1.0, were 1.9 and 1.6, respectively (Table II, Fig 6).

DISCUSSION

Morphology and spatial relationships of the condyle and the fossa have been studied with radiographic techniques that included conventional tomography[30,31] and computed tomography (CT).[32,33] MRI has been used to assess disc displacement, changes in bony outline, and inflammation in the bone marrow.[9,12,34,35] Although conventional tomography is thought to allow good visualization of joint morphology with slices through the joint, it does not delineate tissues of different densities as clearly as CT because the thickness of the slices is 1.0 to 3.0 mm. This creates difficulties in the detailed assessment of changes in surface morphology of the condyle and the fossa. The submentovertex image used to calculate the long axis of the condyle is only 2-dimensional and not as precise as the method of determining the long axis from 3D images. The recently developed LCBCT method produces as high-resolution or even superior images to high-speed spiral CT, as reported in some studies.[36,37] Kobayashi et al[36] found that the measurement error was significantly less with the same LCBCT machine as used in this study than with spiral CT. Ten joints per side were measured at 2 times to determine the error of measurement in this study. The mean difference between the repeated measurements was only 0.07 mm. The contributions of errors to the total variance were also small, from 0.01% and 0.07%. These results indicate that LCBCT allows accurate morphologic evaluation of the TMJ.[14]

Table I. Statistical data for the subjects by sex

	Males (n = 11)		Females (n = 13)		
Variable (mm)	*Mean*	*SD*	*Mean*	*SD*	T *test*
PS	2.2	0.2	2.1	0.3	NS
SS	2.5	0.5	2.5	0.6	NS
AS	1.4	0.2	1.3	0.3	NS

NS, Not significant.

Table II. Statistical data for the 24 subjects

Variable (mm)	*Mean*	*SD*	*Ratio*
PS	2.1	0.3	1.6
SS	2.5	0.5	1.9
AS	1.3	0.2	1.0

Although more recent studies have recruited asymptomatic subjects with normal disc position based on MRI data, no references were made to articular function.[38,39] Our subjects were selected based not only on the absence of clinical symptoms in the joint, but also on MRI data regarding mediolateral and anteroposterior disc position, joint effusion, and hypertrophy of the disc. We also incorporated axiographic criteria for optimum joint function; mandibular border movements starting from the THA; coinciding tracings of protrusive, mediotrusive, and opening movements for the first 8 mm from the THA[15]; and no reverse curved tracing near the THA.[16] Furthermore, data from the condylar position indicator were collected to confirm that the subjects' centric occlusion and centric relationship discrepancies at the joint level were less than 1.0 mm in the sagittal plane and less than 0.5 mm in the transverse plane.[19] Joints satisfying all inclusion criteria were judged as optimal for assessment with LCBCT in this study.

Although Kinniburgh et al[38] found a significant difference in the superior joint space between the sexes using conventional tomography, the data from this LCBCT study showed no significant sex difference in AS, SS, or PS. The data for both sexes were therefore combined for statistical analysis. The linear measurements made on the LCBCT images of the 24 optimal joints averaged 1.3 mm (SD ± 0.2 mm) for AS, 2.5 mm (SD ± 0.5 mm) for SS, and 2.1 mm (SD ± 0.3 mm) for PS. The ratio of AS to SS to PS was 1.0 to 1.9 to 1.6. The values reported by Kinniburgh et al[38] for male and female subjects were 1.86 mm (SD ± 0.47 mm) and 1.99 mm (SD ± 0.56 mm) for AS, 3.78 mm (SD ± 0.86 mm) and 3.42 mm (SD ± 0.90 mm) for SS, and 3.03 mm (SD ± 0.88 mm) and 2.86 mm (SD ± 0.74 mm) for PS. The SS distance in their study was greatest in both sexes, followed by PS and AS; this agrees with the results of our study. However, all joint-space values obtained in this study were smaller than those of Kinniburgh et al,[38] indicating that the condyle and the fossa are in closer proximity in optimal joints.

We also found extremely small standard deviation values compared with those of Kinniburgh et al.[38] This suggests that there might be less variability in condylar position in the fossa in joints with optimal function, and normal disc position and morphology. An MRI study demonstrated that the posterior band of the disc in normal joints was at the 12 o'clock position where the disc was the thickest, and that the thinnest intermediate zone of the disc was in contact with the head of the condyle.[40] The LCBCT images in this study also showed large SS and small AS distances, closely reflecting the morphology of the disc depicted by MRI.

This study included the joints of relatively young subjects. Hansson et al[40] directly measured disc thickness in autopsy materials and found that the mean thicknesses of the anterior band, intermediate zone, and posterior band were 2.0, 1.1, and 2.9 mm, respectively. Although the thickness of the soft tissues covering the condyle, fossa, and eminence must be considered with approximately a 10% change that is expected during sample processing, these values are near the joint-space values obtained in this study. Sicher et al[41] wrote that, in all synovial joints in the human body, the articulating surfaces of the opposing bones are kept in firm contact by the associated ligaments and musculature, and that firm contact is maintained with the disc closely fitted between the opposing articular surfaces throughout the range of jaw movement. If this close relationship between the eminence and the condyle is lost due to disc displacement, there should be changes in joint space. The altered joint space would not be within the optimal ranges found in this study. Such a discrepancy between the optimal and the altered joint spaces might indirectly indicate disc displacement. Major et al[31] found an association between disc displacement and changes in joint space. Christiansen et al[42,43] evaluated computed tomograms of TMJs to study changes in joint space associated with disc displacement. Their results showed that the anterosuperior joint space was consistent across the joint from lateral to medial when the disc was positioned normally, and that the anterosuperior joint space was the smallest in the normal joint compared with the superior and posterosuperior spaces. These findings agree with our results. Their studies included joints with no signs of TMD as normal samples based only on radiographic and chair-side examinations, leaving the possibility of undetected disc displacements. In addition, the normalcy of disc position in a static mandibular position does not ensure its functional normalcy. The older age range of the subjects might be associated with an increased risk of disc displacement and morphologic changes in joint structures.[40,44] We focused on the central cuts of optimal joints in the sagittal plane. The landmarks used for joint-space measurement could be located with relative ease up to 3.5 mm medially and laterally to the central cut, whereas landmark identification was difficult outside this range because of the anatomy of the glenoid fossa, as indicated in Figure 7. There were minimal variations in the joint spaces (AS, SS, PS) among the optimal joints when measured within the 3.5 mm range medially and laterally to the center of the condyle.

It is important to carefully examine the status of the condyles and discs when performing 3D occlusal

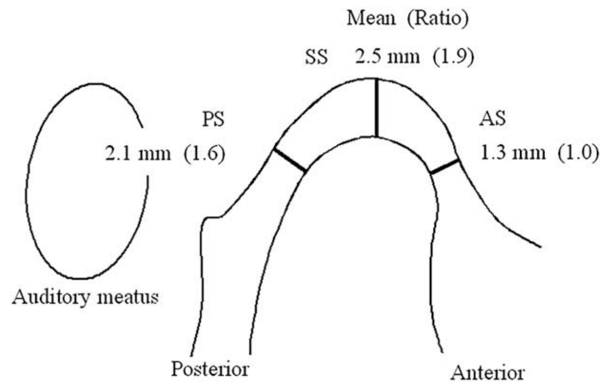

Fig 6. Mean distances and ratios for optimal condylar position.

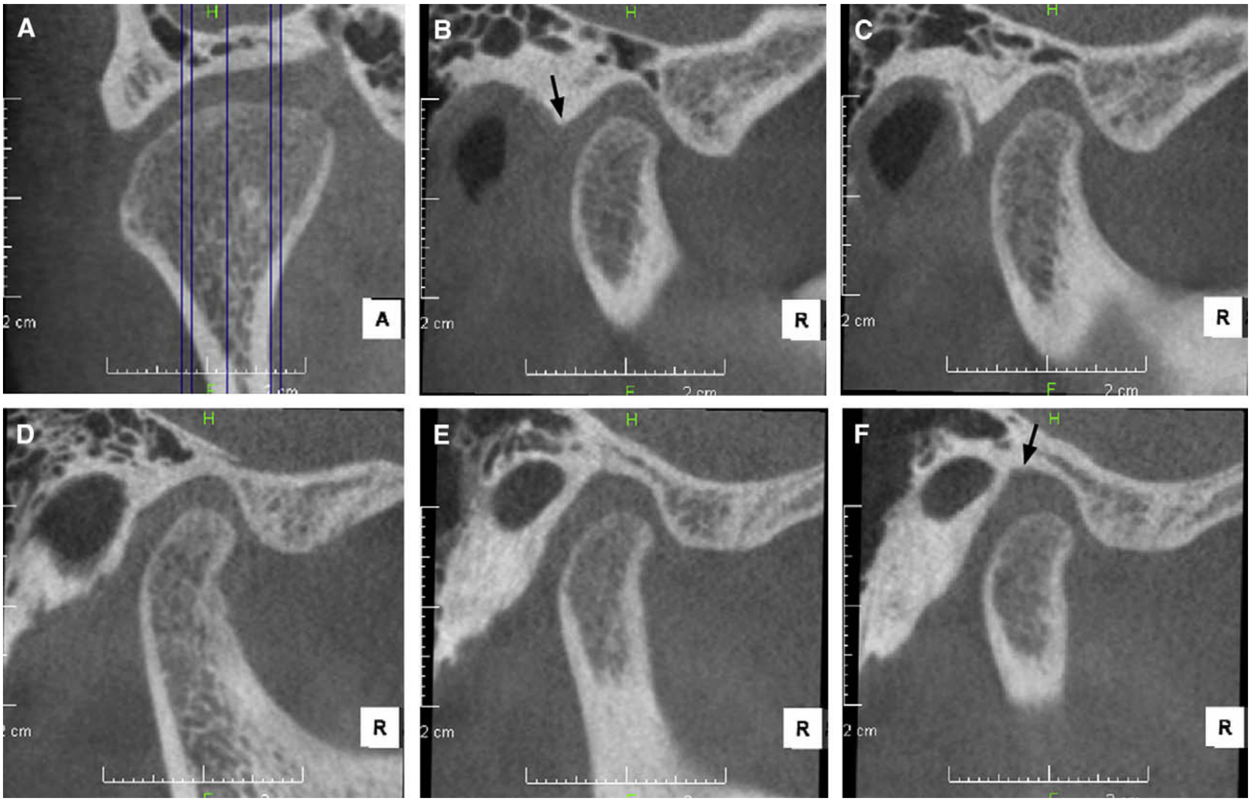

Fig 7. Coronal view of the LCBCT image of the right joint with lines for sagittal cuts (same subject as Figs 1 and 4): **A,** 5 cuts in coronal view; **B,** 4.5-mm lateral cut; **C,** 3.5-mm lateral cut; **D,** central cut; **E,** 3.5-mm medial cut; **F,** 4.5-mm medial cut. *Arrows* in B and F show loss of landmarks.

reconstruction by orthodontic, prosthodontic, or other modalities. In this regard, the data we obtained pertain to the position of morphologically and functionally optimal joints and might provide clinically useful information on optimal condylar position in assessing joint status with LCBCT.

CONCLUSIONS

Optimal spatial relationships between the condyle and the fossa in healthy joints were measured, and the mean AS, SS, and PS values were 1.3 mm (SD ± 0.2 mm), 2.5 mm (SD ± 0.5 mm), and 2.1 mm (SD ± 0.3 mm), respectively. The ratio of AS to SS to PS was 1.0 to 1.9 to 1.6. There was no sex difference in any joint-space value. The data from the optimal joints might be a useful reference for clinical assessment of condylar position with LCBCT.

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