Accuracy of measures of temporomandibular joint space and condylar position with three tomographic imaging techniques

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Fourteen temporomandibular joints in seven dry skulls, representing the distribution of horizontal and vertical condylar axis inclinations of a larger population, were imaged with three tomographic projection techniques. Closest anterior and posterior joint spaces were measured on radiographs, and sectioned plaster casts were made from impressions of actual joint space. Individualized horizontal and vertical correction of the condylar axis produced significantly more accurate ($p < 0.005$) measures of condylar space than either standard 20-degree horizontal correction (SHC) or individualized horizontal correction (IHC) of the axis. Representations of joint space by SHC and IHC were not significantly different from each other. Numbers of uninterpretable images displayed a similar pattern of 9.5% for individualized horizontal and vertical correction, 14% for IHC, and 17% for SHC. This study supports the use of fully individualized condylar axis correction with temporomandibular joint tomography for increased accuracy of visualization of the osseous anatomy of the joint.
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The 1983 American Dental Association President's Conference on Temporomandibular Disorder (TMD), noting variability in the results of studies assessing the correlation of temporomandibular joint (TMJ) space or condylar position with the presence of TMD, concluded that condyle-fossa eccentricity is not a valid diagnostic sign of TMD.[1] A recent report of a high percentage of condylar retropositioning in a subgroup of TMD patients without evidence of osseous changes associated with chronic disease has renewed interest in the potential use of radiographically measurable variables in the diagnosis of TMD.[2] This investigation evaluates the accuracy of linear tomographic imaging of the TMJ, testing the effect of three technique variations on measurement of intra-articular space. Technique variations included a standard view incorporating a 20-degree horizontal rotation of the head, a horizontally corrected view where the correction of the condylar axis in the horizontal plane was calculated from the submentovertex radiograph, and a horizontally and vertically corrected view where the correction of the condyle in the horizontal and vertical planes was calculated from the submentovertex view and anteroposterior (AP) tomogram, respectively. Using a method that allowed direct measurement of the joint space on dry skull material, we addressed the question of how well each technique accurately represented the true joint space. Our null hypothesis was that there is no difference in accuracy of joint space measurement among the various techniques.

Inherent difficulties in imaging the TMJ with plane film techniques have encouraged the development of tomographic methods. Tomography is recommended for its ability to rid the image of unwanted intervening anatomy while preserving anatomic relationships. During the years refinements in technique and use of cephalometric head-holding devices have allowed investigators to demonstrate superior anatomic visual-

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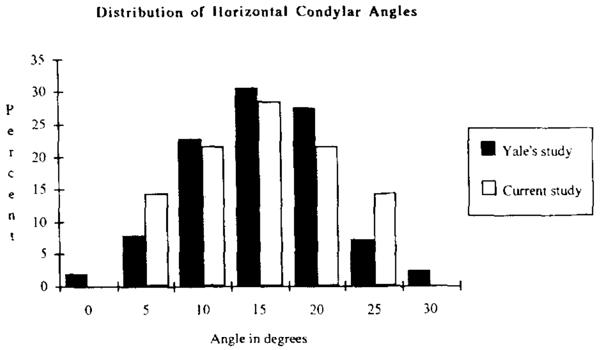

Fig. 1. Distribution of horizontal component of condylar axis in previously sampled and current study populations.

ization and reproducible image production in comparison with conventional transcranial techniques.[3,4] Using a modified cephalostat, we sought to improve further the accuracy of anatomic visualization in linear tomographic TMJ images.

Yale et al.[5] documented a wide range in condylar form and angulation, showing significant variation within and between persons. This normal anatomic variation has been the basis of arguments calling for varying degrees of correction in the vertical and horizontal planes to obtain an improved image of joint structure and a more accurate assessment of the anatomic relationship of the condyle and fossa. The varying degrees of horizontal and vertical correction may be identified as follows: facial contour–directed correction, where the head is rotated so that the zygomatic arch and lower jaw are parallel to the film holder; standard 20-degree horizontal correction (SHC), where the head is rotated 20 degrees in an effort to approximate a typical or average horizontal condylar angulation; individualized horizontal correction (IHC), where the horizontal angulation of the condyle is taken from the submentovertex radiograph and the head is rotated by this measurement; and individualized horizontal and vertical correction (IHVC), where the submentovertex is used for rotation in the horizontal plane and an AP tomogram is used to calculate compensatory head tilt for the vertical plane.

Although clinicians commonly use a SHC of 20 degrees,[6] investigators citing wide variations in horizontal condylar angles have advocated an IHC technique.[6-8] Blaschke[9] reported that although IHC is expected to produce the most accurate detection of structural defects and bony relationships, no comparative studies of linear tomography have ascertained the diagnostic benefits obtained with the use of IHC versus SHC. Rosenberg and other authors have pro-

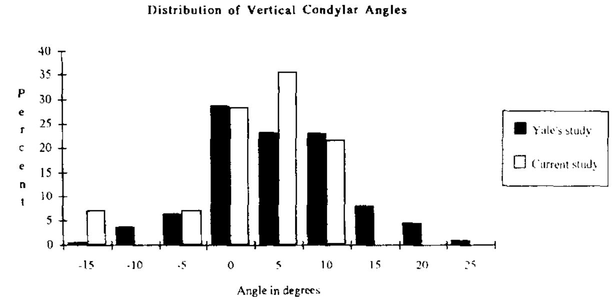

Fig. 2. Distribution of vertical component of condylar axis in previously sampled and current study populations.

Table I. Images with uninterpretable joint spaces by technique

Technique	*Total No. of images*	*No. of uninterpretable images (%)*
SHC	42	7 (17)
IHC	42	6 (14)
IHVC	42	4 (9.5)

moted correction in the vertical and the horizontal plane, to provide a true cross-sectional image.[10-12] Heffez et al.[13] evaluated the accuracy of joint space measurements on dry skull material and found that IHVC produced a more accurate representation of the true joint space than did SHC or IHC techniques. However, their study made no attempt to select skull material that showed variation in condylar angulation, nor were angulations reported.

Evidence suggests that anterior disk position precedes disk deformation in internal derangement of the TMJ.[14] An area of significant controversy in TMJ imaging involves the issue of condylar position as a diagnostic predictor of internal derangement. Nonconcentric condyle-fossa relationships have been associated with abnormal temporomandibular function.[15-19] Pullinger et al.,[20] examining 102 patients with TMJ dysfunction, found a significantly greater proportion of posteriorly displaced condyles among patients with diagnosed internal derangement than those patients with myalgia disorders or arthritic changes. Ronquillo et al.,[21] assessing a group of 143 patients referred for arthrography, noted that 61% of the condyles were posterior in the subgroup of 72 patients with arthrographically evident disk displacement with reduction. Kirk,[22] indexing measured joint space in tomograms with disk position demonstrated by magnetic resonance (MR) images, found that 56% of 25 joints with disk displacement or dislocation

Fig. 3. Independent vertical adjustment of cephalostat device with replacement ear rod assembly.

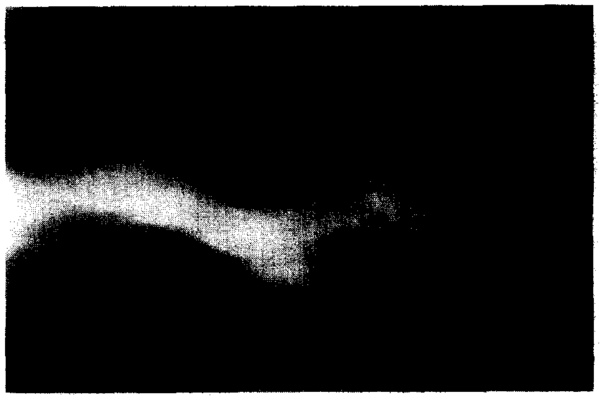

Fig. 4. Example of IHVC image.

showed a tendency for condylar displacement from a centric position. In a blind study of 243 patients, Brand et al.[2] found that among persons with internal derangement without evidence of degenerative TMJ disease, 90% demonstrated retropositioning of the condyle.

Other investigators reported no such association of condylar position and TMJ dysfunction, raising serious doubts concerning the diagnostic value of condylar position and the role that condylar position should play in the diagnosis of disease and treatment of patients.[23, 24] In a prospective clinical investigation, Katzberg et al.[23] compared tomographic radiographs of asymptomatic joints with joints demonstrating the most severe grade of internal derangement (meniscus displacement with or without perforation) as confirmed by arthrography. There was no significant difference in condylar position between the internal derangement group and the asymptomatic group. Another group of 29 orthognathic patients with mandibular autorotation after superior maxillary repositioning failed to demonstrate correlation between condylar position and the presence of joint symptoms.[24] Blaschke and Blaschke[25] also showed that within the asymptomatic population a wide variation of condylar positions exists, prompting the conclusion that "there is a need for comprehensive study of the dispersion of normal condyle positions before the term *abnormal* can confidently be applied to any given condyle-temporal bony relationship."

The conflicting evidence on the significance of condylar position and the role it should play in diagnosis and treatment of TMJ dysfunction may be possible to reconcile. The sensitivity and specificity of many diagnostic tests vary widely, depending on the stage of a disease process and the development and disappearance of diagnostic markers. The acute cases reported by Brand et al. and the severe chronic cases reported by Katzberg et al. may reflect this type of variation in the sensitivity of condylar position as a diagnostic marker for disk displacement. High sensitivity early in the disease process may decline to low levels as changes associated with chronic disease appear. Even if posterior condylar position is a good marker for anterior disk displacement, it is possible that tomography is an insufficiently accurate tool for measuring its more subtle presentations. This study investigates the basic question of how well linear tomographic techniques actually record joint spaces. Although it has been reasoned that tomographic images that have been corrected in the horizontal and vertical planes should produce a more accurate image of the joint structure, it remains to be seen whether this accuracy is significant.

MATERIAL AND METHODS

Vertical and horizontal condylar axis angles were measured in a sample of 100 skulls from a collection housed in the University of Michigan Department of Anatomy and Cell Biology. Measurements were made on disarticulated mandibles with a protractor and rulers to estimate axis angles. Inclusion criteria required that a skull have a dentition sufficient to allow stable interdigitation and fixation of the jaws. With the axis measurements, 14 joints in seven dry skulls were selected to reflect the distribution of condylar angulations described in Yale's sample of 2957 condyles from the Terry collection of contemporary Negro and Caucasian skeletons.[5]

A submentovertex film was exposed, and an AP tomogram was made on each of the skulls to confirm horizontal and vertical condylar inclinations. The an-

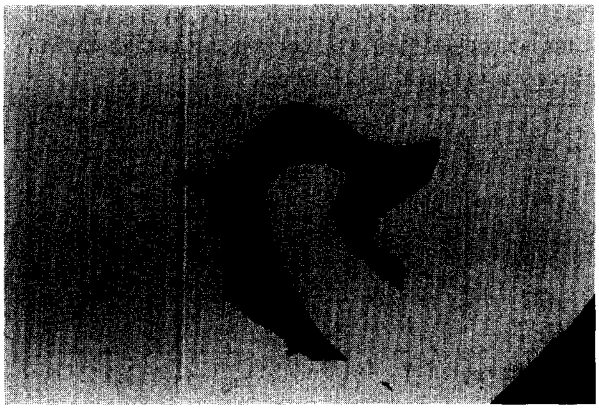

Fig. 5. Example of plaster block–impression section.

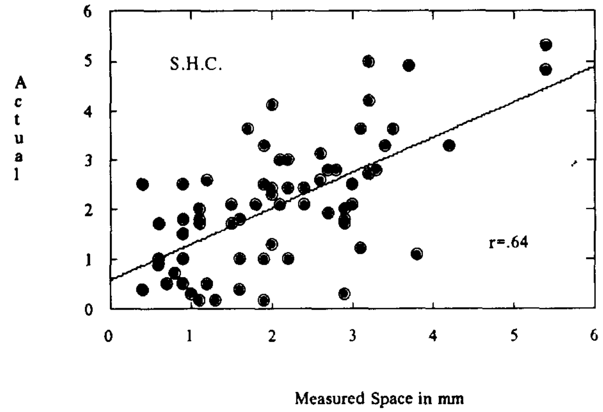

Fig. 6. Distribution of measured versus actual joint space measurements on SHC images.

Table II. Standard error of dual linear measurements of subjective closest joint space in 10 tomograms

Observer	Location of measurement	Dual measurement difference		
		SE	*Mean*	*Range*
1	Posterior	0.29	0.35	0.1-0.7
	Anterior	0.20	0.21	0.0-0.5
2	Posterior	0.47	0.36	0.0-0.9
	Anterior	0.41	0.48	0.2-1.3

gle formed by the intersection of the line passing through the lateral and medial condylar poles and the transporionic axis was traced and measured with a protractor. Positive horizontal values were assigned to those condylar angles where the lateral pole was more anterior than the medial pole. Similarly, positive vertical values were assigned when the medial pole was directed superiorly to the transporionic axis. Horizontal and vertical condylar angulations were measured and verified for accuracy by two observes. The distributions of condylar inclinations to the nearest 5 degrees are seen in Figs. 1 and 2.

To document the position of the tomographic section with the radiographic image, orthodontic ligature wire was wrapped over the condylar head and neck surface within planes perpendicular to the axis of the condyle. Middle, lateral, and medial thirds of the condyle were marked at their midpoints with approximately 4 cm lengths of 0.010-inch wire. Wires were held in position with small amounts of dental inlay wax. Distinctive bends placed at the ends of each wire allowed identification of a wire's plane of section. To document condylar position further, low-viscosity hydrophilic vinyl polysiloxane impression material was injected into the temporomandibular fossa and the mandible was positioned to achieve its best fit. The maxillary and mandibular teeth were luted together with dental compound material to ensure rigid fixation of the mandible to the skull throughout the study.

Lateral tomography was performed with horizontal linear motion with the Denar Quint X-Ray Sectograph radiography unit. Modification of the cephalostat by replacing the ear rod assembly provided continuously variable adjustment of the source side ear rod (Fig. 3). The ear rod is raised or lowered for IHVC images until the vertical axis of the condyle of interest is parallel to the plane of the x-ray beam. The amount of rod movement was calculated as the product of the distance between the ear rods as positioned within the external auditory canal and the tangent of the condyle's vertical angle.

SHC, IHC, and IHVC techniques were carried out on all joints. For each technique three tomographic cuts were made at 5 mm intervals corresponding to the position of ligature wires at the middle, medial, and lateral aspect of each condyle. Images were made with a cassette with a single calcium tungstate screen (X-Omatic Regular) and matching film (X-Omat RP)* (Fig. 4). Films were processed under safelighting (GBX-2) with a large-format automatic film processor (RP X-Omat model MG-N) with automatic replenishment of chemicals (RP X-Omat).* Finished

*Eastman Kodak Co., Rochester, N.Y.

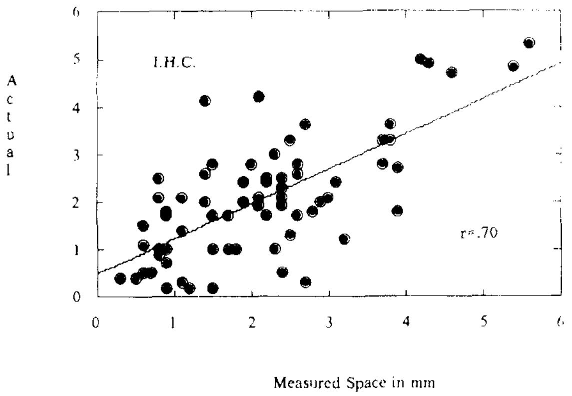

Fig. 7. Distribution of measured versus actual joint space measurements on IHC images.

radiographs were randomized and numbered to avoid identification of technique. On completion of imaging procedures the impression material was removed from the joints and poured in orthodontic plaster. Plaster blocks were sectioned to the depths of each ligature wire and photocopied at a 1:1 ratio (Fig. 5).

To document the examiner's perception of the cortical contours of the joint, each tomogram was traced at zero magnification and linear measurements of the narrowest anterior and posterior joint spaces were made as described by Pullinger and Hollender.[18] Measurements were made to the nearest 0.1 mm with the Scriptel RDT-1212 digitizing tablet and Dentofacial Planner software. Identical measurements were made on photocopies of the corresponding plaster models. Radiographic space measurements were adjusted for a magnification factor of 1.08 and compared with the actual joint space dimensions as measured on the plaster model.

Photocopies of the sectioned plaster models were made, and linear measurements were taken from those reproductions. Standard errors were calculated on paired measurements taken directly from the plaster block and from corresponding measurements on the photocopy. Standard error for 20 trials was 0.08 mm, with a range of 0 to 0.29 mm. Anterior and posterior joint space measures did not differ significantly. Standard error was also used to evaluate intraobserver and interobserver variation in the tracing of tomograms. Ten radiographs were traced on two separate occasions by evaluators. Posterior and anterior linear joint space values were compared for each observer.

To evaluate the accuracy of the radiographic techniques' ability to record joint space dimensions, two forms of analyses were used. The Pearson correlation coefficient *(r)* was calculated for correction technique versus plaster model measures. Scatterplots of the data are presented with the linear regression estimate to identify deviation from truth (a straight line with a slope of 1 and an *x,y*-intercept at [0, 0]). Correlation coefficients were recalculated with the subset of measures with complete data across all techniques and the plaster model. With these *r* values the null hypothesis of equality between pairs of correlation coefficients was tested on all pair combinations with a *t* statistic.[26]

Table III. Significance of difference with *t* tests of comparisons of pairwise correlation coefficients of three radiographic techniques

Technique	*r*	*n*	*t*	*p < 0.005*
SHC IHC	0.617 0.634	60	0.27	NS
SHC IHVC	0.617 0.794	60	3.30	Significant
IHC IHVC	0.669 0.794	60	3.31	Significant

NS, No significant difference at $p < 0.5$.

RESULTS

A total of 126 tomograms were made at the level of the lateral, central, and medial aspects of 14 joints. Of these radiographs, 17 were uninterpretable, resulting in the distribution seen in Table I. Casts of impression material, which recorded the spatial relationships of the joint, provided a possible 42 sections for photocopying. One of the 42 sections was destroyed during preparation, reducing the total possible number of linear measurements from 84 to 82.

Evaluation of interobserver and intraobserver film tracing error is seen in Table II. For both observers the anterior values revealed smaller error values for the mean and standard error, but in all cases the second observer had larger error values than the first observer. Tracings used as the data base for the remainder of the study were done by observer 1.

Accuracy of measurement of joint space dimension by radiographic technique is represented by the *r* values, scatterplot of measured versus actual dimension, and linear regression estimate as seen in Figs. 6 to 8. An analysis of the *r* values for both SHC and IHC reveal moderate correlation ($r = 0.64$ and 0.70, respectively). The IHVC correlation is substantial ($r = 0.81$). Table III demonstrates no significant difference in the *t* test of the *r* values of SHC and IHC images, but a significant difference between IHVC and other techniques is present at the $p = 0.005$ level.

DISCUSSION

In this study the horizontal and vertical condylar angulations of the dry skull material roughly approximated the normal distribution of condylar angulations reported by Yale et al.[5] Our intent was to avoid the potential threat to validity found in earlier studies where sampled joints were not random, or where no attempt was made to match the distribution of condylar angles found in clinical populations. In our representative sample of condylar angles the IHVC radiographic technique produced tomographic images that represented joint space with a significantly higher degree of accuracy than did SHC or IHC techniques. Further analysis revealed no statistically significant difference between SHC and IHC techniques. These findings are in agreement with those of Heffez et al.[13]

Orienting the long axis of the condyle parallel to the mean tomographic beam direction increases the overall interpretability of the tomographic images. This is supported by the trend of uninterpretable images in our study where, with respect to IHC technique, SHC technique resulted in a 21% increase in uninterpretable films whereas IHVC technique had a 32% decrease in uninterpretable films. However, even when the mean beam direction is oriented through the long axis of the condyle, distortion of the radiographic image is probable. The highest level of accuracy produced with the IHVC technique resulted in an *r* value of 0.81 ($R^2 = 0.66$). This indicates that 34% of the measurement error seen in Fig. 8 is unexplained by the linear regression estimate.

Distortion of the tomographic image may result from layer summation and incomplete blurring from incongruent zones. Elements of the joint lying just outside of the tomographic layer in favorable tangential positions can misleadingly extend the morphologic boundaries for the layer of interest.[27] Boundary extension is influenced by the pattern of tube head and film movement. In horizontal linear tomography, streaking patterns (parasitic lines) extending from the anterior to the posterior aspect of the joint may affect the accuracy of measurements taken from the anterior and posterior joint spaces. If these values are used to make inferences about condylar position, measurement error may lead to diagnostic error.

In addition to limitations in the reproduction of TMJ anatomy that are imposed by a particular imaging technique, the ability of the clinician to estimate reliably the true surfaces of the condyle and glenoid fossa from the film is another source of variability that contributes to overall error in recording joint spaces. In this study an effort was made to minimize this source of error by having a single investigator trace and measure all the tomographic images. The standard error of the investigator for the anterior joint space was found to be 0.29 mm, whereas the standard error for the posterior joint space was found to be 0.20 mm. These findings are in agreement with those of Rosenquist et al., where standard error of joint space measurements was found to be 0.22 mm.[28]

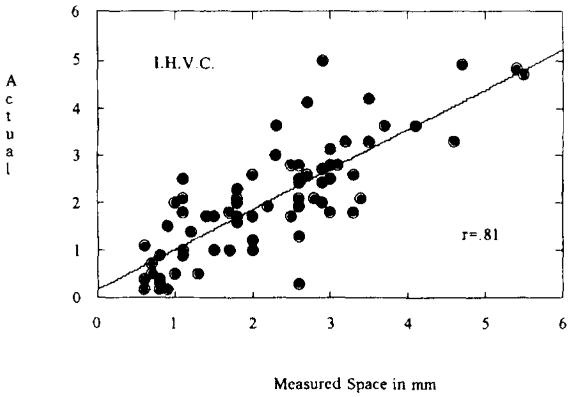

Fig. 8. Distribution of measured versus actual joint space measurements on IHVC images.

The limitations of this study, as with other similar radiographic studies, center on the use of dry skull material as a substitute for vital human subjects. The combination of lack of soft tissue and lower kilovolt peak produced higher contrast than what might be seen clinically. Although increased scatter radiation from soft tissues tends to obscure diagnostic information in real patients, the closely collimated technique that we used minimized this effect. A final problem with this model involves the use of metal wires to confirm the depth of cut for the tomographic image and the plane and level of section for the plaster model. The wires that identified the lateral, central, and medial aspects of the joint tended to obscure the cortical outline of the condyle and possibly affected the precision and accuracy of the measurements taken from the radiographs.

Westesson et al.,[29] comparing computed tomographic and MR depiction of disk position with frozen sections of 15 TMJ autopsy specimens, found both imaging modalities detected abnormal disk position with 86% success. Hansson et al.,[30] comparing 0.3 and 1.5 T MR imaging with frozen sections of 39 TMJ autopsy specimens, found detection of abnormal disk position varied from 46% with the smaller magnet to 85% with the larger.[30] The study of Brand et al.[2] suggested that when a patient population is sufficiently categorized by clinical suspicion of internal derangement and radiographic absence of degenerative joint disease, tomographic evidence of posterior condylar position may provide accuracy (90%) similar to that of computed tomographic or MR imaging for predicting abnormal disk position. The statistically significant increases in accuracy of recording joint space dimensions and the decreased number of uninterpretable radiographs reported in this study support the view that a more interpretable and accurate tomographic image of the TMJ is produced when horizontal and vertical angles are customized for each patient. The use of this technique in future studies of the relationship between joint space and various subgroups of patients with TMD is encouraged.

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