Evaluation of Tomographic Technique of Temporomandibular Joint using COMMCAT IS-2000™ Imaging System

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Abstract : The COMMCAT IS-2000™ (Imaging Sciences International, Hatfield, PA, USA) is a tomographic machine for scanning the dentomaxillofacial region and is capable of imaging the sagittal and coronal sections of the temporomandibular joint (TMJ). The feasibility and accuracy of tomography for the TMJ were examined by use of the COMMCAT IS-2000™ and four dried human skulls with radiopaque steel markers.

To assess the setting accuracy of the slice position, a steel marker was fixed at the center of the superior surface of the condyle, and images of five sagittal sections were taken, i.e., directly above the marker and 1 mm and 2 mm distance from it in both the medial and distal planes. The deviation of the slice position was found to be within ± 1 mm for all test subjects.

To evaluate the dimensional accuracy of this method, the difference between the actual value and the graphically observed value with respect to the tomographic image of the condyle was examined using a digital caliper. The difference between values for the anteroposterior distance was 0.43 mm and that for the mediolateral distance was 0.52 mm.

The effect of the difference in tomographic motion and slice thickness on the image quality was then evaluated. Under identical exposure conditions, hypocycloidal tube motion and the slice thickness of 1 mm produced the best image quality because blurring of the image and the degree of superimposition of the surrounding structures were minimal.

These results suggest that the COMMCAT IS-2000™ is a high-quality diagnostic tool for visualizing the bone structure of the TMJ.

Key words : COMMCAT IS-2000™, temporomandibular joint, tomography

Introduction

Simple plane radiography has been utilized as a conventional method to examine the morphology and position of the bones comprising the temporomandibular joint (TMJ) in patients with temporomandibular disorder (TMD). However, due to overlapping of the surrounding bones and the opposing temporomandibular structure, these radiographic images can be difficult to interpret[1, 2]. Although oblique lateral transcranial projection (OLTP) techniques such as those proposed by Gillis[3] and Issac[4] have been developed to overcome these problems, the oblique incidence of x-rays produces distorted images and the positional relationship of only the one third of the lateral aspect of the mandibular condyle can be recorded[5,6].

In contrast, tomography produces clear images without superimposition of the surrounding bone structures. Furthermore, serial tomographic sections provide for the radiographic examination of more than the lateral one third of the condyle[7,8]. Lately, diagnostic studies using large tomographic units designed for imaging the entire body have been conducted in an attempt to visualize the TMJ[9,10]. Recently, spurred by the need to assess the anatomy of the jaw prior to placement of dental implants and to conduct detailed examinations of increasing numbers of patients with TMD, tomographic equipment designed specifically to image the maxillofacial region has been developed and marketed. Various studies have reported on the performance of these devices[11,12,13].

COMMCAT IS-2000™ (Imaging Sciences International, Hatfield, PA, USA) is a tomographic unit designed specifically for the maxillofacial region. The desired slice layer can be selected through a computer interface displayed on a monitor. Complex tomographic tube motions are possible at a slice thickness of 1.0 mm and the unit offers several imaging modes. Although some reports have investigated the performance of transverse section imaging for the mandible of this unit[14,15], none have focused on the performance of the TMJ imaging mode.

Dried human skulls were utilized to investigate the performance of the COMMCAT IS-2000™ unit in tomographic imaging of the TMJ. The accuracy of the setting slice positions and the resulting dimensional accuracy on film was evaluated. A comparison of the image quality due to different tube motions and the slice thickness was also conducted.

Materials and Methods

1. Test subjects, imaging conditions, film and development

Eight TMJs of four dried human skulls were used as the test subjects. The operating parameters of the tomographic unit were : tube voltage, 59 to 63 kVp ; tube current, 5 mA ; exposure time, 100 ms ; and beam size, 2.0×2.0 mm. Tissues such as muscle and skin that are normally present over the surface of the human skeletal structure were simulated by mounting a 1.5-mm thick copper sheet on the front of the exposure slit and adjusting the film density to that approximating a clinical image. Each skull in turn was placed on an acrylic sheet attached to the chin holder of the tomographic unit. The skull was immobilized by inserting an ear rod into

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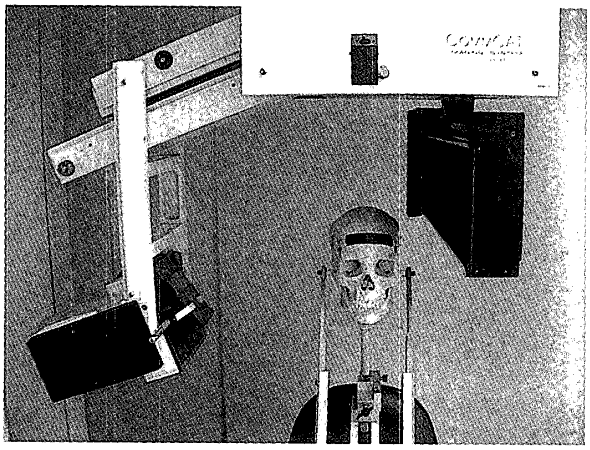


Fig. 1. View of the equipment. The dried human skull was placed on the acrylic plate (chin holder) and fixed using ear rods. The Frankfort plane was kept parallel to the cassette.

the external auditory canal on both sides (Fig. 1). A 10 in.×12 in. film (T-MatG/RA-1, Eastman Kodak, Rochester, NY, USA) was cut in half (2 pieces 5 in. ×12 in.) and used to record the tomographic images. An intensifying screen (Ektavision extraoral imaging screen, Eastman Kodak, Rochester, NY, USA) was also used. The exposed film was developed at 32℃ in an automatic processor (RD X-omat Processor Model M 7 B, Eastman Kodak, Rochester, NY, USA).

2. Procedure to determine slice position

Using the TMJ mode of the COMMCAT IS-2000™ system, a submentovertex (SMV) projection was taken of the dried skull in a fixed position (using ear rods) in order to produce an image to determine the slice positions. The recorded image was then scanned (CanoScan 600, Canon, Tokyo, Japan) and displayed on the monitor of a computer (P-5 133, Gateway 2000, San Diego, CA, USA). The condylar long axis was determined by mapping the medial and lateral poles on both sides. The length and horizontal inclination of the condylar long axis of both sides were then

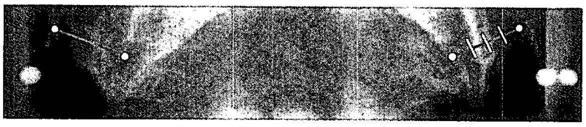


Fig. 2. Scanned image of a submentovertex (SMV) radiograph. The yellow dots indicate the medial and lateral poles and the blue lines show the long axis of each mandibular condyle. The yellow lines indicate selected slice layers. The horizontal condylar inclination was corrected automatically, and so the tomographic projection was oriented perpendicularly to the condylar axis.

automatically calculated. The slice position could be set at any point perpendicular to the condylar long axis as shown in Fig. 2.

3. Evaluation of accuracy of the determined slice position

A radiopaque steel marker placed at the center of the superior margin of the mandibular condyle on both sides was fixed using sticky wax (GC, Tokyo, Japan) and an SMV projection was taken. After scanning the developed SMV film, slice positions were set at a total of five locations as viewed on the monitor of the personal computer. Positions were set directly above the marker and at the points of 1 mm and 2 mm apart in both the mesial and distal planes. Images of the sagittal sections measuring 1-mm thick were taken using the hypocycloidal tube motion. A cross section with the clearest marker image was then examined to assess the degree of deviation from the set slice position by five well trained dental radiologists as the most proper slice position.

4. Evaluation of dimensional accuracy of the tomograph

Radiopaque markers were positioned at the center of the superior surface and at the

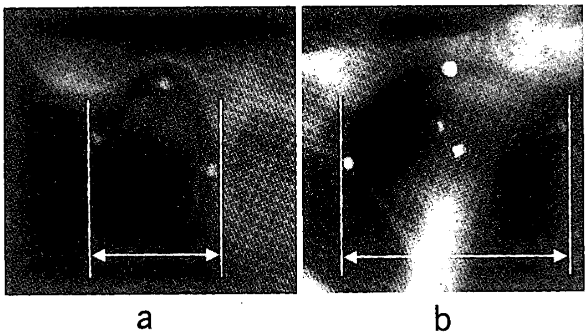


Fig. 3. Measurements from sagittal and coronal tomograms.
a : Anteroposterior distance of condyle
b : Mediolateral distance of condyle

Table 1. Deviation of slice layers determined on the steel maker on the condyle.
0 : No deviation ; +1 : 1-mm shift lateral ; −1 : 1-mm shift medial

TMJ No.	Deviation (mm)
1	+1
2	0
3	−1
4	0
5	−1
6	+1
7	0
8	0

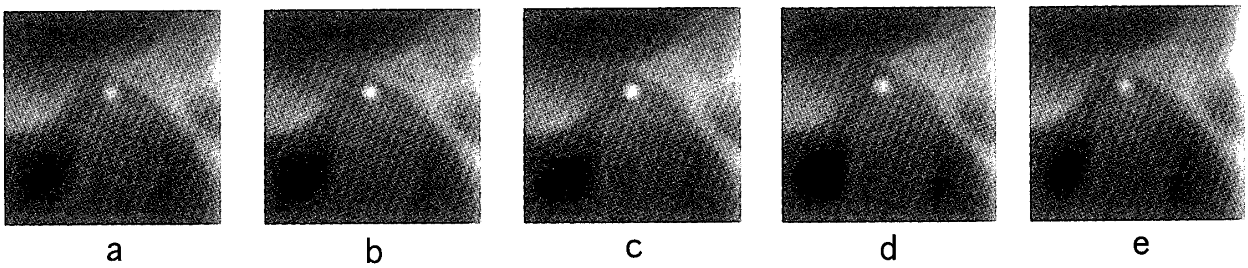


Fig. 4. A steel shot marker was placed on the articular surface of the condyle to assess the accuracy of the slice layer placement for this machine. The marker was depicted most clearly in the tomogram with the slice position just above the marker, with images becoming more indistinct further away from the marker.
a : 2-mm medial to marker
b : 1-mm medial to marker
c : Just above marker
d : 1-mm distal to marker
e : 2-mm distal to marker

anterior, posterior, medial, and distal edges of the mandibular condyle, and then fixed using sticky wax. The upper and lower dentitions were fixed in the intercuspal position and recorded using sagittal tomography. Dental paraffin wax (Shofu, Kyoto, Japan) was inserted between the maxillary and mandibular dental arch in order to remain the mandible in an antero-inferior direction, then coronal tomography was undertaken with the jaw in a simulated open position. The slice thickness was 1 mm and the tube motion was set to hypocycloidal. The anteroposterior and mediolateral dimensions of the condyle were compared in terms of the actually measured dimensions and those measurements obtained from the tomographic images as shown in Fig. 3. Using a digital caliper (CD-20CP, Mitsutoyo, Kawasaki, Japan), dimensional data were obtained by five dental radiologists. Measurements were taken three times and the mean was established as the measured value. Since film magnification of the tomographic unit under study was 1.26×, all tomographic measurements were corrected by a factor of 1.26.

5. Image quality evaluation : Tube motion and slice thickness

The midline of the condylar long axis was established as the slice plane. The slice thickness was set at 1 mm and sagittal tomography of the identical location was performed using hypocycloidal, spiral, circular, elliptical, linear vertical, and linear horizontal motions. In addition, hypocycloidal and sagittal tomographic slices measuring 1-, 2-, 3-, 6-, and 15-mm thick were taken. The effect of the differences in the tube motion and the slice thickness on the image quality was then evaluated.

Results

1. Accuracy of determined slice position

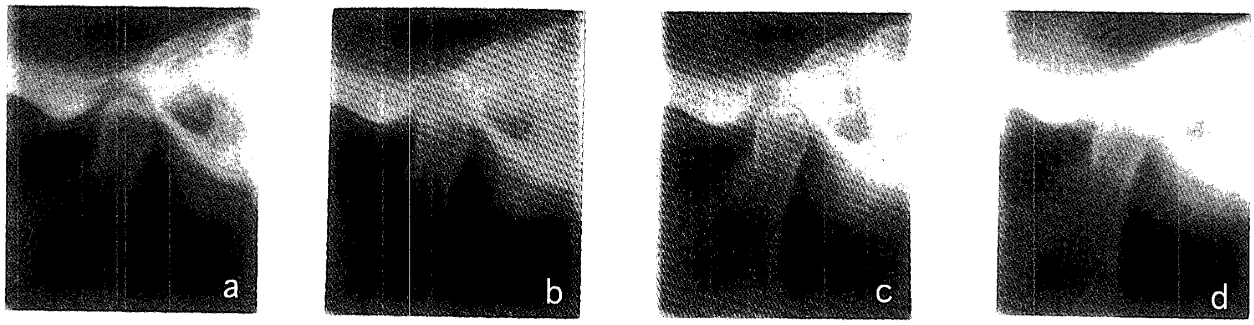
The obtained experimental results for one case are given in Fig. 4. The radiopaque marker was the most distinct in the film where the slice line was set directly above the marker, and the images on the film became progressively obscure further away from the marker. All the five dental radiologists agreed for the clearest maker determination in all the tested images. A slice position determined by the radiologist was assigned " 0 " as center of the condylar head, the position indicated in negative as deviation to medial direction , and the position in positive as deviation to lateral direction. The deviation range between the set slice position and the actual recorded image was within ± 1 mm for all the test subjects (Table 1.).

2. Dimensional accuracy of exposed tomographs

The differences in values between the actual cranial measurements and the sagittal and coronal section exposures are given in Table 2. The error between the actual values and those obtained from the

Table 2. Differences in anteroposterior (AP) and mediolateral (ML) distances of the condyle between tomographic images and actual values.

TMJ No.	AP (mm)	ML (mm)
1	0.38	0.60
2	0.34	0.49
3	0.49	0.54
4	0.80	0.33
5	0.24	1.02
6	0.58	0.26
7	0.25	0.62
8	0.32	0.32
mean±SD	0.43±0.19	0.52±0.24



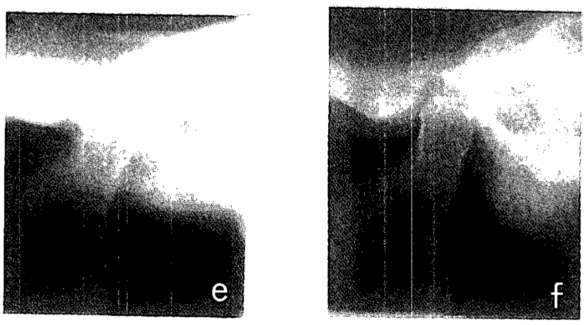


Fig. 5. Comparison of tomographic images for six tomographic tube motions. Hypocycloidal was best for assessing the bone structures of the temporomandibular joint.
a : Hypocycloidal, b : Spiral, c : Circular, d : Elliptical, e : Linear horizontal, f : Linear vertical

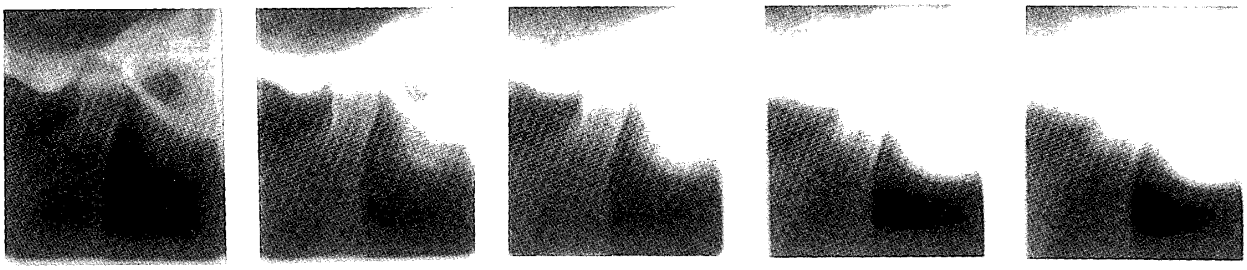


Fig 6. Comparison of tomographic images for five slice thicknesses. Increased slice thickness resulted in decreased image quality due to obstructive shadows.
a : 1-mm, b : 2-mm, c : 3-mm, d : 6-mm, e : 15-mm

films was 0.24 to 0.80 mm (mean 0.43±0.19 mm) for the sagittal sections and 0.26 to 1.02 mm (mean 0.52±0.24 mm) for the coronal sections.

3. Image quality as a result of the differences in tube motion and slice thickness

Tomographic images taken at the same location for the same test joint are shown in Fig. 5 (six tube motions) and Fig. 6 (five slice thicknesses). Images produced by complex tube motions were of superior image quality, with images from hypocycloidal tube motion producing the best image quality. Blurring occurred from elliptical, linear horizontal, and linear vertical motions, resulting in obscure images. Furthermore, increasing the slice thickness caused the surrounding anatomical structures to appear on film, thus the image sharpness was degraded. Under identical exposure conditions, the test subjects filmed at a slice thickness of 1 mm produced the best image quality.

Discussion

When examining the bone structures that comprise the TMJ (i.e., mandibular condyle, glenoid fossa, and articular eminence) in patients with TMD, ascertaining the morphological changes in addition to the positional relationships of each anatomic structure is essential. Although simple plane radiographic techniques have been employed for quite some time in imaging these structures, superimposition of the mastoid process and the opposing condyle prevent accurate assessment of the TMJ morphology. One radiographic method to circumvent the superimposition of the surrounding anatomical structures is OLTP, in which the central rays enter obliquely from the opposite side. However, image distortion produces dimensional changes in the images and deviations in the positional relationship between the glenoid fossa and the mandibular condyle. For these reasons, plane radiography appears limited in its ability to assess morphologically the TMJ[5].

By blurring anatomical structures present in the superficial and deep layers, tomography is able to provide distinct images of objects in the selected plane. Rozencweig[7] reported that tomographic images are useful in accurately assessing TMJ morphology *in vivo*, due to magnification factor accuracy and the lack of superimposition of the surrounding anatomical structures. Others have utilized whole-body tomography units to examine TMJ and investigate the reliability of images, and have reported favorable results

[9, 10]. However, whole-body tomography units are quite large and present problems for use in many dental clinics due to their size.

Recently, tomography has become an important dental imaging tool due to the need to assess jaw anatomy prior to placement of dental implants. Tomographic equipment (with built-in functions for TMJ imaging) designed specifically for dental applications has been developed and marketed by various companies. A number of studies have reported on the performance and utility of these units[11, 12, 13].

COMMCAT IS-2000™ is a multi-directional tomographic system designed specifically for the maxillofacial region, and has six programmed tube motions, including four multi-directional modes (hypocycloidal, spiral, circular, and elliptical) and two linear modes (linear horizontal and vertical). Slice thickness can be selected from 1 mm, 2 mm, 3 mm, 6 mm, or 15 mm settings. In addition, the unit includes SMV, implant (maxillary / mandibular sagittal and cross-sectional), maxillary sinus, and TMJ (frontal and lateral positions) modes. Panoramic and cephalometric radiographs can also be taken.

Shoji *et al*[16] evaluated the performance of the implant mode of the COMMCAT IS-2000™. The report mentioned the superior slice positioning performance and film dimensional accuracy of the unit, verifying the excellent quality of the tomographic images. However, they did not investigate the performance of the unit's TMJ mode. The purpose of the present study is to investigate the performance of the TMJ imaging mode of this system.

Hiruma *et al*[11]. performed sagittal tomography of the TMJ at a slice thickness of 2 mm and slice spacing of 2 mm using the another multi-directional tomographic unit designed specifically for maxillofacial applications. The results indicated that in one of the four layers of the obtained image, the target slice was recorded and the retainers used to fix the dried skulls influenced the deviation of the slice plane. With the COMMCAT IS-2000™, the devpiation of the slice designated on the monitor was within a ±1.0 mm deviation range for a slice thickness of 1 mm and slice spacing of 1 mm, suggesting excellent repeatability of the slice positions. When sagittal radiography of the TMJ is performed, image distortion resulting from the articular surface not facing the direction of the projection on film becomes a problem. In order to circumvent this, an SMV projection is taken beforehand to calculate the horizontal condylar inclination, and the angle of incidence for the x-ray must be corrected[1, 2, 17, 18]. The COMMCAT IS-2000™ has the following characteristics with respect to selecting the slice position in the TMJ imaging mode. First, the SMV image is scanned into the computer, after which the lengths and horizontal inclinations of the long axes of the bilateral mandibular condyles are automatically calculated. This allows the operator to set, on screen, the slice position in a vertical direction with respect to the long axis of the mandibular condyle and this function is mounted on only this machine. Deviation of the slice position is assumed to be minimal, since tomography and SMV projection are both performed after fixing the head position with ear rods. The deviation in slice position may have been caused by slight marking deviations that the operator made when selecting the position on screen.

In order to assess the dimensional accuracy of the TMJ tomography on film, the actual measurements of the anteroposterior and mediodistal dimensions of the mandible were compared with those measured on the images. The results indicated that the dimensional error for the anteroposterior dimension was 0.24 to 0.80 mm (mean 0.43±0.19 mm) and 0.26 to 1.02mm (mean 0.53±0.24mm) for the mediodistal dimension. Many studies use the repeatability of the distance between the glenoid fossa and condyle as a parameter for evaluating errors in TMJ tomography. Hiruma *et al.*[19] reported that the maximum tomographic measurement error for the distance between the glenoid fossa and mandibular condyle was 0.8 mm, with the mean of 0.3 mm. Knorenschild *et al.*[2] reported that the difference between the anatomical and image-measured values was 0.43 mm, 0.53 mm, and 0.38 mm for the anterior, superior, and posterior joint spaces, respectively. Measurement errors for this study were practically identical to those reported in other studies. However, considering that the objects measured in this study were the anteroposterior and mediodistal dimensions of the mandible (a relatively large anatomical structure), the dimensional accuracy of the tomographic image obtained with this unit is quite excellent. The small dimensional changes on film are likely associated with the minimal image distortion, made possible by the fact that sections perpendicular to the long axis of the condyle can be taken.

Comparison of the image quality obtained by the six selectable tube motions of the unit demonstrated that multidirectional paths produce clearer images than do linear paths. In particular, hypocycloidal motion produced the best image quality. Furthermore, the thinner the slice, the better the image quality, with 1-mm thick slices producing the clearest images. There is otherwise no tomographic machine for maxillofacial region which the imaging in hypocycloidal motion and 1-mm thick slice is possible. Kimura *et al.*[20] altered the tube motions and compared cranial sections. They reported that hypocycloidal or spiral motions, which minimize disturbing shadows, produce superior images of bone structures where high contrast is required. In a study to investigate the accuracy and reliability of tomographic images, Takahashi *et al.*[21] utilized a whole-body tomographic unit to record condylar phantoms. They reported that hypocycloidal motion was most effective in minimizing blurring and maintaining image quality, and the clearest sections were obtained using the tube with a maximum exposure angle of 23 degrees. Our study indicates that the maximum exposure angle of the tube was 25 degrees when taking sections at a thickness of 1 mm, which produced the best image quality. The results obtained in this study resemble those reported by Takahashi *et al.*[21]

The TMJ imaging mode of the COMMCAT IS-2000™ multidirectional tomographic system produced accurate slice positions and displayed a high degree of dimensional accuracy. The high image quality suggested the utility of this equipment in visualizing the TMJ bone morphology. The drawbacks to the unit include extreme image degradation when duplicating film, as contour blurring cannot be avoided, and an inability to adjust image contrast or density due to the fact that an analogue image is produced. In the past few years, digital technology has rapidly progressed in the dental field. Imaging methods such as panoramic tomography and cephalography are now digitally processed. The addition of a digital image processing capability by incorporating an imaging plate is necessary to further improve the image quality of the COMMCAT IS-2000™.

Conclusions

The performance of the COMMCAT IS-2000™ tomographic unit in the dentomaxillofacial region was evaluated by visualizing the TMJ of dried human skulls. The following results were obtained :

1. Accuracy of the unit's unique method of setting the slice position by selecting a slice line onscreen was within the deviation range of ±1.0 mm.
2. Image quality for the six types of tube motion and five slice thicknesses was compared. Hypocycloidal motion and a slice thickness of 1 mm produced the best image quality.
3. Comparison of actual measurements of the anteroposterior and mediodistal dimensions of the mandible with those measured on film indicated mean errors of 0.43 mm and 0.52 mm, respectively.

The results outlined above suggest that the COMMCAT IS-2000™ offers superior slice positioning capability and excellent film dimensional accuracy. The high tomographic image quality of the unit makes it a useful diagnostic tool for visualizing the TMJ.

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