Three-Dimensional Imaging of the Temporomandibular Joint in vitro and in vivo

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Abstract
Interpretational difficulties experienced with currently used diagnostic radiation techniques can be reduced via the use of 3-D images constructed from conventional CT data. Each 1.5 mm CT section yields interpolated sections (6 or 8) containing cubic voxels. Structures to be imaged separately are masked in the interpolated sections prior to windowing for the appropriate tissue. A special algorithm detects the surface boundary of the selected structure. The surface pixels are assigned gray levels based on their distance and attitude from the observer. When displayed, this produces a simulated 3-D image. The image can be rotated and sectioned. Rotations permit otherwise hidden surfaces to be examined. Images of two temporomandibular joints are presented, a) bony components; b) bony components & meniscus. It is concluded that the 3-D imaging process is potentially useful in diagnosing TMJ pathology.

Introduction
Current dental practice utilizes several radiologic techniques to diagnose temporomandibular joint (TMJ) pathology; conventional radiology, plain tomography, contrast tomography, and computerized assisted tomography (CT). All these techniques yield results which may be difficult to interpret.

Compared with tomographic techniques, the data yield of conventional radiology is relatively poor because superimposition of structures frequently makes morphologic interpretation difficult, and where bones are in close contact, as in joints, the contiguous surfaces cannot be evaluated.

In detection of certain kinds of pathology, the orientation of the x-ray beam may become a critical factor, necessitating multiple views to ensure that false negative results are not obtained.

Conventional tomography2,3,4 (which includes laminography, planigraphy, sectography, pleuridirectional tomography, etc.) avoids the problem of image superimposition, but again, the plane of the tomographic sections becomes a critical factor in identifying certain pathology. A fracture occurring within the plane of the section is extremely difficult to identify and is not identifiable if it occurs mainly within the thickness of a single section. Multiple scans in different planes may be required and the level of exposure (even using very high speed film) may become prohibitive.

A poor feature of this technique is that the final image represents only a relatively small percentage of the tissues irradiated.

Computer aided tomography offers several advantages1,6; and superimposition of the images does not occur, and irrelevant detail is eliminated. The x-ray beam is finely collimated, allowing the operator to select and scan small, precisely defined areas of tissues, such that sensitive organs can often be avoided, and beam scatter is minimal. A significant advantage is that if the clinician decides that the plane of the initial sections is not optimal for the demonstration of the suspected pathology the sections can be reconstructed in alternative planes without further radiation.

The major drawback of CT scanning (which is shared with conventional radiology and tomography) is the difficulty of evaluating three-dimensional structures and relationships from data presented on a two-dimensional display. In addition, structural information which can be shown to exist in a CT section, may elude detection if its presence is not suspected. This is because of the partial information provided in each section. The difficulty of interpretation is further exacerbated if the sections are in a plane unfamiliar to the clinician. Hence, 3-D medical imaging7,10,11 can reduce many of these limitations.

Material and Methods
1. CT Scan Procedure
Conventional CT scans are made of the area of interest (TMJ). Section thickness is 1.5 mm, transport is 1 mm. Data overlap is 1/3 in all except the terminal sections.

2. Targeting
When a CT section is reconstructed the "raw" data may be used directly, or it may be averaged. The averaging procedure is referred to as 'targeting'. CT numbers of rectangular groups of voxels in the plane of the section (X-Y plane) are averaged to yield a new data matrix comprised of larger voxels. The amount of averaging is ex-
pressed in terms of a target factor. Target factor 3 averages 4 original voxels; target factor 4 uses the original voxels without averaging. Images constructed from data targeted at less than 3 may result in a 'blocky' image. The CT section used here were reconstructed with a target factor of 3.

2. Interpolation

The anisotropic pixels of the original CT sections are divided to form "cubile" voxels. This process produces 6-8 "interpolated" sections depending on the original target factor. For this purpose the data are considered to vary linearly within the original section.

4. Masking

If a part of a structure is to be imaged (i.e. just the mandibular condyle) that part is masked via operator interaction with the individual within the original section. For this purpose the data are considered to vary linearly outside the mask, are imaged subsequently.

5. Windowing

Tissues which are not required in the final image are removed by appropriate interactive adjustment of window level and range. To image bony components and meniscus, the windowing process was performed twice, once for bone and once for soft tissue. The images are combined later.

6. Boundary surface detection

This process is performed by a sophisticated algorithm. The surface of the bone or soft tissue component to be imaged is detected, and the three-dimensional coordinates of the pixels forming this boundary are determined.

7. Shaded-surface display

Visible pixels are identified and shaded according to criteria which include their orientation and their distance with respect to the plane of the monitor screen. Display of the shaded faces results in an image which appears to be three-dimensional.

8. Image manipulation

4. rotation

The image is rotated in three-dimensional space by recalculating 3-D location of its voxels with respect to the plane of the monitor. The axis of rotation may be in any direction but vertical and horizontal axes sufficed for most viewing situations.

ii. image recombination

Individually reconstructed components such as the condyle and meniscus were recombined in their original relationships. Soft tissues were displayed in a 'transparent mode' which permitted their relationships to the bony structures to be seen clearly.

Materials:

A block of tissue containing the TMJ was cut from an embalmed cadaver head. It was scanned in the coronal plane. Reconstructions of the bony joint and the bony joint + meniscus were prepared.

Results

Images of the joint with and without the meniscus were shown in Figs. 1 - 8.

Conclusions

Potentially interesting tissue relationships of the TMJ and bone contours may be displayed in the 3-D. To the extent that the observed relationships can be verified by controlled studies, the technique may have significant value in diagnosis and treatment of TMJ pathology.

Literature cited


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Fig. 1. CT section through TMJ showing condyle, meniscus and glenoid fossa.

Fig. 2. CT section through TMJ with mask drawn around the meniscus.

Fig. 3. Lateral aspect of the complete joint. A marker pin inserted into the posterior aspect of the condyle is visible; immediately above and to the right of it is the petrotympanic tissue.

Fig. 4. Posterior aspect of the joint with the posterior portion of the cranial component dissected away. The joint space in the glenoid fossa can be seen clearly.
Fig. 5 A composite showing the complete joint (lower right), the separated mandibular bone (lower left) and the cranial component (upper). The petrotympanic fissure and glenoid fossa can be clearly seen in the cranial component.

Fig. 6 Posterior aspect of the complete joint with the reconstructed meniscus in situ.

Fig. 7 Anterior aspect of the complete joint with the meniscus in situ.

Fig. 8 Composite showing the separated meniscus (left) and the condyle separated from the cranial component but with the meniscus in situ. Note the apparent fenestration of the meniscus, this could be an artifact.