Three-dimensional reconstruction system for imaging of the temporomandibular joint using magnetic resonance imaging

Mitsuru Motoyoshi, P. Lionel Sadowsky, Wanda Bernreuter, Mineo Fukui and Shinkichi Namura

Department of Orthodontics, Nihon University School of Dentistry, Tokyo 101-8310
Department of Orthodontics, The University of Alabama School of Dentistry at Birmingham, Alabama 35294-0007
Department of Radiology, University of Alabama Hospital, Alabama 35233-6830

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Abstract: This study was undertaken to develop a three-dimensional reconstruction system using magnetic resonance (MR) images in order to visualize three-dimensional images of the temporomandibular joint (TMJ) including the disk. The computerized reconstruction program (written using Visual Basic for Windows, Microsoft Corp.) could reliably generate three-dimensional images of the TMJ. Image processing techniques made the tracing of images unnecessary, reduced complex human manipulation and associated measurement errors. This system, capable of treating fifty thousand pixels or more, generates smooth three-dimensional images of the TMJ. (J. Oral Sci. 41, 5-8, 1999)

Key words: TMJ; MRI; three-dimensional image.

Introduction

The American Dental Association (ADA) recommends to restrict the use of invasive imaging of the temporomandibular joint (TMJ) in those cases of temporomandibular disorder (TMD) that may require a change in treatment strategy as a result of imaging the joint (1,2). Magnetic resonance imaging (MRI) can visualize the disk-condyle complex without invasion (1,2,3). Magnetic resonance imaging is indispensable for diagnosing the condition of internal derangement of the TMJ (4).

The disk-condyle relationship is very complex. Disk displacements can occur anteriorly, posteriorly, medially or laterally, or a combination of the above. Two-dimensional MR images are insufficient to diagnose multidirectional disk displacements in detail. Three-dimensional MR images have poor signal-to-noise ratio, and are technically difficult to perform. This study was undertaken to develop a three-dimensional reconstruction system using MR images acquired in two dimensions.

Materials and Methods

Two-dimensional MR images were obtained from patients who had visited the Radiology Department of the University of Alabama Hospitals at Birmingham for imaging of their TMJs. Magnetic resonance imaging was carried out on using a Siemens Impact scanner operating at 1.0T strength. The scans were T1 weighted (TR500, TE15), with a 15 cm field of view. A pair of two-turn flat coils of 15 cm diameter were used for TMJ imaging. During imaging, the patient's head was fastened into a head holder attached to the table top, and images were taken at a pause at the intercuspal position, such that the movement was restricted. The middle sagittal plane and Frankfort horizontal plane were positioned perpendicular to the floor. Temporomandibular joints diagnosed as normal on MR images were selected in order to develop and perfect the three-dimensional reconstruction system.

A diagram of this system is shown in Fig. 1. Five cross sections were obtained per joint in planes perpendicular to the condylar long axis. The thickness of slices was fixed at 3 mm. Each MRI section of the joint was scanned using a GT-9000 image scanner (Epson Co., Tokyo, Japan) with 300 dpi and stored into an FMV/Tp1120 computer (Fujitsu Co., Tokyo, Japan). An image of a MRI section stored is shown in Fig. 2. An outline abstraction of the TMJ image was then performed using an image processing technique.

Following these processes, two sections (1mm intervals) were estimated between each two MRI sections (3mm intervals) using a cross-fade method to smooth the reconstructed images. The cross-fade method interpolates the transition from one image (first image) to another (second image), and forms sequential images located at the midpoint between the two images. Pixel
values on the first image gradually shift toward corresponding pixels on the second image. The cross-fade image can be constructed by compression or expansion of the pixel information when the second image is different from the first image in size. In this study the cross-fade image process was performed using MORPH program (Gryphon Software Corp., San Diego). Figure 4 shows all sections including the estimated images.

For the three-dimensional reconstruction, all sections obtained by the above mentioned technique were used. The computer program was written using Visual Basic (Microsoft Corp.). At reconstruction, two-dimensional images of thirteen sections stored in the computer were converted into color information and two-dimensional coordinates (X,Y) of each pixel in order to calculate three-dimensional coordinates. Pixel information in black area (Fig. 3, 4; parts except the disk and condyle) was subtracted automatically in order to extract images of the disk and condyle using a programmed low-pass filter. Image information of each section was stored in the computer with reference to the depth of the section (coordinate Z). Z coordinates (depths) are defined as 0 mm at the most external section, and as 12 mm at the most internal section. Using a solid display program, the reconstructed image can be rotated, making the relationship between the disk and the condyle observable from any direction. This program was also written with Visual Basic for Windows Ver. 4.0.

To perform the above mentioned techniques including image processing, three-dimensional reconstruction and solid display, a reading device (GT-9000 image scanner; Epson Co., Tokyo, Japan) and a personal computer (FMV/TpII20; Fujitsu Co., Tokyo, Japan) with a 200 MHz Pentium Pro processor, 97 Mbytes RAM, and a 3 Gbytes hard disk were used.

Results

Figures 5 and 6 show original MR images and three-dimensional images of TMJs reconstructed with this system. The condyle-disk relationships of case 1 and 3 appear normal; the condyle shows normal shape, and the disk is located in an anterior and superior position (posterior band at 12:00 position of condyle). An image of the internally deranged TMJ is shown in case 2. Anterior disk displacement and bone deformity are revealed. The rotations of subjects in case 1 and 2 were made in the computer screen in Fig.7. The condyle-disk relationships can be observed from any direction. This system can display 50,000 pixels and 16,000,000 colors or more.
Discussion

Several studies (5-9) evaluated three-dimensional reconstruction of craniofacial morphology. Moaddab(5) and Sakuda(9) in particular discussed methods for three-dimensional assessment by means of computed tomographic reconstruction. However, in order to make a precise diagnosis, not only the shape and location of the disk needs to be assessed, but also the shape and location of the condyle should be analyzed. MRI can be used to visualize the disk-condyle relationship and bone-soft tissue morphology. A three-dimensional reconstruction MRI system serves two purposes.

A few studies demonstrating three-dimensional visualization of anatomic structures are presented in recent literature (10,11). Bland and Meyer (10) demonstrated three-dimensional alpha blend/gradient display of the abdomen using MRI. Krebs et al. (11) introduced a method for three-dimensional reconstruction and animation of the TMJ. These authors combined MR images of the TMJ, using an extraoral reference system, with jaw motion data. These methods visualized the desired structures three dimensionally, but the three-dimensional images produced were of insufficient resolution for diagnosing problems with the TMJ. We developed a three-dimensional reconstruction system that can reliably generate three-dimensional MR images of the TMJ with acceptable resolution.

Several possible factors affect the precision of this system. These factors are related to the signal-to-noise ratio of the MR imaging system and the process of measurement of the computer system (the scanning device for the most part).

Some confounding factors which affect MRI include those artifacts originating from patient motion and vascular pulsations. Other confounding factors related to the process of measurement include resolution of the image scanner and image processing. Some artifacts directly distort the original MR image. This distortion results from motion, metallic susceptibility, chemical shift, truncation, aliasing, cross talk and bounce point artifacts. Motion artifact derived from the patient's movement during imaging produces the most distortion. To counteract this effect of motion, the patient's head was fastened into a head holder specifically built for the MRI unit. Images were taken in a pause at the intercuspal position, with the patient's teeth supported by a bite block. High-speed imaging was used to compensate for respiratory movement. The next most important source of distortion was from metallic artifacts. Dental work and braces are examples of metallic substances that produce magnetic inhomogeneity in the field. It is not easy to remove braces before MR imaging, nor is it practical or reasonable to remove dental work fixed in the teeth. Metallic artifact is easily distinguishable from other types of artifact. MRI images used in this study did not show evidence of metal artifact. Vascular artifact was eliminated by the application of appropriate saturation pulses.

The process of measurement may affect the precision of measurement. High precision is attained as the inherent resolution of the image scanner gets higher. The resolution of the scanner used for this work was fixed at 300 × 300 dpi, enough to read individual pixels on MRI images. Furthermore,
we enlarged the MR images four times before scanning to achieve the highest precision. To study the repeatability of the extraction process, the readings and! 

coordinates using the same images were conducted several times. The fact that the same results could be obtained with repeated measurement lead us to conclude that the extraction process in this system is reliable. We then have to consider possible sources of error in image processing. This process is interactive, with an operator visually extracting the disk and condyle from the images. It is relatively easy to outline the disk or condyle on MR images using the mouse pointer. We selected the range of 256 steps of color as adequate to select a precise area. It, of course, depends on the skill of the operator whether the selected area is or is not adequate. The operator in charge of this process should excel in reading MRIs of the TMJ. In order to study the effects of the steps of color selected, the change of the selected area due to the differences of steps of color were assessed; a change of one step of color resulted in a 1-2.5 % change in size (this values depended on the original MR images ).

An estimation technique was then applied using the cross-fade method. By this method, smooth three-dimensional images are produced, despite the possible factors that result in measurement errors. When two original images are different in size, the cross-fade image is estimated by compression or expansion according to their pixel information. The processes of compression and expansion may produce more measurement errors. However, the estimated images are only used to produce three-dimensional visualizations in this system. If it is required to measure sizes and volumes of condyles or disks, pixel information derived from the original MR images should be used directly. This system does not yet include direct measurement of pixel information. We are hoping to develop such a measurement system. Another limitation of this system is caused by influences from the thickness of slices during MR imaging. If it is required to visualize minute deformities (less than 1 to 2 mm) of the disk and condyle, the thickness should be fixed at 1 mm or less.

Our system has also a low-pass filter technique for automatic pixel cancellation such that it is capable of individually extracting needed images. This could reduce the need for time-consuming human manipulation and may improve the accuracy and reproducibility of the measurements. The major advantage of this system is its ability to acquire visual information of the TMJ from multiple directions, which may be useful to simulate surgical operations.

Conclusion

Our purpose was to develop a three-dimensional reconstruction system using MRI images in order to visualize three-dimensional images of the TMJ including the disk. After developing this system, we have made the following conclusions:

A computerized reconstruction program can reliably generate three-dimensional images of the TMJ from two-dimensional MR images, with acceptable resolution. This system abstracts the condyle and disk portion of the image, and saves three-dimensional coordinates and the color information of each pixel. An image scanner directly read the MRI images, and can abstract the condyle and disk automatically. Such image processing techniques make tracing the images with the mouse button unnecessary. This reduces complex human manipulation, and reduces associated measurement errors. This system, capable of treating fifty thousand pixels or more, generates smooth three-dimensional images of TMJ, which facilitate clinical diagnosis and intervention.

References