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ORIGINAL ARTICLE

Comparison of conventional MRI and 3D reconstruction model for evaluation of temporomandibular joint

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Abstract The aim of this work was to define the diagnostic value of a method for 3D reconstruction of MRI images for the assessment of temporomandibular joint. Sixty subjects, 42 diagnosed with unilateral temporomandibular disorders (TMD) with disc displacement and 18 without signs or symptoms of TMD (control group) were included. All subjects had both temporomandibular joints scanned by MRI. Three-dimensional imaging reconstructions of temporomandibular joint were generated by segmentation software, allowing visualization of the components of temporomandibular joint (articular disc, condyle and temporal bone) on arbitrary planes. Disc displacement was observed in 83% of 3D reconstruction and 81% of conventional MRI. The agreement between 3D diagnosis and MRI findings was significant and high. The present analysis suggested that 3D reconstruction is a useful and accurate method for the assessment of the temporomandibular joint in TMD ID.

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Introduction

The temporomandibular joint (TMJ) is a synovial joint between the condyle of mandible and glenoid fossa of squamous temporal bone [21]. Interposed between the osseous articular surfaces of the joint there is a fibrous cartilage disc.

Temporomandibular disorder (TMD) is a heterogeneous group of disorders affecting the temporomandibular joints, the masticatory muscles, or both, with a reported prevalence of 5–12% [4, 7, 16]. TMJ internal derangement (TMD ID) is the most frequent type of TMD and is characterized by several stages of dysfunction that involve the condyle-disc relationship [10, 21]. The most frequent type of disc displacement described has been anterior disc displacement [11, 23].

Imaging of TMJ is a valuable instrument in the diagnosis of TMD in addition to its clinical findings [15, 17]. Magnetic resonance imaging (MRI) of the TMJ is up-to-date diagnostic method, widely used as it yields excellent anatomic detail in static examination with high sensitivity, specificity and accuracy [9, 22]. MRI allows analysis of disc position in both sagittal and coronal planes, as well as, dynamic assessment of condylar translation and disc movement during opening and closing, disc morphology, joint effusions, synovitis [1, 6, 8, 18, 24]. However, the spatial resolution of MRI may not be sufficient for accurate imaging of all structures of TMJ, and it do not exhibit detectable contrast and thus remains poorly visible or invisible at anatomical MRI leading a wrong diagnosis.

The need for accurate visualization of hard and soft tissues leads the reconstruction of 2D imaging into 3D to become an important tool for understanding anatomical structures. Three-dimensional reconstruction techniques have been introduced in the study of the TMJs with good results and potential advantages to diagnosis support [2, 3, 14, 19].

Most patients with articular disc displacements either improve spontaneously or can be managed efficiently with appropriate non-surgical therapy. Some patients, however, may become refractory to conservative treatment and require surgical intervention to relieve the troublesome TMJ symptoms. Appropriate case selection is the mandatory requirement for successful surgical intervention, in order to achieve the relief of pain and functional improvement [5]. Three-dimensional reconstruction technique could give critical information that can assist the treating surgeons with clinical decision-making and surgical planning.

So far, few works have evaluated a 3D reconstruction of TMJ [18–21] and none showed a comparison between MRI and 3D reconstruction in the assessment of diagnostic of internal derangements.

The aim of the present study was to evaluate a 3D reconstruction method for visualization of TMJ in a group of patients with TMD ID, comparing to conventional MRI, which was considered the standard of reference.

Materials and methods

Study design

A total of 60 individuals were studied. The patient group consisted of 42 consecutive subjects (35 females, 7 men; range 16–83 years), referred to TMJ ambulatory of Dentistry Service of the University Hospital at UNICAMP, Campinas for evaluation of TMJ complaints. We applied the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) [6] to diagnose unilateral TMJ related TMD internal derangements (disc displacement with and/or without reduction). Criteria for excluding patients were signs and symptoms that characterize history of trauma, rheumatic disease and splint appliance therapy.

The control group comprised 18 healthy subjects (13 women, 5 men; range 22–39 years) who had no previous or present clinical signs and symptoms of TMJ disorders including pain, no previous or present treatment for TMJ disorders and no joint sound on auscultation with a stethoscope or palpable noises. All patients and controls signed an informed consent approved by the Ethics Committee of our university hospital.

MRI protocol

All subjects underwent bilateral MRI of the TMJ obtained in a 2 T scanner (Elscint Prestige, Haifa, Israel) with surface coils of 40 mm of diameter. MRIs were corrected to the horizontal angulation of the long axis of the condyle [18, 24]. T1-weighted SE sagittal images (TR = 650 ms, TE = 22 ms, matrix = 316 × 240, flip 160°, slice thickness = 1.5 mm, field of view = 10 × 10, NEX 1). Among these images, we selected, on each side, the one that showed the best view of the condyle. This image was named "localizer section" and was used to determine the parasagittal sections (perpendicular to the long axis of the condyle); images were acquired in open and closed mouth position. In the open mouth position, a stepped plastic bite-block was placed between the upper and lower incisors.

Imaging assessment

MR images were assessed by a radiologist (investigator 1) without prior knowledge of clinical diagnosis of each subject. The position of the disc was determined according to previous established criteria for normal disc position versus disc displacement [13]. Normal disc position was defined as the posterior band of the disc being located at the superior or 12 o'clock position relative to the condyle, using sagittal images in closed and open mouth position to evaluate disc reduction. The status of the disc was analyzed in the sagittal plane only and defined: (1) normal disc position, (2) anterior disc displacement with reduction and (3) anterior disc displacement without reduction. This was done because this is the most commonly used plane and the single stated criteria [20].

The MRI images were evaluated twice by the radiologist. After the initial interpretation, the analyses of images were repeated.

3D image reconstruction

We used the software MRICro (www.mricro.com) to convert the high-resolution T1-weighted images acquired in DICOM format to the ANALYZE format.

After format conversion, we used image analysis software (ITK-SNAP, http://www.itksnap.org/download/snap/) to segment the joint. ITK-SNAP is free interactive image segmentation software developed to implement an active contour segmentation of anatomical structures, allowing regional segmentation by employing user-initialized deformable implicit surfaces that evolves to the most appropriate border between neighboring structures [25]. With manual segmentation, the reader draws a line around the structures, assigning different colors to each anatomic structure. Subsequent to the segmentation, the software generated 3D images, enabling to see the components of

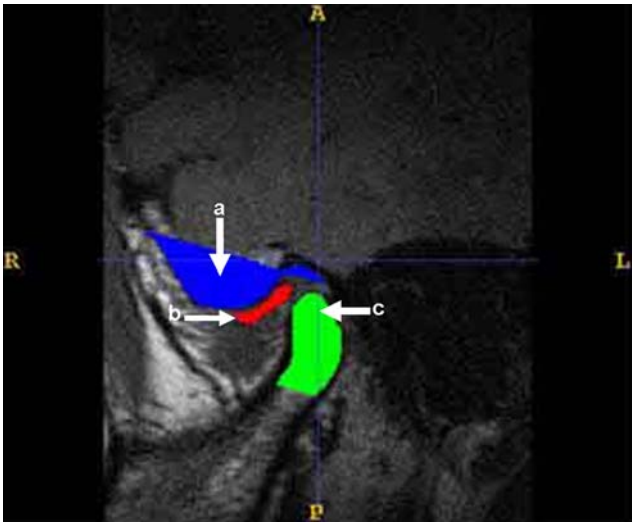

Fig. 1 Image showing the segmented structures of TMJ in sagittal plane: **a** temporal bone, **b** articular disc, **c** condyle

TMJ from any viewpoint (Fig. 1). The software can separate a component from its neighboring structures; this allows evaluating an area that is hidden by others.

Segmentation rules

Segmentation is the process by which appropriate image points (voxels) are assigned to a specific anatomic structure. Images were randomized in order to prevent the operator to be aware of the condition (patient or control) from the scan he was segmenting. Manual segmentation was performed by the same radiologist who assed MRI, drawing a line around the articular borders (temporal bone, condyle and disc), enclosing all the structure, on every single MRI slice with a computer mouse. The operator selected the points to produce a visually appropriated tracing of the surface contour, following carefully and making the appropriated realignment of the region of interest. When necessary, the process was repeated for each image slice until the TMJ had been fully segmented.

For the 3D reconstruction, only the complaint side of TMJ of each TMD patient was considerate. For the control group, the image of one side was selected randomly. The total number of joints studied was 60.

3D imaging assessment

The analyses of 3D reconstruction images were performed by an independent radiologist (investigator 2) in close and open mouth position, without knowledge of patient's clinical or MRI findings. The position of the disc was determined according to the same criteria of MRI [13]. The images were evaluated twice by the same operator. Figure 2 illustrates 3D reconstruction obtained in a multiple series.

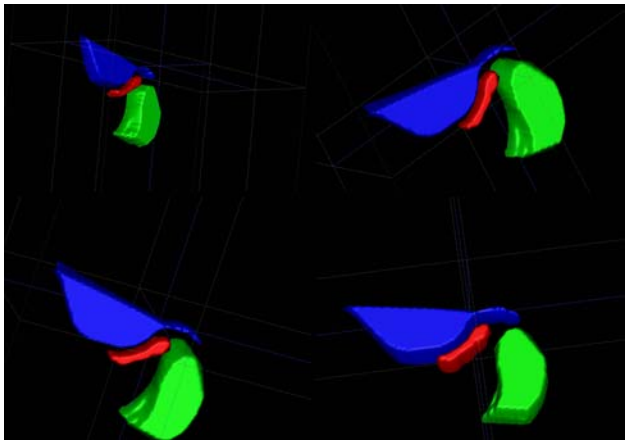

Fig. 2 Multiple series of three-dimensional reconstruction of the TMJ in closed mouth position from MR images taken from a patient with anterior disc displacement with reduction

Data analysis

The statistical analysis was carried out by applying chi-square test to compare distribution of frequency of MRI findings and 3D reconstruction between patients and controls. To determine inter- and intra-observer agreement, the results were analyzed with the Cohen's kappa coefficient. Distribution of frequencies and continuous variables were evaluated using the Fisher's exact test and Mann–Whitney *U* test, respectively. The analyses were performed with the software Systat 7.0 for Windows package (SPSS, Inc., Chicago, Illinois).

Results

The mean age in the patient group was 32.1 years [SD = 10.7], versus 29.9 years [SD = 14.4] in the control group. Groups of patients and controls were balanced to gender and age ($P = 0.15$ and $P = 0.18$, respectively).

The disc status in MRI and 3D reconstruction in all subjects groups are summarized in Fig. 3. In control group, normal disc position was established in 15 subjects on MRI, 14 on 3D reconstruction. Anterior disc displacement with reduction was seen in two subjects on MRI and in three on 3D reconstruction. Only one subject showed anterior disc displacement without reduction on MRI and 3D reconstruction.

In the group of patients, anterior disc displacement with reduction was the most common finding, seen in 22 patients on MRI, 23 on 3D reconstruction. Twelve patients had anterior disc displacement without reduction on MRI and 3D reconstruction. Normal disc position was seen in eight patients on MRI and seven on 3D reconstruction. Chi-square testing revealed an acceptable agreement for

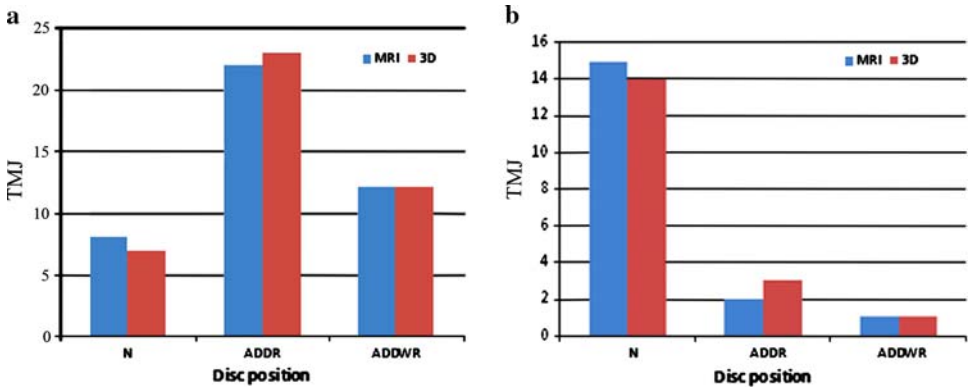

Fig. 3 TMJ disc position in MRI and 3D reconstruction in patient group (**a**) and control group (**b**)

diagnostic accuracy ($P = 0.9$) between MRI findings and 3D reconstruction in control group and patients group.

The concordance of two examinations of MRI performed by the same radiologist was high (Cohen's kappa = 0.9) as well the agreement between the diagnosis of 3D reconstruction by the same radiologist on different occasions (Cohen's kappa = 0.9).

Discussion

In the present study, we investigated a computer model of the TMJ generated from MRI. The ability to obtain good quality 3D images was found to be dependent on MRI resolution, slice thickness, and patient compliance, as showed in a previous study [3].

Earlier reports have addressed the 3D reconstructions in study of TMJ morphology [2, 3, 14, 19]. Chirani et al. [2] discussed the likelihood of a 3D approach to be used in clinical practice. Disc position is of prime importance because the presence of displacement is a significant sign in TMD patients (8, 9, 10, 18). Taking into account that disc displacement is also frequently observed in asymptomatic volunteers (12, 15), we also investigated the accuracy of 3D technique for determining disc status in healthy volunteers. We identified disc displacement in four control subjects with 3D reconstruction and three with MRI. The prevalence of asymptomatic subjects with disc displacement showed with MRI can be one-third in healthy volunteers [12].

In this present work, 3D reconstructions showed an excellent correlation with MRI according to predictable disc displacement. Internal derangement was found on 3D reconstruction in 39 subjects, 37 of whom they were proven on MRI. Cohen's kappa statistics was used to estimate inter- and intra-observer agreement in the evaluation of MR images and 3D reconstruction of the TMJ ID. The results are, therefore, fairly representative and suggest that computer 3D reconstruction assessment agrees well with MR in the diagnosis of TMJ disc position. For our knowledge, this is the first work that investigated inter- and intra-observer agreement in a 3D assessment of TMJ disc status.

Conclusion

The present analysis is a useful method for the diagnostic of the TMJ ID and can be applied successfully as a complementary tool. The high quality of the images obtained associated to the safety of MRI and the easy interpretation of 3D reconstructions makes this imaging technique an excellent non-invasive method of investigation.

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