Evaluation of the usefulness of magnetic resonance imaging in the assessment of the thickness of the roof of the glenoid fossa of the temporomandibular joint

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Objective. The aim of this study was to evaluate the usefulness of magnetic resonance imaging (MRI) in measuring thickness of the roof of the glenoid fossa (RGF) of the temporomandibular joint (TMJ).

Study design. Minimum RGF thickness in 95 TMJs of 59 patients with temporomandibular disorders were measured and compared on both sagittal-section MRI and cone-beam computed tomography (CBCT). RGF thickness on MRI was also compared with MRI, CBCT, and arthrographic findings.

Results. Minimum RGF thickness was greater on MRI (1.46 mm) than on CBCT (0.90 mm). Spearman’s correlation coefficient by rank for these 2 types of measurements was 0.63. RGF thickness on MRI differed significantly between those with and without degenerative joint changes (1.69 vs 1.32 mm; \( P < .01 \)) and between those with and without disk displacement (1.58 vs 1.35 mm; \( P = .04 \)), but showed no associations with disk deformity, joint effusion, or disk perforation.

Conclusions. MRI is useful in measuring RGF thickness from diagnostic as well as radiation protection standpoints.


Thickening of the roof of the glenoid fossa (RGF) of the temporomandibular joint (TMJ) is considered to represent a compensation for various types of stimulation and is not associated with age or gender. 1,2 Several studies have suggested that thickening of the RGF is associated with disectomy, 3 disk perforation, 4 osteoarthritic change of the condyle, 5, 6 and joint effusion (JE). 6 Honda et al. 3 reported that the thickening process is thought to represent progressive remodeling of the TMJ. Tsuruta et al. 5 concluded that thickening of the RGF could help to resist the increased mechanical stress accompanying bony change of the condyle. Matsumoto et al. 6 suggested that this thickening has clinical implications, such as pain. Thickening of the RGF is thus considered an important finding in diagnostic imaging of the TMJ.

Plain radiography, panoramic tomography, magnetic resonance imaging (MRI), computed tomography (CT), and cone-beam CT (CBCT) are widely used for diagnostic imaging of the TMJ. Of these, MRI is accepted as the most reliable modality on which to base TMJ diagnosis and therapeutic decisions. 7,8 MRI is good at evaluating the disk position, disk shape, and JE and bone marrow changes, but is generally inferior to CBCT and CT for evaluating small regions of hard tissue. CBCT and CT produce high-resolution bone images, and CBCT is particularly suitable for evaluation of small bony structures. Our previous study showed that CBCT offers high accuracy in measuring the thickness of the RGF. 9 Nonetheless, although CBCT provides a high level of detail in TMJ diagnosis; MRI is generally superior to CBCT for diagnostic imaging in patients with temporomandibular disorders (TMD), from the perspectives of both diagnosis and minimizing radiation.

Preidler et al. 10 used MRI for measurement of femoral cortical bone, and concluded that this modality was useful for semiquantitative analysis of cortical thick-
ness. Eckstein et al. reviewed the utility of quantitatively analyzing knee cartilage using MRI and concluded that reliable and quantitative data on cartilage status could be obtained. MRI allows cartilage to be visualized, enabling the measurement of cartilage thickness in large joints. However, the cartilage of a small joint like the TMJ cannot be clearly demonstrated. This means that MRI cannot accurately measure the actual bone thickness of the RGF of the TMJ, and it was predicted that such measurements would be overestimated by MRI when compared with CBCT. If a strong correlation could be observed in RGF thickness between MRI and CBCT, then measuring RGF on MRI may have clinical value in TMJ diagnosis.

The purpose of this study was to verify whether measurement of minimum thickness of the RGF using MRI is useful for TMJ diagnosis and to evaluate relationships between RGF thickness and findings on MRI, CBCT, and arthrography.

MATERIAL AND METHODS

Patients
We evaluated 95 TMJs of 59 patients (10 males, 49 females; mean age, 40.0 years; range, 16-69 years) who consulted the Nihon University Dental Hospital for detailed examination and treatment of TMD. Exclusion criteria were as follows: history of facial trauma, luxation, fracture, ankylosis, neoplasm, growth abnormality, surgery of TMJ, systemic arthritides (rheumatoid arthritis, psoriatic arthritis, or gout), or contraindications for MRI. In addition, patients younger than 15 years were excluded from the present study. All patients underwent both MRI and CBCT. The use of clinical data in this study was reviewed and approved by the bioethics committee of the Nihon University School of Dentistry (No. 2008-22). All patients provided written informed consent to participate in this study.

Acquisition of and measurement on MRI and CBCT images
MRI was performed using a 1.0-T Harmony system (Siemens, Erlangen, Germany) with a TMJ surface coil. Modified sagittal (sliced with the short axis parallel to the condyle) T2-star images (repetition time [TR], 350 ms; echo time [TE], 14 ms; matrix size, 256 × 256; field of view, 12 cm; slice thickness, 3 mm) were used for measurement. Minimum thickness of the RGF on MRI (minimum distance between the lower and upper borders of the temporal fossa, shown as a no-signal to low-signal intensity zone on T2-star images) was measured using digital calipers (Fig. 1; resolution, 0.01 mm) on printed-out film. Measurements on MRI were adjusted for the magnification and these calibrated values were noted.

CBCT images (3D Accu-I-tomo; Morita, Kyoto, Japan) were modified and sagittally sliced in the same way as for MRI. Minimum thickness of the RGF on CBCT images was measured using the imaging tool of I-View (Morita) on a personal computer monitor. After identifying the thinnest area, minimal thickness of the RGF was measured 3 times for each modality by 2 oral radiologists (K.M., K.H.), with the average value of measurements used in statistical analyses (Figs. 2 and 3).

Assessment of the TMJ on MRI and CBCT
Joints were categorized according to the presence or absence of degenerative joint changes (DJC), disk displacement, disk deformity, and JE. This resulted in the following subgroups: DJC+ versus DJC−; disk displacement+ versus disk displacement−; disk deformity+ versus disk deformity−; and JE+ versus JE−.

DJC was diagnosed using CBCT when the condyle or the temporal component showed cortical erosion, osteophyte formation, or bone sclerosis; subjects with systemic arthritides (rheumatoid arthritis, psoriatic arthritis, or gouty arthritis) were excluded before image evaluation. Other subgroups were diagnosed using MRI. All image evaluations were performed by 2 oral and maxillofacial radiologists (K.M., K.H.).

The position of the disk with the mouth closed was classified as normal or slightly displaced (disk displacement−) or moderately or severely displaced (disk displacement+). The status of disk position was interpreted as follows: "normal position," intermediate zone of the disk interposed between the head of the condyle and the posterior slope of the articular eminence in the closed-mouth position; "slightly displaced position," intermediate zone of the disk displaced
slightly anteriorly from between the osseous articular components; “moderately displaced position,” intermediate zone of the disk completely displaced from between osseous articular structures, with the head of the condyle in contact with the junction between the posterior band of the disk and the bilaminar zone; “severely displaced position,” anterior displacement of the entire articular disk relative to the posterior slope of the articular eminence and head of the condyle, and interposition of the bilaminar zone of the disk between the osseous articular structures and occupying the narrowest joint space. The disk was classified as biconcave (disk deformity−) or other shape (disk deformity+).

Modified sagittal T2-weighted imaging (TR, 300 ms; TE, 96 ms; other factors were the same as the T2-star imaging sequence) was used to evaluate JE and the criteria of Segami et al. were used to classify JE: grade 0, no area of high signal intensity; grade 1, high-intensity lining or spots along the articular surface; grade 2, high-intensity band; or grade 3, high-intensity collection with pooling in the superior articular space. For statistical analysis, the degree of JE was dichotomized into 2 groups in accordance with the findings of Westesson and Brooks: JE−, grade 0 or 1; JE+, grade 2 or 3.

Presence or absence of disk perforation
Arthrography using CBCT was performed for clinical purposes in 30 joints (27 patients; 2 males, 25 females; mean age, 46 years). The details of arthrography using CBCT have been reported elsewhere. Based on the results of this arthrography, patients were divided into a disk perforation+ group (10 joints, 8 patients; mean age, 54.5 years) and a disk perforation− group (20 joints, 19 patients; mean age, 43.2 years).

Fig. 2. The thinnest RGF measurement. The mandibular condyle was normal. The first measurement was 0.52 mm on CBCT (A) and 0.92 mm on MRI (B). Arrowhead shows the area of minimum thickness for the RGF. Image is available in color at www.ooooe.net.

Fig. 3. The thickest RGF measurement. The mandibular condyle showed osteophyte formation and the disk perforation was confirmed by arthrography. The first measurement was 2.51 mm on CBCT (A) and 2.98 mm on MRI (B). Arrowhead shows the area of minimum thickness of the RGF. The asterisk shows that the upper joint cavity is inflated with air during double contrast arthrography. Image is available in color at www.ooooe.net.
Statistical analysis

The Wilcoxon signed-rank test and Spearman’s correlation coefficients by rank were used for comparison of measurements from MRI and CBCT. The Mann-Whitney U test was used to compare the groups with and without DJC, disk placement, disk deformity, JE, and disk perforation. All statistical analyses were performed using IBM SPSS Statistics 19 software (Japan IBM, Tokyo, Japan). A probability level of less than 5% ($P < .05$) was considered statistically significant.

RESULTS
Comparison of RGF thickness between MRI and CBCT

Mean RGF thickness was 1.46 mm (SD, 0.43; range, 0.84-3.57 mm) on MRI and 0.90 mm (SD, 0.39; range, 0.43-2.58 mm) on CBCT (Table I). The Wilcoxon signed-rank test showed a significant difference between the 2 modalities in terms of thickness measured ($P < .01$). Spearman’s correlation coefficient by rank between measurements as determined using the 2 modalities was 0.63, indicating a moderately strong correlation.

Table I. Measurements of RGF thickness on MRI and CBCT

<table>
<thead>
<tr>
<th>Modality</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRI</td>
<td>1.46</td>
<td>0.43</td>
<td>0.84–3.57</td>
</tr>
<tr>
<td>CBCT</td>
<td>0.90</td>
<td>0.39</td>
<td>0.43–2.58</td>
</tr>
</tbody>
</table>

(n = 95)
The Wilcoxon signed-rank test showed a significant difference between the 2 modalities ($P < .01$).

CBCT, computed tomography; MRI, magnetic resonance imaging; RGF, roof of the glenoid fossa.

Fig. 4. Scatter plot comparing thicknesses of the RGF as measured by CBCT and MRI. Spearman’s correlation coefficient by rank between measurements as determined using the 2 modalities was 0.63, indicating a moderately strong correlation.

Table II. Comparison of RGF thickness on MRI and imaging findings

<table>
<thead>
<tr>
<th>Joints</th>
<th>Mean RGF thickness</th>
<th>Range</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>DJC+</td>
<td>36</td>
<td>1.69*</td>
<td>1.01–3.57</td>
</tr>
<tr>
<td>DJC−</td>
<td>59</td>
<td>1.32*</td>
<td>0.84–1.96</td>
</tr>
<tr>
<td>Disk deformity+</td>
<td>36</td>
<td>1.59</td>
<td>0.87–3.57</td>
</tr>
<tr>
<td>Disk deformity−</td>
<td>59</td>
<td>1.39</td>
<td>0.84–2.30</td>
</tr>
<tr>
<td>Disk displacement+</td>
<td>47</td>
<td>1.58*</td>
<td>0.84–3.57</td>
</tr>
<tr>
<td>Disk displacement−</td>
<td>48</td>
<td>1.35*</td>
<td>1.10–2.30</td>
</tr>
<tr>
<td>JE+</td>
<td>30</td>
<td>1.46</td>
<td>1.10–2.14</td>
</tr>
<tr>
<td>JE−</td>
<td>65</td>
<td>1.47</td>
<td>0.84–3.57</td>
</tr>
<tr>
<td>Disk perforation+</td>
<td>10</td>
<td>1.80</td>
<td>1.01–3.57</td>
</tr>
<tr>
<td>Disk perforation−</td>
<td>20</td>
<td>1.44</td>
<td>0.96–2.08</td>
</tr>
</tbody>
</table>

DJC, degenerative joint change; JE, joint effusion; MRI, magnetic resonance imaging; RGF, roof of the glenoid fossa.

*There was a significant difference in RGF measurements between the DJC+ and DJC− groups, and between the disk displacement+ and disk displacement− groups ($P < .05$).

Relationships between RGF thickness on MRI and image findings

Mean minimum thickness of the RGF on MRI was 1.69 mm in the DJC+ group versus 1.32 mm in the DJC− group; 1.59 mm in the disk deformity+ group versus 1.39 mm in the disk deformity− group; 1.58 mm in the disk displacement+ group versus 1.35 mm in the disk displacement− group; 1.46 mm in the JE+ group versus 1.47 mm in the JE− group; and 1.80 mm in the disk perforation+ group versus 1.44 mm in the disk perforation− group (Table II). A significant difference in RGF thickness was seen only between the DJC+ and DJC− groups ($P < .01$), and between the disk displacement+ and disk displacement− groups ($P = .04$).

DISCUSSION

Our results predictably demonstrated that measurements of RGF thickness were thicker on MRI than on CBCT. This is because MRI measurements included not only bone, but also cartilage and periosteum. We found a moderately strong correlation between these 2 measurement modalities. Although it is questionable whether measuring small structures of about 1 to 3 mm
provides accurate data and has value, experimental studies have reported 1.5-T MRI as useful for semi-quantitative analysis when measuring cortical thickness of the femur. In addition, quantitative studies using MRI have shown relatively good results for measuring cartilage thickness in the patella, tibia, and other bones. These findings give some support to concept of using MRI to measure small structures, as evaluated in the present study. Although articular surface cartilage can be visualized in large joints with some MRI sequences, the cartilage in the TMJ is too thin. In terms of diagnosis, the actual thickness of the RGF cartilage is noteworthy because surface cartilage changes precede bony changes. Currently, however, the TMJ cartilage cannot be assessed without resorting to invasive methods like arthroscopy.

Measuring the thickness of the RGF, including the soft tissue, is challenging with MRI, and, to the best of our knowledge, the use of MRI for this purpose has not been reported. MRI measurement depends on the MRI sequence, magnetic field intensity, and resolution. A variety of MRI sequences have been evaluated for cortical and cartilage assessment. Preidler et al. used proton density-weighted images, and fast spin-echo T1- and T2-weighted images for measuring cortical thickness of long bone. In cartilage evaluation, fat-suppressed T1-weighted spoiled gradient echo sequence is currently accepted as the best sequence for imaging. In this study, we used a T2-star-weighted sequence for analysis. This type of imaging sequence is mainly used for evaluating intracerebral hemorrhage. When applied to the joint, this sequence cannot directly visualize cartilage tissue, but offers advantages in measuring RGF thickness. The resulting image allows clear visualization of both anatomical structures (bone, including cartilage and articular disk) and JE with high contrast. We therefore considered T2-star-weighted images suitable for measuring RGF thickness.

In general, MRI systems with higher magnetic field strength display an increased signal-to-noise ratio and therefore produce clearer images. Maslak et al. confirmed that 3.0-T MRI yielded increased accuracy and provided higher-quality images compared with 1.5-T MRI in the assessment of knee cartilage in a porcine model. Schmid-Schwab et al. showed that 3.0-T MRI was superior to 1.5-T MRI in evaluating components of the TMJ. However, the optimal sequence and magnetic field intensity for evaluating the RGF using MRI remain yet to be determined.

Image resolution is the most important parameter when analyzing image quality. Our MRI parameters were 256 × 256 image matrix, 12-cm field-of-view, and 3-mm slice thickness. Although these parameters are similar to those of other studies, the partial volume effect can markedly influence small joints and thin structures, such as the RGF, potentially introducing bias in the present measurements of RGF thickness. However, the correlation coefficient between MRI and CBCT measurements was moderately good. Measuring RGF thickness on MRI thus appears valuable and can be considered an alternative to measuring this structure on CBCT. However, the methodology in the present study has some clinical limitations. First, this method is unsuitable for patients in whom the glenoid fossa is pneumatized or contains an air space. Although our previous studies the young population (<15 years old) was therefore excluded from the subject population to avoid the bias caused by pneumatic RGF in the present study. Second, RGF thickness on the MRI of patients with a history of trauma, surgery, or systemic arthritis may be increased more than those in the healthy population. We therefore excluded these patients to induce the bias in the present study. Third, this method was not applied for MRI scanning itself in patients who had a heart pacemaker, metal foreign bodies in eye and aneurysm clips in brain, and patients with severe claustrophobia. CBCT and CT can be used to measure RGF thickness in these patients with contraindications to MRI, although the diagnostic significance differs between CT and MRI. Alternatively, double-contrast CT/CBCT, which has been used for measuring ankle cartilage thickness, might offer a good substitute for measuring RGF thickness, including soft tissue or actual cartilage thickness of the TMJ.

When we compared RGF thickness on MRI with imaging findings, patients with DJC and those with disk displacement showed significantly greater RGF thickness than those without such findings. Regarding the comparison between patients with and without DJC of the condyle, the present findings agree with those from a CT study by Tsuruta et al. They also support the findings of our previous study, which showed that the minimum thickness of the RGF averaged 0.6 mm in normal joints, but increased to an average of 1.1 mm in response to osteoarthritis. Thickening of the RGF on MRI does not directly reflect cartilage thickening, and instead may reflect thickening of either the bone and/or the cartilage. This finding may be associated with remodeling or may occur in response to mechanical stress. The present results regarding the comparison between joints with and without disk displacement does not support the findings of our previous study using CBCT, but agrees with our other report. The lack of agreement between our present and previous studies...
can be explained by differences of study populations and classification of disk displacement. The present results suggest that thickness of the soft tissue (cartilage and periosteum) in RGF increases as mechanical stress associated with disk displacement rises. Jonsson et al. 20 reported that cartilage thickness of the articular eminence increased in joints with disk displacement compared with joints without this finding. They interpreted the thickening of the soft tissue on the articular eminence as an adaptation to the difference in the joint space and interposition of joint components resulting from the initial replacement of the disk by the posterior disk attachment occurring during disk displacement. 26 Unfortunately, cartilage of the RGF was not investigated in that study.

Our previous report 14 found significant differences in minimum RGF thickness between normal joints and those with disk perforations and suggested that progressive TMJ remodeling with thickening of the RGF correlated with perforation of the disk or posterior attachment. Williams and Warwick 27 have postulated in detail regarding the functions of the articular disk, ascribing roles, such as shock absorption, improvement of the fit between bony surfaces, facilitation of combined movements, distribution of weight over a larger area, protection of the edges of the articular surfaces, and spread of the lubricating synovial fluid. Many of these functions may become disturbed following trauma, surgery, or disease of the joint. These changes may involve the hard tissue or soft tissue components of the joint directly or indirectly, as in a compensatory response to some dysfunction. We therefore thought that assessment of RGF thickening on MRI might be clinically useful for detecting disk perforation, and this was the basis for the present study. However, we found no significant difference in RGF thickness between joints with and without disk perforation. Kuribayashi et al. 28 reported that temporal posterior attachment (TPA) of the posterior disk was one of the characteristic MRI findings of TMJs with disk perforation. They found that TPA visualization in TMJs with disk perforation was significantly inferior to that in TMJs without perforation and in asymptomatic TMJs. Complex multiple classification analysis with variables, including RGF thickness and TPA factors might more accurately detect disk perforation using only MRI, and remains to be studied.

In conclusion, measurements of RGF thickness on MRI were thicker than those on CBCT, but a moderately strong correlation existed between measurements by these 2 modalities. We believe that MRI is useful in measuring RGF thickness from both diagnostic and radiation protection standpoints.

REFERENCES
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