Comparison of altered signal intensity, position, and morphology of the TMJ disc in MR images corrected for variations in surface coil sensitivity

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Objective. The purpose of this study is to evaluate the corrections of signal intensity of the temporomandibular joint (TMJ) disc caused by variations in sensitivity of the magnetic resonance imaging (MRI) surface coil, to compare the modified signal intensities of the posterior and anterior bands, and then to evaluate the relationship of the signal intensity difference to altered disc position and morphology in a group of TMJ patients.

Study design. MRI was performed on 96 joints. All patients underwent imaging in axial, coronal, and sagittal planes using fast-spin echo sequences (FSE). The images were taken in the closed, partially opened, and maximum opened mouth positions in 2 sequences. Classifications were made according to the position and morphology of the disc. TMJs were divided into normal, anterior disc displacement with reduction (ADDwR), anterior disc displacement without reduction (ADDwoR), and partial anterior disc displacement with reduction (PDDwR). Disc morphology was subdivided as biconcave, lengthened, biconvex, thick posterior band, and others (defined as folded and rounded).

The correction of the inhomogeneous sensitivity of the surface coil was done with the original software. The signal intensities (SI) of the posterior band and anterior band of TMJ discs were measured. The correlations among the groups of TMJs and disc morphologies and SI were statistically analyzed by using Bonferroni/Dunn multicomparison method test.

Results. Of the total number of joints studied with the help of MRI, 37 were normal, 12 exhibited ADDwR, 32 ADDwoR, and 9 PDDwR. The corrected MR images indicated that SI of the posterior bands were higher than the anterior band of the discs. It can also be concluded that the SI of the posterior bands increased significantly in the following order: normal, PDDwR, ADDwR, and ADDwoR, while there is no statistical difference in the SI of the anterior band of the discs. In ADDwR and ADDwoR, thick posterior band is the most common shape. In normal TMJ, the biconcave shape is identified as the most frequently encountered shape.

Conclusions. It was demonstrated that the SI of the posterior bands increase with the progress of internal derangement, and was found to be higher than that of the anterior band of the discs. It appears that disc degeneration starts from the posterior band of the disc.

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Magnetic resonance imaging (MRI) has been used to obtain information regarding articular disc position within the temporomandibular joint (TMJ) in patients.[1] It provides a direct form of soft tissue visualization with excellent spatial and contrast resolution on sagittal and coronal MR images of the TMJ.[2-4] One major advantage of MRI over all other radiographic imaging techniques is the absence of patient radiation. It also offers the advantage of being noninvasive, painless, and of minimal risk potential than the other imaging techniques.[2,5-10] TMJ MRI has been shown to be more accurate than arthrography, except for demonstrating disc perforations and adhesions, which are better investigated with arthrography.[11-13] In addition, MRI of the TMJ can also provide essential information about position,[11,14] morphology,[11,15-20] and signal intensity characteristics of the TMJ structures.[21-24] Previous studies were reported about signal intensity alterations that may be found in the joint compartments and in the condylar bony changes of both asymptomatic and symptomatic TMJs.[1,25-28] In imaging TMJ, experts have recently been using surface coils widely because it has become evident that spatial resolution and improved

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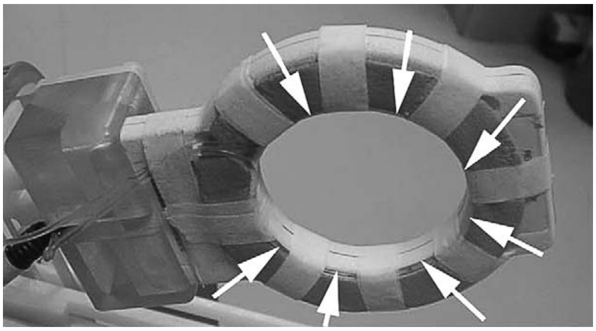


Fig. 1. Photograph showing the proton marker ring attached onto the surface coil.

signal-to-noise ratio (SNR) are more advantageous than the other coils. However, it must be noted that it is sometimes difficult to visualize soft tissues in MR images because of the inhomogeneous sensitivity of these surface coils.[29-36] The correction of the inhomogeneous sensitivity of the surface coil is necessary in order to compare the signal intensity in those tissues. Moyher et al.[37] developed an analytical correction method and applied it to correct the signal intensity nonuniformity caused by the inhomogeneous sensitivity of the surface coils. This method is based on the Bio-Savart law for sensitivity correction of approximately every linear part segmented from the whole coil. This correction considerably improves visual interpretation of the images, and application of this technique yields increased resolution and SNR without the penalty of image nonuniformity. The purpose of this study is to evaluate the correction of the signal intensity of the TMJ disc caused by variations in sensitivity of the MRI surface coil, to compare the modified signal intensities (SI) of the posterior and anterior bands, and finally to evaluate the relationship of the signal intensity difference to altered disc position and morphology in a group of TMJ patients.

PATIENTS AND METHODS

This study was based on MR images of 96 joints from 48 patients having signs and symptoms of internal derangement, who were referred to the dental hospital outpatient clinic at Osaka University because of TMJ complaints. Thirty-eight females (mean age 39.8 years) and 10 males (mean age 29.6 years) were included in this study group. The clinical inclusion criteria were one or more of the following complaints; pain in the TMJ region; limitation or deviation in mandibular range of motion; and TMJ sounds (clicking, popping, and crepitus during mandibular function). Exclusion criteria for the study group were systemic diseases, dentofacial deformity, jaw trauma, previous TMJ surgery, and previous steroid injection in the TMJ.

All joints were studied with a 1.5-T magnet using a dual-phased 3-inch array coil (Signa; GE Medical Systems, Milwaukee, Wis). First a proton marker ring was attached onto the surface coil to determine the coil orientation and its position in the static magnetic field (Fig. 1). Then all patients underwent imaging in axial, coronal, and sagittal planes using fast-spin echo sequences (FSE). The images were taken in the closed, partially opened, and maximum opened mouth positions in 2 sequences.

Imaging parameters were as follows: Sequence 1—For closed mouth position, repetition time (TR) = 2500, echo time (TE) = 17 eff. echo train length (ETL) = 10, 192 × 256 matrix, 3-mm slice thickness, number of excitations (NEX) = 2. Sequence 2—For closed, partially opened and maximum opened mouth positions, TR = 800, TE = 17 eff. ETL = 4, 192 × 256 matrix, 3-mm slice thickness, NEX = 2.

The proton marker ring was displayed as 2 points set on axial and coronal images (Fig. 2). DICOM 3.0 formatted MR images were sent to the DICOM server system, and downloaded onto a personal computer (Pentium MMX 800 MHz, Microsoft Windows 2000, CA). The original application software developed in our laboratory using JAVA (SUN version 1.1 with JBuilder2.0, Borland, CA) was used for the correction of inhomogeneous sensitivity of the surface coil and evaluation of MR images. The method of operation of the software is based on improving inhomogeneous sensitivity caused by B_1 magnetic field of the circular coil. To correct inhomogeneous sensitivity, general solution of the magnetic field caused by constant current passing through the circular coil has to be found. This solution was described in previous studies.[37,38] We modified this solution for the obliquely oriented TMJ surface coil (Fig. 3). To perform this solution, the center point of the coil and the normal vector of the coil plane have to be calculated. The 3-dimensional position of the points on each image was calculated by using the information of image orientation described in the DICOM header. The center point of the coil and the normal vector of the coil plane were calculated with the location of the points of the proton marker rings, which were displayed on axial and coronal images. The original program was made in such a way that we only click the points of the marker ring to get the necessary values. With these values, the center point of the coil and the normal vector of the coil plane were calculated and inhomogeneous sensitivity of the surface coil corrected.

Two radiologists evaluated and interpreted the images twice, separately, without knowing the prevailing clinical conditions of the patients. When the assessments were different, the final diagnosis was obtained by repeating the evaluation and discussion between the

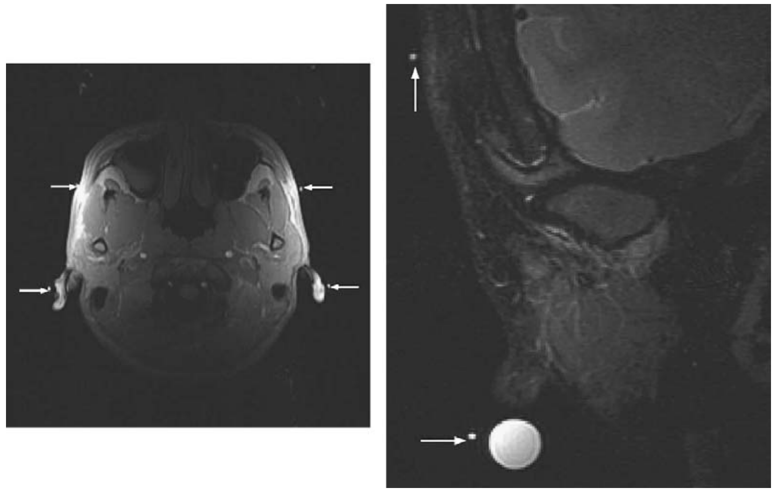
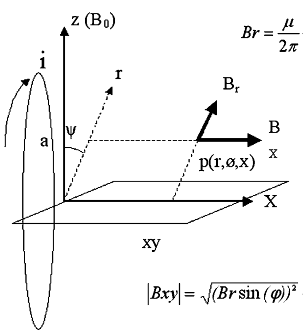


Fig. 2. The appearance of the proton marker ring on axial and coronal images.



$$Br = \frac{\mu}{2\pi}\frac{X}{r\sqrt{(a+r)^2+X^2}}\left[-K+\frac{a^2+r^2+X^2}{(a-r)^2+X^2}E\right]$$

$$B_\varphi = 0$$

$$B_x = \frac{\mu}{2\pi}\frac{1}{\sqrt{(a+r)^2+X^2}}\left[K+\frac{a^2-r^2-X^2}{(a-r)^2+X^2}E\right]$$

$$|Bxy| = \sqrt{(Br\sin(\varphi))^2} + \sqrt{(Bw\cos(\varphi) - Br|\cos(\varphi)|\sin(\varphi))^2}$$

K,E= the 1st and 2nd complete elliptic integrals

Fig. 3. This figure shows the B_1 field as the general solution of magnetic field caused by constant current through the circular coil. The B_0 field is parallel to the z-axis. The coil plane is tilted by the ψ-angle to the xy-plane. The point of p (r, ø, X) is on the circular cylindrical coordinates.

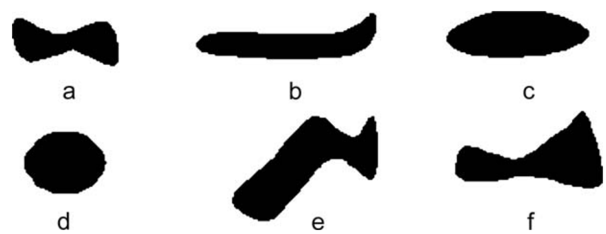


Fig. 4. Types of disc morphological change. a, normal (biconcave); b, lengthened; c, biconvex; d, rounded; e, folded; f, thick posterior band.

radiologists. The TMJs were classified according to the following MR criteria.[6-8,11,26,27,39,40]

Normal state

In the closed mouth position, the posterior band of the disc is located superior to the condyle in which the posterior band of the TMJ disc is at the apex of the condylar head (12:00 position). When the jaw is opened, the disc remains interposed between the osseous components and moves anteriorly in a synchronized fashion. In the coronal plane of imaging, the disc is centered perfectly on the condylar head.

Partial anterior disc displacement with reduction (PDDwR)

A disc exhibiting anterior displacement in the lateral or in the medial slices as well as a normal position in the other sagittal slices, which was not displaced either laterally or medially in the coronal slices, and when the jaw is opened, the disc is recaptured by the condyle and the disc condyle relation appears as normal, was considered to feature PDDwR.

Anterior disc displacement with reduction (ADDwR)

In the closed mouth position, the posterior band of the disc is anterior to the condylar head in all sagittal sections. When the jaw is opened, the disc is recaptured by the condyle and the disc condyle relation appears as normal.

Anterior disc displacement without reduction (ADDwoR)

In the closed and open mouth positions, the posterior band of the disc is anterior to the superior aspect of the condylar head in all sagittal sections. When the jaw is opened, the disc is anteriorly compressed, whether its shape is modified or not.

In line with previous studies,[11,15-20] disc morphology was classified into 5 categories as biconcave (a disc with

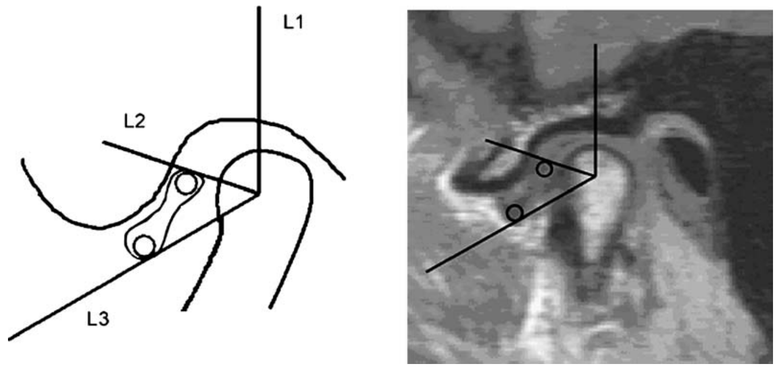


Fig. 5. The selection of ROIs in MR images.

Table I. Distribution of the morphological changes in the study group

Morphology	*Joints, n (%)*
Biconcave	44 (48.8)
Lengthened	6 (6.7)
Biconvex	3 (3.3)
Thick posterior band	26 (28.8)
Others	11 (12.2)

clearly identifiable posterior and anterior bands and tapered intermediate zone), lengthened (a disc with equal thickness in all 3 parts), biconvex (a humped disc), thick posterior band (a disc with the posterior band thicker and longer anteroposteriorly), and others (defined as folded and rounded) (Fig. 4). The SI of the posterior band and anterior band of TMJ disc were measured with an elliptic region of interest (ROI) on corrected MR images. ROIs were selected as follows: first the outlines of the articular disc, then the midpoint on the most anterior bulge of the anterior band, and finally the midpoint on the most posterior bulge of the posterior band were defined. Three lines were then drawn; one vertical line through the center of the head of the condyle (L_1) and others from the center point to the midpoint on the most bulging points of the posterior band (L_2) and anterior band (L_3) of the disc. Similar methods from previous studies were used for the assessment of the disc position.[2,41,42] After these, we drew elliptic ROIs 3 mm in diameter, tangent to the lines of the posterior (L_2) and anterior bands (L_3), and these ROIs were localized inside the anterior and posterior band of the discs (Fig. 5).

STATISTICAL ANALYSIS

The correlations among the groups of TMJs, disc morphology, and SI were statistically analyzed through the use of the Bonferroni/Dunn multicomparison method test. Differences of a *P* value of less than .05 were considered statistically significant.

RESULTS

Of the total number of joints studied by MR, 37 were normal, 12 exhibited ADDwR, 32 ADDwoR, and 9 PDDwR. Six joints were excluded from the study. The images of 4 joints were blurred and the discs were not recognizable or visible, and 2 joints had been diagnosed as possible perforations. When the jaw was opened, the patients were very uncomfortable because of the distracted pain, and this led to motion artifacts in MR images, making the discs unrecognizable, and thus they were excluded from the study. Table I shows the distribution of the disc morphology. Using the original software, increased resolution and SNR were obtained and MR images of the TMJs were corrected (Fig. 6).

The corrected MR images showed that posterior band SI increased significantly with the progress of internal derangement in the following order: normal, PDDwR, ADDwR, ADDwoR. The SI of the posterior bands was found to be higher than that of the anterior bands. There was no statistical significance found for the SI of the anterior band of the discs with the progress of internal derangement.

As indicated in Figures 7 and 8, SI and standard deviation are seen in each group at Sequence 1 and Sequence 2.

In Sequence 1 (closed mouth position), there is a statistical significance in the SI of the posterior bands among normal-ADDwR, normal-ADDwoR, and PDDwR-ADDwoR groups ($P < .05$) (Fig. 7). In Sequence 2 (closed, partially opened mouth and maximum opened mouth positions), there is also a statistical significance in the SI of the posterior bands between normal and ADDwoR groups, whereas there is no statistical significance among all groups in the partially opened mouth position ($P < .05$) (Fig. 8).

We found that thick posterior band is the most common shape that we identified in ADDwR and ADDwoR. Biconcave shape is identified as the most frequently encountered shape in normal TMJ (Table II).

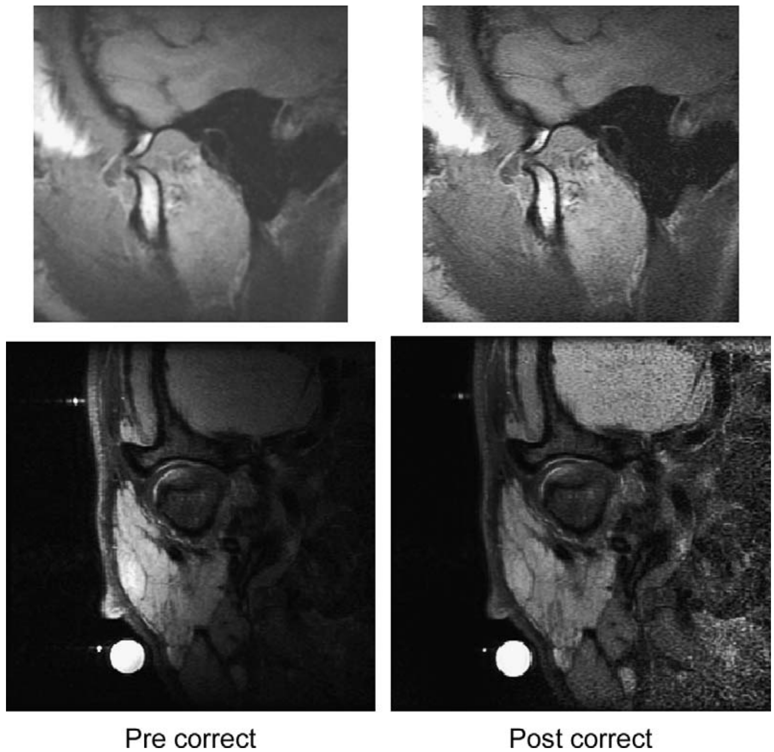


Fig. 6. The appearance of pre- and post-corrected MR images in the sagittal and coronal planes.

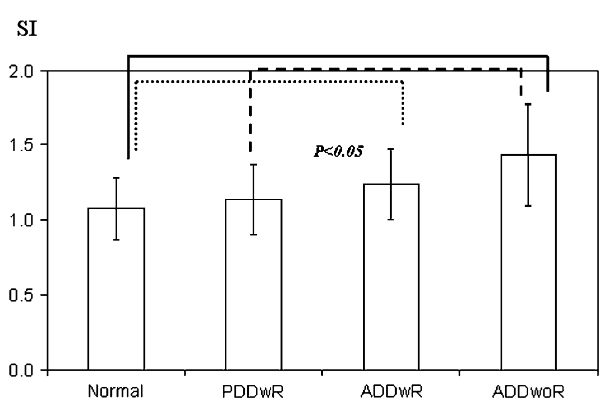


Fig. 7. Sequence 1 (FSE 2500/17) $P < .05$. SI in closed mouth position at each TMJ group.

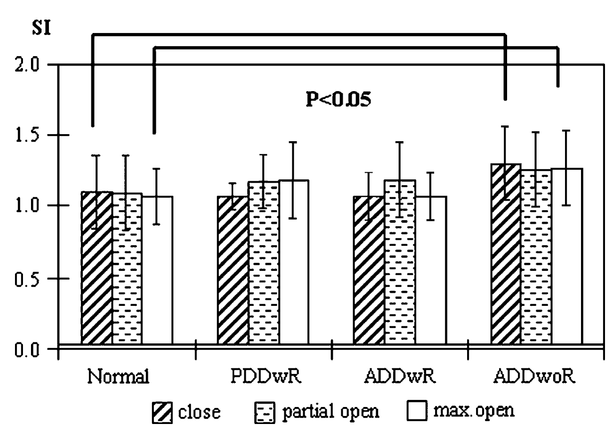


Fig. 8. Sequence 2 (FSE 800/17) $P < .05$. SI in closed, partially opened, maximum open mouth position at each TMJ.

The SI of the posterior band is higher in the thick posterior band than all other disc shapes, and there is a statistical significance for biconcave-thick posterior band, biconcave-biconvex, lengthened-thick posterior band, and lengthened-biconvex ($P < .05$) (Fig. 9).

DISCUSSION

MR imaging of TMJ and TMJ disorders has been fully discussed. From previous reports, we know that the normal TMJ disc consists of dense fibrous tissue made up of proteoglycans and composed chiefly of anteroposterior oriented bundles of collagen fibers together with randomly oriented elastic fibers.[43-47] These structures have a degree of hydration that is easily seen with MR imaging.[4]

Because fibrous connective tissue of the disc has low signal intensity, the disc can be distinguished from the surrounding tissues, which have higher signal intensity. Katzberg[7] reported in routine imaging that the disc has low signal intensity at all pulse sequences. The posterior

Table II. Distribution of the disc morphologies according to the TMJs in the study group

	Normal	*PDDwR*	*ADDwR*	*ADDwoR*
Biconcave	32	7	3	2
Lengthened	—	—	1	5
Biconvex	1	1	1	—
Thick posterior band	—	1	7	18
Others	4	—	—	7
Total	37	9	12	32

TMJ, temporomandibular joint; *PDDwR,* partial anterior disc displacement with reduction; *ADDwR,* anterior disc displacement with reduction; *ADDwoR,* anterior disc displacement without reduction.

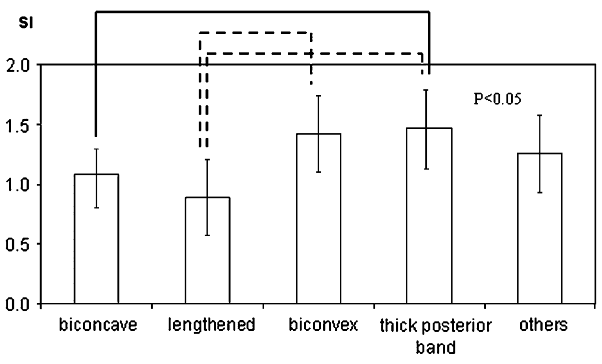


Fig. 9. Sequence 1 (FSE 2500/17) $P < .05$. Correlation between disc morphology and SI.

disc attachment has a bright signal relative to the posterior band of the disc due to a rich network of fatty tissue contrasted with low signal intensity of the fibrous disc. Several studies are reported in the literature about signal intensity changes for TMJ.[1,14,24-26,48]

Schellhas et al.[26] compared TMJ disc with knee meniscus and stated that normal TMJ disc has low signal intensity throughout, and as the TMJ disc degenerates it becomes high in signal intensity. Helms et al.[24] reported normal TMJ demonstrates intermediate to high signal intensity on MR images, and with degeneration the signal intensity diminishes. Sano and Westesson[48] reported that T2 signal from the retrodiscal tissue is higher in painful joints than in nonpainful joints. However, to our knowledge, no studies exist in the literature about the comparison of anterior and posterior band SI of the disc by using MRI.

Throughout this study, we examined SI in normal TMJ and internal derangements. In normal TMJ, the disc itself showed low signal intensity, and the cortical of articular eminence and condyle had low signal intensity. With the degeneration of the TMJ disc, we detected a significant increase in the SI of the posterior bands. A comparison of the SI between anterior band and posterior band of the TMJ discs were made. We found out that the SI of the posterior bands were higher than that of the anterior bands of the disc. It was also concluded that posterior band SI increased significantly with the progress of internal derangement, while there is no significant difference between internal derangements and anterior bands.

Previously, studies were reported about histological features of TMJ disc in asymptomatic and symptomatic patients.[17,47] Kurita et al.[17] reported a proliferative layer of fibrous connective tissue in the inferior-anterior part of the thickened posterior band of the patient's surgically removed discs. Kurita et al.[17] also reported about blood vessels that were located at the posterior band of the disc and surrounded by a high-density of fibroblasts. Paegle et al.[47] found blood vessels in posterior disc attachment, which extended relatively frequently through the posterior band into the intermediate zone of the disc in symptomatic patients. The volume density of blood vessels was significantly higher in patients than in controls. These findings support ours. As previously reported, blood vessels and connective tissue at the posterior band of the discs may account for the increased signal intensity of the posterior band. In our opinion, internal derangements affect first the posterior band of the disc, which is where the degeneration of the disc starts. However, further studies need to be conducted to clarify this connection.

Table II summarizes the distribution of the disc morphologies according to the TMJs in the study group. In ADDwR and ADDwoR, a thick posterior band is the most common morphological change in the disc that we have identified. In normal TMJ, we identified biconcave as the most frequently encountered morphology. These findings are in accordance with findings of Şener and Akgünlü,[14] Incesu et al.,[15] Heffez and Jordan,[16] Kurita et al.,[17] and Wajima et al.,[18] but do not coincide with Milano and Sato.[11,49]

Several different methods have been described for determining the surface coil intensity profile and for correcting inhomogeneous distribution of coil sensitivity on MR images. These methods use either a theoretically generated model[37,38,50-52] of the coil or the information in the image itself[33,53] to generate the expected coil sensitivity map. In the first case, knowledge of the location and orientation of each surface coil is required in addition to a B_1 field map generated from the coil geometry. In the second case, the coil intensity profile can be approximated by a low-pass filtered version of the original image. This approach has been demonstrated in various forms.[33,53-56]

Axel et al.[33] used the original MR image of the wrist of a patient by blurring to suppress the details of the wrist and divided this blurred image into the original image. Although it "flattens out" the overall effective sensitivity, it cannot improve the local signal-to-noise ratio. Cohen et al.[54] described a method of compensating for the purely intensity-based effects by using a Gaussian filter. They specifically segmented the white matter in selected sagittal sections near the midline of the brain and within the occipital lobe. The gains for their application in image segmentation are substantial but improved accuracy is required for segmentation. Tincher et al.[55] also designed a filter to remove the artifact and correct inhomogeneities in a 3-step method. They applied the method to a data set consisting of the liver and subcutaneous fat of a patient. It can be assumed that the model can be used on inhomogeneity introduced by the radiofrequency coil with variations in corrected resultant images. Liney et al.[56] reported a simple method for the intensity inhomogeneity experienced when using endorectal surface coils in prostate imaging. They used a series of proton-density-weighted images acquired to demonstrate the sensitivity profile of the coil and used to correct T2-weighted images acquired in the same plane. The results demonstrate improved image uniformity and visualization of prostatic anatomy.

Moyher et al.[37] used a theoretically generated model for the sensitivity correction to every approximately linear part segmented from the whole coil. They applied this method for the imaging of the brain. The correction considerably improved visual interpretation of the images by modeling and removing the dependence of signal intensity on distance from the coil, but in this method the number of segments is closely related to the accuracy of the correction. Consequently, the filtering method was easier than the method based on the theoretically generated models, but it is difficult to apply the filtering method to an area as complex as the TMJ. Thus, we used the theoretically generated model. Although this method requires the information of the coil shape and position in the magnetic field, it was seen that the homogeneity of the image could be improved in the area of TMJ with this method.

In conclusion, the SI of the posterior bands were found to be higher than those of the anterior bands, and also that the SI of the posterior bands increases with the progress of internal derangement. We did not detect a statistical difference for the anterior band. Thus, it appears that disc degeneration starts from the posterior band of the disc. We found out that the SI of the posterior band are higher in a thick posterior band, and there is a significant correlation among the groups of biconcave-thick posterior band, biconcave-biconvex, lengthened-thick posterior band, and lengthened-biconvex. Therefore, similar to other studies,[14,19,21,49] it can be concluded that as the displacement progresses, the disc becomes deformed. Additional studies will need to be conducted to ascertain how these findings can be useful in terms of clinical application.

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