

Original Article

Parameters for Diffusion Weighted Magnetic Resonance Imaging for Temporomandibular Joint

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Abstract

The purpose of this study was to determine optimum diffusion parameters for diffusion weighted imaging (DWI) techniques, including echo planer imaging (EPI), single-shot fast spin echo (SSFSE), and steady-state free precession (SSFP) in Magnetic Resonance Imaging (MRI) of the Temporomandibular Joint (TMJ). A polyethylene tube with distilled water was individually positioned at the external acoustic meatus foramen in each of three volunteers with normal healthy TMJs. Images were obtained using three types of DWI at differing diffusion parameters, b-factors, and diffusion moment. Signal intensity and imaging ability for various anatomical structures, including the distilled water, were evaluated from each image. The details of the anatomical structures of the TMJ were unidentifiable in the images produced with EPI and SSFSE, but were identifiable on the SSFP images. A diffusion moment value from 100 mT/m² to 150 mT/m² for SSFP, in particular, restrained the signal intensity of the water, thereby protecting the comparably high image quality of the TMJ structure. In conclusion, only SSFP is capable of allowing interpretation of emerging pathologic conditions in the TMJ region, when used with a diffusion moment set at between from approximately 100 mT/m² to 150 mT/m².

Key words: Magnetic resonance imaging (MRI)—Diffusion weighted imaging (DWI)—Temporomandibular joint (TMJ)—b-factor—Diffusion moment

Introduction

Magnetic Resonance Imaging (MRI) is a very useful imaging modality for diagnosing disorders of the Temporomandibular Joint (TMJ). This modality allows non-invasive imaging of the position and shape of the articular disc, alteration in bone marrow and change in morphology of the mandibular

condyle. Furthermore, use of T2-weighted MRI which allows elucidation of pathologic conditions by means of fluid, enables visualization of the abnormal accumulation of TMJ fluid known as TMJ effusion. TMJ effusion, which typically appears as a bright signal on T2-weighted MR images^{6,18,19}, has been recognized as a possible sign related to pain in patients with TMJ disorders^{9,25,28}. Therefore,

at our hospital, T2-weighted MR images are routinely obtained from patients, with suspected TMJ disorders characterized by symptoms of inflammation. However, the clinical significance of TMJ effusion remains to be clarified. Some authors question the relationship between TMJ effusion and pain^{1,5,15,17}. Recently, an advanced MRI technique focusing on fluid conditions, referred to as Diffusion Weighted Imaging (DWI), has come into practical use in the medical field according to Le Bihan *et al.*¹⁰ and Moseley *et al.*¹⁴. DWI reflects the diffusion coefficient of water molecules in body tissue with the application of strong Motion Probing Gradient (MPG). T2-weighted MRI reflects all water molecules in body tissue as a bright signal, whereas DWI selectively reflects water molecules in which Brownian movement is restricted as a bright signal. DWI makes it possible to detect initial inflammatory changes unidentified by T2-weighted MR images¹⁴. This technique traditionally required a long time to obtain images and image quality had a low signal-to-noise ratio. However, developments in both hardware and software have overcome these faults.

DWI has been applied to many cases of brain parenchyma disease, and has consequently contributed to the diagnosis of acute cerebral infarct^{3,4,11,13,14}. The diagnosis of an acute cerebral infarct results from the fact that intracellular edemas caused by acute brain ischaemic diseases depress the diffusion of water molecules, and this abnormal phenomenon in the body tissue is then described with a bright signal on the MR image. This advanced MRI technique was also very effective in discriminating cystic lesions in the brain as a result of differing viscous behavior of contents between cystic lesions²². Recently, this technique has also been used for diseases other than those in the cerebral region, for example, in vertebral diseases² such as fracture and neoplastic lesion. Furthermore, DWI has also been discussed as a way forward in the differentiation of benign and malignant tumors originating in musculoskeletal tissue^{7,26}. DWI studies involving the knee joint¹² and salivary gland²¹ have been also reported. However, to

the best of our knowledge, there have been no reports on the use of DWI in the diagnosis of the temporomandibular joint diseases.

DWI offers a possible method for the representation of clinical state, especially in terms of stages of inflammatory change in disorders of the TMJ. However, the limited imaging area of the TMJ region, and adjacent anatomical structures surrounding the TMJ as typified by air and bone, may provide obstacles to obtaining adequate MR images for diagnostic purposes. Therefore, the purpose of this preliminary study was to investigate adequate imaging conditions for imaging diagnosis in the TMJ region, by comparing several types of DWI technique.

Materials and Methods

MRI was performed with a 1.5 Tesla MR imager (Magnetom Symphony Maestro Class, Siemens, Muenchen, Germany). The TMJ surface coils used as receivers were 8 cm in diameter. Six normal healthy TMJs in three volunteers were subjected to MRI. None of these six TMJs showed clinical signs or any anatomical abnormalities on MRI. All volunteers gave their consent to take part in the study. The study was approved by the Ethics Committee of our institute and was carried out in accordance with the Helsinki Declaration.

As described above, DWI represents the diffusion coefficient of water molecules characterized by Brownian movement on MR images as a so-called "bright signal." To compare water signal intensity on TMJ images among several types of DWI technique, consisting of echo planer imaging (EPI), single-shot fast spin echo method (SSFSE), and steady-state free precession method (SSFP), we prepared a polyethylene tube containing distilled water (Fig. 1). The tube was 6 cm in diameter and 4 cm in bore diameter, and was individually positioned at the external acoustic meatus foramen in each of the three volunteers. First, we carried out Proton Density Weighted Imaging (PDWI) according to the usual imaging procedure at our department,

as this method is routinely applied to patients with TMJ disorders. Consecutively, a series of images was obtained using each DWI technique. To obtain a DWI, a setup motion probing gradient (MPG) strength, which affects the degree (pitch) of diffusion weight, is required. This degree is actually expressed as a b-factor for both EPI and SSFSE, and as a diffusion moment for SSFP. In an environment

marked by slightly affected MPG, water molecules are generated a bright signal, regardless of level of Brownian movement. On the other hand, a strong MPG degrades the ratio of signal-to-noise on MR images. To minimize the effects of diffusion weight in imaging, therefore, the numeric values of the b-factor and diffusion moment used were 0 and 10, respectively, which provided conditions with the lowest MPG in the MRI system used. Other imaging factors are shown in Table 1. A total of four images were printed out on a film to evaluate diagnostic viability. Four oral and maxillofacial radiologists independently evaluated whether the shape of the mandibular condyle could be identified as an anatomical landmark on each DWI image, referring to the PDWI. Viewing conditions were standardized with the usual ambient lighting and masking of extraneous light from the view box. Based on the results of the evaluation, another additional experiment was carried out. A total of six SSFP images was additionally obtained with diffusion moment set at 10, and varying from 50 to 250 in 50 increments. The number of TMJs and volunteers was the same as in the initial study. Thereafter, using viewer software adapted for an MR imager, a region of interest (ROI) 0.02 cm^2 in size was set at the water area in the tube, the bone marrow area of the mandibular con-

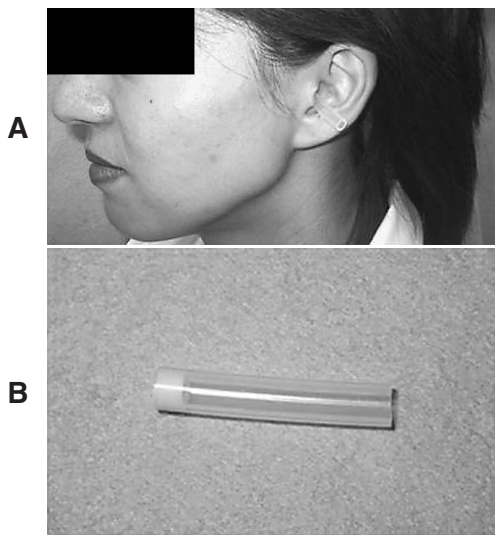


Fig. 1 Polyethylene tube (seen on A) inserted into external acoustic meatus foramen (shown on B)

Table 1 Parameters for each diffusion weighted imaging (DWI) technique

	EPI	SSFSE	SSFP
TR	5,700	4,730	18.8
TE	200	133	7.4
FOV	130	130	13
Slice Thickness (mm)	3	3	3
Average	32	20	8
Flip Angle	90	180	60
Matrix	256	256	256
b-factor (s/mm^2)	0	0	10*
Band Width (Hz/Px)	750	195	100
Scan Time (m)	3:08	4:45	4:22

* diffusion moment (* $\text{mT}/\text{m}^*\text{msec}$)

Decision factor of diffusion weight for EPI and SSFSE was b-factor, and that for SSFP as diffusion moment.

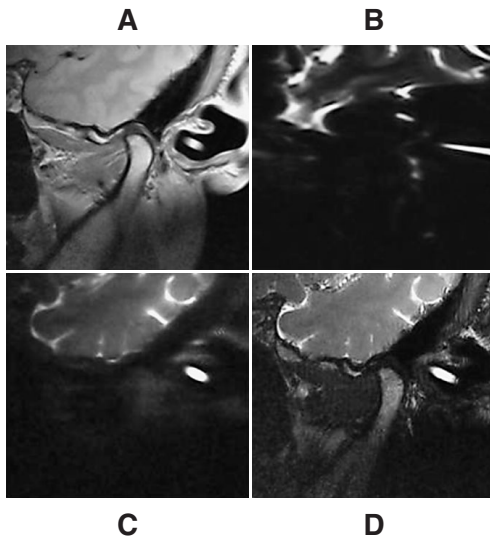


Fig. 2 Proton density weighted image and three types of diffusion-weighted image of TMJ from 35 years male

- A: Proton density weighted image routinely taken showing TMJ structures clearly.
 B and C: Neither echo planer imaging (EPI) image (B) nor single-shot fast spin echo (SSFSE) image (C) detecting mandibular condyle, at all.
 D: Only Steady-state free precession (SSFP) image presented shape of mandibular condyle.

dyle, and the brain parenchyma area on each image, and signal intensity on each ROI was measured.

Results

Figure 2 shows the DWI and PDWI obtained. Nobody could identify the shape of the mandibular condyle on the images obtained with EPI and SSFSE, whereas all observers could identify the SSFP-generated image.

Figures 3 and 4 show the six SSFP images obtained with varied diffusion moments and signal intensities at the water area, the bone marrow area of the mandibular condyle, and the brain parenchyma area on each image, respectively. Signal intensities measured at the water, bone marrow, and brain parenchyma areas for minimum diffusion moment (10mT/m*msec) were 814, 223 and 141,

and 30, 115 and 49 for maximum diffusion moment (250 mT/m*msec), respectively. As the diffusion moment value increased, the signal intensities for each area and signal-to-noise ratio commonly decreased. This tendency was particularly marked in the water area. The signal intensity in the water area was similar to that in bone marrow when the diffusion moment was set at 100 mT/m*msec, whereas the former was less than the latter, and was similar to the signal intensity of brain parenchyma set at 150 mT/m*msec.

Discussion

Diffusion-weighted MRI is a new concept that was introduced as intravoxel incoherent motion. In tissue, the apparent diffusion coefficient (ADC), which is the reference index for evaluating variation in signal intensity influenced by increase of MPG, reflects local water mobility *in vivo*. In recent years, DWI has been investigated extensively in the brain, and has been shown to be especially sensitive in the early detection of cerebral ischemia²⁴. Acute brain infarct using DWI technique generates a high intensity signal, reflecting the decrease in ADC in such lesions. This may result from brain cellulos edema and narrow intercellular space causing a decrease in the number of water molecules in which Brownian movement is possible^{3,20,23}. More specifically, failure of the sodium potassium pump causes cytotoxic cell swelling that results in a decrease in interstitial space, and, therefore, the dephasing of water spins is reduced. When MPG is applied, signal intensity in healthy cells with high diffusion power, that is a high ADC, reduces, but that in abnormal cells in ischemic regions remains high.

In many clinical cases, EPI does not provide an adequate image for diagnosis, except in lesions of the brain parenchyma. This is a result of the strong magnetic susceptibility artifact produced by the presence of complex structures consisting of air, bone, soft tissue, and others, which differs from the relatively homogeneous structures found in the brain

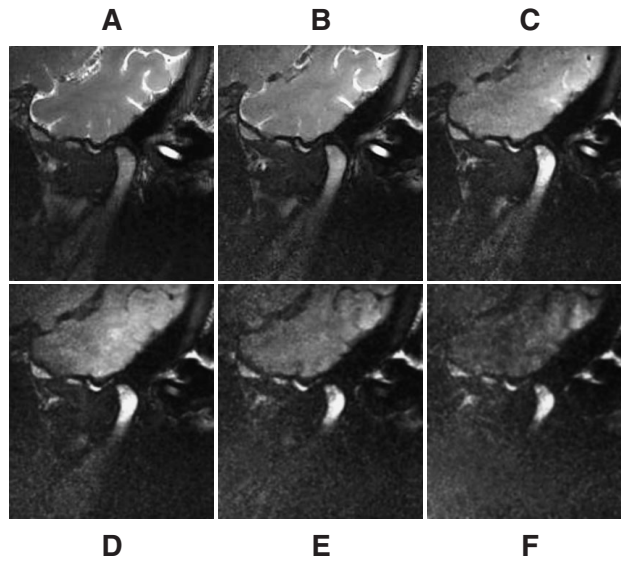


Fig. 3 Steady-state free precession (SSFP) images obtained with different diffusion moments

A: 10 mT/m*msec B: 50 mT/m*msec C: 100 mT/m*msec
 D: 150 mT/m*msec E: 200 mT/m*msec F: 250 mT/m*msec

When diffusion moment value increased, signal intensities for each area (water in auditory canal, bone marrow of condyle and brain parenchyma) decreased. Signal intensity in water area, in particular, dramatically decreased.

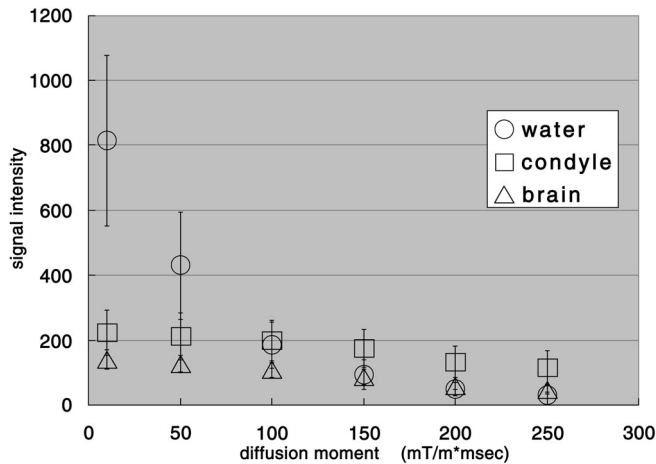


Fig. 4 Relationship between signal intensity at each area (water in auditory canal, bone marrow of condyle and brain parenchyma) and diffusion moment

region. On the other hand, SSFSE and SSFP provide images with little distortion due to the slight magnetic susceptibility artifact. In EPI and SSFSE, MPG is decided by the value of the b-factor (s/mm^2), which reflects the

degree (pitch) of diffusion weight. However, MPG in SSFP is decided by diffusion moment ($mT/m*msec$), which multiplies MPG strength by MPG application time.

In our study, DWIs produced by EPI and

SSFSE did not allow identification of the entire TMJ structure or the mandibular condyle, respectively, when b-factor was set at the minimal 0. The strong magnetic susceptibility artifact produced by the presence of complex structures in the TMJ region resulted in a degradation of image quality. We believe that, even if the value of the b-factor was increased in EPI and SSFSE, image quality would not be improved. It has been suggested that EPI and SSFSE sequences are not suitable for the clinical diagnosis of TMJ, especially with regard to inflammatory change at the primary stage of onset of disorder. The results of this study also indicate that EPI and SSFSE should be applied to regions with relatively homogeneous structures such as the brain region, as many previous reports regarding brain parenchyma disease²⁷. In this study, only SSFP allowed identification of the mandibular condyle. Therefore, DWI produced by using SSFP sequences were additionally performed with incrementation of the value of diffusion moment.

A comparison of the three regions—distilled water, brain parenchyma, and bone marrow of the mandibular condyle—with the signal intensity set at 10 mT/m²msec revealed that the minimal value of diffusion moment was highest in the distilled water area, followed by the bone marrow of the mandibular condyle, and the brain parenchyma. At 250 mT/m²msec which is the maximal value of diffusion moment, the highest value was found in the bone marrow of the mandibular condyle, followed by the brain parenchyma and distilled water. These results suggest that signal intensity of water molecules with a relatively high diffusion coefficient was restrained in strong MPG. The strong MPG produced by a diffusion moment of 250 mT/m²msec indisputably degraded the ratio of signal-to-noise in the diffusion-weighted MR images, whereas the signal intensity in water did not reach zero. Signal intensity in the distilled water area taken at 100 mT/m²msec was inferior to that in the bone marrow of the mandibular condyle, and was superior to that in the brain parenchyma. However, the signal intensity

of water at 150 mT/m²msec was inferior to those in both the bone marrow of the mandibular condyle and the brain parenchyma. In conclusion, setting the value of diffusion moment at between 100 mT/m²msec to 150 mT/m²msec for SSFP restrains the signal intensity of water, and thereby protects the comparably higher image quality of TMJ structures. In particular, a diffusion moment of 100 mT/m²msec for SSFP appears to offer a good basis for taking DWI images of the TMJ region.

Andera *et al.*²⁾ reported that SSFP was very effective in identifying the cause of vertebral fractures, although the anatomical structure surrounding the vertebrae is complicated, as in the TMJ region. Clinical image diagnosis of the TMJ region using DWI requires the maximum possible image quality (high ratio of signal-to-noise) of both anatomical structures and accurate description of water molecules with slight diffusion such as found in the initial stage of inflammatory change. The results of other studies suggest that DWI is capable of detecting bone marrow abnormalities, while not being so useful in differentiating spinal infection and malignancy¹⁶. However, another report has suggested that DWI offers a potential tool for therapy monitoring which would allow us to revise the way in which cancer patients are managed⁸.

When these requirements have been met, DWI, especially SSFP, will provide an effective clinical tool in the interpretation of emerging pathologic conditions in the TMJ region, for instance, offering an alternative to T2-weighted MRI in the evaluation of the abnormal accumulation of TMJ fluid.

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