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ORIGINAL ARTICLE

Test–retest reliability of MRI-based disk position diagnosis of the temporomandibular joint

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Abstract This study evaluated the test–retest reliability for determining the temporomandibular joint (TMJ) disk position, diagnosed using magnetic resonance imaging (MRI). These assessments were done as a base-line measurement for a prospective cohort study, which examines the risk factors for precipitation and progression of temporomandibular disorders. Fifteen subjects (mean age, 24.2±0.94 years; male/female=8/7) were recruited from the students of Okayama University Dental School. Sagittal MR TMJ images were taken with a 1.5-T MR scanner (Magneton Vision, Siemens) in close and maximal open positions twice at about 1-week (6–11 days) interval. The images were displayed using 200% magnification on a computer screen with a commercially available image software package (OSIRIS, UIN/HCUG). Three calibrated examiners diagnosed the disk positions using the standardized criteria. The disk position of each joint was classified as normal, anterior disk displacement with or without reduction, and others. The first and second disk position diagnoses were compared, and the test–retest reliability level was calculated using the kappa index. The second disk position diagnosis was consistent with the first in 27 out of 30 joints. The calculated kappa value representing the test–retest reliability level between the first and second disk position diagnosis was 0.812. These results indicated that the test–retest reliability of MRI-based diagnosis of TMJ disk positions at about 1-week interval was substantially high, even though they were not completely consistent.

Keywords Temporomandibular disorders (TMD) · Magnetic resonance imaging (MRI) · Temporomandibular joint disk position · Diagnosis · Reliability

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Introduction

Magnetic resonance imaging (MRI) can accurately depict the temporomandibular joint (TMJ) disk position. One major advantage of MRI over all other radiographic imaging techniques is that it does not expose the patient to radiation. It is also non-invasive, painless, and of minimal risk potential in comparison to other imaging techniques [1–7]. However, the most crucial element is that the image accurately depicts the TMJ disk position and configuration. The validity of MRI in the assessment of the

TMJ disk position has been evaluated using autopsy specimens. Westesson et al. [8] first compared the disk position of sagittal and coronal MR images with corresponding sagittal cryosections using 15 fresh TMJ autopsy specimens. They demonstrated that MRI correctly delineated the position of the disk in 11 (73%) joints [8]. This accuracy rate is slightly lower than has been reported for arthrography [9, 10]. However, there have been substantial improvements in imaging hardware, coupled with several software upgrades. Schwaighofer et al. [11] reported that MR images accurately assess the TMJ disk position at the rate of 86%. In addition, the most recent study using a larger number of samples (55 joints) by Tasaki and Westesson [12] demonstrated that MRI was 95% accurate in the assessment of disk position and disk form and 93% accurate in the assessment of osseous changes. They concluded that MRI should therefore be considered the prime imaging modality for analyzing the soft- and hard-tissue changes of the TMJ.

On the other hand, with regard to the reliability of disk position assessment, some studies evaluated the effect of examiner calibration on inter-examiner agreement levels on disk position assessment. These studies suggested that performing the suitable examiner calibration programs can reduce the examiner variation [13, 14]. Another study evaluated whether the difference of TMJ disk status influences inter-examiner reliability of the disk position assessment. Nebbe et al. [15] reported that the kappa statistics of agreement indicated moderate agreement among all four examiners for both the medial and lateral components of the joints. In addition, they demonstrated that disk displacement without reduction was the category with the greatest agreement among all examiners (kappa= 0.914). Furthermore, the inter-examiner reliability was excellent for diagnosing disk displacements with reduction (kappa=0.78) and for disk displacement without reduction (kappa=0.94), when the image analysis criteria developed by Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) Validation Project was utilized [16].

However, no study has so far attempted to assess the test–retest reliability of plurally MRI-scanned individual joint disk positions. Such information is useful and indispensable, because an MRI-based disk position assessment would be questionable for clinical and research application if the test–retest reliability is not reliable. Therefore, this study investigated the test–retest reliability levels of MRI-based disk position assessment in asymptomatic volunteers. The study subjects underwent MRI scanning of the TMJ twice with the jaws in closed and maximally open positions in a 1-week interval, and the results of the disk position assessment were compared between the initial and second scans. Plural examiners participated to assess the disk positions in order to evaluate the disk position accurately, and an examiner calibration program was performed to standardize the inter-examiner assessment ability before the investigation. In addition, since the three-dimensional assessment using sequential multi-slice images of each joint may possibly diagnose the disk position more accurately, this study detected the disk position using seven sequential images of each joint.

Materials and methods

Subjects

This study was incidentally conducted as a base-line measurement of a prospective cohort study on risk factors for the precipitation and progression of TMD. The study subjects of this large cohort study are the students of Okayama University Dental School. The participants in the current study were recruited from the above larger subject population. In total, 30 subjects (male/female=16/14; mean age, 24.1±2.97) participated in this study, and all of them fulfilled the following subject criteria. The inclusion criteria were (1) willing to participate in the study and (2) less than 30 years old. The exclusion criteria of this study were (1) having claustrophobia and (2) not willing to undergo MR imaging twice. Half of those subjects (male/female=8/7; mean age, 23.9±0.24) were involved in the preliminary examiner calibration program. MR images of their TMJs were taken twice, and the mean interval between the initial and second MRI scanning was 38.4±1.24 (from 31 to 48) days. Another 15 subjects (male/female=8/7; mean age, 24.2±0.24) participated in the main study in this report. They also had MR images of their TMJs taken twice with a mean interval of 7.1±0.3 days (range from 6 to 11 days). This study protocol was approved by the Ethical Committee for Human Research in Okayama University Graduate School of Medicine, Dentistry, and Pharmaceutical Sciences (No. 13).

Clinical examination

The clinical signs and symptoms of each subject were examined by any of two examiners (C.S-N and T.O) before the MR images were obtained. Both two examiners were TMD specialists, and the calibration was performed before the experiment. The clinical examination involved the mouth opening range measurement and the palpation of the TMJ noise. In addition, the subjects provided information concerning pain in the TMJ and the history of the TMJ noise. This process was also performed twice before each scan was performed, and the examiner was randomly assigned at each examination.

MRI scanning technique

Bilateral sagittal MR images of the TMJs with intercuspal and maximally jaw-opening positions were taken twice in each subject. Scans were performed with a 1.5-T MR imaging system (Magnetom Vision: Siemens, Erlangen, Germany) by the same technical expert (H.Y.). Sagittal proton density-weighted images were taken with a fast spin echo technique (repetition time, 2,400 ms; slice thickness, 3 mm; field of view, 125 mm; matrix, 256×80) and through the use of a unilateral surface coil (127 mm). Each subject's head was placed with the Frankfort plane parallel to the opening of the scanner. The head was fixed in position with adhesive tape on a foam rubber support.

Criteria to interpret the disk status

Continuous multi-slice images (at intervals of 3 mm) were obtained in both the close and open jaw positions. The images were magnified (200%) and displayed on a computer screen using a commercially available imaging software program (OSIRIS, UIN/HCUG, Geneva, Switzerland). First, the individual disk position of the images was examined separately by three examiners (T.K., T.O., and C.N.) All examiners were the TMD and orofacial pain specialists. All examiners were blinded to age, gender, symptoms of each subject, and the results of the disk position assessment by other examiners. The criteria for disk position on the image were in accordance with the IZ (intermediate zone) criteria described by Orsini et al. [17, 18]. These criteria determine the disk position by judging the position in relation to the line where the center of two circles is connected and the posterior and anterior bands [19] (Fig. 1). The position of the disk was considered to be normal if the IZ was located between the anterior-superior aspect of the condyle and the posterior-inferior aspect of the articular eminence in the middle or above a line that joined the centers of two imaginary circles which were fitted to these structures. These circles were positioned to closely approximate the condyle and the eminence outlines [20]. On the other hand, the judgment of the disk position was "anterior disk displacement" when the posterior band was located anterior from the line (Fig. 2). Furthermore, the judgment of the disk position

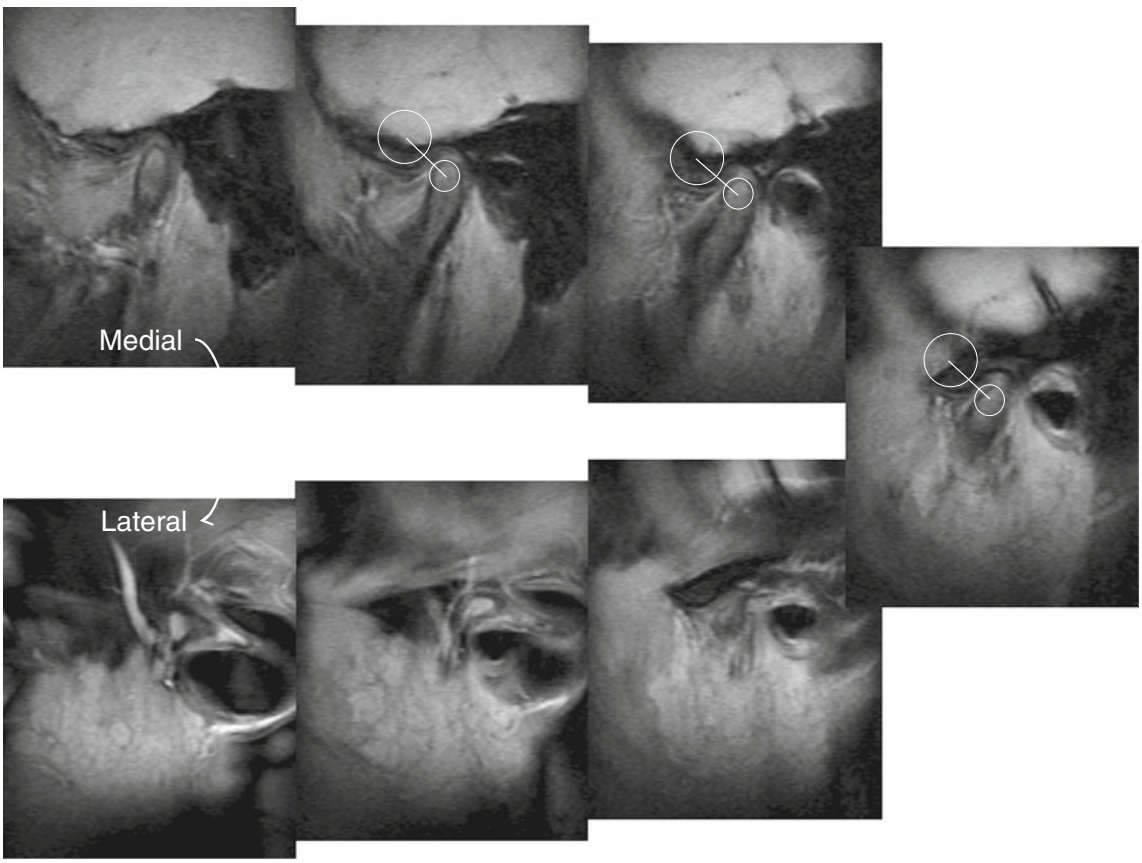

Fig. 1 The images of the subject who was diagnosed as normal disk position using the criteria in this study. The images reveal that the *line*, connecting the center of the two *circles*, is located between the anterior and posterior bands

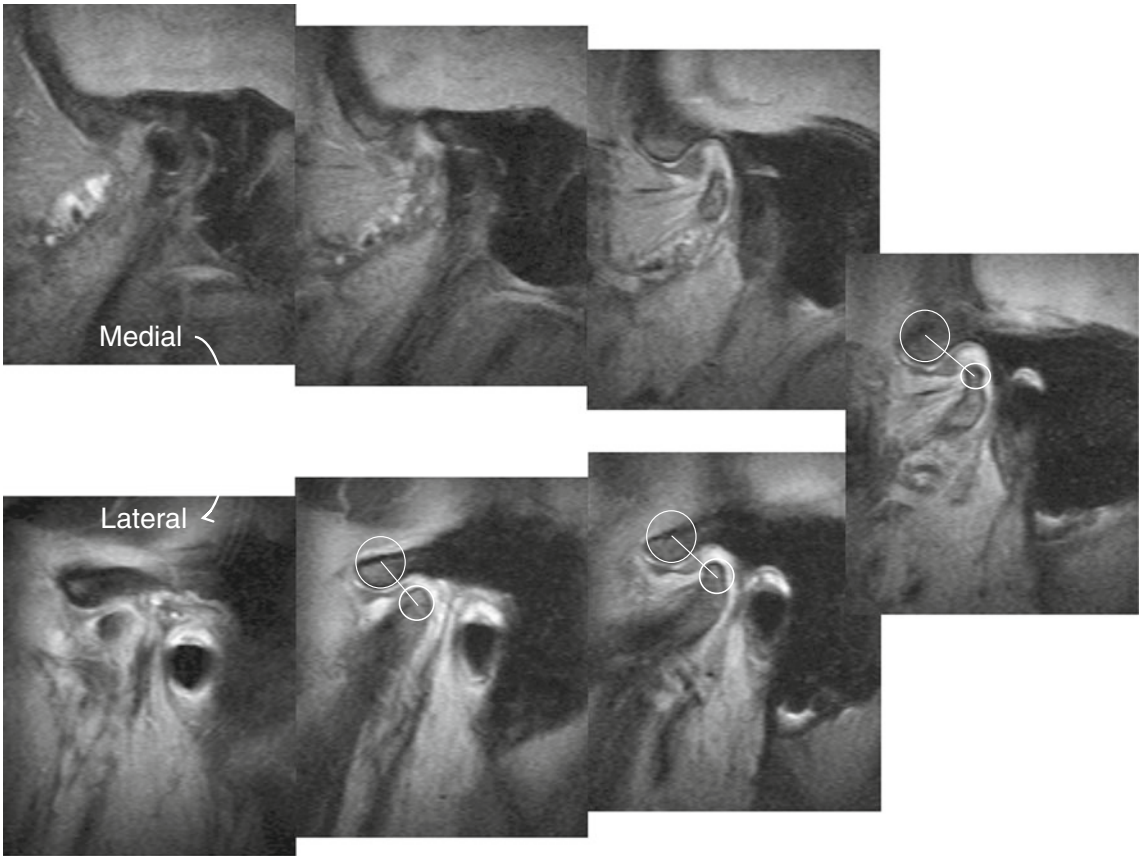

Fig. 2 The images of the subjects who were diagnosed as anterior disk displacement using the criteria in this study. The posterior band was located anterior from the *line*, connecting the center of the two *circles*

was "posterior disk displacement" when the anterior band was located from the line backward, and others were regarded as normal position. The disk position of the joint was considered displaced when at least one of the seven slices in each TMJ was diagnosed as displaced. The disk position, assessed in both the open- and the closed-mouth, was combined, and the final categorization of the joint disk status was formulated for each joint, e.g., normal, anterior disk displacement with or without reduction (ADDwR or ADDwoR), or posterior disk displacement either with or without reduction (PDDwR or PDDwoR).

Calibration procedures for the three examiners

First, the three examiners separately diagnosed the initial set of the 30 MR images with the aforementioned criteria. Then, all examiners discussed the result of their joint disk position assessment, and when disagreement existed, a mutual consensus on the disk position assessment criteria was reached. This calibration discussion took approximately 2 min for each joint disk position. Therefore, 1 h was necessary to assess 30 joints. Next, the three examiners diagnosed the second set of the 30 joints' MR images. The inter-examiner agreement before and after calibration were calculated by using a kappa index. Those indices were calculated between the examiners (A, B, and C) two by two (AB, AC, and BC).

Test–retest reliability of the categorization of TMJ disk status

The three calibrated examiners next assessed another 30 TMJ disk status (15 subjects) using the MR images scanned twice at a week interval (mean interval, 7.1± 0.3 days). This new examination was performed under the same conditions as the previous calibration program. A diagnosis was considered to have been achieved for the final individual joint disk position when at least two of the three examiners agreed on the diagnosis. The results of diagnosed disk position at both the initial and second scans were compared, and these agreements were evaluated using the kappa index calculations (Fig. 3).

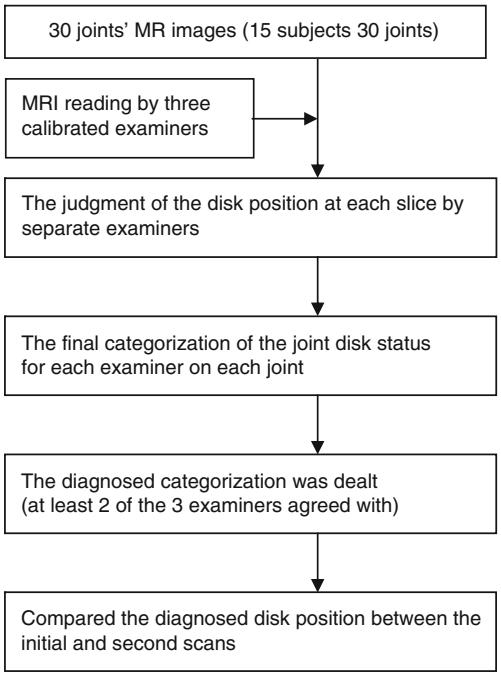

Fig. 3 A flow sheet for the test–retest reliability assessment of the MRI-based diagnosis of the TMJ disk position

Results

Effect of examiner calibration on the TMJ disk status assessment

The comparisons of inter-examiner agreement between before and after calibration are shown in Fig. 4. The mean kappa values among the three examiners increased from κ= 0.377 (before) to κ=0.812 (after) as a result of the calibration program. This kappa value after the calibration program reached almost the perfect level, which was proposed by Landis and Koch [21]. These results clearly suggest that the inter-examiner agreements significantly improved by the examiner calibration utilized in this study.

Test–retest reliability levels of MRI-based assessment of TMJ disk status

Table 1 shows the comparisons of the joint disk status and clinical signs and symptoms between the initial and the second MRI scan in each subject of the main study. Nineteen of 30 joints were diagnosed to be in a normal position, and others were regarded as disk displacement in both the initial and second scans. However, the results of the disk position status of several joints were not consistent between the initial and second scans. While the disk position of 27 joints were consistently diagnosed same positions between initial and latter scans, the disk position of the three joints varied between two scans. The kappa value calculated using the results obtained from two scans was κ=0.812. These results suggest that the test–retest reliability of MRI-based classification of TMJ disk status at 1-week interval was substantially high, even though it was not completely consistent.

A couple of subjects showed a fluctuation between the examinations performed at a 1-week interval. While one of the subjects (subject No. 1) did not show any joint clicking at the first examination (at the initial MRI scanning), it was seen at the second examination (at the second MRI scanning) on the right side TMJ. The joint disk status diagnosed by MRI was also changed from ADDwoR (initial scan) to ADDwR (second scan) in this subject. On the other hand, two subjects showed a fluctuation of joint clicking between the initial and second examination (right side TMJ of subject Nos. 2 and 15). Interestingly, the joint disk statuses of those subjects were both in the normal position and did not change between the initial and the second MRI scanning. In addition, the joint disk statuses of two of the subjects (Nos. 3 and 5) changed from normal to ADDwR between initial and second scanning. However, none of those subjects showed any joint clicking during both the initial and second clinical examination.

Discussion

A review of the literature suggests that MRI is the optimal way to image the hard and soft tissues of the TMJ in patients with signs and symptoms of TMD [22, 23]. It can accurately depict abnormalities of disk position and morphology, and has therefore been used to substantiate the clinically suspected existence of disk displacement. Although a large number of studies reveal the excellent validity of the MRI-based diagnosis of TMJ disk position [11, 12], few studies have tested the reliability. Several

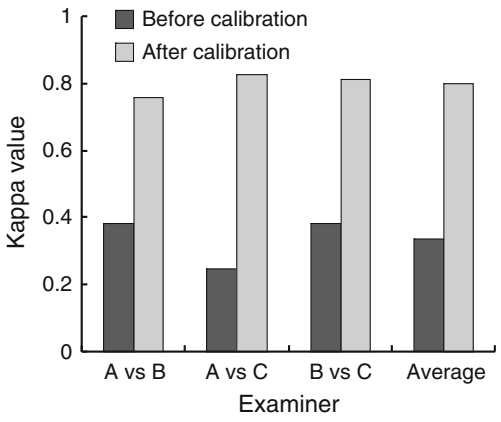

Fig. 4 The comparisons of inter-examiner agreement between before and after the calibration program

Table 1 The comparisons of the joint disk status and clinical signs and symptoms of the second subject group between the initial and second MRI scans

	Gender	Age	Joint disk status				Clicking				History of clicking				TMJ pain during jaw opening					
			Right TMJ		Left TMJ		Right TMJ		Left TMJ		Right TMJ		Left TMJ		Right TMJ		Left TMJ		Maximum range of mouth opening (mm)	
			Initial	Second	Initial	Second	Initial	Second	Initial	Second	Initial	Second	Initial	Second	Initial	Second	Initial	Second	Initial	Second
No. 1	Female	23	ADDwR	ADDwR	ADDwoR[a]	ADDwR[a]	−	−	−[a]	+[a]	−	−	−	−	−	−	−	−	51	52
No. 2	Male	24	Normal	Normal	Normal	Normal	+[a]	−[a]	+	+	−	−	−	−	−	−	−	−	57	56
No. 3	Female	24	Normal	Normal	Normal[a]	ADDwR[a]	−	−	−	−	−	−	−	−	−	−	−	−	40	42
No. 4	Male	23	Normal	Normal	Normal	Normal	−	−	−	−	−	−	−	−	−	−	−	−	64	64
No. 5	Female	23	Normal	Normal	ADDwR[a]	Normal[a]	−	−	−	−	−	−	+	+	−	−	−	−	50	49
No. 6	Male	23	ADDwoR	ADDwoR	ADDwoR	ADDwoR	−	−	+	+	−	−	−	−	−	−	−	−	57	54
No. 7	Female	24	Normal	Normal	Normal	Normal	−	−	−	−	−	−	−	−	−	−	−	−	53	55
No. 8	Female	25	Normal	Normal	ADDwoR	ADDwoR	−	−	+	+	−	−	−	−	+	+	−	−	45	49
No. 9	Male	25	Normal	Normal	Normal	Normal	+	+	+	+	−	−	−	−	−	−	−	−	50	48
No. 10	Male	25	ADDwoR	ADDwoR	ADDwR	ADDwR	+	+	−	−	−	−	−	−	−	−	−	−	44	41
No. 11	Female	24	Normal	Normal	Normal	Normal	−	−	−	−	−	−	−	−	−	−	−	−	43	42
No. 12	Male	25	Normal	Normal	Normal	Normal	−	−	−	−	−	−	−	−	−	−	−	−	48	47
No. 13	Female	24	ADDwoR	ADDwoR	ADDwR	ADDwR	−	−	+	+	−	−	−	−	−	−	−	−	55	51
No. 14	Male	25	Normal	Normal	Normal	Normal	−	−	−	−	−	−	−	−	−	−	−	−	65	64
No. 15	Male	24	Normal	Normal	ADDwR	ADDwR	−[a]	+[a]	+	+	−	−	−	−	−	−	−	−	66	66

ADDwR anterior disk displacement with reduction, *ADDwoR* anterior disk displacement without reduction

[a] Different findings were observed between two examinations or MRI scans

studies have evaluated the inter-examiner reliability of reading MR images of TMJ disk position and morphology [13–15], and reported that inter-examiner agreement is high when an examiner calibration program is performed [14] or a quantification technique is used to interpret MR images. Indeed, the current study also evaluated the effect of an examiner calibration program on the inter-examiner reliability of detecting the TMJ disk position and demonstrated that only one calibration training session substantially improved the inter-examiner reliability levels. However, the test–retest reliability levels of plurally MRI-scanned individual joint disk position have not yet been assessed. The current study is the first report to evaluate the test–retest agreement level of the TMJ disk position using two separate MR images. The results showed that 90% of TMJ disk position diagnosis was consistent between both initial and second images, which were scanned at a week interval. These results provided new evidence that the reliability level of the MRI-based diagnosis of TMJ disk positions at 1-week interval is substantially high. In addition, this reconfirmed that it is sufficiently valuable to apply TMJ disk position diagnosis in clinical and academic settings. In addition to the highly efficient capability of MRI for depicting the TMJ disk, other factors possibly elevated the reliability levels. This study employed sequential multi-slice images of each joint for the detection of the TMJ disk position. This was different from previous studies, which applied a few representative slices from all the images. Therefore, employing an increased number of the slice images might affect the reliability levels for detecting the disk position. However, this study did not evaluate the reliability level of the TMJ disk position using a few selected representative slices from all the images. Future studies which evaluate the influence of the number of the sliced images for detecting the disk position are therefore expected to clarify this point.

On the other hand, this study also demonstrated that a mismatch was observed in three of 30 joints between two scans, and a perfect match was not obtained. One of the possible reasons for these results is that the different detections of the disk position between initial and second MRI scan were due to the examiners' failure. Another possible reason is that the TMJ disk position in some of the participants may have changed within a 1-week interval. Since previous studies reported that existence of TMJ sound fluctuates [24], a positional fluctuation is also a possibility, especially if a patient has an intermittent locking disorder [25, 26]. Indeed, while one of the subjects in this study (No. 1) did not show joint clicking at the initial examination, which was performed prior to the initial MRI scanning, this subject did show joint clicking at the second examination. The joint disk status of this subject actually indicated the changes from ADDwoR to ADDwR. These findings strongly suggested that the disk position of this subject changed within a 1-week interval.

However, the clinical signs and symptoms of two other subjects (Nos. 3 and 5), whose TMJ disk status was different between two scans, did not show obvious changes at a 1-week interval. Although neither subject showed TMJ clicking at both the initial and second clinical examination, the TMJ disk status was diagnosed as ADDwR at either MRI scan. Of course, this might be due to the examiners' failure, but the absence of joint clicking for ADDwR individuals is not a rare finding [27]. In addition, the ADDwR condition has been speculated to develop from an intermittent joint displacement [28]. Therefore, either possibility may explain the difference of disk position status between two scanning. Future studies with larger samples are therefore desirable to clarify this point.

In conclusion, this study indicated the test–retest reliability of MRI-based diagnosis of TMJ disk positions by well-calibrated plural examiners at a 1-week interval and found a substantially high agreement. The reliability level suggested the possibility that MRI-based TMJ disk position diagnosis by the examiners in this study is sufficiently reliable and employs MRI image evaluation in an ongoing prospective cohort study on risk factors of the precipitation and progression of TMDs.

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Conflict of interest The authors declare that they have no conflict of interest.

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