Objective. As part of the Multisite Research Diagnostic Criteria For Temporomandibular Disorders (RDC/TMD) Validation Project, comprehensive temporomandibular joint diagnostic criteria were developed for image analysis using panoramic radiography, magnetic resonance imaging (MRI), and computerized tomography (CT).

Study design. Interexaminer reliability was estimated using the kappa (κ) statistic, and agreement between rater pairs was characterized by overall, positive, and negative percent agreement. Computerized tomography was the reference standard for assessing validity of other imaging modalities for detecting osteoarthritis (OA).

Results. For the radiologic diagnosis of OA, reliability of the 3 examiners was poor for panoramic radiography (κ = 0.16), fair for MRI (κ = 0.46), and close to the threshold for excellent for CT (κ = 0.71). Using MRI, reliability was excellent for diagnosing disc displacements (DD) with reduction (κ = 0.78) and for DD without reduction (κ = 0.94) and good for effusion (κ = 0.64). Overall percent agreement for pairwise ratings was ≥82% for all conditions. Positive percent agreement for diagnosing OA was 19% for panoramic radiography, 59% for MRI, and 84% for CT. Using MRI, positive percent agreement for diagnoses of any DD was 95% and of effusion was 81%. Negative percent agreement was ≥88% for all conditions. Compared with CT, panoramic radiography and MRI had poor and marginal sensitivity, respectively, but excellent specificity in detecting OA.

Conclusion. Comprehensive image analysis criteria for the RDC/TMD Validation Project were developed, which can reliably be used for assessing OA using CT and for disc position and effusion using MRI. (Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;107:844-860)
cluded as an imaging option in the original RDC/TMD, it has been recommended as a screening tool for TMJ pathology.\(^3\) With the increasing use of CT and MRI, it was necessary to develop comprehensive criteria for image analysis using these techniques as a part of the RDC/TMD.

The multisite RDC/TMD Validation Project was initiated, in part, to assess the reliability and validity of the current RDC/TMD Axis I clinical disorders and to revise them, if indicated. To enhance the operational specification of the RDC/TMD, we developed a set of criteria for acquiring and analyzing panoramic, MRI, and CT images to evaluate the TMJ. Radiologists and TMD clinicians, some of whom were part of the original RDC/TMD proposal, developed these image analysis criteria. These diagnostic criteria were developed from a review of the literature,\(^6\) recommendations by the members of External Advisory Panel appointed by National Institute of Dental and Craniofacial Research (NIDCR) for the project, and suggestions were solicited from members of the TMD and radiology community. This methodology for developing the image analysis criteria suggests that they have content validity.

For the RDC/TMD Validation Project’s outcomes to be meaningful, its criteria should have acceptable interexaminer reliability. The clinical assessment for RDC/TMD has shown high reliability for both intraexaminer and interexaminer agreement.\(^9\) Owing to lack of imaging specifications and detailed criteria in the original RDC/TMD, the reliability of the radiologists in interpreting TMJ images using these criteria has not been previously assessed.

The purpose of the present paper is to report the image analysis criteria for the RDC/TMD Validation Project. This study also assessed the interexaminer reliability of the radiologists in the RDC/TMD Validation Project to interpret panoramic, MR, and CT images of the TMJ for OA and MR images for disc displacement or effusion. Finally, we assessed the criterion validity of panoramic radiography and MRI to assess osseous tissue changes, using CT as the reference standard.

**MATERIALS AND METHODS**

**Participants and research locations**

Study participants were consecutively recruited from August 2003 to September 2006 at the University of Minnesota (UM), Minneapolis, University of Washington (UW), Seattle, and University at Buffalo (UB), New York. The study was approved by the Institutional Review Boards of the 3 universities. Informed consent was obtained for all participants. Health Insurance Portability and Accountability Act guidelines were followed.

**Imaging modalities**

The RDC/TMD assessment protocol specified the use of 3 imaging modalities: panoramic radiography, MRI, and CT. At the University of Minnesota, Sirona Orthophos digital panoramic machine, Siemens Vision 1.5T and Siemens Avanto 1.5T, and Siemens Sensation 16 MDCT were used. At the University of Washington, Siemens Orthophos panoramic machine, GE Signa 1.5 T MRI scanner, and GE LightSpeed VCT were used. At the University at Buffalo, Siemens Orthophos 3 panoramic machine, Siemens Symphony 1.5T system, and Toshiba Aquilion CT were used.

**Image acquisition**

Panoramic radiography. Panoramic radiographs were obtained without any modification of the protocols used in the respective clinics. Diagnostic quality digital or film-based panoramic images were of acceptable density and contrast as determined by the radiologist. The radiographs were acquired with proper subject positioning as recommended by the manufacturer of the panoramic equipment. The radiographs showed the maxilla and mandible, including both of the condyles as well as the dentition.

Magnetic resonance imaging

Participant preparation. To prepare for closed-mouth MR examination, the TMD clinician instructed the participants to put their back teeth together in the position where these fit the best. The clinician then verified this position visually. The same written instructions were given to the radiology technologist, to read to the participant before acquiring the MRI in the closed-mouth position. To prepare for the open-mouth position MR examination, the TMD clinician instructed the participants to open as wide as they could tolerate. The maximum open position was determined clinically. The TMD clinician then placed a mouth opening device (Burnett Bidirectional TMJ Device; Medrad, Pittsburgh, PA) between the participant’s teeth and opened it to the maximum that the participant could tolerate. The amount of opening was recorded by the clinician and this information was given to the radiology technologist so that he or she could place the Burnett Bidirectional TMJ Device to the desired opening. The technologist had permission to reduce the amount of mouth opening on the Burnett device during the procedure if the participant could not tolerate it.

Magnetic resonance image acquisition. The closed-mouth MR images were acquired in proton density (PD) and T2 algorithm by using a dedicated TMJ surface coil. For open-mouth MR images, only PD images were acquired, because effusion was not evaluated in open-mouth views. A minimum of 6 slices of each joint were obtained in sagittally and axially corrected coronal views. The PD images had TR 2,000.0
and TE 17.0, and the T2 images had TR 2,000.0 and TE 102.0. The axially corrected coronal views were obtained in closed-mouth views only, where the sections were made through the long axis of the condyles.

**Computerized tomography**

**Participant preparation.** Similarly to preparing the participants for MRI examination, the TMD clinician instructed the participants to put their back teeth together in the position where they fit the best. The TMD clinician verified this position visually. The same written instructions were given to the radiology technologist to read to the participant before acquiring the CT scan.

**Computerized tomography image acquisition.** All images were obtained from a multidetector CT and reconstructed in a hard-tissue algorithm. A minimum of 12 sections of each condyle (1-mm-thick slices) were generated in sagittally and axially corrected coronal views. On axially corrected coronal views, the sections were created through the long axis of the condyles. No soft tissue analysis was made in the CT images. Because range of translation of the condyle was evaluated in MRI and to reduce radiation exposure, open-mouth views were not obtained with CT.

**Image interpretation criteria**

The radiologists at UM and UW were diplomates of the American Board of Oral and Maxillofacial Radiology, and the radiologist at UB was a diplomate of the American Board of Radiology and Neuroradiology; they each had between 12 and 23 years of experience interpreting TMJ images. In the Validation Project, the diagnostic criteria used by the radiologists to identify panoramic-

---

**Table I. Hard tissue assessment using panoramic, magnetic resonance (MRI), and computerized tomography images**

<table>
<thead>
<tr>
<th>Scoring option</th>
<th>Scoring criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condylar head: (score Yes/No for each of the 11 criteria)</td>
<td>1. Condylar hypoplasia: Condylar morphology is normal but the size is small from all dimensions. This is associated with either an increase in the joint space in a normal articular fossa, or a small articular fossa.</td>
</tr>
<tr>
<td></td>
<td>2. Condylar hyperplasia: Condylar morphology is normal but the size is large in all dimensions. This is associated with either lack of joint space in a normal articular fossa or an enlarged articular fossa to accommodate the large condyle.</td>
</tr>
<tr>
<td></td>
<td>3. Articular surface flattening: A loss of the rounded contour of the surface.</td>
</tr>
<tr>
<td></td>
<td>4. Subcortical sclerosis: Any increased thickness of the cortical plate in the load-bearing areas relative to the adjacent nonload-bearing areas. With MRI, this is identified as low signal intensity in bone marrow on proton density and T2 study.</td>
</tr>
<tr>
<td></td>
<td>5. Subcortical cyst: A cavity below the articular surface that deviates from normal marrow pattern.</td>
</tr>
<tr>
<td></td>
<td>7. Osteophyte: Marginal hypertrophy with sclerotic borders and exophytic angular formation of osseous tissue arising from the surface.</td>
</tr>
<tr>
<td></td>
<td>8. Generalized sclerosis: No clear trabecular orientation with no delineation between the cortical layer and the trabecular bone that extends throughout the condylar head.</td>
</tr>
<tr>
<td></td>
<td>9. Loose joint body: A well defined calcified structure(s) that is not continuous with the disc or osseous structures of the joint. With MRI, this is identified as low and/or high signal on proton and T2 study.</td>
</tr>
<tr>
<td></td>
<td>10. Deviation in form: Condylar deviation in form is defined as a departure from normal shape, such as concavity in the outline of the cortical plate, and not attributable to flattening, erosive changes, osteophytes, hyper or hypoplasia.</td>
</tr>
<tr>
<td></td>
<td>11. Bony ankylosis: Continuous osseous structure between the condyle and temporal bone associated with no discernable joint space and no translation of the condyle in the open mouth views.</td>
</tr>
<tr>
<td>Fossa/eminence (score Yes/No for each of the 3 criteria)</td>
<td>1. Articular surface flattening: A loss of the rounded contour of the surface.</td>
</tr>
<tr>
<td></td>
<td>2. Subcortical sclerosis: Any increased thickness of the cortical plate in the load-bearing areas relative to the adjacent nonload-bearing areas. With MRI, this is identified as low signal intensity in bone marrow on proton and T2 study.</td>
</tr>
<tr>
<td>Condylar position: (select 1 of the 4 options)</td>
<td>1. Concentric position with normal joint space.</td>
</tr>
<tr>
<td></td>
<td>2. Concentric position with decreased joint space.</td>
</tr>
<tr>
<td></td>
<td>3. Anterior position.</td>
</tr>
<tr>
<td></td>
<td>4. Posterior position.</td>
</tr>
<tr>
<td>Condylar translation: sagittal open-mouth MRI (select 1 of the 3 options)</td>
<td>1. Apex of the condyle translates to less than the apex of the articular eminence.</td>
</tr>
<tr>
<td></td>
<td>2. Apex of the condyle translates to the apex of the articular eminence.</td>
</tr>
<tr>
<td></td>
<td>3. Apex of the condyle translates beyond the apex of the articular eminence.</td>
</tr>
<tr>
<td>Panoramic radiographs only (score Yes/No for each of the 2 criteria)</td>
<td>1. Odontogenic pathology(ies).</td>
</tr>
<tr>
<td>MRI only: (score Yes/No)</td>
<td>Condylar edema: Any high signal intensity within the bone marrow of the condyle present on T2 study.</td>
</tr>
</tbody>
</table>
Table II. Osseous diagnoses for the TMJ from panoramic radiographs, computerized tomography, and magnetic resonance imaging. (Scoring options are A, B, or C as in the table below)

A. No osteoarthritis
   i. Normal relative size of the condylar head; and
   ii. No subcortical sclerosis or articular surface flattening; and
   iii. No deformation due to subcortical cyst, surface erosion, osteophyte, or generalized sclerosis.

B. Indeterminate for osteoarthritis
   i. Normal relative size of the condylar head; and
   ii. Subcortical sclerosis with/without articular surface flattening; or
   iii. Articular surface flattening with/without subcortical sclerosis; and
   iv. No deformation due to subcortical cyst, surface erosion, osteophyte, or generalized sclerosis.

C. Osteoarthritis
   i. Deformation due to subcortical cyst, surface erosion, osteophyte, or generalized sclerosis.

MRI-, and CT-disclosed osteoarthritis and MRI-disclosed disc displacements are shown in Tables I-IV. The images were interpreted in the following sequence: panoramic radiographs, MR images (both osseous and nonosseous component assessments), and CT images. All of the available slices from CT and MRI were evaluated. For the reliability studies, a different protocol was used and is described in the appropriate section. The radiologists in both situations were blind to the clinical histories or clinical diagnoses of the participants.

Overview

Scoring criteria. For CT and MRI, multiple slices of a joint were evaluated, and the “worst case” scenario was scored when there were different findings in the different slices. For example, in the case of disc displacements, if in the closed-mouth position the disc was clearly anteriorly displaced only in 1 section but “normal” in all other sections, the diagnosis was anteriorly displaced disc. If in the open-mouth position the disc reduced in all but 1 of the sections, it was diagnosed as a nonreducing disc.

Two exceptions to the above rule were allowed: 1) In case of disc deformity, “best case” scenario was recorded, i.e., if the disc was deformed in the closed-mouth position but not in the open-mouth position, then it was not considered to be deformed; and 2) for condylar concentricity, radiologists could check multiple answers when there were different impressions in different sections; for example, if the condyle was anterior in one section and posterior in another, the radiologist checked both applicable responses.

The scoring options were mostly Yes/No. To overcome the limitations of categorizing by Yes/No choice, the scoring form provided options to indicate conditions that did not fall within the diagnostic scheme for OA. In addition, for each image type, the radiologist had an area on the scoring form to comment on the findings or on the quality of the images.

Osseous component. The TMJ osseous component features were assessed using panoramic radiography, MRI, and CT. Evaluation of the joints was recorded on a scoring form. Each scoring factor had a Yes/No option. Definitions of these factors are provided in Table I. For panoramic radiography, in addition to the observation of TMJs, odontogenic and nonodontogenic findings were recorded.

Osseous component analysis criteria. For the condylar head, features to note were gross hypoplasia or hyperplasia, flattening of the articular surface, subcortical sclerosis or cyst, surface erosion, osteophytes, generalized sclerosis, loose joint bodies, and deviation in form. For the fossa, the criteria included flattening of the articular eminence, subcortical sclerosis, and surface erosion. For the joint, condylar position and ankylosis were also noted. On completion of these observations, a diagnosis was made, categorizing the joint as normal, indeterminate, or affected with OA. A diagnosis of ankylosis was also allowed. Condylar edema was noted on MRI.

Table II describes the diagnostic conclusions. Examples of osseous changes are displayed in Figs. 1-3.

Position and translation of the condyle. Position of the condyle in relation to the articular fossa was evaluated on sagittal PD MR and sagittal CT images. Translation of the condyle was evaluated on open-mouth sagittal PD MR images.

Nonosseous component. Assessment of the nonosseous component was limited to MRI. Range of motion was assessed only with MRI sections in the open-mouth position. Evaluation of the joints was recorded on a scoring form. Each scoring factor had a Yes/No option. Definitions of these factors are provided in Table III.

Nonosseous component analysis criteria. Using PD and T2-weighted MR images, the following nonosseous features were observed: position of the intermediate zone and posterior band of the disc in relation to the condylar head in the closed- and open-mouth sagittal views, disc shape, disc rotation (position in the mediolateral direction), effusion, and presence of loose calcified bodies in the soft tissues. Subsequent to such observation, the diagnoses for the soft tissues were: normal, anterior disc displacement with reduction, anterior disc displacement without reduction, disc not visible, or indeterminate. Table IV describes the diagnostic conclusions for nonosseous components. Examples of various changes associated with the nonosseous components of the joint are shown in Figs. 4-7.
Table III. Nonosseous component assessment criteria using magnetic resonance imaging

<table>
<thead>
<tr>
<th>Scoring option</th>
<th>Scoring criteria</th>
</tr>
</thead>
</table>
| Disc position: closed-mouth sagittal and axially corrected coronal views (score Yes/No for each criteria) | Normal disc position  
  i. In the sagittal plane, relative to the superior aspect of the condyle, the border between the low signal of the disc and the high signal of the retrodiscal tissue is located between the 11:30 and 12:30 clock positions,85 and  
  ii. In the sagittal plane, the intermediate zone is located between the anterior-superior aspect of the condyle and the posterior-inferior aspect of the articular eminence; and  
  iii. In the oblique coronal plane, the disc is centered between the condyle and eminence in the medial, central, and lateral parts. |
| Indeterminate  
  i. In the sagittal plane, relative to the superior aspect of the condyle, the low signal of the disc and the high signal of the retrodiscal tissue are located anterior to the 11:30 position,85 but the condyle contacts the intermediate zone located between the anterior-superior aspect of the condyle and the posterior-inferior aspect of the articular eminence; or  
  ii. In the sagittal plane, relative to the superior aspect of the condyle, the low signal of the disc and the high signal of the retrodiscal tissue are located between the 11:30 and 12:30 clock positions,85 but the intermediate zone of the disc is located anterior to the condyle; and  
  iii. In the axially corrected coronal plane, the disc is positioned between the condyle and eminence in the medial, central, and lateral parts. |
| Disc displacement  
  i. In the sagittal plane, relative to the superior aspect of the condyle, the low signal of the disc and the high signal of the retrodiscal tissue are located anterior to the 11:30 clock position; 85 and  
  ii. In the sagittal plane, the intermediate zone of the disc is located anterior to the condylar head; or  
  iii. In the axially corrected coronal plane, the disc is not centered between the condyle and eminence in either the medial or the lateral parts. |
| Disc not visible: Neither signal intensity nor outlines make it possible to define a structure as the disc. |
| Disc shape: closed-mouth sagittal views (score Yes/No for each criteria) | Normal: The disc in the sagittal plane is biconcave. |
| Deformed: All shapes other than biconcave in the sagittal plane. |
| Disc not visible: Neither signal intensity nor outlines make it possible to define a shape of the disc. |
| Effusion: open- or closed-mouth sagittal views (score Yes/No for each criteria) | None: No bright signal in either joint space in the T2-weighted images. |
| Slight effusion: A bright signal in either joint space that conforms to the contours of the disc, fossa/articular eminence, and/or condyle. |
| Frank effusion: A bright signal in either joint space that extends beyond the osseous contours of the fossa/articular eminence and/or condyle and has a convex configuration in the anterior or posterior recesses. |
| Loose calcified bodies: closed-mouth sagittal views (score Yes/No) | Single or multiple discrete low signal intensity objects are present in the joint spaces, and are not attached to the condyle, fossa or eminence in any plane. |

**Calibration of the radiologists**

Two board-certified oral and maxillofacial radiologists and 2 board-certified medical radiologists representing the 3 research locations participated in the calibration and reliability studies. The first calibration and reliability study was conducted at UB. This exercise spanned 2 days. The training and calibration was done on the first day by projecting and discussing slides of panoramic radiographs, CT images, and MRI showing all characteristics of normal and indeterminate osseous conditions and OA. In addition, slides of MRI were used for demonstrating all characteristics of soft tissues, including disc position, shape, and joint effusion.

**Initial reliability study methods**

On the second day of the exercise, the reliability of the radiologists was evaluated. Each radiologist viewed panoramic radiographs, representative axially corrected coronal and sagittal slices from CT, and open- and closed-mouth sagittal views of PD MRI and T2 MRI. For the initial reliability study, the images were collected from earlier studies or teaching files from the 3 research locations. For subse-
Disc diagnosis for temporomandibular joint (TMJ) using magnetic resonance imaging (scoring options are A, B, C, D, or E)

A. Normal: Disc location is normal on closed- and open-mouth images.
B. Disc displacement with reduction: Disc location is displaced on closed-mouth images but normal in open-mouth images.
C. Disc displacement without reduction: Disc location is displaced on closed-mouth and open-mouth images.
D. Indeterminate: Disc location is not clearly normal or displaced in the closed-mouth position.
E. Disc not visible: Neither signal intensity nor outlines make it possible to define a structure as the disc in the closed-mouth and open-mouth views. If the images are of adequate quality in visualizing other structures in the TMJ, then this finding is interpreted to indicate a deterioration of the disc, which is associated with advanced disc pathology.

In the RDC/TMD Validation Project, a total of 1,247 participants were screened, and 734 participants were enrolled. After excluding 10 dropouts or incomplete assessments, 724 participants (1,448 joints) were assessed with panoramic, CT, and MR imaging. For osseous tissue diagnosis of OA based on panoramic radiographs, the interexaminer reliability of the radiologists was poor (k = 0.16; Table V). The reliability of the radiologists on diagnosing hard tissue status was fair (k = 0.47) when using PD MR images. Reliability was good when diagnosis of hard tissue status was conducted using CT images (k = 0.71), almost reaching the threshold for excellent reliability (k >0.75).

Data analysis for reliability studies

For the reliability studies, the RDC/TMD requires dichotomous radiologic ratings to be used in the clinical TMD diagnosis algorithm. Therefore, OA ratings were categorized as present (frank) versus absent (normal or indeterminate); disc position was categorized as displaced versus nondisplaced with not visible, indeterminate, and other ratings excluded; and effusion was categorized as present (frank) versus absent (normal or indeterminate). Reliability was estimated using the kappa (κ) statistic. According to Fleiss et al.,11 k values of <0.40 are considered to be poor reliability, values from 0.40 to 0.75 are considered to be fair to good reliability, and values of >0.75 are considered to be excellent reliability. To account for the dependence of left and right images from one individual, 95% confidence intervals (CIs) for kappas were calculated using the bootstrap method with 5,000 replications.12

In addition to the reliability coefficients, agreement for pairs of raters was calculated. For example, in the case of 4 raters, 6 pairwise comparisons exist. Overall percent agreement is calculated as the sum of the 2 numbers in the diagonal of a 2-by-2 pair-wise agreement table divided by the total number of ratings. It represents the percentage of ratings where raters agree. The positive percent agreement is defined as the percentage of positive readings that both readers agree on in pairwise comparisons divided by all of the positive readings for both readers. Negative agreement is defined as the percentage of negative readings that both readers agree on in pairwise comparisons divided by all of the negative readings for both readers.

RESULTS

In the RDC/TMD Validation Project, a total of 1,247 participants were screened, and 734 participants were enrolled. After excluding 10 dropouts or incomplete assessments, 724 participants (1,448 joints) were assessed with panoramic, CT, and MR imaging.

For osseous tissue diagnosis of OA based on panoramic radiographs, the interexaminer reliability of the radiologists was poor (k = 0.16; Table V). The reliability of the radiologists on diagnosing hard tissue status was fair (k = 0.47) when using PD MR images. Reliability was good when diagnosis of hard tissue status was conducted using CT images (k = 0.71), almost reaching the threshold for excellent reliability (k >0.75).
For analysis of nonosseous components using MRI, the reliability was excellent ($k = 0.84$) for disc displacement. Reliability for disc displacement with reduction ($k = 0.78$) was lower than for disc displacement without reduction ($k = 0.94$), although both had excellent reliability ($k > 0.75$).
Agreement in diagnosing hard and soft tissue conditions between pairs of raters was always high; overall percent agreement was ≥82% for OA or disc displacement (Table VI). However, although percent negative agreement was always high (≥88%) for both osseous and nonosseous conditions, percent positive agreement varied substantially among diagnoses. For diagnosing OA using panoramic radiographic images, 19% agreement was observed. The percent positive agreement increased to 59% for diagnosing OA using MRI. The diagnosis of OA reached 84% positive agreement only when CT images were assessed. Percent positive agreement for diagnosing disc displacement equaled or exceeded the percent positive agreement for diagnosing OA using CT. For disc displacement without reduction, the percent positive agreement (96%) almost equaled the percent negative agreement (98%), which indicated that raters agreed on the presence and on the absence of the condition to a similar degree.

The reliability of the radiologists on diagnosing effusion based on T2-weighted MR images was good (k = 0.64; 95% CI 0.39 to 0.88), and effusion was present in 53% of the observations. Overall percent agreement for effusion was 81%, and positive and negative percent agreements were similar (82% and 80%, respectively).

For assessing the criterion validity of the criteria, we analyzed the images of all the participants in the project. Using the CT diagnosis as the reference standard, the sensitivity and specificity for OA diagnoses based on panoramic radiographs and MRI were determined (Table VII). For MRI and CT, 1,448 joints were compared. On panoramic radiographs, 13 joints were nondiagnostic, therefore, 1,435 joints were evaluated against CT. The sensitivity of panoramic radiography in detecting osteoarthritis was low, whereas the specificity was high. The sensitivity of PD MR images was marginal, whereas the speci-
The diagnostic accuracy was high. When OA was detected on CT, 26% of the panoramic radiographs and 59% of the MR images displayed positive finding of OA. When OA was not detected on CT, 99% of panoramic radiographs and 98% of MR images were also negative for OA.

Fig. 4. Sagittal proton density magnetic resonance views representing examples of changes in the soft tissue components of the temporomandibular joint observed in corresponding disc diagnoses. A, B, Normal disc location: normal biconcave disc shape, posterior band is at 11:30-12:30 position, intermediate zone is in contact with the condylar head. C, Normal disc location: thinning of the disc, posterior band is at 11:30-12:30 position, intermediate zone is in contact with the condylar head. D-E, Indeterminate for disc location: normal biconcave disc shape, posterior band is at 11:30-12:30 position, intermediate zone is not in contact with the condylar head. F, Anteriorly displaced disc: normal biconcave disc shape, posterior band is at <11:30 position, intermediate zone is not in contact with the condylar head. G, Anteriorly displaced disc: intermediate zone is not visible. H, Anteriorly displaced disc: thickened disc.

Fig. 5. Sagittal proton density magnetic resonance views representing examples of changes in the soft tissue components of the temporomandibular joint observed in corresponding disc diagnoses. Images on the top row are in closed-mouth position. Images in the bottom row are in open mouth position. A, Anteriorly displaced disc: thickened disc. B, Anteriorly displaced disc: deformed disc shape, posterior band is thickened, generalized sclerosis of the condylar head. C, D, Anteriorly displaced disc: deformed disc shape. E, Reduction of the disc position (while the mouth is open): normal disc shape, intermediate zone is in contact with the condylar head. F, Reduction of the disc position (while the mouth is open): posterior band is thickened, intermediate zone is in contact with the condylar head. G, Nonreduction of the disc position (while the mouth is open): intermediate zone is not detectable. H, Nonreduction of the disc position (while the mouth is open): intermediate zone is detectable.
DISCUSSION

The image analysis criteria reported here have content validity, because they were developed from review of the literature, recommendations by the members of External Advisory Panel appointed by NIDCR for the project, and suggestions from members of the TMD and radiology community. The study demonstrated that, using these criteria, the reliability of the radiologists for assessment of osseous diagnosis with CT was good, disc diagnosis with MRI was excellent, and effusion diagnosis with MRI was good. Using CT as the reference standard for diagnosing OA, panoramic radiography and MRI had poor and marginal sensitivity, respectively, but excellent specificity.

The RDC/TMD is currently used by at least 45 research groups and has been translated into 18 languages. The clinical component of the RDC/TMD has also been tested in various ethnic communities. Although the scope of the RDC/TMD is robust, its application in image interpretation has not been equally useful owing to lack of well defined diagnostic criteria. With cross-sectional imaging modalities widely available, reliable criteria for image analysis are essential both for research endeavors and for use by TMD clinicians.

The image analysis criteria reported in the present paper were developed to fill the void in the RDC/TMD as well as for clinical use. The image analysis criteria were established before initiating the RDC/TMD.
TMD Validation Project. On all 724 participants, we acquired panoramic, MR, and CT images. The interpretations of the images were done strictly according to these criteria. In this large group of research participants, the criteria were suitable and comprehensive for recording all findings related to OA, disc position, and other joint-related conditions. After the initial reliability study, the annual reliability studies used images obtained from participants of present project. Therefore, the results of this imaging reliability study contribute to the demonstrated diagnostic reliability and accuracy of the RDC/TMD Validation Project.

Nomenclature

This study raised issues related to diagnostic nomenclature. The original RDC/TMD classified joint disorders as arthralgia, osteoarthritis, and osteoarthrosis. Although arthralgia and osteoarthritis have pain as a major discerning component, osteoarthrosis is a degenerative change without any pain-related signs or symptoms. In medical literature, such differentiation is usually not noted, and the terms osteoarthrosis and osteoarthritis are often used interchangeably, with osteoarthritis the more prevalent and common term. Another term used for this condition is degenerative joint disease. Stegenga reviewed terminologies such as TMD, osteoarthrosis, and osteoarthritis and advocated the use of osteoarthritis as the preferred term. For the present radiographic criteria, we have adopted the use of the term osteoarthritis (OA), although degenerative joint disease might be the best term to use for interpretation of radiographs and images when no clinical information is available.

Classification schemes for other joints

The radiographic classification of OA for any joint is challenging. Major work on OA classification has focused on knee joints. The pioneer work on classifying OA was proposed by Kellgren and Lawrence using plain-film radiography. In this classification, the presence of both osteophytes and subcortical sclerosis are used to grade OA (grade range 0-4). In another classification system by the American College of Rheumatology/Knee Arthroscopy, osteophytes are the radiographic marker for OA. This classification system uses criteria based on clinical findings as well as radiographic or arthroscopic observation to arrive at the

Table V. Sample characteristics and reliability coefficients for radiologic diagnoses

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>No. of joints</th>
<th>Prevalence of diagnosis, %</th>
<th>Kappa</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osteoarthritis—panoramic radiography</td>
<td>179</td>
<td>9</td>
<td>0.16</td>
<td>0.04-0.27</td>
</tr>
<tr>
<td>Osteoarthritis—MRI</td>
<td>145</td>
<td>20</td>
<td>0.47</td>
<td>0.33-0.58</td>
</tr>
<tr>
<td>Osteoarthritis—CT</td>
<td>145</td>
<td>41</td>
<td>0.71</td>
<td>0.63-0.79</td>
</tr>
<tr>
<td>Any disc displacement</td>
<td>143</td>
<td>64</td>
<td>0.84</td>
<td>0.76-0.91</td>
</tr>
<tr>
<td>Disc displacement with reduction</td>
<td>143</td>
<td>30</td>
<td>0.78</td>
<td>0.68-0.86</td>
</tr>
<tr>
<td>Disc displacement without reduction</td>
<td>143</td>
<td>33</td>
<td>0.94</td>
<td>0.89-0.98</td>
</tr>
</tbody>
</table>

CI, Confidence interval; MRI, magnetic resonance imaging; CT, computerized tomography.

*Prevalence of diagnosis is from the images used for reliability studies.

Table VI. Overall, positive, and negative percent agreement for radiologic diagnoses

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>% agreement</th>
<th>% positive agreement</th>
<th>% negative agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osteoarthritis—panoramic radiography</td>
<td>88</td>
<td>19</td>
<td>93</td>
</tr>
<tr>
<td>Osteoarthritis—MRI</td>
<td>82</td>
<td>59</td>
<td>89</td>
</tr>
<tr>
<td>Osteoarthritis—CT</td>
<td>86</td>
<td>84</td>
<td>88</td>
</tr>
<tr>
<td>Any disc displacement</td>
<td>93</td>
<td>95</td>
<td>91</td>
</tr>
<tr>
<td>Disc displacement with reduction</td>
<td>91</td>
<td>84</td>
<td>94</td>
</tr>
<tr>
<td>Disc displacement without reduction</td>
<td>97</td>
<td>96</td>
<td>98</td>
</tr>
</tbody>
</table>

% positive agreement = percentage of images radiologists agreed on for presence of the condition; % negative agreement = percentage of images radiologists agreed on for absence of the condition. Abbreviations as in Table V.

Table VII. Diagnostic accuracy (%) of panoramic radiography and magnetic resonance imaging (MRI) for osteoarthritis (OA)

<table>
<thead>
<tr>
<th>OA of TMJ</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panoramic radiography vs. CT</td>
<td>26.2</td>
<td>99.3</td>
</tr>
<tr>
<td>95% CI</td>
<td>21.0-31.6</td>
<td>98.6-99.7</td>
</tr>
<tr>
<td>MRI vs. CT</td>
<td>59.4</td>
<td>98.0</td>
</tr>
<tr>
<td>95% CI</td>
<td>53.7-64.9</td>
<td>97.0-98.8</td>
</tr>
</tbody>
</table>

For this analysis, the diagnoses of normal and indeterminate were combined as no OA, which was then compared with frank OA. TMJ, Temporomandibular joint; CI, confidence interval; CT, computerized tomography.
diagnosis. Yet another classification system of knee OA was proposed by Ahlbäck,25 based on radiographs of patients in an upright standing position. This system evaluates the range of attrition from minimal narrowing of the articular space to the maximum attrition of more than 15 mm. Ahlbäck’s classification does not use osteophytes as an indicator of OA. The Brandt et al.26 radiographic classification is based on that of Kellgren and Lawrence and considers joint space narrowing, osteophytes, subcortical sclerosis, and subcortical cysts. Using MRI as the diagnostic tool, a new classification system named Boston-Leeds Osteoarthritis Knee Score has been developed.27 This classification uses bone marrow lesions, osteophytes, effusion, and meniscal lesions as criteria for OA. Erosion of femoral cortex is also a feature of knee OA.28 For analyzing OA of the hand, interphalangeal joint erosion is a common feature.29

The radiographic criteria for knee or hand arthritis cannot be directly translated to TMJ disorders. We primarily modeled our criteria with the criteria of the Kellgren-Lawrence knee OA analysis system, and incorporated published radiographic criteria for TMJ analysis.30-32 This produced a comprehensive list of radiographic features for osseous and nonosseous tissue analysis on panoramic, CT, and MR images as well as criteria for OA.

Classification scheme for osseous components

**Joint space.** Joint-space narrowing is an important radiologic diagnostic feature for knee joints, which bear weight when radiographs are acquired in a standing position. Unlike knees that depend on gravity to “standardize” the load on the joint, it would be difficult to determine the “standard” loading force to use when assessing the TMJ. For the TMJ, wide anterior joint space has been correlated to anterior displacement of the disc and presence of osteophytes.33-35 In addition, narrowed joint space may be a feature of TMJ OA.36 Because the joint space can vary during pressure, such as with mastication, as well as in the open-mouth position,37 the present criteria determine the joint space only when the mouth is closed in a comfortable position. Because deviation of the joint space can occur in normal joints and with OA (owing to osteophytes) or without OA (owing to disc displacement only), we have not included joint space variation as a reliable indicator of OA.

**Sclerosis.** In the knee joints, localized subcortical sclerosis is not a reliable indicator of OA.38 In patients with TMJ pain, subcortical sclerosis is present in one-third of the patients and changes slightly with progression of disease.39 For diagnosing OA, we considered subcortical sclerosis of the condylar surface or the fossa to be indeterminate, that is, an indication of variation of normal, especially as it relates to aging or remodeling. However, in the present criteria, generalized sclerosis of the subcortical bone was considered to be a sign of OA, because it is associated with cartilage degradation.40 When generalized scleroses were considered to be a sign of OA, such lesions were adjacent to the articular surfaces.

**Flattening of the margins.** Flattening of the articulating surface of the condyle, fossa, and eminence without the evidence of osteophyte formation is not a reliable indicator of OA.38 Kurita et al.41 have indicated that flattened eminence is related to OA of TMJ; however, they did not indicate if such flattening was associated with erosion of the cortical margin. When the cortical margin was intact, but the condyle or eminence showed flattened appearance, we graded them as indeterminate. In addition, flattening and localized subcortical sclerosis were viewed as a sign of remodeling and graded as indeterminate for OA. Remodeling is a function of age as well as duration and degree of disc displacement. Whether it will progress to frank OA is not currently predictable.

**Erosion of the cortical plate and subcortical cyst formation.** Surface erosion is one of the features of OA in hand or knee joints28,42 as well as for TMJ.43-47 The current criteria use erosion as an important feature of OA. In advanced erosion, several joints also displayed subcortical cyst formation, which we considered to be another feature of OA.43 Subcortical cyst is a misnomer, because it is not a true cyst but rather an area of osseous degeneration.

**Osteophytes.** Most knee joint classification use osteophytes as a commonly used radiographic feature for OA. Osteophytes indicate cartilage degradation38 and are associated with pain in the joint.48 An osteophyte, even if small, is an indicator of progression of OA.49 Several atlases have been developed to orient clinicians in identifying osteophytes in the knee, hip, and hand.50-52 In the RDC/TMD, all 3 imaging modalities were used to determine the presence of osteophytes. Figure 2 provides examples of osteophytes as viewed on sagittal CT views. On panoramic radiography, we can see only limited areas of the anterior surface of the condyles.47 Most osteophytes are located on the anterior surface and are not adequately displayed on panoramic radiographs unless large or located on the anterolateral aspect of the joint. This limitation partly explains the low sensitivity of panoramic radiographs in detecting OA. The moderate sensitivity of MRI is likely due to the difficulty in detecting small osteophytes or small erosive changes in the cortical plates.

**Calcified loose bodies in the soft tissues.** We treated presence of loose calcified bodies as a sign of OA when other features of OA were also present. Without other
signs, presence of loose calcified bodies was not considered to be a sign of OA, because they can also represent synovial chondromatosis, i.e., calcified cartilage embedded in synovial tissues, or chondrocalcinosis. Although loose calcified bodies are more common in large joints, they produce similar clinical symptoms in TMJ (e.g., pain, limitation of movement, crepitation, and inflammation).

In summary, the imaging analysis criteria use erosion, subcortical cyst, osteophyte, and generalized sclerosis to diagnose TMJ OA. Flattening and/or sclerosis, unless the latter is generalized, are considered to be indeterminate signs for diagnosing OA. As such, the criteria do not overdiagnose frank OA. We believe that the review of the radiologic literature of the TMJ and other joints justifies the items in our criteria for diagnosing OA.

Classification scheme for nonosseous components

The nonosseous criteria included shape and position of the disc in both open and closed mouth and the presence of joint effusion. The nonosseous components were evaluated in proton density and T2 weighted MR images only.

Disk shape and position. We adopted the classification by Orsini et al. for identifying the location of the posterior band of the disc and location of the intermediate zone both in closed and open mouth. Tasaki et al. classified the disc position into 9 categories, with an additional category of indeterminate. Although our criteria considered and evaluated all of these 10 possible positions, the results were classified into only 5 types (Table IV). In general, increasing the diagnostic options often results in reduced reliability. Therefore, the proposed RDC/TMD imaging criteria for disc position are simple, have excellent reliability, and still include all possible positions/shapes of the disc in relation to the osseous components as used in the current literature.

Effusion. The relationship of fluid effusion to pain and OA is not yet clear. It is now understood that effusion occurs with disc displacement and is a sign that may appear before osteoarthritic changes occur. Therefore, we have not included effusion as a criterion for identifying OA. However, in a knee joint study, moderate or frank effusion and osteophytes reliably correlated with symptoms of OA. In our grading, effusion was rated as absent, slight, or frank. Both the upper and the lower joint spaces were evaluated to arrive at a diagnosis of effusion.

Translation of the condyles. In the present study, we used open-mouth MRI to view translation of the condyles. The same images were also used to identify disc position or shape. Because CT does not reveal disc shape or position, to minimize radiation exposure, and because condylar translation is adequately assessed with open-mouth MRI, we did not acquire open-mouth CT images. From MRI, we graded the translation of the condyle in relation to the apex of articular eminence in 1 of 3 ways: the condyle translated: 1) less than the apex; 2) to the apex; or 3) beyond the apex. Takatsuka et al. have classified the range of motion as positive, limited, or negative, which appears to be subjective for research or clinical use. Those authors also reported that the presence of OA does not always limit the translation.

Consistent terminology and proper diagnosis are essential in clinical TMD practice. To eliminate or minimize the bias of the radiologists, the research diagnostic criteria described in the present report can reliably be used to interpret panoramic, CT, and MR images for OA and MR images for disc displacement. The criteria specifically avoid charting the range or extent of disorders. Although range designations such as mild, moderate, and severe are useful for clinical description, these are often subjective, are difficult to standardize, and reduce reliability. Likewise, we have avoided terminologies such as acute or chronic. To overcome the limitations of categorizing, the scoring form we used provided options to indicate conditions that do not fall within the diagnostic scheme for OA. In addition, for each image type, an area on the scoring form was available for the radiologist to comment on the images or findings.

In the present study, the results show that comprehensive image analysis criteria developed for the RDC/TMD Validation Project can effectively be used in assessing TMD, because the study radiologists achieved good reliability in detecting OA using CT, excellent reliability in identifying disc position, and fair to good reliability in detecting fluid effusion.

Reliability for interpreting radiographs and images

In the present study, the scoring options for panoramic radiography were normal, indeterminate, and frank OA. The reliability of the radiologists was poor in interpreting panoramic radiographs for OA. When the scores of normal and indeterminate were grouped together and compared with frank OA, the agreement improved to moderate. A position paper by the American Academy of Oral and Maxillofacial Radiology (AAOMR) indicated that panoramic radiographs may be useful to detect gross TMD pathoses only. Earlier studies have also indicated that inter-examiner reliability of detecting TMJ pathosis from panoramic radiographs was low to moderate. In addition to the inability of the panoramic radiographs to reveal osteophytes, erosion of the articular margin of the condyle is not properly revealed owing to
superimposition by other bony structures. The inherent limitation of panoramic radiographs in demonstrating the contours of the condyle and the articular fossa is the likely reason for the poor agreement in interpreting such images.

When MR images were used for diagnosing OA, the reliability of the radiologists was fair (k = 0.47). In knee joint MR studies, radiologists have been found to have similar moderate reliability in diagnosing OA (for osteophytes: k = 0.65). For the present reliability study, the radiologists examined only 1 representative image from open- and closed-mouth sagittal views. It is possible that the reliability would change if all of the sections through the condylar head were made available to the radiologists. In another study, high agreement (94%) was achieved in detecting osseous changes on MRI when 2 examiners were calibrated for 7 months using several hundred images. A recent study for TMD reported that higher reliability in clinical diagnosis can be achieved by recalibrating the examiners during the course of the study. In the present project, we recalibrated the radiologists on an annual basis.

The present results indicate that the reliability of the radiologists was excellent (k = 0.84) when they diagnosed the disc position using PD MR images. Earlier studies reported moderate to good interexaminer agreement on disc position. One study indicated that the interexaminer reliability can be improved to good by selecting high-quality MR images and by calibrating the examiners.

A systematic review of the literature on the efficacy of MRI in diagnosing TMJ disorders showed that the results from the literature are inconsistent and that the evidence is insufficient. The authors of that review indicated that the poor performance of the examiners was partly due to different diagnostic procedures used by the investigators and lack of defined diagnostic criteria. Another study has shown that when the examiners were not calibrated, the kappa values for interexaminer agreement on TMJ disc position or configuration were poor. These issues were addressed in the present study, because the radiologists were calibrated and used clearly defined image analysis criteria. In detecting effusion, one study reported poor reliability (k = 0.36) for noncalibrated examiners; however, the calibrated examiners in our study had good reliability (k = 0.64). Our data suggest that the image analysis criteria developed for the RDC/TMD Validation Project and calibrated examiners led to more reliable interpretation than other reports.

The superiority of CT over panoramic radiography or MRI in displaying the features of TMJ OA has been well documented and has wide acceptance. Using multidetector CT images in the present study, the reliability of the radiologists was good (k = 0.71) and the agreement of the radiologists in diagnosing OA was high (86%). A systematic review indicated that cone-beam CT (CBCT) maybe superior to multidetector CT, although the reviewers suggested that further studies were needed to determine the usefulness of CBCT compared with multidetector CT. When the present project was proposed and conducted, CBCT was not widely available and was not accessible to the project radiologists. Previously, several investigators had used tomography and arthrotomography as a method for cross-sectional imaging to assess osseous changes in the TMJ. These studies indicated that the interexaminer reliability using this technique was fair (k = 0.56) to excellent (k = 0.40-0.80).

**Criterion validity**

In our validation assessment study, we considered the CT findings to be the reference standard for diagnosing OA using images. The sensitivity of panoramic radiography in detecting OA was low (Table VII). These results conform to the recommendation of the position paper from AAOMR that panoramic radiography is only useful in diagnosing advanced OA. In identifying OA, the sensitivity of MR images was marginal compared with CT findings. We used 1.5-T magnets in acquiring MR images. Stehling et al. reported that visualization of the disc is similar at 1.5 and 3.0 T, although the anatomic details were substantially better at 3.0 T. TMJ surface coils were used in all 3 research sites for achieving high-quality images. Although the sensitivity of panoramic radiography and MR ranged from low to marginal, the specificity of these techniques in detecting OA was high compared with reference standard CT (Table VII).

The results indicate that about 75% of CT-diagnosed OA is not detected using panoramic radiography, and about 40% with MRI. Therefore, this suggests that clinical or research studies of OA should use CT when possible despite the increased radiation. As in this study, radiation exposure can be decreased by limiting CT study to the closed-mouth position. Another option may be to use CBCT, which can provide diagnostic information equal to multidetector CT. Cone-beam CT has been shown to be a better diagnostic option for TMJ erosion compared with panoramic radiography or linear tomography. The image resolutions of different brands of CBCT differ; therefore, it remains to be determined if images generated from different brands of CBCT are indeed more diagnostic than those generated from multidetector CT. Finally, future research should attempt to improve the resolution and definition of MR images so they can be used instead of CT for assessing osseous structures.
There were several limitations to this study. The initial calibration and reliability study was done at one site, with all 4 radiologists in the same location. Subsequent recalibration and reliability studies were done separately, which reduced the discussions between the radiologists. This may have led to a lower reliability than if the radiologists were together for the annual studies. The 3 geographical locations were chosen to assemble an experienced team of investigators and to increase the number of participants in the study. However, the distance created logistic problems. Conference calls is a substitute for physical presence of the radiologists, but a better option would be to conduct recalibration at one site. In addition, for logistic purposes a single representative slice of CT or MRI from a joint was selected for the reliability examination in the study. Evaluation of multiple slices would have reflected clinical situations for total assessment of the joint. The 4-year length of the study added an unexpected variable. The hospital at UM replaced its MRI unit during the course of the study; therefore, the images obtained at the beginning of the study were different than the images obtained later. The 3 study sites used different brands of panoramic, CT, and MR units. Although the images were completely diagnostic, there were differences in the image quality of each unit, which may have affected reliability outcomes.

In conclusion, panoramic radiography had poor reliability and low sensitivity, compared with CT, for detecting TMJ-related osseous changes. These findings suggest that this imaging modality has limited utility for assessing the TMJ. Magnetic resonance imaging had fair reliability and marginal sensitivity in diagnosing osseous changes compared with CT. Therefore MRI is not an ideal imaging technique for detecting osseous changes, and CT remains the image of choice for assessing osseous tissues. Regarding soft tissue assessment, MRI had excellent reliability for assessing disc position and good reliability for detecting effusions. Overall, the criteria proposed in this study for image analysis covered all possible osseous and non-osseous conditions of TMJ in a large group of participants in the multisite RDC/TMD Validation Project. The image analysis criteria presented in this paper are reliable for diagnosing osseous and nonosseous components of TMJ using CT and MRI, respectively. We recommend that they be used in both clinical and research settings.

This study was supported by NIH/NIDCR U01-DE013331 to Dr. Eric L. Schiffman, the study principal investigator for the RDC/TMD Validation Project and for the research site at the University of Minnesota School of Dentistry, Minneapolis, MN. Drs. Edmond Truelove and Richard Ohrbach are the Validation Project site principal investigators at the University of Washington School of Dentistry, Seattle, WA, and the University at Buffalo, Buffalo, NY, respectively. Dr. David L. Berens, MD, University at Buffalo, provided valuable guidance in developing the criteria. We gratefully acknowledge Drs. Sharon Brooks and Samuel Dworkin, who were members of the NIDCR’s External Advisory Panel for this study, for critically reviewing our criteria.

REFERENCES
17. Schiffman EL, Truelove EL, Ohrbach R, Anderson GC, John MT, List T, Look JO. Assessment of the validity of the research


36. Tanaka E, Detamore MS, Mercuri LG. Degenerative disorders of the temporomandibular joint in female patients with TMJ pain or dysfunction. A seven year follow-up. Acta Radiol Diagn (Stockh) 1988;24:159-76.


47. Masood F, Katz JO, Hardman PK, Glaros AG, Spencer P. Comparison of panoramic radiography and panoramic digital subtraction radiography in the detection of simulated osteophytic lesions...


