The Mediolateral Temporomandibular Joint Disc Position: An In Vivo Quantitative Study

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Aims: *Temporomandibular joint (TMJ) discs displaced simultaneously, dorsoventrally, and mediolaterally are assumed to be rotated. However, a pilot study performed with individualized oblique-axial scans on supposedly rotated discs did not show disc rotation consistently. The aim of this study was the quantitative evaluation of disc rotation on a larger sample size, assessing the mediolateral disc geometry and position by the use of a reference system determined by the condylar long axis.* ***Methods:*** *Eighty-five TMJs from 50 subjects were analyzed. One series of sagittal and 1 of 14 individualized oblique-axial magnetic resonance (MR) scans were taken for each joint. The dorsoventral disc position was diagnosed by means of the sagittal scans. The mediolateral disc width and position were then measured on every oblique-axial scan. The width and midline was computed for each disc and its deviation from the perpendicular to the condylar long axis was calculated. Finally, a statistical analysis was performed to study whether the disc width and the direction of the disc midline varied between discs normally positioned and anteriorly displaced.* ***Results:*** *The disc width varied significantly more within the anteriorly displaced discs than within the normal ones. The midline of the anteriorly displaced discs deviated more from the perpendicular to the condylar long axis than that of normally positioned discs and was mostly in a lateral direction. The disc midline also deviated more in the ventral than in the dorsal part of the disc.* ***Conclusion:*** *Most anteriorly displaced discs were laterally displaced and showed a larger width variation than normally positioned discs. This fact seems to indicate disc deformation.*
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Key words: temporomandibular joint, mandibular condyle, temporomandibular joint disc, magnetic resonance imaging, comparative study

Autopsy studies have shown that the temporomandibular joint (TMJ) disc can be displaced medially or laterally, other than anteriorly.[1–5] The concept of disc rotation in anteromedial or anterolateral direction was thus introduced.[3,6–8] Unfortunately, arthography or magnetic resonance imaging (MRI) with coronal planes are often unreliable or unsatisfactory in depicting in vivo the mediolateral disc position.[1,9] Indeed, conventional coronal MRI scans do not reveal the disc/condyle complex clearly if the disc is anteriorly displaced. Therefore, it has been proposed to use a series of sagittal MRI scans to analyze the mediolateral disc position.[8]

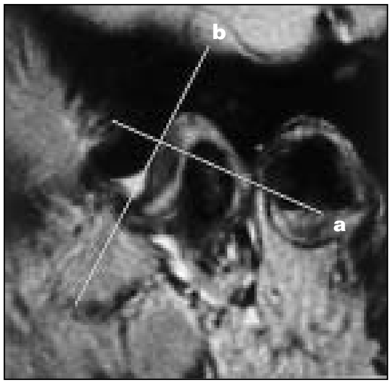

Fig 1 The orientation of the oblique-axial scanning planes is adjusted to be perpendicular (a) to the posterior slope of the articular eminence (b).

Individualized oblique-axial MRI scanning planes for the TMJ yield a better visualization of the mediolateral disc position than conventional coronal scans,[10] especially for anteriorly displaced discs, because of the greater number of images that simultaneously depict condyle and disc.[10] Furthermore, the partial volume effect is reduced with this imaging protocol. Thus, the oblique-axial scans are potentially useful also for the study of rotational disc displacement. Surprisingly, a preliminary MRI study showed that the series of sagittal images and those of the oblique-axial images indicated, quite often, opposite senses of disc rotation, possibly because of disc deformation and noncubic voxels differently oriented in the 2 scan series (Rotational disc displacement in TMJs, Proceedings of the Third International Conference on Orofacial Pain and Temporomandibular Disorders, Seoul, May 2000).

In addition to the problems mentioned above, the lack of clearly established and generally accepted criteria for the definition of the mediolateral disc position make this diagnosis even more difficult. For instance, the anatomic landmarks for the description of the mediolateral disc position have never been clearly defined. Previous researchers used either the medial and the lateral poles[3] or the medial and lateral 1/6 of the condylar width.[10] However, these landmarks cannot be used, for instance, in the case of a severely anteriorly displaced disc, even with the individualized oblique-axial scans because in some images, the disc is depicted in relation to the condylar neck and not to the condylar head. This makes it impossible to diagnose the mediolateral disc-condyle relationship in these regions. Thus, disc position and geometry in the mediolateral direction should be analyzed with a reference system not affected by the disc position itself. Such an approach was the goal of this study that aimed at assessing the mediolateral disc geometry and position by the use of a reference system determined by the condylar long axis.

Materials and Methods

Subjects

MRI scans of 85 TMJs from 50 patients (37 females, 13 males, 31.8 ± 12.2 years) of the Clinic for Masticatory Disorders and Complete Dentures were analyzed in this study. A total of 21 patients had a unilateral clicking and 9 had a bilateral clicking, 15 had a mouth-opening limitation, 1 had a TMJ subluxation, 1 had a unilateral osteoarthrosis (only the non-arthrotic joint was analyzed), and 3 had normal joints. The subjects signed an informed consent before participation. The protocol was approved by the ethical committee of the Center for Dental and Oral Medicine and Maxillofacial Surgery of the University of Zurich.

MRI Technique

MRI images were recorded with the subject biting in maximum intercuspation, by means of a 1.5 T MRI scanner (Philips Gyroscan NT) with bilateral TMJ coils of 8.0 cm diameter centered directly over the TMJs. The scanning procedure started with a preliminary axial scan in order to determine the angulation of the condylar long axis. Next, a series of 14 sagittal images were taken perpendicularly to the condylar long axis. One of these images, located in the lateral third of the condyle, was used to determine the steepness of the posterior slope of the eminence. Thereafter, a series of 14 contiguous individualized oblique-axial images were taken[10] (Fig 1).

The scanning parameters for all sagittal and oblique-axial images were: fast field echo (FFE) pulse sequences (comparable to the GRASS pulse sequences of the GE scanner and FISP pulse sequences of the Siemens scanner), T_R 500 ms, T_E 17 ms, flip angle 35°, field of view (FOV) 130 mm, rectangular FOV 50%, a 256 × 256 matrix, slicing thickness 2 mm, and 4 signal averages for a scanning time of 3'50". All digital images were then transferred to a Pentium class PC, converted to Windows bitmap files, and interpolated from 256 × 256 to 512 × 512 pixels with self-developed software (for details see Chen et al[10]).

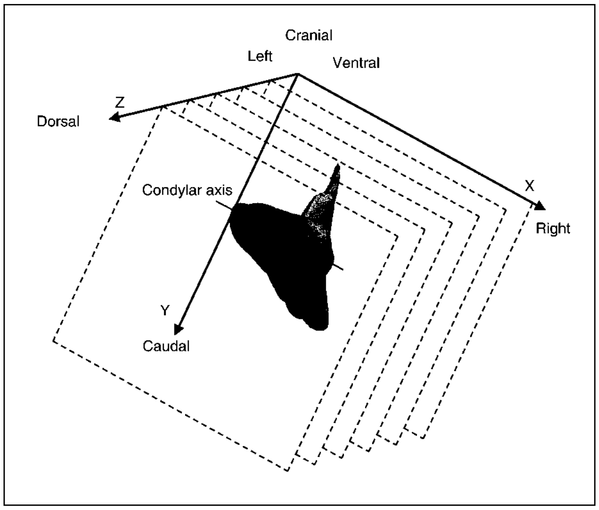

Fig 2 Orientation of the individualized coordinate system used to take the oblique-axial MRI scans. Note that the Y-axis points inferiorly.

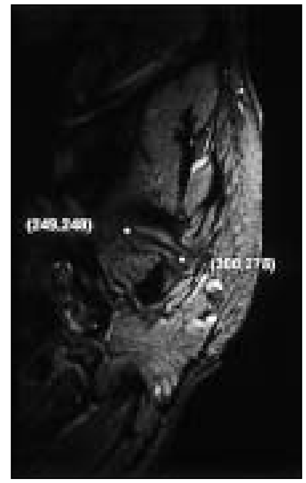

Fig 3 Measurement of the disc border points on a MRI scan of a left TMJ. The origin of the coordinate system is in the upper left corner. In this example, the most medial and lateral border points of the disc are located at (249,248) and (300,275), respectively.

Evaluation of the Dorsoventral Disc Position

The dorsoventral disc position was determined in each of the 14 sagittal images according to the clock-face criteria of Katzberg and Westesson.[6] The diagnosis of the whole dorsoventral disc position was then given according to the following criteria:

- Noon position: the dorsal band of the disc was located on all sagittal images at or dorsally to the 12 o'clock position relative to the cranial aspect (vertex) of the condyle.
- Partial anterior displacement: the dorsal band of the disc was located in some contiguous images ventrally to the 12 o'clock position and was at noon position in the remaining images.
- Complete anterior displacement: the dorsal band of the disc was located on all sagittal images ventrally to the 12 o'clock position.

Evaluation of the Disc Width and of the Mediolateral Disc Position

The disc width and the mediolateral disc position were determined from the oblique-axial images after detection of the mediolateral disc boundaries and the disc middle points. The measurements were referred to an individualized Cartesian coordinate system with the X-axis parallel to the condylar long axis, the Y-axis perpendicular to the X-axis and to the tangent of the posterior slope of the articular eminence, and the Z-axis perpendicular to the X- and Y-axes. Therefore, the images lay in planes parallel to the XY-plane whereas the dorsoventral position of the single oblique-axial images was described by the Z-axis (Fig 2).

A self-developed computer program was used to mark interactively the medial and lateral disc border points and to store the corresponding coordinates. Since the FOV was 130 × 130 mm, the pixel width was approximately 0.25 mm (130/512 mm). As common in computer graphics, the origin of the coordinate system of each oblique-axial image was located in the upper left corner (Fig 3). The slices were contiguous and 2 mm thick; therefore, from slice to slice the Z-coordinate changed by 2-mm increments. The disc was identified as an area of continuous lower gray level located between the darker fossa and condyle structures and delimited mediolaterally by abrupt intensity changes. When the disc boundaries appeared unclearly on an image, the disc border points were input consistently with those of the contiguous images.

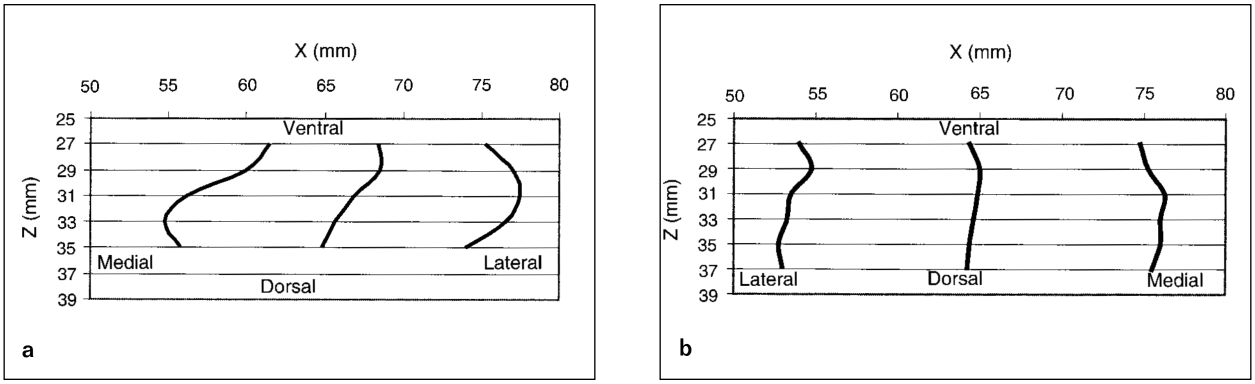

Fig 4 Medial and lateral disc boundaries and disc main direction for a partially anteriorly displaced left-side disc (a) and for a noon-positioned right-side disc (b). Notice how the width of the displaced disc varies dorsoventrally and how the disc main direction deviates from the Z-axis. On the contrary, the width of the noon-positioned disc remains fairly constant and its main axis is quite parallel to the Z-axis.

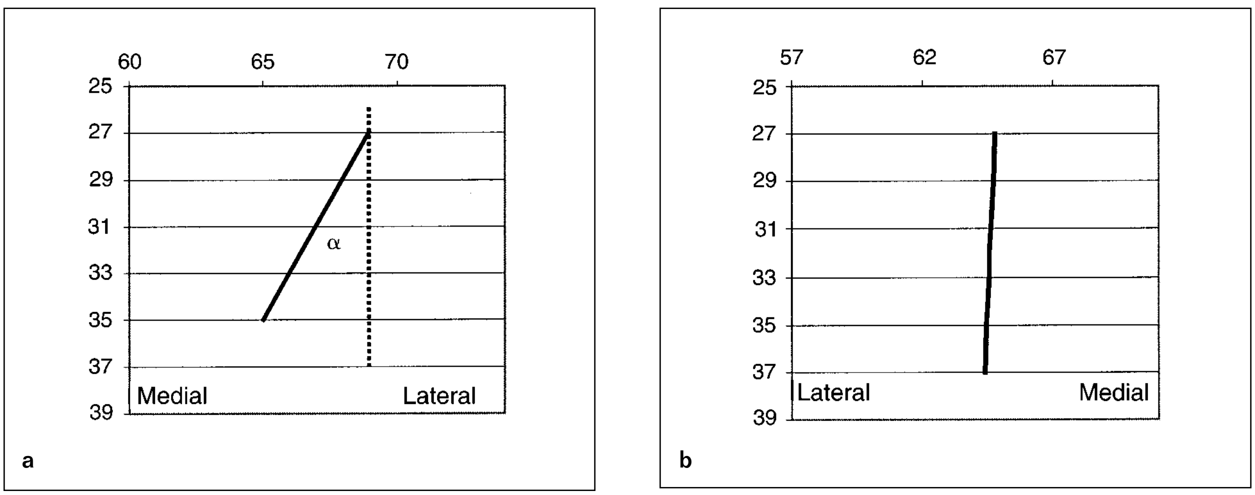

Fig 5 Regression lines drawn through the disc midpoints corresponding to the disc of Figs 4a and 4b. The angle α in (a) is 26 degrees and in (b) is 2 degrees. The directions of the regression lines indicate a lateral deviation in (a) and a slightly medial deviation in (b).

Disc Width

The disc width was calculated for every image as the length of the segment connecting the projections of the disc border points on the XZ-plane. The disc middle point corresponded to the middle point of this segment. The mediolateral boundaries of the disc were then constructed by connecting the projected medial and lateral border points of each image. Similarly, the disc midline was constructed from the disc middle points (Fig 4). Therefore, since the discs shown in the oblique-axial slices are generally curved, a calculation of the disc width was not made, but rather the width of the disc projection on the XZ-plane. This was also the case for the disc midline.

Disc Direction

The position of the disc on each oblique-axial slice determined the disc direction. The *disc main direction* was defined by the angle α between the Z-axis and the regression line through the coordinates (X, Z) of *all* disc middle points (Fig 5). Two other regression lines were also determined after the oblique-axial images were divided into 2 groups belonging to the ventral and to the dorsal disc halves. These lines described the direction of the ventral and dorsal disc halves (*ventral half direction,* angle α_v, and *dorsal half direction,* angle α_d, Fig 6).

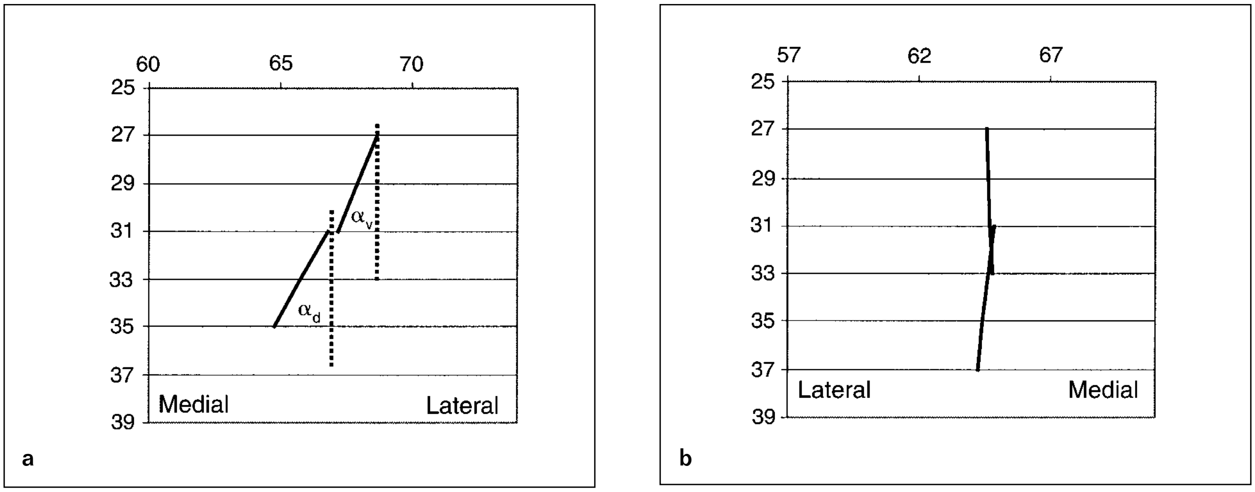

Fig 6 Regression lines through the midpoints of the discs of Fig 4 calculated separately in the ventral and the dorsal half. The angles α_v and α_d are 20 degrees and 26 degrees in Fig 5a and 1.7 degrees and 5.7 degrees for Fig 5b.

Reproducibility of the Measurements

For the assessment of the reproducibility of the measurements, 12 different individualized oblique-axial image series (4 TMJs with noon-positioned discs, 4 TMJs with partially anteriorly displaced discs, and 4 TMJs with completely anteriorly displaced discs) were randomly displayed on the computer screen to 3 evaluators, blind to the diagnosis of the dorsoventral disc position. The evaluators input the disc border points 3 times at 3 different days.

Statistical Analysis

For each disc border point, the intra- and interobserver maximum differences among the repeated measurements of the X-coordinates were calculated. Similarly, the intra- and interobserver maximum differences among the angles α obtained from each measurement were also calculated. Means and standard deviations of the intra- and interobserver maximum differences were then determined. ANOVA with Scheffé's post hoc test was used to test whether the disc widths and the angles α, α_v, α_d varied with statistical significance with different disc positions. Paired *t* tests were used to check for statistical differences between the angles α_v and α_d within the same discs and χ^2 tests (1 sample goodness-of-fit test) to analyze whether the angles α_v and α_d differed significantly with different dorsoventral disc positions. An overall significance level of $P < .05$ was chosen. All tests were computed by means of SSPS for Windows.

Results

Reproducibility of the Measurements

The intraobserver maximum difference for the determination of the coordinates of the disc boundaries was 0.75 ± 0.50 mm (max 2.5 mm) and that for the angles α 2.7 ± 1.4 degrees (max 5.1 degrees). The corresponding interobserver maximum differences were 2.1 ± 0.9 mm (max 4.8 mm) and 5.2 ± 2.3 degrees (max 9.6 degrees).

Dorsoventral Disc Position

Of the 85 joints, 22 discs were noon-positioned, 25 partially anteriorly displaced, and 38 completely anteriorly displaced.

Disc Width

The mean disc width was 21.2 ± 2.1 mm for the noon-positioned discs, 18.3 ± 2.8 mm for the partially anteriorly displaced discs, and also 18.3 ± 2.8 mm for the completely anteriorly displaced discs (Table 1). The noon-positioned discs were significantly wider than the partially and completely anteriorly displaced ones (ANOVA, $P < .05$).

Table 1 Disc Width, Width of the Most Ventral Slice, and Ratio Between the Mean Width of the Most Ventral Slice and the Mean Disc Width

Dorsoventral disc position	Disc width	Width of most ventral disc slice	Ratio
Noon-positioned	21.2 ± 2.1 mm	20.7 ± 2.1 mm	97 ± 9%
Partially anteriorly displaced	18.3 ± 2.8 mm	13.8 ± 4.3 mm	74 ± 15%
Completely anteriorly displaced	18.3 ± 2.8 mm	13.4 ± 3.4 mm	73 ± 13%

Table 2 Disc Direction

Dorsoventral disc position	Angle α (degrees)	Angle α_v (degrees)	Angle α_d (degrees)
Noon-positioned	6.9 ± 5.4	9.2 ± 9.1	7.2 ± 5.6
Partially anteriorly displaced	17.2 ± 11.5	25.9 ± 16.6	13.4 ± 10.0
Completely anteriorly displaced	14.1 ± 8.9	20.5 ± 13.4	13.5 ± 8.7

Angle α: main disc direction; angle α_v: ventral half direction; angle α_d: dorsal half direction

Table 3 Side of the Disc Main Direction

Dorsoventral disc position	Disc main direction pointing...		χ^2 test
	Laterally	Medially	*P*
Noon-positioned	9	13	n.s.
Partially anteriorly displaced	20	5	< .05
Completely anteriorly displaced	31	7	< .05
Total	60	25	

The disc width varied from ventral to dorsal. The mean standard deviation of the disc width was 2.0 ± 1.7 mm for the noon-positioned discs, 3.3 ± 1.5 mm for the partially anteriorly displaced discs, and 3.3 ± 0.9 mm for the completely anteriorly displaced discs. The noon-positioned discs showed a significantly smaller width variation along the dorsoventral direction than the partially and completely anteriorly displaced ones (ANOVA, $P < .05$).

The anteriorly displaced discs were narrower in the most ventral slice than the noon-positioned discs: 20.7 ± 2.1 mm for the noon-positioned discs, 13.8 ± 4.3 mm for the partially anteriorly displaced discs, and 13.4 ± 3.4 mm for the completely anteriorly displaced discs, the difference between noon-positioned and partially or completely displaced discs being statistically significant (ANOVA, $P < .05$). The ratio between the width of the most ventral slice and the mean disc width was on average 97% for the noon-positioned discs, 74% for the partially anteriorly displaced discs, and 73% for the completely anteriorly displaced discs. The ratio of both groups of the anteriorly displaced discs were significantly smaller than that of the noon-positioned discs (ANOVA, $P < .05$).

Disc Direction

The disc main direction of the noon-positioned discs deviated from the perpendicular to the condylar long axis significantly less than in partially and completely anteriorly displaced discs (ANOVA, $P < .05$), ie, angle α 6.9 ± 5.4 degrees for the noon-positioned discs, 17.2 ± 11.5 degrees for the partially anteriorly displaced discs, and 14.1 ± 8.9 degrees for the completely anteriorly displaced discs (Table 2). In the noon-positioned discs, 9 regression lines deviated laterally and 13 deviated medially, but the difference was not statistically significant. The disc main direction of the majority of the partially and completely anteriorly displaced discs deviated laterally (χ^2 test, $P < .05$, Table 3). There was no significant difference between the ventral half direction (angle α_v) and the dorsal half direction (angle α_d) of the noon-positioned discs (paired *t* test, $P > .05$). Conversely, α_v was significantly larger than α_d in the partially or completely anteriorly displaced discs (paired *t* test, $P < .05$). Furthermore, the angle α_d of all anteriorly displaced discs was significantly larger than the corresponding angle of the noon-positioned discs (*t* test, $P < .05$).

Discussion

The present study has shown that the mediolateral disc width and direction differed significantly between noon-positioned and anteriorly displaced discs. The noon-positioned discs were significantly wider than those of the other 2 groups, and the width variation of the disc in dorsoventral direction was significantly more pronounced in the anteriorly displaced discs than in the noon-positioned ones. Moreover, the mean width in the most ventral part of the anteriorly displaced discs was significantly smaller than that of the noon-positioned discs, both in absolute and relative value.

The disc main direction of the noon-positioned discs was approximately perpendicular to the condylar long axis and did not deviate predominantly to 1 side. In contrast, the disc main direction of all anteriorly displaced discs not only deviated more from the perpendicular to the condylar long axis (Z-axis) but the deviation was mostly in lateral direction. In addition, the angle α_v was larger than α_d, indicating that the lateral deviation of the anteriorly displaced discs was more pronounced in the ventral than in the dorsal disc half. Finally, also the dorsal half direction of the anteriorly displaced discs deviated significantly more from the Z-axis than that of the noon-positioned discs.

These findings seem to indicate first that noon-positioned discs are more evenly wide and more perpendicular to the condylar long axis than anteriorly displaced discs and second that anteriorly displaced discs are deformed in mediolateral direction and deviate more often laterally than medially. This last conclusion is supported by other studies.[11–13] However, the ratio between the disc lateral deviation and medial deviation in our findings is much higher than in the other reports. This discrepancy is possibly due to different approaches and different imaging techniques used to analyze the mediolateral disc position. MRI scans the object in small volume units (voxels). The voxels used in this study had a rectangular prism shape of 2.0 × 0.5 × 0.5 mm. The orientation of a noncubic voxel influences the gray level of the scans.[14] Indeed, since the signal intensity within a voxel is the sum of all MRI signals emitted by the tissues within it, a partial volume effect—essentially a false signal level—occurs if the tissues within the voxel are not homogeneous.

In the sagittal scans, the longest sides of the voxels run mediolaterally, whereas in the individualized oblique axial scans they run almost dorsoventrally. Therefore, the resolution for the detection of the condyle-disc relationship is higher (0.5 mm) and the partial volume effect lower for the individualized oblique-axial scans than for the sagittal ones (2 mm). Hence the detection of structural changes in the mediolateral direction is harder from the sagittal scans than from the individualized oblique-axial ones. This is further explained by means of Fig 7 and Fig 8. Figure 7 shows a series of sagittal scans through a TMJ with a partially anteriorly displaced disc and the 3D reconstruction of the disc/condyle complex obtained from them. The disc and the condyle appear to terminate in the same planes both medially and laterally. However, the reconstruction obtained from the series of oblique-axial scans (Fig 8) shows that the same disc extends more laterally as well as medially than the condylar poles. This is due to the better mediolateral resolution of the oblique-axial scans. In the sagittal scan series shown in Fig 7 the demarcation of the disc/condyle complex in the most lateral slice (image a) is much poorer than in most other slices (images b to j). Therefore, the fact that the disc extends more laterally than the condyle is possibly overlooked.

The same happens in images k and l on the most medial side of the joint. Since the individualized oblique-axial MRI scans of the TMJ are more sensitive to anterior disc displacement and their mediolateral resolution is higher, this technique appears particularly suitable to investigate in vivo mediolateral or rotational disc displacements. Given the limitations of each scanning technique, it is likely that the best disc reconstruction could be obtained only by combining both sagittal and coronal scans. Such a reconstruction technique would require though a perfect registration system in order to correctly superimpose both data sets.

In their 3-dimensional finite element model,[15] Korioth and Hannam have shown that the human mandibular condyles are load-bearing and the distribution of the condylar loading varies depending on the tasks that the jaw performs: the highest condylar loading shifts mediolaterally between the intercuspal clenching and the incisal clenching. Gallo et al have also demonstrated that the stress-fields represented by the minimal TMJ space translate mediolaterally during opening/ closing movements (6 ± 3 mm),[16] the value of the minimal condyle-fossa distance being mostly smaller in the lateral aspect of the condyle. These models seem to provide possible explanations for our findings. As a matter of fact, recent research has demonstrated that the viscoelastic behavior of the disc is anisotropic, the tissues being much weaker mediolaterally than dorsoventrally.[17–19] Mediolateral stress-field translation might therefore damage the weaker mediolateral cross-link of the disc.[16] Also autopsy studies have

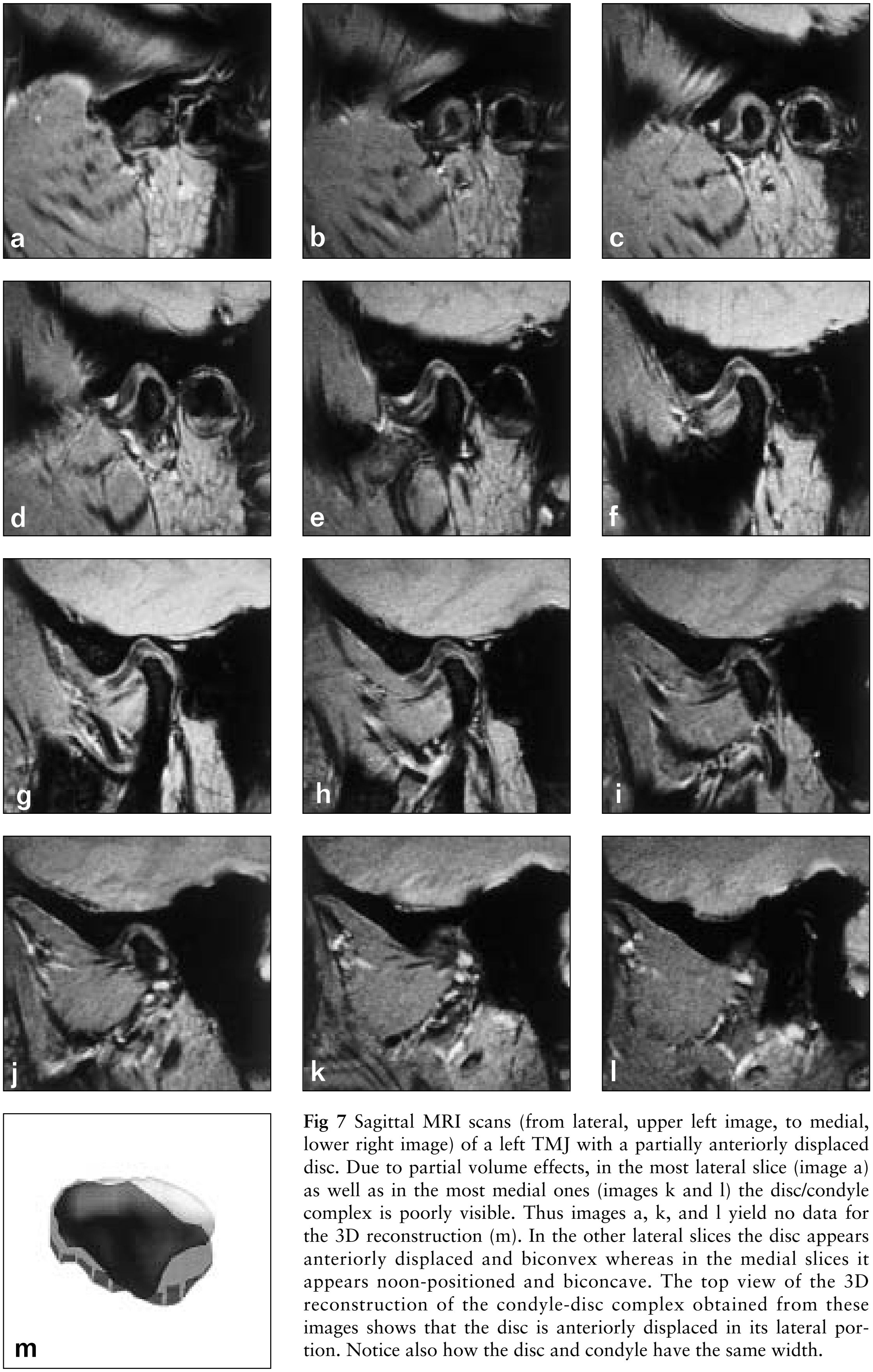

Fig 7 Sagittal MRI scans (from lateral, upper left image, to medial, lower right image) of a left TMJ with a partially anteriorly displaced disc. Due to partial volume effects, in the most lateral slice (image a) as well as in the most medial ones (images k and l) the disc/condyle complex is poorly visible. Thus images a, k, and l yield no data for the 3D reconstruction (m). In the other lateral slices the disc appears anteriorly displaced and biconvex whereas in the medial slices it appears noon-positioned and biconcave. The top view of the 3D reconstruction of the condyle-disc complex obtained from these images shows that the disc is anteriorly displaced in its lateral portion. Notice also how the disc and condyle have the same width.

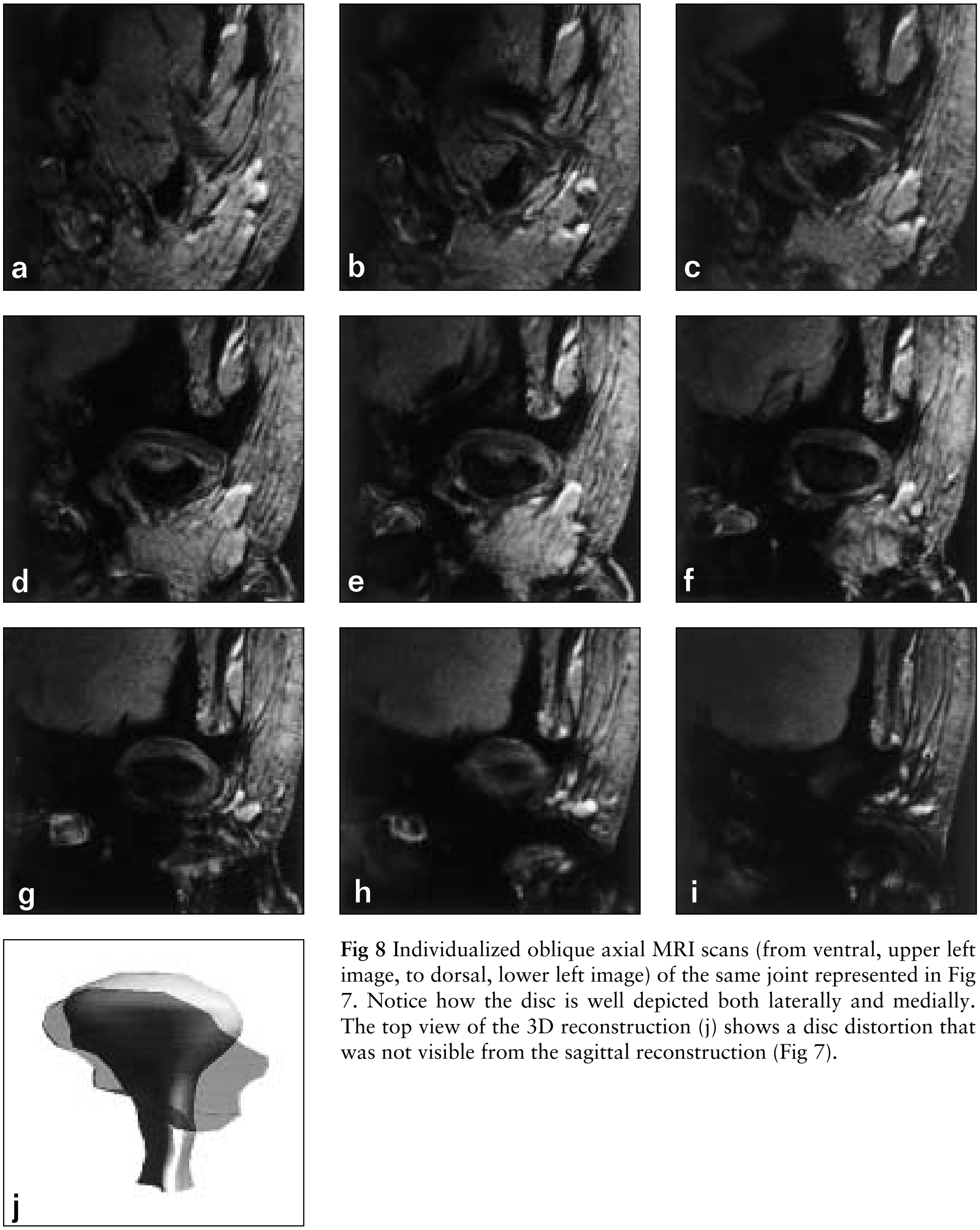

Fig 8 Individualized oblique axial MRI scans (from ventral, upper left image, to dorsal, lower left image) of the same joint represented in Fig 7. Notice how the disc is well depicted both laterally and medially. The top view of the 3D reconstruction (j) shows a disc distortion that was not visible from the sagittal reconstruction (Fig 7).

shown that anteriorly displaced discs have often lost their biconcave shape especially in the lateral part.[17,18] Thus, it is likely that disc deformation occurs not only dorsoventrally but also mediolaterally as reported by our observations. Of course, our observations must be interpreted cautiously, first because the measurements have been performed only in vivo and therefore without anatomical correlate, and second because of the limitations inherent to the MRI technique, ie, the difficulty in determining the disc boundary. The reproducibility of the measurements indicated a low intraobserver variability (0.75 ± 0.50 mm) but a higher interobserver variability (2.1 ± 0.9 mm). The high interobserver variability certainly arose from the difficulty in the exact determination of the mediolateral disc border, especially when the gray level changes were not very abrupt. However, also the interobserver variability was far lower than the difference in width and direction found between the noon-positioned and the anteriorly displaced discs, so that the intra- and interobserver variability cannot fully explain the differences in the appearance of the noon-positioned and of the anteriorly displaced discs.

Terms such as "anterior disc displacement," "sideways disc displacement," or "rotational disc displacement" are currently used to describe abnormal disc positions. The word "displacement" is sometimes misleading, as it implies that TMJ disc abnormalities are simple positional phenomena. However, a disc deformation, as indicated in this study, might be as important as the disc position itself. Therefore, it could be wise to try and reconsider the use of the word "displacement" for the description of TMJ internal derangement.

Within the limits of this study, it seems that the majority of anteriorly displaced discs are also deformed in the mediolateral direction. These deformations appear to be more severe in the ventral than in the dorsal region.

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