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Morphology of the mandibular fossa and inclination of the articular eminence in patients with internal derangement and in symptom-free volunteers

Tonguç Sülün, DMD,[a] Taylan Cemgil,[b] Jean-Marc Pho Duc, DMD,[c] Peter Rammelsberg, DMD,[d] Lorenz Jäger, MD,[e] and Wolfgang Gernet, DMD,[f] Istanbul, Turkey; Nijmegen, The Netherlands; and Munich, Germany
THE UNIVERSITY OF ISTANBUL, THE UNIVERSITY OF NIJMEGEN, AND THE UNIVERSITY OF MUNICH

Objective. The purpose of this study was to evaluate temporomandibular joint morphology and to compare possible structural variations in the temporomandibular joint anatomy of symptomatic anterior disk displacement patients with possible structural variations in the temporomandibular joint anatomy of symptom-free volunteers.
Study design. Fifty-six symptomatic patients and 25 symptom-free volunteers were included in this study. All subjects had bilateral high-resolution magnetic resonance imaging scans performed in the sagittal (closed and open) positions. Disk positions were evaluated with these images, and the patients were accordingly classified into 4 diagnostic groups. The angulation between the Frankfort horizontal plane and the posterior slope of the articular eminence, as well as the width and depth of the glenoid fossa and the articular tuberculum, were automatically measured with the aid of a computer.
Results. The Mann-Whitney *U* test demonstrated significant differences in the angular and linear values obtained in disk displacement with reduction patients in comparison with the values obtained in patients with disk displacement without reduction and in symptom-free volunteers.
Conclusion. It is proposed that a steeper posterior slope and higher tuberculum articulaire are predisposing factors for the development of disk displacement with reduction. Flattening of the eminence may progress in time, leading to the onset of disk displacement without reduction.
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Scientific findings with respect to the etiology of internal derangement of the temporomandibular joint (TMJ) have not been well documented in the literature. Some of the suggested predisposing factors leading to disk malposition are absence of posterior teeth, Class II Division 2 occlusion, occlusal disharmony, jaw trauma, luxation of the joint, and mechanical differences in the morphology of the joint.[1-5] It is also frequently speculated that a steep slope of the articular eminence and the slope of the mandibular fossa predispose to certain disorders in the condyle-disk relationship.[6-11] Biomechanically, a steep slope causes an increase in posterior rotation of the disk, and this might lead to loosening of the ligaments that attach the disk to the condyle. The temporal and masseter muscles retract the condyle while the jaw is being brought to the closed position. At this position, the force vectors of the jaw elevator muscles are also related to the steepness of the articular eminence. Thus, a more forward position of the disk and a posterior position of the condyle at the closed-mouth position have been hypothesized in cases with a steep slope.[6,12]

Many authors have discovered a positive correlation

[a]Research Assistant, Department of Prosthetic Dentistry, University of Istanbul.
[b]Research Assistant and PhD Student, SNN Department of Medical Physics and Biophysics, University of Nijmegen.
[c]Research Assistant, Department of Prosthetic Dentistry, University of Munich.
[d]Professor, Department of Prosthetic Dentistry, University of Munich.
[e]Department of Diagnostic Radiology, University of Munich.
[f]Professor and Director, Department of Prosthetic Dentistry, University of Munich.
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Fig 1. Central slice of magnetic resonance scans without any contrast adjustment.

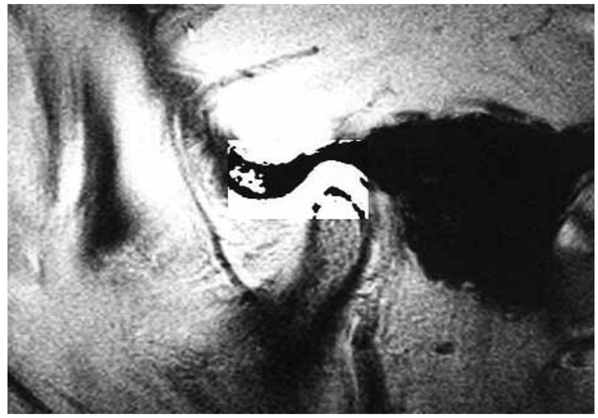

Fig 2. Contrast value was adjusted with Optimas software.

between a steeper slope and the anterior displacement of the disk forward.[7,8,11] Other studies[9,10,13,14] have found no such correlation between these 2 variables. Furthermore, Ren et al[15] observed a steeper posterior slope in symptom-free volunteers than in patients with internal derangement.

Panmekiate et al[9] and Galante et al[14] noted that flattening of the articular eminence was observed in disk displacement without reduction (DDN) patients in comparison with the patients with disk displacement with reduction (DDR). However, no reduction was observed in the posterior slope steepness.

A positive correlation was detected between a steeper eminence and the depth of mandibular fossa,[16] whereas a negative correlation was found between a steeper eminence and the overlying articular soft tissue thickness.[10,17] Most reports on direct measurements[18,19] of various slices of the mandibular fossa of dry skulls and cadaver specimens, as well as reports on radiographic examinations of the tomograms,[20] have demonstrated major differences in the steepness of the articular eminence. Consequently, it has been noted that studies performed with only a single slice or with transcranial or panoramic radiographic examinations, in cases in which no slices could be made, may not depict a true representation of the articular eminence.[4]

The aim of this study was to evaluate the morphology and the angulation of the various slices of the articular eminence with respect to the progress of internal derangement stages.

MATERIAL AND METHODS

Sixty-eight symptomatic patients with either restricted mouth opening or TMJ clicking bilaterally or unilaterally who were referred to the Department of Prosthetic Dentistry, the University of Munich, and 33 symptom-free dental student volunteers participated in this study. A questionnaire from the German Oral and Maxillofacial Disorders Association (1990) was used to evaluate the history and the clinical functional analysis of each of the 101 subjects. There were no objections to this study from the ethics committee of the University of Munich.

Bilateral high-resolution magnetic resonance imaging scans were made for all subjects with a Magneton-Impact 1 Tesla machine (Siemens, Erlangen, Germany) by using a surface coil to improve the signal-to-noise ratio. Each subject's head was placed so that the Frankfort plane was parallel to the portal—and perpendicular to the table or gantry—to obtain a consistent orientation of sagittal images. A light beam in the sagittal orientation enabled the researchers to correctly orient the subject's head with respect to angulation. The position of the head was then maintained with an adhesive band on a foam rubber support. After we obtained an axial localizer image, sagittal scans of 3-mm slices were obtained in the closed-mouth position (maximum intercuspidation of the teeth) and at the maximum opening by using a mouth prop. Scanning parameters were as follows: 2D-Flash Sequence; 35°; time of repetition = 400 ms; time of echo = 12 ms; 256 × 256 matrix; number of excitations = 4.

The scanning data were recorded to be analyzed with Optimas software, Version 5.2 (Media Cybernetics, L.P., Baltimore, Md). Because Optimas 5.2 software could not fully support the Magneton files, certain parameters, which will not be described in detail, had to be changed in the program.

The midpoint of the condyle was located, and a straight line was drawn from this point to the Frankfort horizontal plane to measure the disk position, thereby representing the 12 o'clock position. The angles

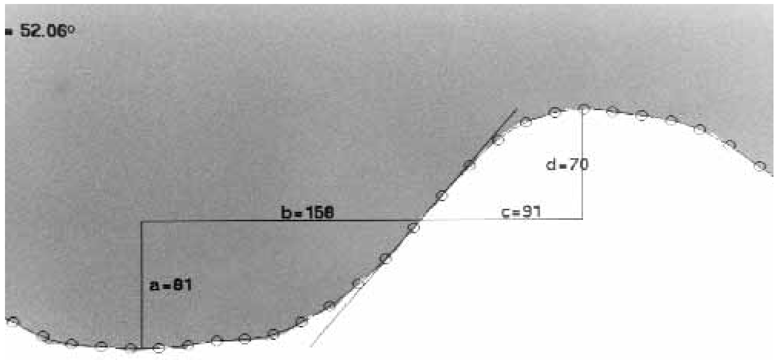

Fig 3. Automatic measurements on tomograms with Matlab software.

Table I. Analysis of reliability of the experimental method

	Correlation coefficient r	*Sample n*	*P value*
Angle	0.9557	40	<.001
a	0.9017	40	<.001
b	0.7881	40	<.001
c	0.8811	40	<.001
d	0.8951	40	<.001

between this straight line and the rear margin of the posterior band of the disk were measured in every slice. Positive values represented an anterior disk position, whereas negative values indicated a posterior disk position. An angle within ±30°(ie, the 11 to 1 o'clock position) range was assumed to be normal, whereas angles outside this range were assumed to indicate pathologic findings.

Symptom-free volunteers and symptomatic patients were classified into 4 diagnostic groups accordingly:

1. Asymptomatic volunteers (AV)
2. Disk displacement with reduction (DDR)
3. Disk displacement without reduction (DDN)
4. Asymptomatic side of the patients (ASP).

Eight volunteers who had unilateral or bilateral disk displacement and 12 patients who had no disk malpositions in either TMJ were excluded from this study because they did not belong to any of the aforementioned groups. Thus, this study was performed on a total of 81 subjects, of whom 25 were symptom-free volunteers (11 men, 14 women; mean age, 23.87 years) and 56 were symptomatic patients (12 men, 44 women; mean age, 33.35 years). The diagnosis of the patients was as follows: 18 bilateral DDR, 15 unilateral DDR; 5 bilateral DDN, 8 unilateral DDN patients; and 10 patients who had DDR on one side and DDN on the other side.

Three slices were selected for each joint to evaluate the morphology of the mandibular fossa and to determine the inclination of the articular eminence: the central, the most lateral, and the most medial slices in which the glenoid fossa and the condyle were visible. These images were input by using the Optimas software in tiff format (Fig 1). The region of the image containing the glenoid fossa was magnified 8 times. Contrast values were adjusted until the border of the compact bone around the fossa could be distinguished (Fig 2). Any visible margins of the condyle and the disk were removed from the image. In only one TMJ of a unilateral DDN patient, the fossa border of the lateral slice of the affected side could not be detected visibly and therefore it was not analyzed. Then the data were transferred to the Matlab package (The Mathworks, Inc, Natick, Mass).

The most superior point in the roof of the fossa, the most inferior point at the crest of the articular eminence, the inflection point, and the angle of the posterior slope were found on the magnetic resonance images with the aid of a computer (Fig 3). An analytic function (a piecewise continuous polynomial) was fit on these points by using the smoothing-spline method. Once the analytic expression was known, the minima and maxima points were located where its first derivative vanished and its second derivative was negative and positive, respectively. The inflection point was the point at which the second derivative vanished. By using the minima, maxima, and inflection point estimates, *a*, *b*, *c*, and *d* values were computed. The tangent passing through the inflection point of the slope and Frankfort horizontal plane forms angle α (Fig 4).

The sum of *a* and *b* values (fossa depth) and the ratio of the angulation values of the various posterior slope slices were calculated for further analysis.

To eliminate possible bias, a researcher who had no information about the classification of the patients and the volunteers performed measurements of the articular eminence.

Statistical analysis was conducted on a personal

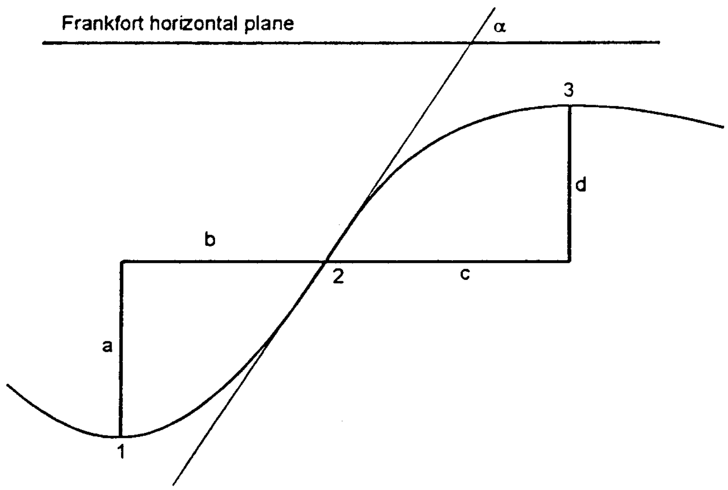

Fig 4. Measurements of articular eminence. *1,* The most inferior point at crest of articular eminence. *2,* Inflection point. *3,* Most superior point in roof of fossa. *a,* Height of tuberculum. *b,* Width of the tuberculum. *c,* Width of fossa. *d,* Height of fossa. *α,* Angle between tangent through inflection point and Frankfort horizontal plane.

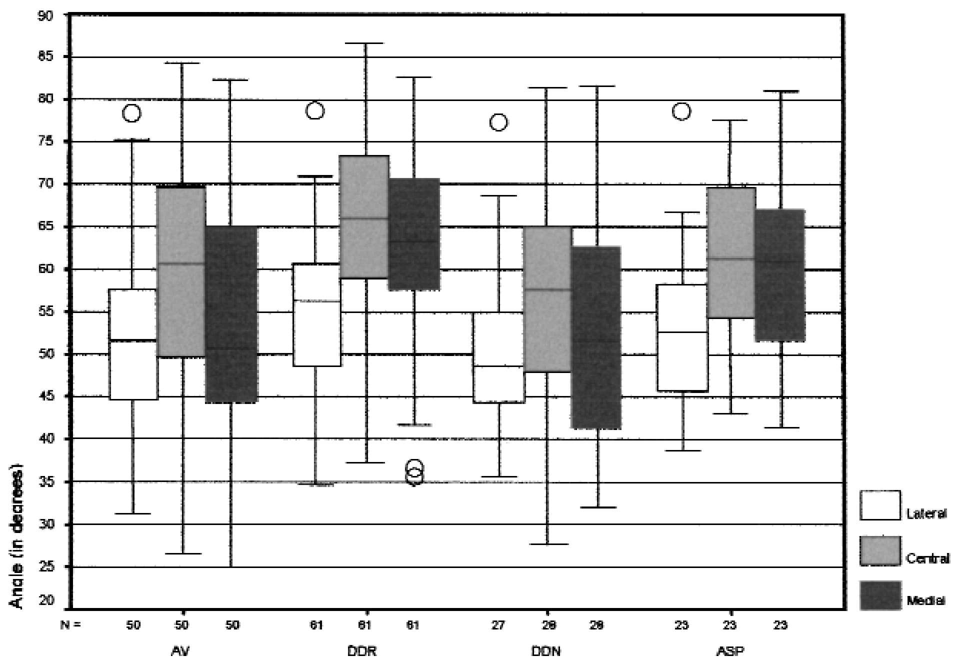

Fig 5. Comparison of posterior slope angles in 3 slices of diagnostic groups.

computer with the program SPSS/PC for Windows. The nonparametric Mann-Whitney *U* test was used to analyze differences among the diagnostic groups. Differences between the tomograms of the same joint and between the left and right joints of the same patient were analyzed with the Wilcoxon matched pairs test. To test the reliability of the experimental method, 40 magnetic resonance imaging scans were randomly selected and the measurements were analyzed by using the Spearman rho correlation.

RESULTS

Experimental method was found to be statistically reliable based on the Spearman rho test. Table I represents the correlation coefficients (*r*) and *P* values of *a*, *b*, *c*, and *d*, and *α* values measured at 2-week intervals.

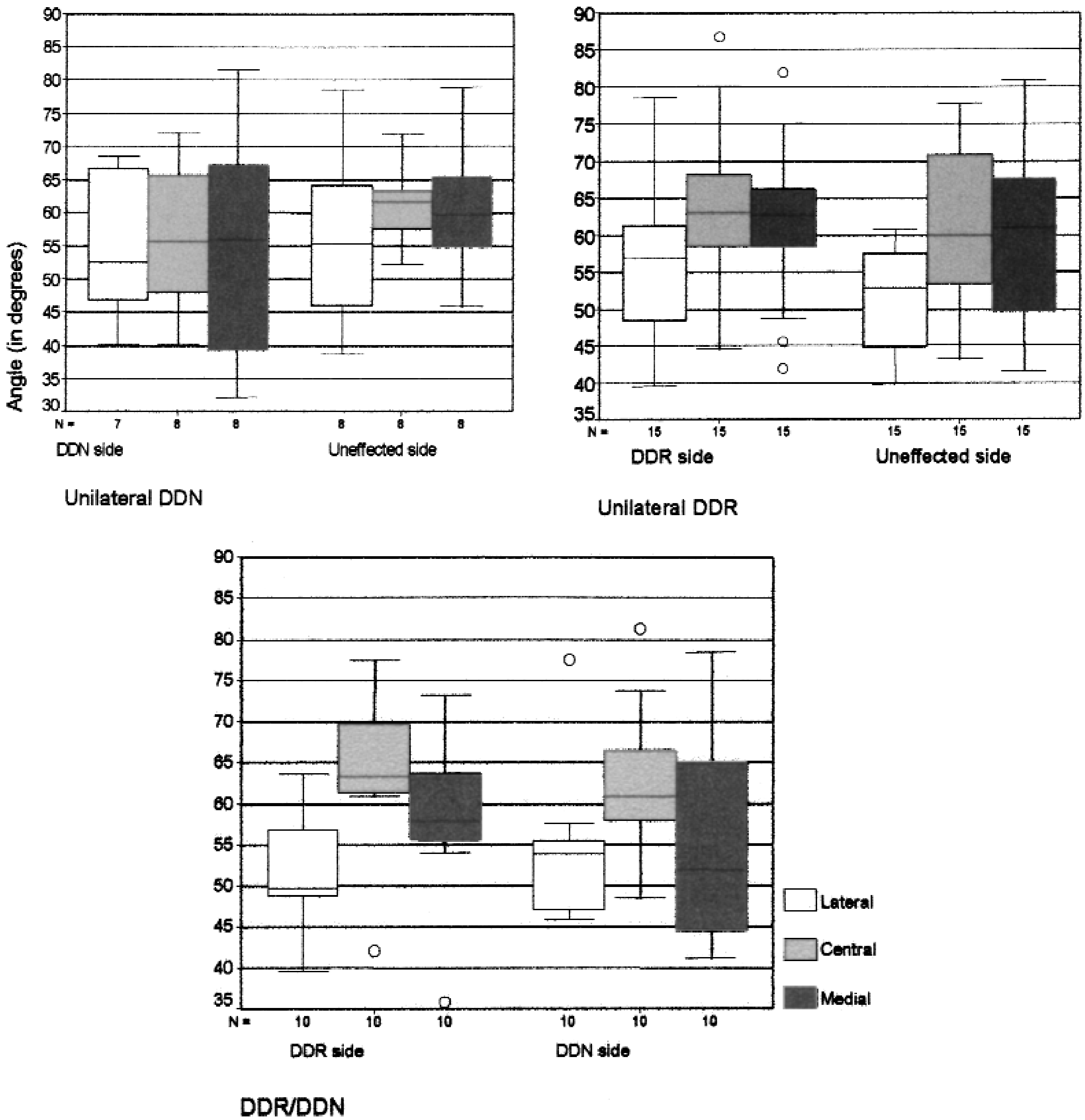

Fig 6. Comparison of posterior slope angles of unilateral DDN and DDR patients and patients who had DDR on one side and DDN on the other side.

No statistically significant differences were found between the left and right joints of any groups, and for this reason the data of both sides were pooled together. No correlation could be found between age and angulation values.

By using the Wilcoxon matched pairs test, variations of angulation between the posterior slopes of the lateral and the central slices and between the posterior slopes of the lateral and the medial slices were found to be significantly different ($P < .001$), whereas no statistically significant difference was found between the medial and the central slices.

A significant correlation was observed among the angulation of the posterior slope, the *a* and *c* values, and the fossa depth. The most statistically significant correlation among these values was between the *a* value and the angulation, with $r = 0.638$.

The Mann-Whitney *U* test was used to analyze the

Table II. Means and SDs of values of lateral, central, and medial slices from symptom-free TMJs of volunteers and from ASP group, and symptomatic TMJs of DDR and DDN patients (Angles were measured in degrees; other values in pixels)

	AV	*DDR*	*DDN*	*ASP*
	Mean/SD	*Mean/SD*	*Mean/SD*	*Mean/SD*
Lateral				
Angle	51.79 ± 11.20	54.32 ± 9.57	50.85 ± 10.20	52.78 ± 9.71
a	79.20 ± 27.25	88.01 ± 26.73	80.31 ± 29.43	97.34 ± 32.75
b	136.36 ± 34.88	133.15 ± 33.22	124.85 ± 30.65	149.26 ± 39.73
c	73.94 ± 29.02	83.31 ± 27.12	82.16 ± 24.39	68.92 ± 25.03
d	129.18 ± 40.89	142.57 ± 45.55	140.22 ± 37.12	116.91 ± 51.41
Fossa depth	208.38 ± 50.45	228.94 ± 45.70	220.53 ± 44.84	214.25 ± 58.15
Central				
Angle	60.03 ± 14.35	65.28 ± 11.82	56.07 ± 12.29	61.01 ± 9.48
a	97.47 ± 28.91	109.06 ± 24.22	92.20 ± 28.01	106.58 ± 30.06
b	171.04 ± 37.58	157.26 ± 39.89	155.46 ± 45.01	182.35 ± 36.21
c	69.34 ± 26.17	82.28 ± 26.97	79.71 ± 26.36	69.82 ± 15.52
d	112.62 ± 40.10	112.36 ± 34.74	130.82 ± 35.29	101.17 ± 20.66
Fossa depth	210.09 ± 47.14	221.42 ± 39.67	223.02 ± 39.07	207.76 ± 41.58
Medial				
Angle	53.57 ± 15.52	63.27 ± 10.44	53.28 ± 13.00	60.00 ± 11.09
a	85.60 ± 31.16	104.91 ± 25.18	85.06 ± 26.98	96.80 ± 26.05
b	157.78 ± 40.95	158.28 ± 32.07	151.86 ± 48.78	176.52 ± 41.34
c	57.51 ± 25.46	69.45 ± 24.80	62.38 ± 22.21	61.10 ± 21.67
d	93.46 ± 29.24	100.80 ± 31.63	107.93 ± 40.50	89.61 ± 24.68
Fossa depth	179.06 ± 40.92	205.72 ± 38.51	192.99 ± 51.03	186.40 ± 37.00

differences between the diagnostic groups. When only the lateral slices were evaluated, no difference was obtained between the angulation of the posterior slopes of the diagnostic groups. On the other hand, statistical differences were found between the central and the medial slices from the AV and DDR groups and also between those slices from the DDR and DDN groups (Fig 5). The angulations of the posterior slopes on the central and the medial slices in the DDR group (central, 65.27° ± 11.81; medial, 63.27° ± 10.44) were steeper than those in the joints of AV (central, 60.02° ± 14.35; medial, 53.57° ± 15.57) and in DDN joints (central, 56.02° ± 12.29; medial, 53.28° ± 13.00) (Table II). No significant difference was detected between both joints of the unilateral DDN and DDR patients and the patients who had DDR on one side and DDN on the other (Fig 6).

The ratio of the angulation of the medial slice to the angulation of the lateral slice was higher in DDR joints than in AV and DDN groups. This means that the angulation in the medial slice of the DDR joint is steeper than that in the lateral slice, but the angulation of the lateral and medial slices of the other 2 diagnostic groups (AV and DDN) are approximately equal to one other. The significance between the AV and DDR groups was found to be $P = .002$; the significance between the DDR and DDN groups was found to be $P = .025$. The ratio of the angulation of the medial slices to the central slices in the AV and DDR groups and in the AV and ASP groups was found to be significantly different ($P = .021$ and $P = .031$, respectively). A significant difference between the ratios of the angulation of the lateral to the central slice was found only between DDR and DDN groups ($P = .047$; Table III). No other differences were found with respect to the ratios of the slices between the diagnostic groups.

The tuberculum height (*a* value) of the central and medial slices in the DDR group was statistically significantly higher than that in the AV and DDN groups. The tuberculum height of the lateral slice in the AV group was lower than that in the DDR and ASP diagnostic groups, whereas the tuberculum height in the DDN group was lower than that in the ASP group.

No differences were observed in the fossa depth of the lateral and the central slices, whereas in the medial slices of the AV and DDR diagnostic groups a significant difference of $P = .001$ was obtained.

The tuberculum width (*b* value) of the central and medial slices in the DDR and DDN groups was found to be different than that in the ASP group. This difference was observed only in the lateral slices from the DDR and ASP groups. The tuberculum width of the central slice in the DDR diagnostic group was found to be smaller than that in the AV group.

The fossa width of the lateral slices was not different among the groups. However, on the central and medial

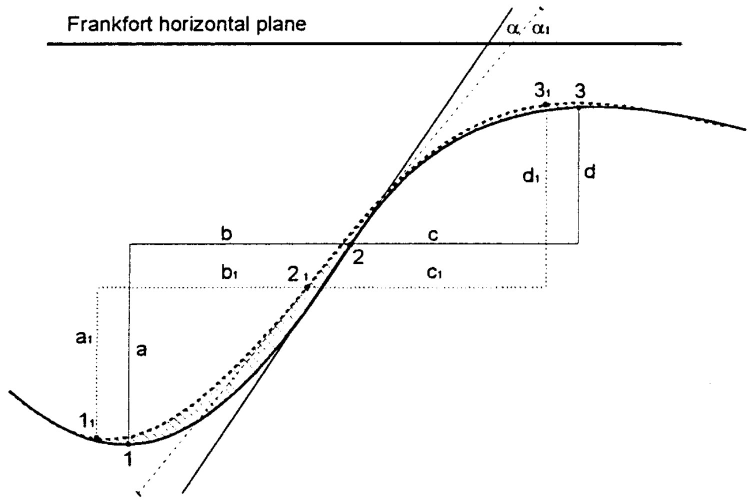

Fig 7. Flattening process of articular eminence in course of progress from DDR to DDN. $\alpha > \alpha^1/a > a^1/b \cong b^1/c \cong c^1/d < d^1$

Table III. Statistical comparison of posterior slope angulation; *a*, *b*, *c*, and *d* values; fossa depth; and ratio of angles in different slices from TMJs of AV, ASP, DDR, and DDN groups using Mann-Whitney *U* test

	AV/DDR	*AV/DDN*	*AV/ASP*	*DDR/DDN*	*DDR/ASP*	*DDN/ASP*
Lateral						
Angle	$P = .136$	$P = .543$	$P = .648$	$P = .070$	$P = .419$	$P = .419$
a	$P = .047^*$	$P = .923$	$P = .015^*$	$P = .099$	$P = .414$	$P = .036^*$
b	$P = .623$	$P = .196$	$P = .254$	$P = .349$	$P = .168$	$P = .044^*$
c	$P = .295$	$P = .295$	$P = .704$	$P = .772$	$P = .061$	$P = .131$
d	$P = .191$	$P = .191$	$P = .102$	$P = .874$	$P = .003^\dagger$	$P = .007^\dagger$
Fossa depth	$P = .165$	$P = .165$	$P = .877$	$P = .322$	$P = .055$	$P = .335$
Central						
Angle	$P = .046^*$	$P = .239$	$P = .821$	$P = .002^\dagger$	$P = .083$	$P = .140$
a	$P = .043^*$	$P = .411$	$P = .462$	$P = .009^\dagger$	$P = .348$	$P = .156$
b	$P = .016^*$	$P = .050$	$P = .226$	$P = .720$	$P = .006^\dagger$	$P = .022^*$
c	$P = .017^*$	$P = .134$	$P = .794$	$P = .387$	$P = .019^*$	$P = .179$
d	$P = .751$	$P = .009^\dagger$	$P = .480$	$P = .013^*$	$P = .290$	$P = .001^\dagger$
Fossa depth	$P = .077$	$P = .088$	$P = .821$	$P = .730$	$P = .136$	$P = .135$
Medial						
Angle	$P < .001^\ddagger$	$P = .950$	$P = .069$	$P = .001^\dagger$	$P = .184$	$P = .054$
a	$P = .001^\dagger$	$P = .967$	$P = .121$	$P = .004^\dagger$	$P = .181$	$P = .173$
b	$P = .787$	$P = .613$	$P = .074$	$P = .353$	$P = .049^*$	$P = .029^*$
c	$P = .017^*$	$P = .239$	$P = .469$	$P = .519$	$P = .154$	$P = .416$
d	$P = .315$	$P = .103$	$P = .699$	$P = .316$	$P = .225$	$P = .080$
Fossa depth	$P = .001^\dagger$	$P = .227$	$P = .454$	$P = .160$	$P = .018^*$	$P = .545$
Angle ratios						
Lat/med	$P = .002^\dagger$	$P = .936$	$P = .069$	$P = .025^*$	$P = .605$	$P = .161$
Lat/cen	$P = .120$	$P = .539$	$P = .821$	$P = .047^*$	$P = .380$	$P = .448$
Med/cen	$P = .021^*$	$P = .428$	$P = .031^*$	$P = .367$	$P = .884$	$P = .353$

Lat, Lateral; *Med,* medial; *Cen,* central.
$^*P < .05$.
$^\dagger P < .01$.
$^\ddagger P < .001$.

slices, the fossa width (*c* value) in the DDR group was higher than that in the ASP and AV groups. No difference was observed in the fossa height (*d* value) of the medial slice, but the fossa height of the central slice in the DDN group was higher than in the other 3 diagnostic groups. Fossa height of the lateral slice in the DDN group was found to be statistically significantly higher than the height obtained in the ASP group.

DISCUSSION

The results of our study indicate that significant angular differences exist between the different slices of the articular eminence. These differences demonstrate the necessity of examining different slices in the interest of scientific research and clinical evaluations. These findings were in accordance with the results of Ichikawa et al.[18,20] In the study by Panmekiate et al,[9] they did not notice any statistical difference in the inclination of different slices. As suggested by them, this outcome might be because of the method used for determining the inclination or the selection of the lateral and medial slices that were too close to the central slice. A positive correlation was found between the angulation of the posterior slope and the depth of the fossa in our study, which is in accordance with the results of the clinical study by Quirch et al.[16] In the present study, a more distinct correlation was determined to exist between angulation and tuberculum height. The angle α between the Frankfort horizontal plane and the tangent that must pass through the inflection point should also be greater in cases in which the inflection point is located in a higher position with respect to the geometry of the articular eminence. Comparison of the diagnostic groups yielded more conclusive evidence of the relationship between internal derangement and tuberculum height than between internal derangement and fossa depth. Compared with the joints of AV, the DDR diagnostic group had a steeper angulation in the posterior slope. This is in agreement with the results of Kerstens et al[7] and Sato et al[11] and supports the statement of Atkinson and Bates[6] with respect to a steeper slope being a predisposing factor for internal derangement. In contrast, Ren et al[15] argued that a steeper slope was not an etiologic factor for internal derangement and hypothesized that the more shallow slope seen in the eminence of those patients as compared with that seen in AV was because of remodeling or degenerative change caused by the disorder itself. A 1-to-1 comparison of their results with ours is not well justified because they did not distinguish between DDR and DDN groups in their study. On the other hand, our results indicating wear on the bone surface at the DDN stage due to remodeling or degenerative change seem to be in agreement with theirs.

Our results also suggest that in addition to the steeper slope factor, a greater tuberculum and a smaller fossa height should also be considered predisposing factors for anterior disk displacement. The angulation of the posterior slope showed significant differences only in the central and medial slices; no significant differences were observed in the lateral slices from the diagnostic groups. In the DDR group, the ratio of the angulation on the medial slices to the angulation on the other 2 slices was found to be larger than in the symptom-free volunteers. This suggests that not only the steepness of the slope but also the value of the medial slice relative to the central and lateral slices could be responsible for the development of disk malpositions.

A steeper slope on all 3 slices of the articular eminence in the DDR group as compared with those in the symptom-free volunteers would have indicated that the condyle traces a steeper pathway during opening and protrusive mandibular movements. The fact that the angulation of the medial slice was steeper than the other slices also required that the nonworking–side condyle trace a steeper pathway inferiorly, anteriorly, and medially during lateral movements in patients with this disorder. This finding suggests that not only the protrusive condylar pathway angulation but also the lateral condylar pathway steepness may be a responsible factor in the development of disk displacements.

The angulation of the posterior slope of the DDN patients was found to be shallower than that of the DDR patients and was close to the angulation values of the symptom-free volunteers. This finding contradicts many other researchers' results. Galante et al[14] observed no difference between the angulations of the 2 diagnostic groups in their laminographic study, but a shallower angulation of the condylar pathway was observed when the results from the DDN/degenerative joint disease diagnostic group were compared with those from the DDR group. Their explanation was that a more shallow condylar pathway inclination was the result of anteroposterior wear in the joints of the DDN/degenerative joint disease group, although the angulation of the posterior slope might not have been changed. In our study, the fact that the DDN group had a significantly smaller a value and a significantly larger d value than did the DDR group indicates a possible displacement of the inflection point in an inferior and anterior direction. The reason for the displacement may be the existence of a flattening around the inflection point. This finding is in accordance with the measurements of the inflection point region made by Panmekiate.[9] Another interesting result is that the medial angulation in the DDN group is smaller than in the DDR group and is almost within normal limits. This observed difference between the 2 groups indicates a flattening process occurring at the medial slice during the prognosis of the disorder. Hugger et al[13] report that the flattening on the bone surface occurs before that in the articular eminence of the condyle. In a former study,[21] the amount of wear was found to be more evident in the DDN diagnostic group than in the DDR and AV groups ($P < .001$). Contrary to the results of Galante et al,[14] the flattening of the articular eminence was not in the anteroposterior direction while the disorder progressed from the DDR to the DDN stage. Starting from the inflection point, the flattening process was in the inferior and in the anterior direction and led to a decrease in the angulation of the articular eminence (Fig 7). The ASP group was significantly different from other diagnostic groups because of the higher tuberculum and larger angulation value on the medial slices of the articular eminence, although in the central slice, the inclination value was very close to its angulation. On the other hand, the absence of any significant difference between the ASP and DDR groups indicates that the joints of the unaffected side are also—at best—at risk of disk displacement.

The comparison of the unilateral DDR and DDN patients and the patients with DDR on one side and DDN on the other side was performed. Especially in medial portions, the DDR side was found to be 2° steeper than the contralateral symptom-free side and the DDN side was found to be 6° more shallow than the contralateral symptom-free side, whereas the DDR side was observed to be 4° steeper than the contralateral DDN side. But no significant differences were found for the angulation values of the posterior slopes between both sides. This phenomenon could be the result of the small sample size of the patients having joints belonging to different diagnostic groups. On the other hand, the joints of these patients were at various stages of the disease when the MR images were taken. We also believe that our conclusion is purely speculation and requires further longitudinal study.

CONCLUSIONS

Angular and linear TMJ variations in patients with internal derangement and in symptom-free volunteers were evaluated in this study. The following conclusions can be drawn from our results:

1. In the DDR group, the angulation of the posterior slope was steeper and the tuberculum was higher than in the AV group. This finding supports the hypothesis that a steeper slope and a higher tuberculum are factors associated with disk displacement.
2. The DDN patients had a more shallow inclination of the posterior slope, a shorter tuberculum, and deeper fossa than did the DDR patients; this could be associated with the flattening observed in the bone surface during the DDN stage.
3. The angulation of the posterior slope of the medial slice was larger than the central and lateral slices in the DDR patients may indicate excessive intra-articular loading. This finding indicates that not only a steeper slope but also the ratio of the angulations at different depths of the fossa may have some relationship to disk displacement.

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Reprint requests:

Peter Rammelsberg, DMD
Poliklinik für Zahnärztliche Prothetik Universität München
Goethestrasse 70
D-80336 Munich, Germany
pram@dent.med.uni-muenchen.de