Improved Interaction Models of Temporomandibular Joint Anatomic Relationships in Asymptomatic Subjects and Patients with Disc Displacement with or without Reduction

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Aims: *To consider temporomandibular joint (TMJ) anatomic interactions in order to refine hard tissue models differentiating (1) joints diagnosed with disc displacement with reduction (DDwR) or without reduction (DDw/oR) from asymptomatic joints (Normals), and (2) DDwR joints from DDw/oR joints.* ***Methods:*** *TMJ tomograms of 84 women with unilateral DDwR and 78 with unilateral DDw/oR were compared against each other and against those of 42 female Normal joints through the use of 14 linear and angular measurements, 8 ratios, and 34 interactions. A classification tree model for each comparison was tested for fit with sensitivity, specificity, accuracy, and log likelihood and compared to logistic regression models.* ***Results:*** *In the classification tree model comparison, the DDwR model versus the Normal model realized 35.9% log likelihood (88.0% sensitivity, 66.7% specificity); the DDw/oR model versus the Normal model realized 38.8% log likelihood (69.6% sensitivity, 85.7% specificity). The DDwR model versus the DDw/oR model realized 33.3% log likelihood (76.0% sensitivity, 73.1% specificity). In the logistic regression model comparison, the DDwR model versus the Normal model realized 40.8% log likelihood (82.1% sensitivity, 78.6% specificity) and the DDw/oR model versus the Normal model realized 61.1% log likelihood (85.9% sensitivity, 90.5% specificity). The DDwR model versus the DDw/oR model realized 21.5% log likelihood (60.3% sensitivity, 79.8% specificity). The addition of interactions to the logistic regression models improved the previously published log likelihood from 99% to 149%.* ***Conclusion:*** *The interactions improved logistic regression models and the data suggest that anatomic characteristics influence joint functional status. Because the models incorporated nearly all considered anatomic measurements, no anatomic factor is redundant in the closed TMJ biological system.* J OROFAC PAIN 2004;18:192–202

Key words: disc displacement with reduction, disc displacement without reduction, multifactorial analysis, temporomandibular joint anatomy

An incidence as high as 9% over 3 years for cases of disc displacement with reduction (DDwR) developing into disc displacement without reduction (DDw/oR) has been reported.[1] Understanding similarities and differences between temporomandibular joint (TMJ) disc displacement with and without reduction would help clarify the potential progression of DDwR. This paper approaches this goal by studying the anatomic differences between joints with DDwR and DDw/oR from asymptomatic joints and also compares DDw/oR joints with joints that have not progressed from DDwR at the time of examination. By adding complex interactions and relationships, it expands upon 2 initial studies[2,3] that come close to recommended levels of prediction accuracy through examination of direct measurements of TMJ intracapsular geometry and some selected ratios in an exploratory search for differences.

Adequate scientific support is scant for the numerous and sometimes incompatible hypotheses for disc displacement development that have been proposed.[4–13] We believe that confusion over the issue is due to the failure to consider the many contingencies that can be revealed from multifactorial models in studies in which patients with DDwR and patients with DDw/oR are differentiated. Previous investigations disagree primarily about the importance of condyle-fossa positional relationships[14–24] and eminence slope angles.[4,25–27] Most of these studies focused on comparing 1 factor at a time and were thus unable to reveal more complex potential relationships reflecting the many inherent biologic interactions.[28] Previously published results by the authors suggest that the low predictive values of isolated variables should not be overinterpreted until re-examined in multifactorial models.[29]

The current classification of internal derangements of the TMJ is based primarily on the staging of disc displacement.[30] The disc was at one time presumably functionally normal,[3] so the derangement is arguably the result of unfavorable joint stability characteristics (rather than the disc being the only dysfunction problem). The current study adds to our understanding by seeking to identify hard tissue anatomic characteristics that distinguish joints with DDw/oR from Normals as well as from joints with DDwR. These could be tested in a future study of factors associated with either progression or nonprogression. The goals of this study were to consider interactions of direct anatomic measurements in order to refine hard tissue anatomic models differentiating *(1)* joints diagnosed with DDwR or DDw/oR from Normals,[2] and *(2)* joints diagnosed with DDwR from those diagnosed with DDw/oR.[3] The tested null hypothesis was that there are no hard tissue central sagittal relationship differences between joints diagnosed with disc displacement with or without reduction versus Normals, or between the 2 disc displacement conditions themselves.

Materials and Methods

Samples

Experimental Samples. Eighty-four dysfunctional joints from female patients diagnosed with unilateral DDwR (mean age 35.2 ± 14.54 years) and 78 dysfunctional joints from female patients diagnosed with unilateral DDw/oR and limited jaw opening (mean age 31.96 ± 12.87 years) were selected retrospectively from a pool of clinical cases[2,30–32] previously differentiated according to the Diagnostic Research Criteria for Temporomandibular Disorders (RDC/TMD)[33] as previously described.[2] Chronic DDw/oR cases without limited opening were not included because the clinical identification of these cases was much less accurate than those with limited opening.[34] The primary inclusion criteria were good-quality axially corrected serial TMJ tomograms and an absence of clinical signs of osteoarthrosis. Only women were studied because too few men have these diagnoses. These criteria have good clinical accuracy for identifying the derangements.[35]

Magnetic resonance imaging (MRI) was not considered a research requirement for defining this substantial sample because the level of expected clinical misclassification (about 10% to 15%) for clinical diagnosis is similar to that reported for MRI.[36–38] Furthermore, MRI-determined "silent disc displacements"[35] may in fact reflect the biological range of normal disc position.[39,40] The use of MRI to define "normal" in the absence of clinical symptoms is presumptive. In the authors' opinion, the primary benefit of MRI would be to add soft tissue variables to expand the model. Other limitations of the methods have been discussed in detail in previous publications.[2,3,28]

Control Sample. The 42 control joints (Normals) were from 21 previously identified totally asymptomatic female subjects (mean age 24.2 ± 2.9 years) who had consented to a tomographic examination of their TMJs.[13] The exclusion criteria were a history of symptoms or findings of TMD, occlusal equilibration, orthodontic treatment, multiple crown restorations, or complaint of headache. Nine of the correlations between the 14 right and left joint measurements in the control samples were significant ($P < .048$ to .001). Thus, the right and left control joint measurements, while not identical, were not completely independent. To allow for a pooling of right and left control joints to realize a much larger normal sample size for comparisons, the statistical analysis was adjusted by the generalized linear model (GLM-SAS PROC Genmod, SAS Institute[41]) in the

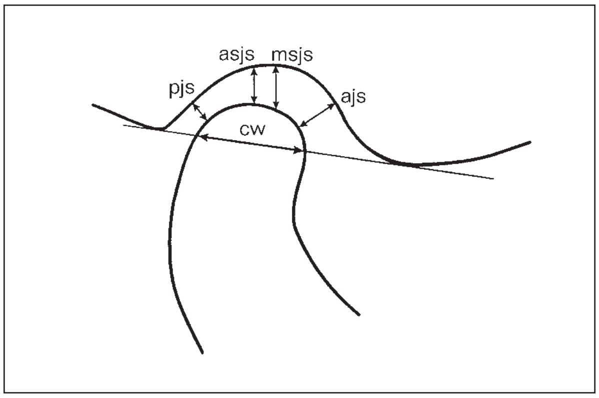

Fig 1a Posterior joint space (pjs) = the smallest distance between the posterior condyle and the fossa; anterior joint space (ajs) = the smallest distance between the anterior condyle and the fossa; absolute superior joint space (asjs) = the vertical distance from the highest point of the condyle to the fossa; maximum superior joint space (msjs) = the vertical distance from the highest point of the fossa to the condyle; condyle width (cw) = the dimension between the anterior and posterior condyle outline along a tangent drawn between the deepest point of the eminence (ie, the eminence crest [ec]) and the post–glenoid process.

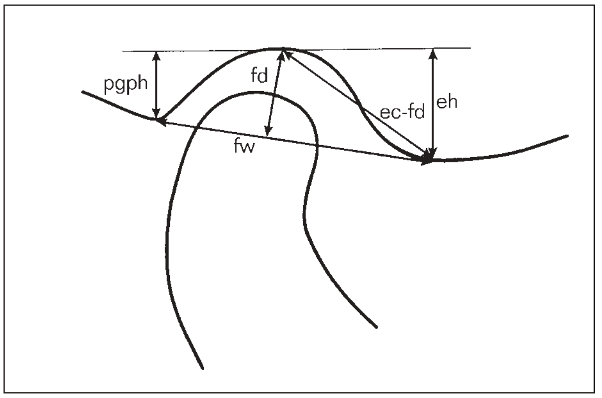

Fig 1b Fossa width (fw) = the distance between the eminence crest and the post–glenoid process; fossa depth (fd) = the distance between the highest point of the fossa and the point where a connecting line meets the fossa width tangent at a right angle; eminence height (eh) = the distance between the eminence crest and a line drawn as a horizontal tangent to the highest point of the fossa; post–glenoid process height (pgph) = the distance between the deepest point of the post–glenoid process and a line drawn as a horizontal tangent to the highest point of the fossa; ec-fd = the distance between the eminence crest and the highest point of the fossa.

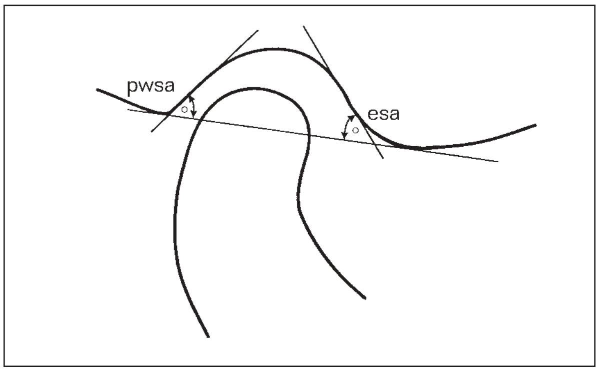

Fig 1c Angles between the tangent connecting the eminence crest with the deepest point on the post–glenoid process and the tangent of the posterior eminence and the tangent of the anterior post–glenoid process (esa = eminence slope angle; pwsa = posterior wall slope angle).

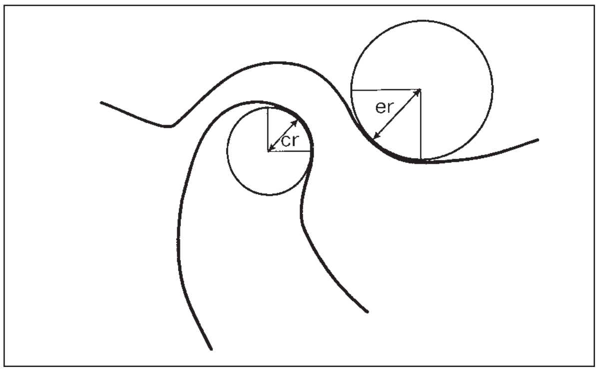

Fig 1d Eminence radius (er) = the radius of a circle fitted to the 6-to-9-o'clock position of the eminence; condyle radius (cr) = the radius of a circle fitted to the 12-to-3-o'clock position of the condyle.

Figs 1a to 1d reprinted from Pullinger AG, Seligman DA, Multifactorial analysis of differences in temporomandibular joint hard tissue anatomic relationships between disk displacement with and without reduction in women, J Prosthet Dent 2001;86:407–419, with permission from the Editorial Council of the *Journal of Prosthetic Dentistry*.

univariate and logistic regression comparisons, taking into account the fact that each asymptomatic person had 2 possibly nonindependent observations. In the classification tree comparisons, only 21 randomly selected right or left control joints were utilized because no statistical correction method was available for this analysis. The contralateral asymptomatic joints in patients were rejected as controls because of potential reciprocal effects.

Measurements

Fourteen anatomic features from images of central section tomograms (condyle size and position; mandibular fossa size and shape; posterior glenoid process size, eminence size, and shape; and actual joint spaces [Figs 1a to 1d]),[3,28] 8 ratios, and 34 second-order interactions of the factors (shown through correlation analysis to be geometrically

Table 1a List of Interactions

ajs/pjs × fw/cw	fw × pgph
cpi × msjs/ajs	fw × pwsa
fw/cw × asjs/ajs	cw × pwsa
fw/cw × cpi	fw/cw × pwsa
fw/fd × cpi	cw × eh/pgph
fw/fd × asjs/ajs	cr × eh/pgph
msjs × eh	cr × pgph
asjs × eh	fw × fd
ec-fd × pjs	ec-fd × eh
ec-fd × msjs	ec-fd × pwsa
ec-fd × cpi	ec-fd × pgph
eh/pgph × pjs	er × fw
eh × pjs	er × ec-fd
msjs/ajs × fw	pgph × eh
asjs/ajs × fw	pgph × cw
msjs/ajs × pwsa	pgph × esa
eh/pgph × cpi	cw × fw

Table 1b List of Ratios

Condyle position index (cpi)*
ajs/pjs
Log ajs/pjs
fw/cw
eh/pgph
asjs/ajs
msjs/ajs
fw/fd

*cpi = (pjs – ajs)/(pjs + ajs) × 100%, and this represents the percentage condyle position from concentric (+ = anterior, – = posterior).

independent) were measured and compared between the control and deranged joints in a blinded manner (Tables 1a and 1b). The measurements were calibrated to real object dimensions and included a magnification factor of the tomographic equipment.[3,28] Accuracy and precision of measurements were described previously[3,28] and are considered good.

Data Analysis and Statistics

The goal was the development of improved multifactorial models associated with DDwR or DDw/oR compared to previously published models that consisted only of noninteracting independent variables and ratios.[2,3]

Classification Tree Analyses. The classification tree method (AnswerTree 2.0; SPSS)[42] was used to search for hidden structure in the data, as published previously by the authors.[2,3] The outcome options (dependent variables) in the trees were always DDwR or Asymptomatic (Asx) (Fig 2); DDw/oR or Asx (Fig 3); or DDwR or DDw/oR (Fig 4). The distribution for each of the terminal nodes in the trees was the mean of 10 successive partitioned set-aside validation samples that were independent of the partitioned remaining samples used for construction of the trees. The method was described previously in detail.[2,3] The validation sample distributions (30% of the entire sample) were used to determine overall accuracy, sensitivity, specificity, and the percentage reduction in the maximum log likelihood (Rescaled Cox and Snell R^2).[43] The control joint sample in Figs 2 and 3 was composed of 1 randomly selected right or left joint from each of the 21 control subjects. The interactions suggested by the pathways to

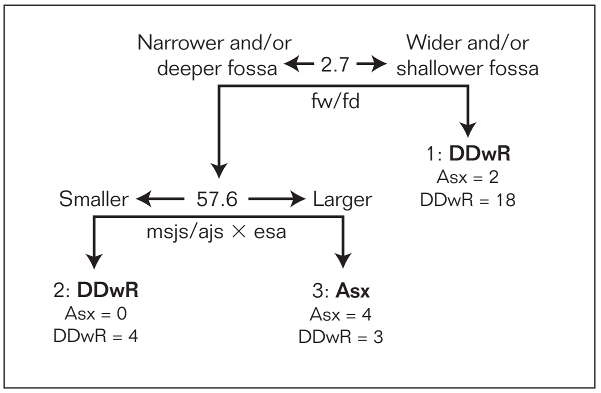

Fig 2 The representative classification tree derived from the tomographic measurements, ratios, and derived interactions for predicting Normal (control) Asx joints versus DDwR joints. The predicted class is given in bold for each terminal node. The tree begins with the fw/fd and follows the arrows downward until a terminal node is reached. For example, the endpoint for node 2 is reached with a fw/fd smaller than 2.7 and msjs/ajs × esa is smaller than 57.6. The distributions for each group are shown for each terminal node for the 30% set-aside testing sample from which the sensitivity, specificity, accuracy, and Rescaled Cox and Snell R^2 are derived. Sensitivity: 88.0%; specificity: 66.7%; Rescaled Cox and Snell R^2 = 35.9%, $P < .0001$; accuracy: 83.9%.

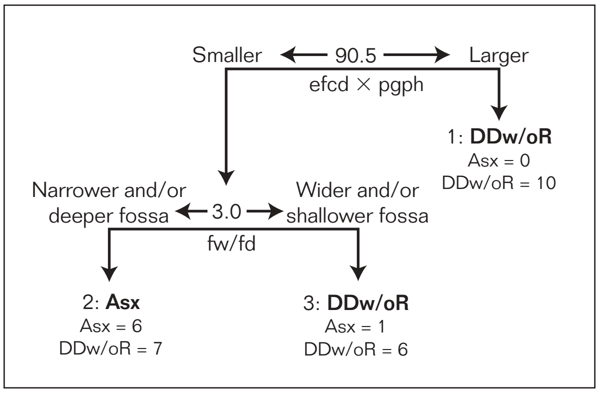

Fig 3 The representative classification tree for predicting DDw/oR joints versus normal joints. For an explanation of how to interpret the tree, see the legend of Fig 2. Sensitivity: 69.6%; specificity: 85.7%; Rescaled Cox and Snell R^2 = 38.8%, $P < .0001$; accuracy: 73.3%.

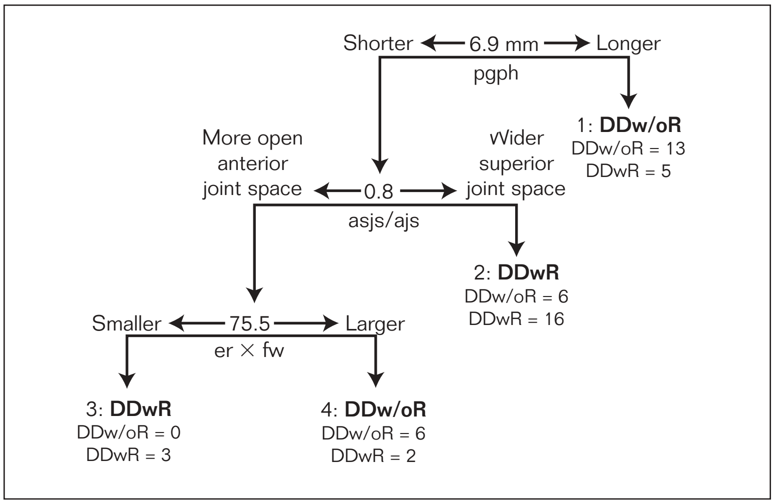

Fig 4 Representative classification tree for predicting DDwR joints versus DDw/oR joints. For an explanation of how to interpret the tree, see the legend of Fig 2. Sensitivity (prediction of DDw/oR): 76.0%; specificity: 73.1%; Rescaled Cox and Snell R^2 = 33.3%, $P < .0001$; accuracy: 74.5%.

the terminal nodes were further interpreted through evaluations of scatter plots with average ranges defined by the normal joint distributions.

Logistic Regression Analysis. All 56 variables were entered into the logistic regression model (SPSS Base 8.0). Selection was made among the potential predictors on the basis of the stepwise backward selection method, as described previously in detail.[2,3,28] For entry, $P \leq .05$ was required for entry and $P \geq .15$ for elimination. The model was then modified by the generalized linear model (GLM-SAS PROC Genmod[41]). The sensitivity and specificity of the model was estimated by fitting the entire sample back into the model. The percent amount of variation in the disc displacement outcome (as measured by the log likelihood) accounted for by the model was computed by the Rescaled Cox-Snell R^2 statistic.[43]

Results

Classification Tree Analyses

DDwR Joints vs Normals. The method generated a tree consisting of 3 terminal nodes (Fig 2). Pathways 1 and 2 identified predominantly DDwR joints, while pathway 3 predominantly identified Normals.

One branch of the DDwR tree model utilized only the fw/fd ratio to assign 72% (18/25) of the DDwR joints (validation sample) to node 1. A second branch utilized the product of the maximum superior joint space/anterior joint space (msjs/ajs) ratio and the eminent slope angle (esa) (msjs/ajs × esa) subordinate to the fossa width/fossa depth (fw/fd) ratio to assign subjects to a DDwR node (2) and to 1 control node (3). Node 2 had no false positive assignments. The entire model accounted for 35.9% of the log likelihood (Rescaled Cox and Snell R^2), with 83.9% accuracy (88.0% sensitivity, 66.7% specificity).

DDw/oR Joints vs Normals. The method generated a tree consisting of 3 terminal nodes (Fig 3). Pathways 1 and 3 identified predominantly DDw/oR joints, while pathway 2 predominantly identified Normals.

One branch utilized the product of the eminence length with the post–glenoid process height (pgph) (ecfd × pgph) to assign 43% of the DDw/oR joints to node 1 without any false positives. Another branch utilized the product of the fw/fd ratio subordinate to the product of ecfd × pgph to assign joints to a DDw/oR node (3) and to 1 control node (2).

The entire model accounted for 38.8% of the log likelihood (Rescaled Cox and Snell R^2) with 73.3% accuracy (69.6% sensitivity, 85.7% specificity).

DDwR Joints vs DDw/oR Joints. The method generated a tree consisting of 4 terminal nodes (Fig 4). Pathways 1 and 4 identified predominantly DDw/oR joints, while pathways 2 and 3 identified predominantly DDwR joints. The tree model utilized the eminence radius (er) × fw interaction (third tier) and the asjs/ajs ratio (second tier), subordinate to the pgph (first tier), to account for 33.3% of the log likelihood (Rescaled Cox-Snell R^2; $P < .0001$), with 74.5% accuracy and a sensitivity (predictive accuracy for DDw/oR) of 76.0%, and a specificity (predictive accuracy for DDwR) of 73.1%.

Multiple Logistic Regression Analysis

DDwR Joints vs Normals. The logistic regression model incorporated 5 direct measurement variables (fd, eh, ecfd length, cr, and pgph), 1 ratio (condyle position index), and 2 interactions (Table 2). The model accounted for more of the log likelihood (40.8% Rescaled Cox-Snell R^2, $P < .0001$) than the tree model (35.9%). The 82.1% sensitivity for identification of DDwR was slightly less than the sensitivity using the tree model (88.0%), and the 78.6% specificity for identification of controls was higher than specificity for the tree model (66.7%).

DDw/oR Joints vs Normals. The logistic regression model incorporated 5 direct measurement variables (fd, cr, pgph, pwsa, and the ecfd length), 5 ratios, and 5 interactions (Table 3). The model accounted for more of the likelihood than the tree model (61.1% Rescaled Cox-Snell R^2, $P < .0001$ versus 38.8% in the tree model). Both the 85.9% sensitivity and 90.5% specificity for the differentiation of DDw/oR from Normals were more than the values in the tree model, 69.6% and 85.7% respectively.

DDwR vs DDw/oR. The logistic regression model incorporated 5 direct measurement variables (pgph, eh, er, posterior joint space [pjs], and the eminence length), 1 ratio, and 3 interactions (Table 4). The logistic regression model accounted for less of the likelihood than the tree model (21.5% Rescaled Cox-Snell R^2, $P < .0001$ versus 33.3% in the tree model). The 60.3% sensitivity for identification of DDw/oR was less than the 76.0% in the tree model, and the 79.8% specificity for identification of DDwR was modestly higher than the 73.1% in the tree model.

Improvement in the Model Predictability when Interactions are Included

Compared to the formerly published noninteracting factor models,[2,3] there was a reduction in the percentage Rescaled Cox and Snell R^2 value for the DDwR joints versus Normals in the tree model (–3%) and improvements in the DDw/oR joints versus Normals (+32%) and the DDwR joints versus DDw/oR joints (+6%) in the tree models when interactions were included (Table 5). There were larger improvements in the Rescaled Cox and Snell R^2 for the logistic regression models, namely +99% improvement for DDwR joints versus Normals, +149% for DDw/oR joints versus Normals, and +117% for DDwR joints versus DDw/oR joints.

Table 2 Final Logistic Regression Model: DDwR vs Normals

	β	*P*
Fossa depth (fd)	–4.3261	.0001
Eminence height (eh)	1.9904	.0009
Condyle position index (cpi)	–0.0360	.0024
Eminence crest to fossa depth length × post–glenoid process height (ec–fd × pgph)	0.3596	.0036
Eminence crest to fossa depth length (ec–fd)	–2.1681	.0070
Condyle radius (cr)	1.8598	.0272
Condyle radius × post–glenoid process height (cr × pgph)	–0.2618	.0374
Post–glenoid process height (pgph)	–1.0738	.4164
Constant	18.1201	.0345

Sensitivity: 82.1%; specificity: 78.6%; Rescaled Cox and Snell R^2 = 40.8%, $P < .0001$; accuracy: 81.0%.

Table 3 Final Logistic Regression Model: DDw/oR vs Normals

	β	*P*
Fossa depth (fd)	–2.8109	.0002
Condyle position index × maximum superior joint space/anterior joint space (cpi × msjs/ajs)	0.0891	.0004
Condyle position index (cpi)	–0.2294	.0010
Eminence crest to fossa depth length × post–glenoid process height (ec–fd × pgph)	0.3182	.0071
Condyle radius × eminence height/ post–glenoid process height (cr × eh/pgph)	1.5929	.0080
Condyle radius (cr)	–1.4326	.0090
Fossa width/condyle width × posterior wall slope angle (fw/cw × pwsa)	0.2235	.0120
Anterior joint space/posterior joint space (ajs/pjs)	–2.4101	.0163
Eminence crest to fossa depth length × posterior wall slope angle (ec–fd × pwsa)	–0.0339	.0217
Fossa width/condyle width (fw/cw)	–9.8368	.0260
Post–glenoid process height (pgph)	–0.7388	.4269
Posterior wall slope angle (pwsa)	–0.1730	.4776
Eminence height/post–glenoid process height (eh/pgph)	–1.2369	.5392
Maximum superior joint space/anterior joint space (msjs/ajs)	–0.5042	.5412
Eminence crest to fossa depth length (ec–fd)	0.2282	.8173
Constant	–23.9374	.1215

Sensitivity: 85.9%; specificity: 90.5%; Rescaled Cox and Snell R^2 = 61.1%, $P < .0001$; accuracy: 87.5%.

Discussion

This is a condition-specific paper characterizing DDwR versus DDw/oR and both versus normal TMJ anatomy. Previously published research on derangement characterization by the authors[2,3] was limited to actual linear and angular measurement

Table 4 Final Logistic Regression Model: DDwR vs DDw/oR

	β	*P*
Post–glenoid process height (pgph)	1.3097	< .0001
Eminence height to post–glenoid process height ratio (eh/pgph)	7.2049	.0021
Eminence height (eh)	–1.9413	.0035
Eminence radius × eminence length (er × ec–fd)	–0.1189	.0078
Eminence radius (er)	1.4660	.0087
Posterior joint space (pjs)	2.2955	.0173
Eminence height to post–glenoid process height ratio × posterior joint space (eh/pgph × pjs)	–1.4695	.0334
Eminence length × eminence height (ec–fd × eh)	0.0876	.0485
Eminence length (ec–fd)	0.2526	.5147
Constant	–14.9426	.0044

Sensitivity (prediction of DDw/oR): 60.3%; specificity (prediction of DDwR): 79.8%; Rescaled Cox and Snell R^2 = 21.5%, $P < .0001$; accuracy: 70.4%.

variables (direct measurement variables) plus ratios of joint spaces to represent anterior-posterior condyle fossa position and relative superior to ajs shape. Those papers demonstrated that the classification tree analysis method is inherently constructed of interactions and provides better predictive values for specific conditions compared to the logistic regression method. The current study thus expands on these earlier investigations by incorporating interaction entry variables expressing TMJ anatomic organization a priori.

The introduction of interaction variables into the logistic regression analysis resulted in a significant 99% to 147% increase in the model Rescaled Cox and Snell R^2 values compared to the former models[2,3] (Table 5). In contrast, the amount of variation in the disc displacement outcome accounted for by the interaction tree models showed a smaller and less consistent change compared to the noninteraction models.[2,3] A major improvement through the use of interaction variables was not anticipated because the tree is de facto already an interaction model.

Of importance, 2 of the interaction logistic regression models and the DDw/oR versus Normals interaction tree model now approach or reach the useful range for prediction of TMD patients as published by Widmer et al.[44] To the authors' knowledge, this has never been achieved previously for anatomic measures. Of biological importance, the logistic regression models incorporated all but 1 of the 14 direct measurement variables in some form, either alone or as an interaction. This indicates that few measured anatomic features can be considered redundant in a closed biologic system such as a synovial joint and that nearly all may be making a potential contribution to anatomically differentiating a joint. Care must therefore be taken not to dismiss prematurely the contribution of a variable studied in isolation.

Multifactorial models such as these may be important to support clinical decisions in the future. Our clinical language already uses interaction terms like relative shape, size, and position, but variables studied in isolation have been subject to overinterpretation because clinical interpretation of complex interaction variables is very difficult. This is especially true of variables expressed in complex mathematical logistic regression models,[45,46] in which understanding the individual factors involves interpretation of positive and negative values and relative risk. Nonetheless, the significant improvements in the logistic models demonstrate the importance of interaction variables and indicate that these must be included in subsequent anatomic studies. However, we can only begin to understand complex multifactorial systems in simpler terms after we can collate the principal messages from a body of research. The current approach is a beginning in this exploration in multifactorial analysis.

It is unknown in this cross-sectional study whether any of the false positives (normals with the characteristics of predominantly derangement pathways; eg, node 1 in Fig 2, with 2 of 6 or 33% of normals) are at any risk for future joint instability, and this is an interesting question for prospective study of risk. We assume that all derangement cases must have been asymptomatic once. Thus, anatomic risk characteristics may be identifiable if they could be understood (unless the etiology were exogenous, eg, by trauma). It may also be that larger numbers would permit refined tree branching, allowing a reduction in false positives.

The false negative classification tree rates (derangement joints with anatomic characteristics of Normals: 12% of DDwR joints; 30% of DDw/oR joints) suggests to the authors that the issues are not always anatomic hard tissue relationships. This raises the question of soft tissue risk characteristics as part of the derangement initiation process. Certainly the prediction accuracy of the hard tissue models (70.4% to 87.5%) and the accounted log likelihood of 5 of the models—33.3% to 61.1%, corresponding to 58% (moderately strong) to 78% (strong) correlations—leave room for a contribution by other tissue factors. Because the contribution is always relative, it is expected that the contribution of anatomic hard

Table 5 Comparison of Log Likelihood Contribution Between the Interactive and Noninteractive[2,3] Models

	Main effects without interactions (%)	Main effects plus interactions (%)	Improvement with interactions (%)
Tree models*			
DDwR vs Normals			
Cox and Snell R^2	37.0	35.9	–3
Sensitivity	70.2	88.0	25
Specificity	90.5	66.7	–26
DDw/oR vs Normals			
Cox and Snell R^2	28.8	38.8	32
Sensitivity	66.7	69.6	4
Specificity	85.7	85.7	0
DDwR vs DDw/oR			
Cox and Snell R^2	31.4	33.3	6
Sensitivity†	82.6	76.0	–8
Specificity‡	65.4	73.1	12
Logistic models			
DDwR vs Normals			
Cox and Snell R^2	20.5	40.8	99
Sensitivity	67.9	82.1	21
Specificity	73.8	78.6	7
DDw/oR vs Normals			
Cox and Snell R^2	24.5	61.1	149
Sensitivity	64.1	85.9	34
Specificity	81.0	90.5	12
DDwR vs DDw/oR			
Cox and Snell R^2	9.9	21.5	117
Sensitivity†	68.0	60.3	–11
Specificity†	59.5	79.8	34

*Derived from validation sample distributions.
†Prediction of DDw/oR.
‡Prediction of DDwR.

tissue factors might in fact be lower in both multifactorial analyses when other factors, such as soft tissues[7,47] or trauma,[32] are introduced.

The authors acknowledge that the predictive value of the hard tissue TMJ models should not be overinterpreted as being of etiologic significance for derangement because cross-sectional investigations like the present study are not designed to address etiology. It is just as probable that the anatomic arrangement is the result of the derangement. However, as discussed in the papers describing direct variables,[2,3,28] we believe that anatomic organization may partly contribute to the risk for propagation of derangement versus resisting propagation.

Anatomic Characteristics of the Derangement Groups

Both the DDwR and the DDw/oR versus Normals interaction tree models were mainly typified by fossa shape and size (Figs 2 and 3). In contrast, the previously published DDw/oR noninteraction model[2] was more typified by measures of condyle position, which in the current study only appeared in the logistic regression formulas. Traditional interest in condyle position, especially when condyle position is studied in isolation, must therefore be curbed. Such study might explain the confusion in simplistic clinical interpretation.

One group of DDwR joints was characterized by either a much wider, a much shallower, or both a wider and shallower than average fossa shape (ie, a larger fw/fd ratio; see Fig 2, node 1). This suggests that the longer condyle pathway expected with a shallower and/or wider fossa might allow for disc ligament laxity. This could be related to the exaggerated disc rotation requirement associated with this anatomic organization. A larger fw/fd ratio was also the most important differentiating feature in the noninteraction tree model.[2]

A second set of DDwR joints was characterized by an average-to-flatter posterior esa, a more wedge-shaped ajs, or both when the fossa shape was narrower, deeper, or both narrower and deeper (Fig 2, node 2). This anatomic organization suggests that when the DDwR fossa is narrower and/or deeper, the disc itself is a major determinant of the joint arrangement because the condyle is seated posterior to the center of the disc (wedge-shaped anterior recess) in the closed-mouth position.

DDw/oR joints were characterized by an average to long eminence length with either a very long posterior fossa wall (Fig 3, node 1), or a shallower and/or wider fossa when the pgph was average to short (Fig 3, node 2). The functional implications have been discussed in a previous publication.[2]

DDwR vs DDw/oR

As in the previous direct measurement models,[3] the pgph was the most powerful hard tissue anatomic differentiator both in the tree model and in the logistic regression model (Fig 4, Table 4). Compared to DDwR, the mean pgph was significantly longer in DDw/oR joints,[3] and its interaction with the eh in the current improved model was a recurring component of the logistic regression equation. Future investigation into the role of the posterior attachment area in the pathogenesis of complete disc displacement is therefore recommended as well as the posterior fossa wall's contribution to fossa shape and disc-condyle stability. However, pgph as a stand-alone variable was only 1 of 9 differentiating variables in the logistic regression model, and the tree required 2 additional contingencies (asjs/ajs and er × fw) to identify most of the cases (Fig 4). Thus, this feature should be considered part of a multifactorial model in the majority of cases.

A second DDw/oR group was differentiated from the DDwR joints in the interaction variable tree by a shorter pgph and a smaller asjs/ajs ratio (suggesting a more open wedge-shaped ajs shape with the superior joint space much smaller than the ajs) and a flatter eminence curve plus wider fossa width (Fig 4, node 4). A trend for a reduced asjs in DDw/oR was also suggested in a previous study.[3] The reader is referred to a prior publication that also discusses the functional implications.[3]

Limitations of the Analyses

The reader is cautioned that the findings in these analyses are associations and that this study is unable to address any potential etiologic anatomic influences on the derangements.

The models approached, and in the case of the DDw/oR logistic regression model, reached, the very conservative parameters for sensitivity and specificity recommended for TMD tests designed to avoid overidentification and overtreatment of TMD (≥ 75% sensitivity and ≥ 90% specificity)[44] (Table 5). Nevertheless, the number of variables considered exceeded the ideal subject/variable ratio, and some exaggeration of the sensitivity and specificity might be expected. Thus, this pilot study must be considered preliminary and subject to further improvement and validation before clinical application.

The "gold standard" in this study was the clinical diagnosis, which may have included false positive and false negative assignments, although the accuracy for the RDC/TMD in the identification of disc displacement is very high.[48] However, there is an unavoidable potential for error in any analysis that uses inclusive and exclusive clinical criteria to define its samples. Nevertheless, the agreement in the results between the 3 analyses and the validation protocol for the classification tree analysis suggest that the findings are supportable.

MRI was not used in this study for diagnostic classification because variation in disc position is not synonymous with disease.[39,40] However, the future use of MRI might allow for additional stratification and the inclusion of soft tissue variables for subsequent prospective study as well as an increased normal population. The normal population was minimized in this study by contemporary ethical standards for nontherapeutic radiation exposure.

The limitations of logistic regression analysis[7,46] have been discussed previously.[2,3]

The contribution of the anatomic hard tissue factors in all 3 analyses may be reduced when other unconsidered factors (eg, soft tissues,[49,50] trauma[32]) are added because the contribution of any factor is always relative. Nevertheless, the authors believe that including an unimportant predictor in an exploratory study would have been worse than falsely excluding a factor that might later prove to be important.

The current study relies on a 2-dimensional single central cut from TMJ tomograms to typify the entire joint. Whereas the authors agree that it would be highly desirable to be able to compare complete 3-dimensional analyses of TMJ anatomical data, the unavailability of the required sample sizes, statistical packages, and microprocessor capacities needed to perform such a huge multifactorial analysis make this goal an impossibility today. The authors instead propose that our studies at least begin this task by identifying a few anatomic relationships that might be of interest in the future if such a project becomes feasible.

Conclusions

1. The predictive value of logistic regression anatomic analysis is enhanced through interaction variables.
2. Nearly all direct measurement factors were used at least once in the 6 multifactorial models, suggesting that few anatomic factors are redundant in a closed biological system such as the TMJ.
3. DDwR joints were characterized by either a much wider and/or deeper-than-average fossa shape, or by an average to flatter-than-average posterior eminence slope angle and/or a more wedge-shaped ajs when the fossa shape was narrower and/or shallower.
4. DDw/oR joints were characterized by an average to long eminence length with either a very long posterior fossa wall or by a shallower and/or wider fossa when the pgph was average to short.
5. Compared to DDwR joints, DDw/oR joints were characterized by either a longer-than-average posterior fossa wall height or, when the posterior fossa height was average, by a narrower superior joint space and relatively wider ajs, as well as a flatter eminence within a wider fossa.

Acknowledgments

This work was supported in part by the National Institute of Dental Research (grant 5 P50 DE 07618-04), the Deutsche Akademie der Naturforscher Leopoldina (grant BMBF-LPD 9901/8-4), and the University of California–Los Angeles Dental Research Institute. We thank Dr Jeffrey Gornbein, Department of Biomathematics, School of Medicine, University of California at Los Angeles, for his help with the statistical model and the analysis; Dr Mike John for his assistance in the study design; and Dr Stephen Harkins and Dr Luis Cueva for their assistance in collection of additional records.

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