ORIGINAL ARTICLE

Treatment decision in adult patients with Class III malocclusion: Orthodontic therapy or orthognathic surgery?

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Class III malocclusion is one of the most difficult anomalies to understand. Because not all Class III patients are candidates for surgical correction, patient assessment and selection remain main issues in diagnosis and treatment planning. The purpose of this study was to separate Class III patients who can be properly treated orthodontically from those who require orthognathic surgery. A large sample size was a necessary to obtain a sufficiently robust model. Thus, a multicentric study design was chosen (Orthodontic Departments of the Universities of Frankfurt, Heidelberg, and Würzburg, Germany). The cephalograms of 175 adult patients with Class III malocclusions were analyzed. The orthodontic group comprised 87 patients, and the surgery group, 88 patients. Twenty linear, proportional, and angular measurements were made. Stepwise discriminant analysis was applied to identify the dentoskeletal variables that best separate the groups. The discriminant function model was highly significant ($P < .0001$); 92% of the patients were correctly classified. The following variables were extracted: Wits appraisal, length of the anterior cranial base, maxillary/mandibular (M/M) ratio, and lower gonial angle. The resulting equation was: Individual score $= -1.805 + 0.209 \cdot \text{Wits} + 0.044 \cdot \text{S-N} + 5.689 \cdot \text{M/M ratio} - 0.056 \cdot \text{Go}_{\text{lower}}$. By means of discriminant analysis, correct classification of adult Class III malocclusion patients succeeded to a very high degree. Of all the variables, the Wits appraisal was the most decisive parameter. (Am J Orthod Dentofacial Orthop 2002;122:27-38)

Class III malocclusion is one of the most difficult anomalies to understand. Studies conducted to identify the etiological features of a Class III malocclusion showed that the deformity is not restricted to the jaws but involves the total craniofacial complex.[1-4] Most persons with Class III malocclusions show combinations of skeletal and dentoalveolar components.[3,5] The factors contributing to the anomaly are complex. They may act synergistically or in isolation, or they may cancel each other out.[4]

Jacobson et al[6] conducted a cephalometric study to identify various types of skeletal Class III patterns. The Class III pattern with the highest frequency was a prognathic mandible combined with a normal maxilla, although true macrognathia of the mandible jaw was uncommon.

Compared with Class I control groups, Class III subjects showed a shorter anterior cranial base, a longer posterior cranial base, a more acute cranial base, a shorter and more retrusive maxilla, more proclined maxillary incisors, more retroclined mandibular incisors, excessive lower anterior face height, and a more obtuse gonial angle.[6-10] The studies also revealed that no single morphologic trait indicating potential Class III development could be isolated because different skeletal combinations exist.

In 1985, Proffit and Ackerman[11] presented the concept of 3 envelopes of discrepancy, showing the limits of what can be corrected by orthodontic treatment alone. However, the data presented were insufficient.

Kerr et al[12] tried to establish some cephalometric yardsticks in adult Class III patients to allocate them to treatment more objectively. The pretreatment lateral cephalograms of patients who had had either surgical or orthodontic correction of their Class III malocclusion were compared by means of univariate statistical methods. The most significant differences between both groups were found in ANB angle, maxillary/mandibular (M/M) ratio (ratio between the maxillary and mandibular lengths), mandibular incisor inclination, and Holdaway's angle. Yet, considering the complex interplay of skeletal and dentoalveolar deviations and

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the wide spectrum of individual variation, it seems highly unlikely that single variables could ever contain enough information to explain the anomaly.[13] Moreover, univariate statistical techniques are considered to be insufficient for the differentiated diagnosis and treatment planning of Class III malocclusion patients.[14] Instead, recent studies suggest that the relationships between craniofacial structure and occlusion can be analyzed best with a multivariate approach.[15-17]

The discriminant analysis, a multivariate procedure, has been especially designed to distinguish between 2 groups from the same population.[18] Most studies exploring the potential of discriminant analysis in orthodontics have been concerned with facial growth.[19-22] Although using the multivariate technique is better than using single factors, its limitations should be kept in mind for the following reasons: (1) multivariate models based on cephalometric analysis are hampered by the difficulties of precise landmark identification; (2) the selected measurements might not include all the variables required to accurately separate the groups[13,15,19,25]; (3) for a robust discriminant model that applies to patients outside the study, a relatively large sample is required[15]; and (4) if the differences between both groups are very small, clear distinction between the groups is difficult.[15]

Hitherto, this multivariate technique has not been widely applied to study Class III malocclusion. In particular, discriminant analysis has been used to identify and classify Class III subjects[15,26,27] and to predict treatment outcome or relapse of orthodontically treated Class III patients.[11,17,22,28-32] However, so far, the literature does not contain an accurate model to distinguish between adult Class III patients who can be properly treated by orthodontic mechanotherapy alone and those who require orthognathic surgery. Because not all of these patients are candidates for surgical correction, patient assessment and selection are essential in diagnosis and treatment planning. The purpose of this study was to distinguish between surgical and nonsurgical subjects presenting with skeletal Class III malocclusions.

SUBJECTS AND METHODS

Subjects

For a sufficiently robust model that also applies to patients not included in the study, a large sample size is a prerequisite. Thus, the present analysis was based on data from 3 orthodontic centers. The material comprised cephalometric radiographs of 175 adult patients, 82 males and 93 females, from the Departments of Orthodontics of the Universities of Frankfurt, Heidelberg, and Würzburg, Germany.

The criteria for inclusion in the study were a Class III molar relationship, a negative overjet, a Wits appraisal ≤ -1 mm, and a negative difference between ANB angle and individualized ANB angle.[33]

Patients with craniofacial syndromes or cleft palates were excluded. The adult patients were divided into 2 groups: the nonsurgery group comprised those for whom orthodontic therapy was sufficient to correct the Class III malocclusion, and the surgery group comprised those who required orthognathic surgery (Fig 1). Grouping was done by 3 experienced orthodontists. Because of the retrospective character of the study, categorization of the patients was based on pretreatment records (plaster casts, cephalograms, extraoral pictures) without clinical examination of the patients. Thus, the validity of the treatment planning processes was limited. The judges were instructed before they separated the patients. The following criteria had to be met for entering the nonsurgery group: (1) stable occlusion in sagittal, transversal, and vertical dimensions; (2) correct overjet and overbite; (3) proper incisal inclination; (4) satisfying facial esthetics; and (5) long-term stability. The orthodontic group comprised 87 patients, and the surgery group, 88 patients.

Methods

Because the lateral cephalograms were taken with different x-ray devices, all linear measurements were first corrected by their respective magnification factors. Each film was traced by the same investigator (G. S.), and 21 landmarks were identified (Fig 2). The coordinates of the landmarks were recorded by means of appropriate software (Winceph, Dentev Compudent, Koblenz, Germany).

The following linear, proportional, and angular measurements were calculated (Fig 3): S-N, anteroposterior length of the cranial base; PoOr-NBa, cranial deflection; ML-NSL, divergence of the mandibular plane relative to the anterior cranial base; NSAr, saddle angle; ArGoMe, gonial angle; Go_{upper}, upper gonial angle; Go_{lower}, lower gonial angle; SNB, anteroposterior mandibular position to the anterior cranial plane; 1-ML, axis of mandibular incisor to mandibular plane; $(180° - [1\text{-ML}]) - (1\text{-ML}_{ind})$, difference between 180° minus axis of mandibular incisor to mandibular plane and individualized 1-ML angle according to the formula: 1-ML_{ind}: $72.5 + 0.5 \cdot \text{ML-NL}$[34]; Wits, length of the distance AO-BO (AO: intersection between a perpendicular line dropped from Point A and the occlusal plane; BO: intersection between a perpendicular line dropped from Point A and the occlusal plane); ANB, anteroposterior relationship of the maxilla and the mandible; ANB-ANB_{ind}, difference between ANB

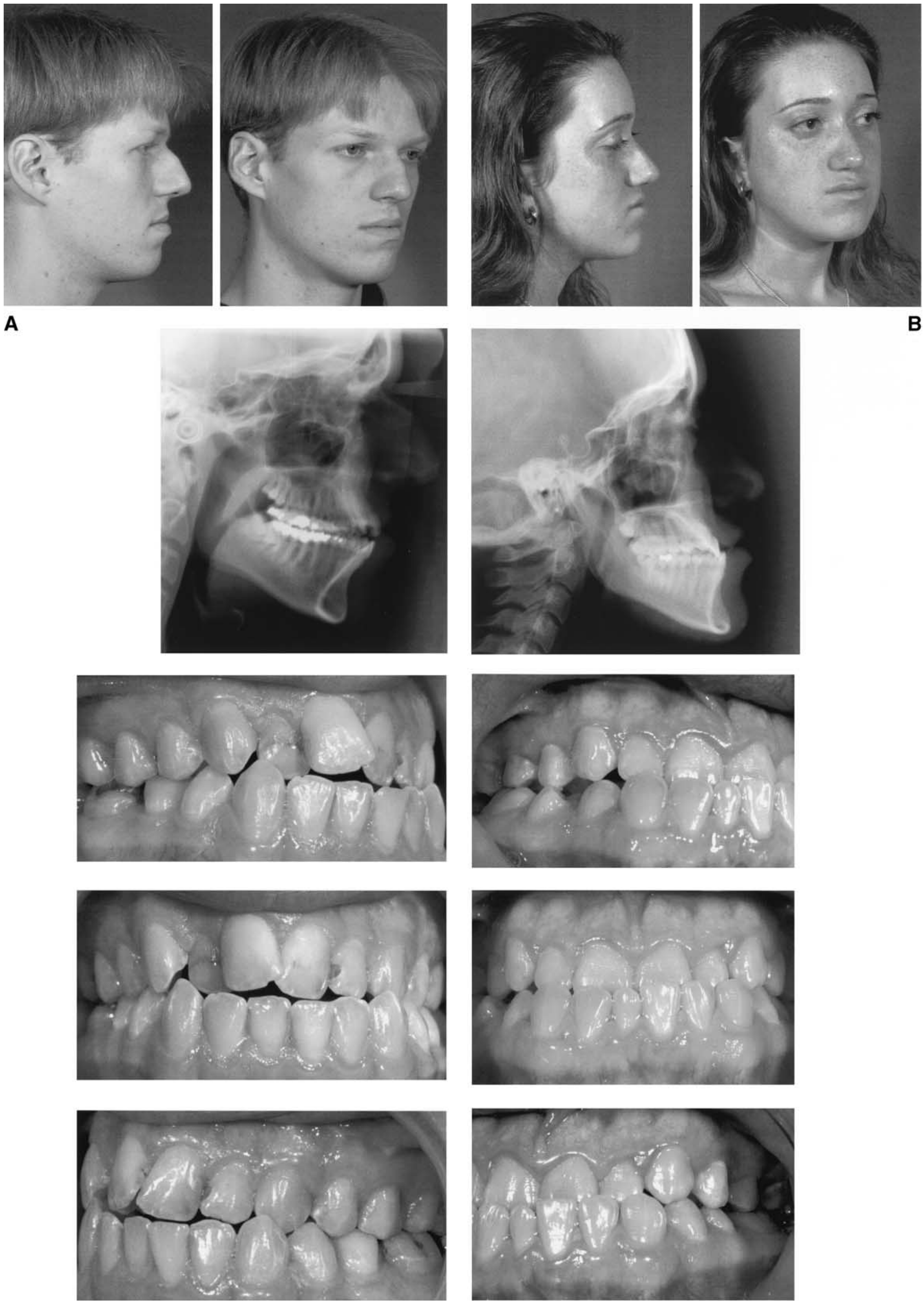

Fig 1. Facial photographs, cephalograms, and intraoral photographs before treatment. **A,** Patient in nonsurgery group; **B,** patient in surgery group.

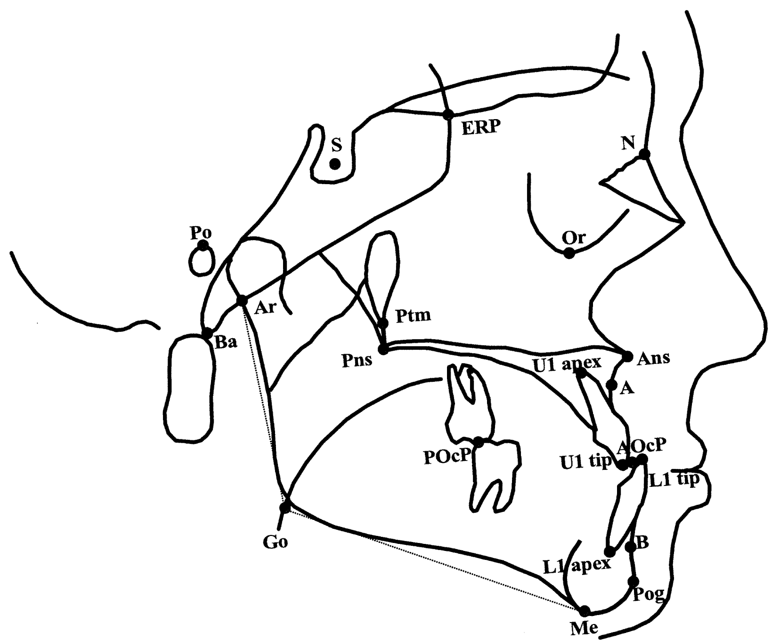

Fig 2. Hard tissue landmarks used in study: sella (S); porion (Po); basion (Ba); articulare (Ar); gonial intersection (Go); menton (Me); pogonion (Pog); Point B (B); apex of mandibular central incisor (L1 apex); tip of mandibular central incisor (L1 tip); tip of maxillary central incisor (U1 tip); apex of maxillary central incisor (U1 apex); Point A (A); anterior nasal spine (Ans); posterior nasal spine (Pns); pterygomaxillary fissure (Ptm); orbitale (Or); nasion (N); ethmoid registration point (ERP); posterior point of occlusal plane (POcP); anterior point of occlusal plane (AOcP).

angle and individualized ANB angle according to the formula: $ANB_{ind} = -35.16 + 0.4 \cdot SNA + 0.2 \cdot ML\text{-}NSL$[33]; M/M ratio, ratio of the anteroposterior length of the maxilla to the anteroposterior length of the mandible; NAPog, angle of convexity; 1/1, angle between the axis of maxillary and mandibular incisors; SNA, anteroposterior maxillary position to the anterior cranial plane; NL-NSL, inclination of the palatal plane in relation to the anterior cranial base; 1-NSL, axis of the maxillary incisor to anterior cranial base; (1-NL)-(1-NL_{ind}), difference between the axis of maxillary incisor to palatal plane and the individualized 1-NL angle according to the formula: $1\text{-}NL_{ind}$: $57.5 + 0.5 \cdot ML\text{-}NL$.[34]

Fifteen films randomly selected from the total observations were retraced and redigitized independently on 2 separate occasions 2 weeks apart. The method error was calculated as recommended by Dahlberg.[35]

Method error in locating and measuring was calculated by the formula:

$$ME = \sqrt{\Sigma d^2/2n}$$

where d is the difference between 2 registrations of a pair, and n is the number of double registrations.

Random linear errors ranged from 0.02 to 1.78 mm and from 0.38° to 1.82° for all angular variables investigated. Systematic error was tested at the 10% level of significance, as recommended by Houston.[36] No systematic errors were found.

Statistical analysis

Data analysis was performed by using SPSS PC +, the Statistical Package for the Social Sciences. The arithmetic means, standard deviations, medians, minima, and maxima were calculated for each variable and group (Table I).

The data were compared by using the Mann-Whitney test for independent samples to assess differences between the craniofacial features of both groups. The levels of significance were set at $P < .05$, $< .01$, and $< .001$ (Table II).

Discriminant analysis

In this study, discriminant function analysis was used to identify the dentoskeletal variables that best separate patients needing orthognathic surgery to correct their malocclusion from those who do not.

In this context, the discriminant function was based only on lateral cephalometric landmarks. Thus, the

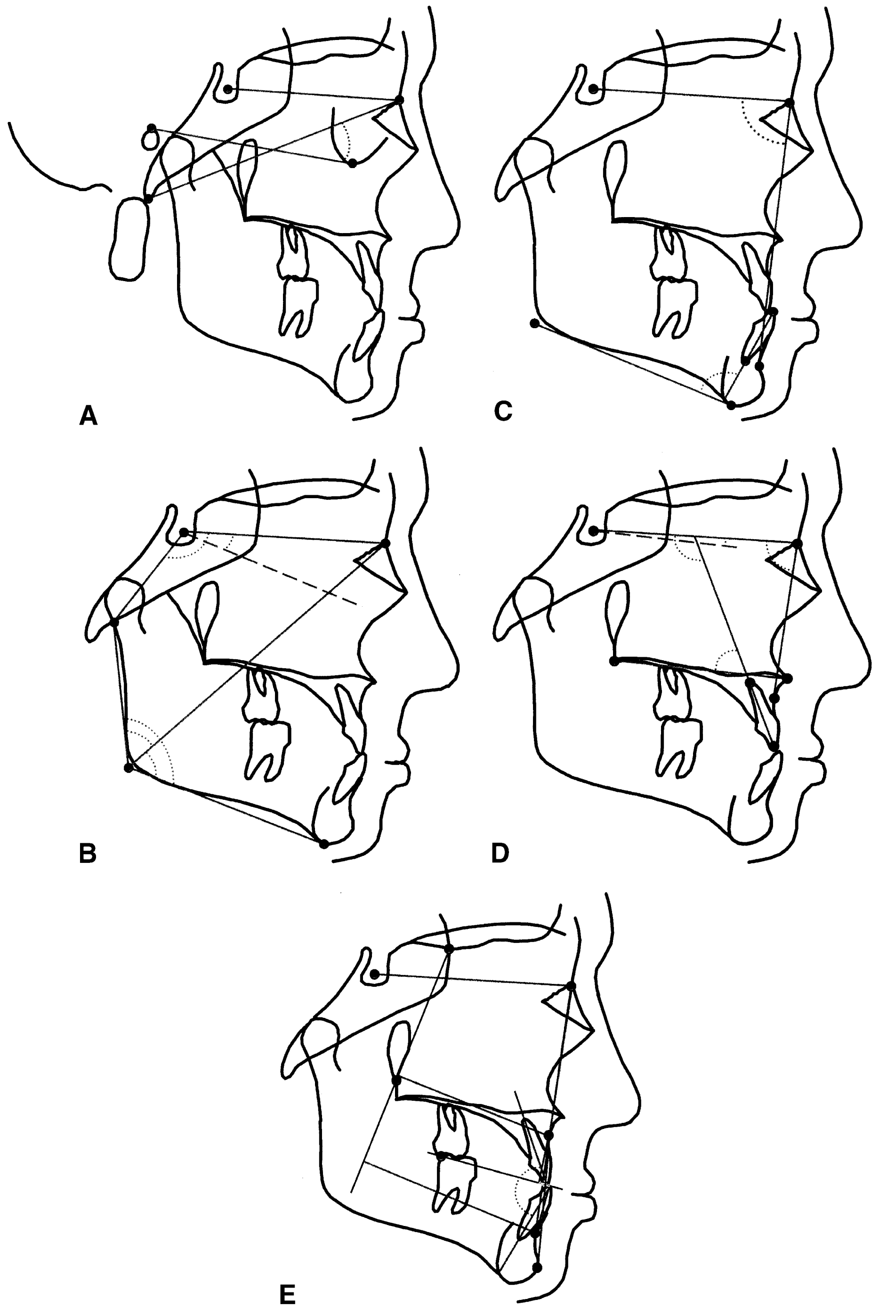

Fig 3. Linear and angular cephalometric measurements used in study. **A,** S-N (mm), anteroposterior length of cranial base; PoOr-NBa, cranial deflection. **B**, ML-NSL, divergence of mandibular plane relative to anterior cranial base; NSAr, saddle angle; ArGoMe, gonial angle; Go_{upper}, upper gonial angle; Go_{lower}, lower gonial angle. **C**, SNB, anteroposterior mandibular position to anterior cranial plane; 1-ML, axis of mandibular incisor to mandibular plane; 1-ML_{ind}, individualized 1-ML angle according to formula: 1-ML_{ind}: $72.5 + 0.5 \cdot$ ML-NL. **D**, Wits (mm), length of distance AO-BO (AO: intersection between perpendicular line dropped from Point A and occlusal plane; BO: intersection between perpendicular line dropped from Point B and occlusal plane); ANB, anteroposterior relation of maxilla and mandible; ANB_{ind}, individualized ANB angle according to formula: $ANB_{ind} = -35.16 + 0.4 \cdot SNA + 0.2 \cdot$ ML-NSL; M/M ratio, ratio of anteroposterior length of maxilla to anteroposterior length of mandible; NAPog, angle of convexity; 1/1, angle between axis of maxillary and mandibular incisors. **E**, SNA, anteroposterior maxillary position to anterior cranial plane; NL-NSL, inclination of palatal plane in relation to anterior cranial base; 1-NSL, axis of maxaillary incisor to anterior cranial base; 1-NL, axis of maxaillary incisor to palatal plane; 1-NL_{ind}, individualized 1-NL angle according to formula: 1-NL_{ind}: $57.5 + 0.5 \cdot$ ML-NL.

Table I. Means, standard deviations, medians, minima, and maxima of nonsurgery and surgery groups

	Nonsurgery group (n = 87)					Surgery group (n = 88)				
Cephalometric variables	*Mean*	*SD*	*Median*	*Min*	*Max*	*Mean*	*SD*	*Median*	*Min*	*Max*
S-N (mm)	68.77	4.33	68.77	55.03	78.32	67.41	5.18	66.92	45.85	80.75
PoOr-NBa (°)	29.45	2.97	29.55	21.21	38.60	29.13	3.39	29.61	18.09	37.53
ML-NSL (°)	34.53	6.41	34.40	20.29	49.99	36.20	7.83	35.61	17.59	69.25
NSAr (°)	121.99	4.80	122.27	111.15	134.68	121.86	5.69	122.85	104.71	135.74
ArGoMe (°)	126.94	6.34	126.15	114.99	145.47	132.86	7.70	133.69	116.07	161.65
Go_{upper} (°)	51.48	4.24	51.12	41.89	63.93	52.50	3.40	51.93	42.38	64.80
Go_{lower} (°)	75.46	5.14	74.74	64.93	89.36	80.37	6.56	79.48	66.65	110.39
SNB (°)	80.15	3.80	79.89	71.33	91.27	83.37	5.20	83.02	70.35	97.24
1-ML (°)	86.15	6.97	86.08	71.00	100.32	78.02	9.19	77.48	46.83	95.66
(180−(1-ML)) −(1-ML_{ind}) (°)	7.72	7.01	7.31	−4.74	24.01	15.27	8.09	15.63	−1.25	31.60
Wits (mm)	−4.61	1.70	−4.79	−8.32	−1.46	−12.21	4.25	−12.15	−24.94	−4.13
ANB (°)	−0.06	2.09	−0.35	−5.25	5.45	−4.22	3.19	−4.01	−13.72	3.15
ANB-ANB_{ind} (°)	−3.85	1.55	−3.76	−8.75	−1.43	−7.47	3.04	−6.90	−16.90	−1.69
M/M ratio (%)	0.92	0.08	0.91	0.76	1.12	0.80	0.07	0.80	0.63	0.97
NAPog (°)	−0.90	2.89	−1.20	−7.78	6.29	−5.23	3.64	−4.79	−17.20	2.90
1/1 (°)	133.09	9.36	132.58	110.97	151.83	139.36	10.83	137.58	120.61	164.22
SNA (°)	80.16	4.03	79.76	70.85	90.50	79.15	4.95	79.43	67.90	91.52
NL-NSL (°)	7.27	3.28	7.50	−2.66	14.03	7.77	4.60	7.08	−7.81	19.90
1-NSL	106.23	6.09	106.21	93.62	123.04	106.43	8.18	106.88	80.40	123.14
(1-NL)−(1-NL_{ind}) (°)	−4.63	5.27	−3.83	−17.23	8.32	−5.90	6.63	−5.92	−25.98	12.61

Table II. Significant differences between nonsurgery and surgery groups

	Mann-Whitney test	
Cephalometric variables	*Z*	*P*
S-N (mm)	−1.986	*
PoOr-NBa (°)	−0.434	NS
ML-NSL (°)	−1.365	NS
NSAr (°)	−0.062	NS
ArGoMe (°)	−5.185	***
Go_{upper} (°)	−1.597	NS
Go_{lower} (°)	−5.157	***
SNB (°)	−4.278	***
1-ML (°)	−5.840	***
(180−(1-ML))−(1-ML_{ind}) (°)	−5.698	***
Wits (mm)	−10.649	***
ANB (°)	−8.647	***
ANB-ANB_{ind} (°)	−8.550	***
M/M ratio (%)	−8.668	***
NAPog (°)	−7.470	***
1/1 (°)	−3.620	***
SNA (°)	−1.158	NS
NL-NSL (°)	−0.580	NS
1-NSL	−0.545	NS
(1-NL)−(1-NL_{ind}) (°)	−1.531	NS

Levels of significance: *, $P < .05$; **, $P < .01$; ***, $P < .001$; *NS*, not significant.

skeletal transverse component of Class III malocclusion was not considered.

A stepwise variable selection was performed to obtain a model with the smallest set of significant cephalometric parameters to avoid redundancy among the various variables. The independent variables were included in the model according to the 5% level of significance. The first variable to be selected was that with the smallest value of Wilks λ where λ is the ratio of the within-group sum of the squares divided by the total sum of the squares. Subsequent variables were chosen by recalculating λ for each variable, and the variable with the next lowest value was selected. For each stage, a test was performed to ascertain whether including the respective variable into the model had improved the separation.

Unstandardized discriminant function coefficients were calculated for each selected variable, with a constant (Table III). This led to an equation that assigns a score to each patient. For each group, discriminant analysis results in a mean score over all subjects in the relevant group. The dividing line halfway between these scores shows to which of the 2 groups a subject belongs (critical score: mean value of group centroids of the 2 groups).

Finally, the classification power of the selected cephalometric variables was tested.

RESULTS

Descriptive statistics for all cephalometric variables for both patients groups are listed in Table II. Significant inter-group differences were found for the parameters representing the sagittal maxillomandibular rela-

Table III. Stepwise discriminant analysis

Predictive variables	*Unstandardized canonical discriminant function coefficients*
Wits	0.209
S-N	0.044
M/M ratio	5.689
Go_{lower}	−0.056
(Constant)	−1.805

Individual score = −1.805 + 0.209 · Wits + 0.044 · S-N + 5.689 · M/M ratio − 0.056 · Go_{lower}. Discriminant scores for group means (group centroids): nonsurgery group, 1.281; surgery group, −1.327; critical score, −0.023.

tionship as indicated by the Wits appraisal, ANB, and $ANB\text{-}ANB_{ind}$. In addition, the variables describing the anteroposterior position of the mandible, the axis of mandibular central incisors, the gonial angle, the lower gonial angle, the interincisal angle, the M/M ratio, the angle of convexity, and the length of the anterior cranial base differed significantly.

In contrast, there were no significant differences in the position and inclination of the maxilla, the axis of maxillary central incisors, the cranial deflection, and the parameters describing the direction of craniofacial growth (ML-NSL, NSAr, Go_{upper}).

Stepwise variable selection resulted in a significant model of 4 variables that accounted for the best discriminant function to distinguish between patients with and without indication of surgical correction.

The variables selected were Wits appraisal (F likelihood to remove = .000), S-N (F likelihood to remove = .034), M/M ratio (F likelihood to remove = .000), and Go_{lower} (F likelihood to remove = .002) (Table III).

Unstandardized discriminant function coefficients of the selected variables, along with a calculated constant (Table III), led to the following equation that gives individual scores for assigning a new patient to 1 of the groups:

$$\text{Individual score} = -1.805 + 0.209 \cdot \text{Wits} + 0.044 \cdot \text{S-N} + 5.689 \cdot \text{M/M ratio} - 0.056 \cdot Go_{lower}$$

The critical score was −0.023, which is the mean value of group centroids of the 2 groups (Table IV). Each new Class III malocclusion patient with an individual score higher than the critical score will be treated successfully by orthodontic therapy alone. On the other hand, each new Class III patient with a more negative individual score than the critical score must be treated by combined orthodontic-orthognathic therapy.

The percentage of correctly classified cases was 92% (Table IV). Two patients of the nonsurgery group (n = 87) and 12 of the surgery group (n = 88) had been misclassified.

The median Wits appraisal in the correctly classified nonsurgical group (n = 85) was −4.76 mm, and the median in the surgical group (n = 76) was −12.97 mm. For the incorrectly classified surgery patients (n = 12), the median of Wits appraisal was −7.21 mm (Table V, Fig 4).

Table IV. Classification results

	Predicted group membership	
Original group membership	*Nonsurgery group*	*Surgery group*
Nonsurgery group	97.7% (n = 85)	2.3% (n = 2)
Surgery group	13.6% (n = 12)	86.4% (n = 76)

Percentage of cases correctly classified: 92.0%.

Table V. Wits appraisal (means, standard deviations, medians, minima, and maxima) of patients according to classification

	Wits appraisal				
	Mean	*SD*	*Median*	*Min*	*Max*
Correctly classified patients of nonsurgery group (n = 85)	−4.54	0.18	−4.76	−8.32	−1.46
Correctly classified patients of surgery group (n = 76)	−13.02	0.45	−12.97	−24.94	−5.35
Incorrectly classified patients of surgery group (n = 12)	−7.03	0.52	−7.21	−9.24	−4.13

DISCUSSION

The present study deals with a pretreatment separation of adult Class III malocclusion patients into surgical and nonsurgical cases. Up to now, the decision regarding which form of treatment was indicated for those patients was usually based on the degree of anteroposterior and vertical skeletal discrepancy, the inclination and position of the incisors, and the dentofacial appearance.

Many lateral cephalometric studies have been conducted to elucidate the growth pattern in Class III subjects compared with eugnathic subjects, the effects of orthopedic therapy, or the stability of treatment outcome.[1,6-10,29,37,38] However, only a few studies have been undertaken to establish some threshold values for pretreatment identification of patients for whom or-

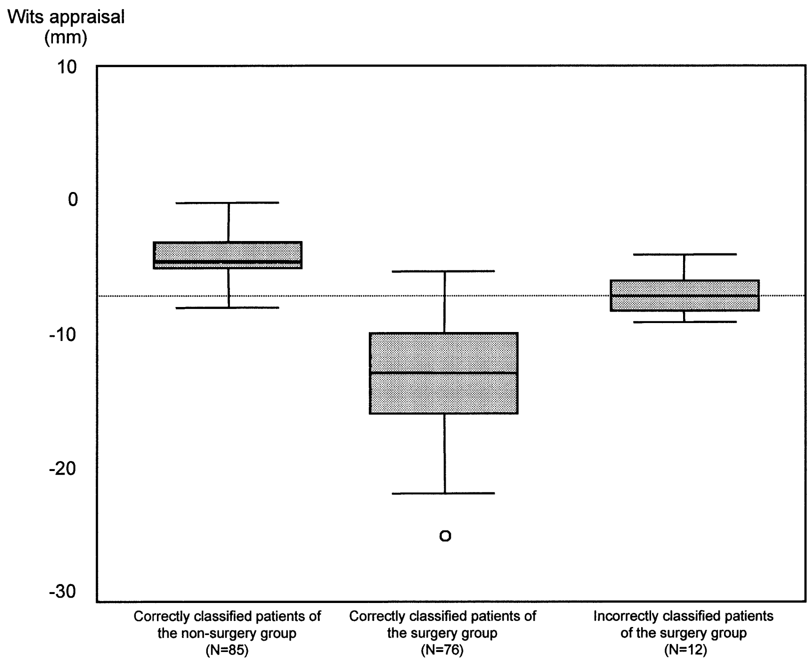

Fig 4. Box plots of Wits appraisal of correctly classified nonsurgery (n = 85) and surgery (n = 76) patients and misclassified surgery patients (n = 12).

thognathic correction would be necessary.[11,12] Proffit and Ackermann[11] presented the concept of 3 envelopes of discrepancies of what can be corrected by orthodontic treatment alone, orthodontic treatment with growth, and surgical treatment. The critical limitation for orthodontic treatment alone was seen in a maxillary incisor protrusion of 2 mm combined with a mandibular retrusion of 3 mm. However, Kerr et al[12] considered these criteria alone to be insufficient for determining which treatment option to prescribe. Therefore, the authors tried to established cephalometric yardsticks that would make the treatment decision more objective. The results of their study indicated that the most important factors that differentiate the surgery and the nonsurgery patients are the size of the anteroposterior discrepancy, the inclination of the mandibular incisors, and the appearance of the soft tissue profile. In contrast, the vertical dimensions (eg, gonial angle or Y-axis) showed little influence on the treatment decision. Because a reduced overbite in adult Class III patients points to a poor orthodontic prognosis, the conclusion was drawn that an open bite tendency is a rare condition in this malocclusion group. On the basis of the overlaps of box-and-whisker plots, the following critical values were set up: ANB, −4°; M/M ratio, 0.84; mandibular incisor inclination, 83°; and Holdaway's angle, 3.5°.

However, taking the overlaps of box-and-whisker plots as critical values for the treatment decision is not an accepted scientific statistical method. Moreover, univariate statistics are regarded as insufficient to reflect the complex craniofacial relationships.[13,23,39]

For these reasons, in this study, discriminant analysis was used to categorize the patients into the nonsurgery and the surgery groups.

The prerequisite for a powerful discriminant model is a relatively large sample, so that when a new patient is classified, his measurements do not fall outside those used in generating the model.[15] Therefore, a multicentric study design was chosen in this study.

Stepwise variable selection of discriminant analysis generated a 4-variable model that produced the most efficient distinction between the nonsurgery and the surgery groups. The variables chosen included Wits appraisal, S-N, M/M ratio, and lower gonial angle. The classificational power of the model was 92% for each new subject.

Since its introduction by Riedel,[40] the ANB angle has been the most commonly used cephalometric measurement to describe the skeletal discrepancies between the maxilla and the mandible. However, its validity as a true indicator of the anteroposterior jaw relationships has been criticized because nasion is not a fixed point, and any change in its anteroposterior position affects ANB.[41-44] In addition, the magnitude of ANB angle is affected by rotation of the jaws relative to the cranial base.[43,45,46] As an alternative way to assess the anteroposterior jaw relationships, the Wits appraisal was introduced by Jacobson.[44] He considered the functional occlusal plane as the most suitable reference for defining the relationship of the jaws. Thus, rotation of the jaws relative to the cranial reference plane does not affect the severity of jaw disharmony. Various authors have investigated the degree of correlation between Wits appraisal and ANB angle, showing only low correlation between those variables.[47-49] Jarvinen[50] analyzed the geometrical relationship between ANB angle and Wits and concluded that it is difficult to compare measurements based on different reference systems.

In this study, ANB angle, $ANB\text{-}ANB_{ind}$ angle, and Wits appraisal showed highly significant differences between the nonsurgery and the surgery groups. However, of these variables, only the Wits appraisal was included in the discriminant model. This and the fact that the Wits appraisal was the first variable that entered the discriminant model point out its significance over the other variables in separating the patient groups.

The second variable that was extracted from the discriminant analysis was the length of the anterior cranial base. According to Battagel,[4] a reduced cranial base is frequently, but not universally, associated with a Class III malocclusion. However, no significant difference in the anterior cranial base length could be found between children with Class III malocclusions and those with normal occlusions.[2,38] Quite differently, in this study, a significant difference was found between adult patients who need surgical correction and those who do not. Patients in the surgery group exhibited a shorter cranial base.

As a third variable, the M/M ratio entered the multivariate model. Similar to Wits appraisal, M/M ratio is a measurement analyzing the anteroposterior discrepancy between the mandible and the maxilla. Thus, no sagittal parameter restricted to the mandible was included in the discriminant model. This finding suggests that the Class III malocclusion is a heterogeneous and complex anomaly. The relationship between the maxilla and the mandible seems to be a more decisive factor for treatment decisions than are morphometric parameters of the mandible alone.

The fourth variable entering the discriminant model was the lower gonial angle. In the literature, several studies have investigated the vertical dimensions of Class III malocclusion.[1,2,4,6,7,51-53] In comparison with infants with normal occlusion, a greater gonial angle was found in children with Class III malocclusion. From these results, the conclusion was drawn that an increased vertical craniofacial growth pattern must be considered an unfavorable sign in the prognosis of Class III malocclusion in the deciduous dentition.[17] Furthermore, the gonial angle played a decisive role for stable treatment outcomes of adolescent patients with Class III malocclusion.[22,39,54]

The importance of the vertical dimension on the treatment decisions of Class III patients was supported by the findings of this study. The lower gonial angle was selected by discriminant analysis as a key determinant. Patients in the surgery group showed significantly greater values (mean: 80.37°) than those in the nonsurgery group (mean: 75.46°).

Because of its predictive power, discriminant analysis appears to be a particularly valuable tool for identifying Class III patients in whom orthodontic treatment is sufficient for therapy. Only 2.3% of the nonsurgery patients were misclassified, but 13.6% of those who needed orthognathic surgery were misjudged. In these patients, Wits appraisal was −7.21 mm compared with −4.76 mm in the correctly classified nonsurgery patients and −12.97 mm in the correctly classified surgery patients. Consequently, the median of the misclassified patients was closer to the median of the correctly classified nonsurgery patients than to the median of the surgery patients. The same was evident with respect to the subsequently extracted variables. Thus, the cephalometric measurements used here did not encompass all factors that clinically contribute to treatment decisions. Especially in borderline surgical patients, additional factors must be considered, such as incisal guidance, soft tissue features, dentofacial esthetics, and long-term stability.[13,17,19,20,25,55] Because Class III patients also frequently show skeletal deficiencies in the transverse dimension, anteroposterior cephalograms should be routinely made and analyzed. If the transverse components and the above-mentioned factors are included in the analysis, the predictive power of the multivariate model should improve.

CONCLUSIONS

By means of stepwise discriminant analysis, separation of adult Class III malocclusion patients who can be treated by orthodontic therapy alone from those who need orthognathic surgery was successful in 92% of the cases. Of 20 different linear, angular, and proportional measurements, the following 4 variables were selected: Wits appraisal, SN, M/M ratio, and lower gonial angle. The fact that parameters in addition to those representing the anteroposterior jaw relationship entered the model suggests that the deformity is not restricted to the jaws but involves the total craniofacial complex.

Nevertheless, the limitations of this multivariate model must be considered: the judgments classifying the patients were based solely on the clinical records, and the cephalometric analysis disregarded the transverse components and the facial esthetics.

This study necessitated a large number of patients. We express our gratitude to Prof Dr Emil Witt for access to the records of the Department of Orthodontics, Würzburg University, and his kind support.

REFERENCES

1. Guyer EC, Ellis EE, McNamara JA Jr, Behrents RG. Components of Class III malocclusion in juveniles and adolescents. Angle Orthod 1986;56:7-30.
2. Chang H-P, Kinoshita Z, Kawamoto T. Craniofacial pattern of Class III deciduous dentition. Angle Orthod 1992;62:139-44.
3. Mackay F, Jones JA, Thompson R, Simpson W. Craniofacial form in Class III cases. Br J Orthod 1992;19:15-20.
4. Battagel JM. The aetiological factors in Class III malocclusion. Eur J Orthod 1993;15:347-70.
5. Ngan P, Hagg U, Yiu C, Merwin D, Wie SH. Cephalometric comparisons of Chinese and Caucasian surgical Class III patients. Int J Adult Orthod Orthognath Surg 1997;12:177-88.
6. Jacobson A, Evans WG, Preston CG, Sadowsky PL. Mandibular prognathism. Am J Orthod 1974;66:140-71.
7. Sanborn RT. Differences between the facial skeletal patterns of Class III malocclusion and normal occlusion. Angle Orthod 1955;25:208-22.
8. Schulhof RJ, Nakamura S, Williamson WV. Prediction of abnormal growth in Class III malocclusions. Am J Orthod 1977;71:421-30.
9. Ellis E, McNamara JA. Components of adult Class III malocclusion. J Oral Maxillofac Surg 1984;42:295-305.
10. Williams S, Andersen CE. The morphology of the potential Class III skeletal pattern in the growing child. Am J Orthod 1986;89: 302-11.
11. Proffit WR, Ackermann JL. A systematic approach to orthodontic diagnosis and treatment planning. In: Graber TM, Swain BF, editors. Current orthodontic concepts and techniques. 3rd ed. Saint Louis: C. V. Mosby; 1985.
12. Kerr WJS, Miller S, Dawber JE. Class III malocclusion: surgery or orthodontics? Br J Orthod 1992;19:21-4.
13. Johnston LE. A statistical evaluation of cephalometric prediction. Angle Orthod 1968;38:284-304.
14. Keeling SD, Riolo ML, Martin RE, Ten Have TR. A multivariate approach to analyzing the relation between occlusion and craniofacial morphology. Am J Orthod Dentofacial Orthop 1989;95: 297-305.
15. Battagel JM. The identification of Class III malocclusions by discriminant analysis. Eur J Orthod 1994;16:71-80.
16. Jäger A, Zittlau O, Luhr HG. Zur differentialdiagnostischen Wertigkeit von skelettalen, dentalen und Weichteilanalysen bei der Planung der kieferorthopädisch-kieferchirurgischen Therapie. Fortschr Kieferorthop 1994;55:269-78.
17. Franchi L, Baccetti T, Tollaro I. Predictive variables for the outcome of early functional treatment of Class III malocclusion. Am J Orthod Dentofacial Orthop 1997;11:80-6.
18. Norusis MJ. Spss/PC+ Advanced Statistics V2.0. Chicago: SPSS Inc, B1-B39; 1988.
19. Kowalski CJ, Nasjleti CE, Walker GF. Differential diagnosis of adult male black and white populations. Angle Orthod 1974;44: 346-50.
20. Kowalski CJ, Nasjleti CE, Walker GF. Dentofacial variations within and between four groups of adult American males. Angle Orthod 1975;45:146-51.
21. Nakasima A, Ichinose M. Role of parental variables in predicting facial growth after treatment of anterior crossbite. Am J Orthod Dentofacial Orthop 1986;90:492-500.
22. Tahmina K, Tanaka E, Tanne K. Craniofacial morphology in orthodontically treated patients of Class III malocclusion with stable and unstable treatment outcomes. Am J Orthod Dentofacial Orthop 2000;117:681-90.
23. Hixon EH. Prediction of facial growth. Transactions of the European Orthodontic Society; 1968; Monte Carlo, France. p. 127-39.
24. Baumrind S, Frantz RC. The reliability of head film measurements. 1. Landmark identification. Am J Orthod 1971;60:111-27.
25. Skieller V, Björk A, Linde-Hansen T. Prediction of growth rotation evaluated from a longitudinal implant sample. Am J Orthod 1984;86:359-70.
26. Miyajima K, McNamara JA Jr, Murata S. A diagnostic index of vertical problems for Class III malocclusions. Int J Adult Orthod Orthognath Surg 1997;12:189-95.
27. Ishikawa H, Nakamura S, Iwasaki H, Tsukada H, Chu S. Dentoalveolar compensation in negative overjet cases. Angle Orthod 2000:70;145-8.
28. Stensland A, Wisth PJ, Boe OE. Dentofacial changes in children with negative overjet treated by a combined orthodontic and orthopaedic approach. Eur J Orthod 1988;10:39-51.
29. Battagel JM. Predictors of relapse in orthodontically treated Class III malocclusions. Br J Orthod 1994;21:1-13.
30. Tollaro I, Baccetti T, Franchi L. Craniofacial changes induced by early functional treatment of Class III malocclusion. Am J Orthod Dentofacial Orthop 1996;109:310-8.
31. Ishikawa H, Nakamura S, Kim C, Iwasaki H, Satoh Y, Yoshida S. Individual growth in Class III malocclusions and its relationship to the chin cap effects. Am J Orthod Dentofacial Orthop 1998;114:337-46.
32. Baccetti T, McGill JS, Franchi L, McNamara JA Jr, Tollaro I. Skeletal effects of early treatment of Class III malocclusion with maxillary expansion and face-mask therapy. Am J Orthod Dentofacial Orthop 1998;113:333-43.
33. Panagiotidis G, Witt E. Der individualisierte ANB. Fortschr Kieferorthop 1977;38:408-416.
34. Schopf P. Kephalometrische "Normwerte" für die Stellung der Inzisivi-eine mögliche Ursache für den Misserfolg kieferorthopädischer Behandlungen? Fortschr Kieferorthop 1988;49:37-47.
35. Dahlberg, G. Statistical methods for medical and psychological students. New York: Interscience Publications; 1940.
36. Houston WJB. The analysis of errors in orthodontic measurements. Am J Orthod 1983;83:382-90.
37. Allen RA, Connolly IH, Richardson A. Early treatment of Class III incisor relationship using the chincap appliance. Eur J Orthod 1993;15:371-6.
38. Battagel JM. Discriminant analysis: a model for the prediction of relapse in Class III children treated orthodontically by a nonextraction technique. Eur J Orthod 1993;15:199-209.
39. Björk A. Prediction of mandibular growth rotation. Am J Orthod 1969;55:585-99.
40. Riedel RA. The relation of the maxillary structures to the cranium in malocclusion and normal occlusion. Angle Orthod 1952;22:140-5.
41. Moore AW. Observations on facial growth and its clinical significance. Am J Orthod 1959;42:399-423
42. Enlow DH. A morphogenetic analysis of facial growth. Am J Orthod 1966;52:283-99.

43. Taylor CH. Changes in the relationship of nasion, point A and B and the effect upon ANB. Am J Orthod 1969;56:143-63.
44. Jacobson A. The "Wits" appraisal of jaw disharmony. Am J Orthod 1975;67:125-38.
45. Ferrazzini G. Critical evaluation of the ANB angle. Am J Orthod 1976;69:620-6.
46. Roth R. The "Wits" appraisal-its skeletal and dento-alveolar background. Eur J Orthod 1982;4:21-8.
47. Rotberg S, Fried N, Kane J, Shapiro E. Predicting the "Wits" appraisal from the ANB angle. Am J Orthod 1980;77:636-42.
48. Bishara SE, Fahl JA, Peterson LC. Longitudinal changes in the ANB angle and Wits appraisal: clinical implications. Am J Orthod 1983;84:133-9.
49. Rushton R, Cohen AM, Linney AD. The relationship and reproducibility of angle ANB and the Wits appraisal. Br J Orthod 1991;18:225-31.
50. Jarvinen S. The relation of the Wits appraisal to the ANB angle: a statistical appraisal. Am J Orthod Dentofacial Orthop 1988;94: 432-5.
51. Björk A. Some biological aspects of prognathism and occlusion of teeth. Acta Odontol Scand 1950;9:1-40.
52. Lavelle CL. A study of mandibular shape. Br J Orthod 1984;6: 59-71.
53. Rakosi T. The significance of roentgenographic cephalometrics in the diagnosis and treatment of Class III malocclusions. Transactions of the European Orthodontic Society; 1970; Hamburg, Germany. p. 155-70.
54. Nanda SK. Growth patterns in subjects with long and short faces. Am J Orthod Dentofacial Orthop 1990;98:247-58.
55. Hirschfeld WJ, Moyers RE. Prediction of craniofacial growth: the state of the art. Am J Orthod 1971;60:435-44.

COMMENTARY

The authors of this study sought to determine what variables in patients' lateral cephalometric database (a transverse skeletal assessment was briefly discussed but was not part of this study) would indicate a surgical or a nonsurgical treatment plan for a large group (175) of Class III patients. The authors chose to use the statistical approach of discriminant analysis to develop a more precise understanding of which cephalometic measurements would best indicate a nonsurgical treatment plan to achieve the following goals: (1) stable occlusion in sagittal, transverse, and vertical dimensions; (2) correct ovejet and overbite; (3) proper incisal inclination; (4) satisfying facial esthetics; and (5) long-term stability.

Three experienced orthodontists analyzed the subjects' records and assigned each into the surgical or the nonsurgical group. Through the combined method of the "experienced judge grouping" and the discriminant analysis of specific cephalometric measurements, the authors found that the Wits measurement was the factor most indicative of whether a patient would require surgery. This information is very important and will give the clinician another objective tool to use as part of the decision-making process when planning treatment for adult Class III patients.

However, with the proliferation of scientific data, there is a critical need for all who use this information to be aware that all data have weaknesses. The authors acknowledged this fact and discussed the weaknesses of their findings. Based on the data in Table I, the nonsurgery group had a Wits appraisal of -4.61 ± 1.70 mm with a range of -1.46 to -8.32 mm, and the surgery group had a Wits appraisal of -12.21 ± 4.25 mm with a range of -4.13 to -24.94 mm. Armed with this information, can a clinician analyze a cephalogram and determine that a patient with a Wits appraisal of -8.0 mm automatically requires surgery? Can a claims reviewer at ABC insurance company assess the cephalometric measurements and determine that all patients with a Wits measurement of less than -4.6 mm should not be covered by insurance for surgical intervention? The answer to both questions is no.

The authors, quite appropriately, make the point that the orthodontists could not examine the patients in this study. As many clinicians have experienced, some adult Class III patients present with dual bites and, because of occlusal interferences, demonstrate Class III malocclusions that would conceivably be documented in their diagnostic cephalograms with the mandible inaccurately positioned (ie, in centric occlusion rather than centric relation). In addition, the authors were careful to mention that, in some borderline Class III surgical cases, the decision to treat surgically or nonsurgically might depend on variables that are not measurable on a cephalogram.

The authors begin by stating that the "Class III malocclusion is one of the most difficult anomalies to understand." It is also one of the most difficult malocclusions for which to develop an optimal treatment plan and to avoid overtreatment or undertreatment. The data in this paper give the clinician more guidance in the use of specific cephalometric measurements to aid in decision making. However, no information in this paper excuses the orthodontist from the standard protocol of (1) examining the patient carefully for mandibular functional shift (deprogramming splint therapy might be necessary before a final diagnosis to record accurate centric relation position of the mandible); (2) deciding whether the patient has the characteristics of a borderline surgical case in which satisfactory facial esthetics could be achieved, but there would be some occlusal compromises because of the need to camouflage the mild or moderate skeletal imbalance; and (3) communicating with the patient regarding the goals of treatment and, if certain goals are prioritized