Children with Class III Malocclusion: Development of Multivariate Statistical Models to Predict Future Need for Orthognathic Surgery

Gabriele Schuster, DDS\(^a\); Christopher J. Lux, DDS\(^b\); Angelika Stellzig-Eisenhauer, DDS, PhD\(^c\)

Abstract: Until now, the literature does not provide an accurate model to predict the future need for orthognathic surgery in prepubertal patients with class III malocclusion. Because not all of these patients are candidates for later surgical correction, patient assessment and selection remain arbitrary with respect to diagnosis and treatment planning. The purpose of the present investigation was to analyze the value of classifying class III children before puberty into patients who can be effectively treated by orthopedic/orthodontic therapy alone and those who require orthognathic surgery. To obtain a robust model, the study design was multicentric (University Orthodontic Departments of Frankfurt, Heidelberg, and Würzburg). A total of 88 patients with class III malocclusion were grouped into orthopedic/orthodontic (n = 65) and surgery patients (n = 23), according to their records after puberty (mean age, 17 years three months). Discriminant analysis (DA) and logistic regression (LogR) were applied to 20 landmarks of the patients’ cephalograms before puberty (mean age, nine years eight months) to identify the dentoskeletal variables that provide the best group separation and the best predictability of group membership, respectively. Both models were highly significant (\(P < .001\)), classifying 93.3% (DA) and 94.3% (LogR) of the patients correctly. The extracted variables were identical for both procedures: Wits appraisal, palatal plane angle, and individualized inclination of the lower incisors. The resulting equation of LogR was individual score = \(-7.968 + 1.323\text{Wits} - 0.363\text{NL-NSL} + 0.153[180 - (L1-\text{ML}) - (L1-\text{ML}_{\text{ind}})]\). We concluded that by means of multivariate statistics, prepubertal children with class III malocclusions may be classified into nonsurgery and surgery patients with high accuracy. (\textit{Angle Orthod} 2003;73:136–145.)

Key Words: Class III malocclusion; Craniofacial growth; Prediction; Surgery; Discriminant analysis; Logistic regression; Multivariate statistics

INTRODUCTION

Class III malocclusion is one of the most severe dentofacial anomalies. Individuals with class III malocclusion frequently show combinations of skeletal and dentotraumal components.\(^1\) Moreover, there are complex interactions of genetic and environmental factors, which may act synergistically or in isolation, or may cancel each other out.\(^2\)

Compared with class I subjects, several aberrant cephalometric measurements have been reported in class III malocclusion patients, such as a shorter anterior cranial base length, a more acute cranial base angle, a shorter and more retrusive maxilla, more proclined maxillary incisors, more retroclined mandibular incisors, an excess of lower anterior face height, and a more obtuse gonial angle.\(^2\)–\(^8\) Because no single morphologic feature is indicative of class III development, treatment outcome is extremely difficult to predict in class III children.\(^9\)

Ricketts\(^10\) introduced the computer-assisted growth prognosis—the so-called visual treatment objective—for prediction of individual treatment outcome. This method is based on empirically obtained mean growth increments, anticipating the influence of orthodontic treatment. However, the prognostic power of dental relationships, dentoskeletal relations, or soft-tissue configurations at the end of treatment was limited.\(^11\)–\(^12\) In particular, overestimation of treatment influences was considered to be responsible for the low predictability of this method.\(^13\)

© 2003 by The EH Angle Education and Research Foundation, Inc.
ualized growth prediction was regarded as nearly impossible because of the diversity and variability of facial growth.14–16

Because of the complexity of class III malocclusion, univariate statistical techniques turned out to be insufficient for diagnosis, treatment planning, and outcome prognosis.17 Instead, recent studies suggested that the relations between craniofacial structure and occlusion would be analyzed best by using a multivariate approach.18–20 Logistic regression (LogR) is one multivariate procedure that estimates the likelihood of a certain event occurring or a group membership.21–24 In orthodontic literature most of the studies using multivariate statistics explored the potential of discriminant analysis (DA).25–28 DA is specially designed to separate two groups of individuals taken from the same population. Until now, it has been successfully applied to separate class III patients from class I subjects.18,29,30 Furthermore, DA was used to predict treatment outcome and relapse of orthodontically treated class III patients.20,28,31–36

Recently, a formula was developed to classify adult class III patients into a group that is treatable solely orthodontically and a group that requires orthognathic surgery.37 However, to date the literature does not provide an accurate multivariate model to distinguish between growing class III patients who can be treated successfully by orthodontics/or-thopedics alone and class III patients who require surgical treatment after termination of dentofacial growth. Because most of the class III malocclusion patients already have undergone orthodontic/orthopedic treatment in early infancy, prediction of future craniofacial growth is an essential issue in clinical orthodontics.

Therefore, the purpose of the present investigation was to develop a statistical model classifying class III children before puberty into patients who can be effectively treated by orthodontic/orthopedic therapy alone and those who require future orthognathic surgery.

**MATERIALS AND METHODS**

**Subjects**

For a sufficiently stable model that is also applicable to patients outside the study, a large sample size is a prerequisite. For this reason, the present analysis was based on the data of three different orthodontic centers (Department of Orthodontics, University Dental School of Frankfurt, Heidelberg, and Würzburg). The three participating universities are located in the same region in the middle part of Germany. The concept and modality of treatment of class III children were similar. In all three centers, treatment of class III malocclusion starts as soon as the malocclusion is detected. Besides chin-caps and reverse headgears, functional appliances are used as a rule, followed by a fixed appliance at the end of pubertal growth. Because of this convergence, pooling of the records was applicable.

Patients with craniofacial disorders such as cleft palate or craniosynostosis were excluded.

The patients were all Caucasians and met the following criteria for inclusion into the retrospective study:

I. Initial records (plaster casts, cephalograms, extraoral pictures) before pubertal growth spurt (mean age, nine years eight months; standard deviation [SD], one year six months):

- presence of a class III molar relationship;
- negative overjet;
- Wits appraisal \( \leq -1 \) mm;
- negative difference between ANB angle and individualized ANB angle.38

II. Final records (plaster casts, cephalograms, extraoral pictures) after puberty (mean age, 17 years three months; at least four years after the initial records).

Three experienced orthodontists grouped the final records into a nonsurgery and a surgery group. For allocation to the nonsurgery group, the following treatment outcome criteria had to be fulfilled:

- stable occlusion in sagittal, transversal, and vertical dimension;
- correct overjet and overbite;
- proper incisal inclination;
- satisfying facial esthetics;
- long-term stability.

Accordingly, the material for the study comprised the cephalometric radiographs of 88 class III malocclusion patients, 39 boys and 49 girls.

The orthodontic group consisted of 65 patients and the surgery group, 23 patients.

**Methods**

Because the lateral cephalograms were taken with different X-ray devices, all linear measurements were corrected by their respective magnification factors. The same investigator traced all films with 20 landmarks (Figure 1) and digitized the data using appropriate software (WinCeph, Dentev Compudent, Koblenz, Germany).

The following linear, proportional, and angular measurements were calculated (Figure 2a–e)—S-N: anteroposterior length of the cranial base; PoOr-NBa (\( \zeta \)): cranial deflection; ML-NSL (\( \zeta \)): divergence of the mandibular plane relative to the anterior cranial base; NSAr (\( \zeta \)): saddle angle; ArGoMe (\( \zeta \)): gonial angle; Go-upper (\( \zeta \)): upper gonial angle; Go-lower (\( \zeta \)): lower gonial angle; SNB (\( \zeta \)): anteroposterior mandibular position to the anterior cranial plane; L1-ML (\( \zeta \)): axis of the lower incisor to the mandibular plane; individualized inclination of the lower incisors (\( \zeta \)) \( 180 - \left( \text{L1-ML} - \left( \text{L1-ML}_{\text{ind}} \right) \right) \); difference between 180° minus axis of the lower incisor to the mandibular plane and individualized L1-ML angle, according to the formula L1-
Random errors ranged from 0.02 to 0.81 mm for the linear measurements and from 0.38° to 1.93° for the angular variables.

Systematic error was tested at the 10% level of significance, as recommended by Houston, and no systematic errors were found.

**Statistical analysis**

Data analysis was performed using SPSS PC+ (version 9.0), the Statistical Package for the Social Sciences. The arithmetic means (mean), SDs, medians (median), minima (min), and maxima (max) were calculated for each variable and group before treatment (T1). To assess differences between the craniofacial features of both groups at the start of treatment, the data were compared using Mann-Whitney U-test for independent samples (Table 2).

For multivariate statistics two procedures were applied to the set of data:

1. **Discriminant analysis**—DA was used to identify those dento-skeletal variables that best separate the patients who need orthognathic surgery for correcting the malocclusion from those who do not.

To avoid redundancy among the various variables, stepwise variable selection was performed to obtain a model with the smallest possible set of significant cephalometric parameters. The independent variables were included in the model according to the 5% level of significance. The first variable selected was the one with the smallest value of Wilks’ lambda, where lambda is the ratio of the within-group sum of squares divided by the total sum of squares. We chose the subsequent variables by recalculating lambda for each of the variables, and the variable with the next lowest value was selected. For each stage, a test was done to ascertain whether the inclusion of the respective variable in the model would significantly improve prediction.

Unstandardized discriminant function coefficients were calculated for each selected variable together with a constant. This leads to an equation that assigns a score to each patient. For each group, DA results in a mean score over all known cases in the relevant group. The dividing line halfway between these scores shows to which of the two groups an individual case belongs (critical score: mean value of group centroids of the two groups).

2. **Logistic regression**—LogR is a variation of ordinary regression, applicable when the observed outcome is restricted to two values, which represent the occurrence (where surgical intervention is necessary for correction of the class III anomaly) or nonoccurrence (where no surgical intervention is necessary for correction) of an outcome event. It produces a formula that predicts the probability of the occurrence of an event as a function of the independent variables. The global P-value of the final model was based on the likelihood ratio test, evaluating the total influence of all variables in the model. The P-values of the single var-

**FIGURE 1.** Hard-tissue landmarks used in the study: S indicates sella; Po, porion; Ba, basion; Ar, articulare; Go, gonial intersection; Me, menton; Pog, pogonion; B, point B; L1 apex, apex of the lower central incisor; L1 tip, tip of the lower central incisor; U1 tip, tip of the upper central incisor; U1 apex, apex of the upper central incisor; A, point A; Ans, anterior nasal spine; Pns, posterior nasal spine; Ptm, pterygomaxillary fissure; Or, orbitale; N, nasion; ERP, ethmoid registration point; PocP, posterior point of the occlusal plane; and AocP, anterior point of the occlusal plane.

ML\textsubscript{ind} = 72.5 + 0.5ML-NL\textsuperscript{a}

Wits appraisal: 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 (\angle): anteroposterior relation of the maxilla and the mandible; ANB-ANB\textsubscript{ind} (\angle): difference between ANB angle and individualized ANB angle according to formula 7, ANB\textsubscript{ind} = −35.16 + 0.4SNA + 0.2ML-NL\textsuperscript{a}; M/M ratio: ratio of the anteroposterior length of the maxilla to the anteroposterior length of the mandible; NAPog (\angle): angle of convexity; 1/1 (\angle): angle between the axis of the upper and the lower incisor; SNA (\angle): anteroposterior maxillary position to the anterior cranial plane; NL-NSL (\angle): inclination of the palatal plane in relation to the anterior cranial base; U1-NSL (\angle): angle of the upper incisor to the anterior cranial base; [(U1-NL) − (U1-NL\textsubscript{ind})] (\angle): difference between the axis of the upper incisor to the palatal plane measured outside and the individualized U1-NL angle, according to the formula U1-NL\textsubscript{ind} = 57.5 + 0.5ML-NL\textsuperscript{a}.

Fifteen films were selected randomly, retraced, and re-digitized on two separate occasions two weeks apart. The method error was calculated as recommended by Dahlberg. The method error in locating and measuring was calculated by the formula:

\[ ME = \sqrt{\frac{1}{n} \sum d^2/2n} \]

where \( d \) is the difference between two registrations of a pair and \( n \) the number of double registrations.
STATISTICAL MODELS PREDICTING NEED FOR FUTURE SURGERY

FIGURE 2. Linear and angular cephalometric measurements used in the study: S-N (mm) indicates anteroposterior length of the cranial base; PoOr-NBa (\(\angle\)), cranial deflection; ML-NSL (\(\angle\)), divergence of the mandibular plane relative to the anterior cranial base; NSAr (\(\angle\)), saddle angle; ArGoMe (\(\angle\)), gonial angle; Go\(_{upper}\) (\(\angle\)), upper gonial angle; Go\(_{lower}\) (\(\angle\)), lower gonial angle; SNB (\(\angle\)), anteroposterior mandibular position to the anterior cranial plane; L1-ML (\(\angle\)), axis of the lower incisor to the mandibular plane; Wits (mm), 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 B and the occlusal plane); ANB (\(\angle\)), anteroposterior relation of the maxilla and the mandible; M/M ratio, ratio of the anteroposterior length of the maxilla to the anteroposterior length of the mandible; NAPog (\(\angle\)), angle of convexity; U1/L1 1/1 (\(\angle\)), angle between the axis of the upper and lower incisors; SNA (\(\angle\)), anteroposterior maxillary position to the anterior cranial plane; NL-NSL (\(\angle\)), inclination of the palatal plane in relation to the anterior cranial base; U1-NSL (\(\angle\)), axis of the upper incisor to the anterior cranial base; and U1-NL (\(\angle\)), axis of the upper incisor to the palatal plane measured outside.

Variables that entered the model were calculated by the Wald test.

Because the study was based on lateral cephalometric landmarks only, the skeletal transverse component of class III malocclusion was not considered.

RESULTS

Univariate cephalometric analysis

Descriptive statistics for all cephalometric variables for both patient groups at T1 are listed in Table 1. The levels of significance at \(P\)-values of *\(P < .05\), **\(P < .01\), and ***\(P < .001\) between the no surgery and the surgery groups are given in Table 2.

Significant intergroup differences were found for parameters representing the sagittal maxillo-mandibular relationship as indicated by ANB, ANB-ANBind, and Wits appraisal. In addition, significant differences were given for length of the anterior cranial base, anteroposterior position of the mandible, ratio between length of the maxilla and length of the mandible and angle of convexity, lower gonial angle, individualized axis of the lower central incisors, and interincisal angle.

In contrast, there were no significant differences in the position and inclination of the upper jaw, the axis of the maxillary central incisors, the cranial deflection, as well as the parameters describing the direction of craniofacial growth (NL-NSL, ML-NSL, NSAr, Go\(_{upper}\)) (Table 2).

Multivariate cephalometric analysis

Discriminant analysis. Stepwise variable selection of DA resulted in a significant model of three variables. The variables selected were Wits appraisal (F likelihood to remove...
individual score = 2.277 + 0.492Wits + 0.116NL-NSL - 0.058[(180 - (L1-ML)) - (L1-MLind)]

The critical score was −0.653, which is the mean value of group centroids of the two groups (Table 3). Each new case with a class III malocclusion that will show an individual score higher than the critical score will probably be treated successfully by orthodontics/orthopedics alone. On the other hand, a new class III patient with a more negative individual score than the critical score should be treated by combined orthodontic-orthognathic therapy after termination of craniofacial growth.

The percentage of correctly classified cases was 93.2% (Table 4). Only 4.6% of the patients in the nonsurgery group and 13.0% of those in the surgery group, respectively, were misclassified. Then, sensitivity amounted to 0.87, and the specificity scored was 0.932 (Table 4).

**Linear regression.** Forward conditional stepwise procedure was run for LogR. Again, the variables Wits appraisal, NL-NSL, and [180 − (L1-ML) − (L1-MLind)] entered the model, resulting in the following equation (Table 5):

individual score = −7.968 + 1.323Wits − 0.363NL-NSL + 0.153[L1-ML] − (L1-MLind)]

The overall percentage of correctly classified cases was 94.3. Only one patient of the nonsurgery group was misclassified, whereas four patients of the surgery group were wrongly classified.
The grouping of the sample according to LogR is shown for Wits appraisal in Figure 3. The sensitivity amounted to 0.985, and the specificity was 0.826 (Table 6).

The sensitivity amounted to 0.985, and the specificity was 0.826 (Table 6).
tion of treatment outcome and relapse in class III patients treated with singular appliances like the chin-cup or a special treatment modality like tooth extraction.\textsuperscript{20,28,31–36}

The aim of the present study was to predict the need for surgical intervention in adolescent children with class III malocclusion. For this reason, multivariate techniques were applied, the DA and the LogR.

The decision as to what kind of treatment is indicated usually is based on degree of anteroposterior and vertical skeletal discrepancy, inclination and position of the incisors, and dentofacial appearance. Several lateral cephalometric studies have been conducted to elucidate the growth pattern in class III subjects when compared with eugnathic subjects and to show up the effects of orthopedic therapy and the stability of treatment outcome.\textsuperscript{3–8,32,33,46} However, only a few studies have been undertaken to establish some threshold values for pretreatment identification of patients for whom orthognathic correction would be necessary.

The “three envelopes of discrepancies” from Profit and Ackerman\textsuperscript{47} represent a guideline for differentiation between orthodontic and combined orthodontic-surgical treatment. Critical limitation for orthodontic treatment was seen in an upper incisor protrusion of two mm combined with a lower retrusion of three mm. Kerr et al\textsuperscript{48} tried to establish cephalometric yardsticks to objectify treatment decision. The most important factors that differentiated between the surgery and the orthodontic patients in this study were size of the anteroposterior discrepancy, inclination of the lower incisors, and appearance of the soft-tissue profile. The vertical dimensions, eg, gonial angle and y-axis, were of limited relevance for treatment decisions. Based on the overlaps of “box-and-whisker plots,” the following critical values were set up: ANB: −4°; M/M ratio: 0.84; lower incisor inclination: 83°; and Holdaway angle: 3.5°. However, univariate statistics are not insufficient to reflect complex craniofacial relationships.\textsuperscript{9,22,49} For these reasons, multivariate statistics were used in the present study to separate the patients into the nonsurgery and the surgery groups.

The prerequisite for a powerful model is a relatively large sample. Thus, when an unknown patient has to be classified, his measurements will not fall outside those used in generating the model.\textsuperscript{52} On this account, a multicentric study design was chosen.

Stepwise variable selection of both DA and LogR generated a three-variable model producing the most efficient separation between the nonsurgery and the surgery groups. The variables chosen were identical: (1) Wits appraisal, (2) NL-NSL, and (3) individualized inclination of the lower incisors. The classification power of the model was 93.2% for DA and 94.3% for LogR.

Since its introduction by Riedel,\textsuperscript{50} ANB angle is the most commonly used cephalometric measurement to describe skeletal relationships between the maxilla and the mandible. However, its validity as a true indicator of the anteroposterior jaw relationships has been questioned by the fact that Nasion is not a fixed point and any change in its anteroposterior position consequently affects ANB.\textsuperscript{51–54} In addition, the magnitude of the ANB angle is affected by rotation of the jaws relative to the cranial base.\textsuperscript{50,52,53} The “individualized ANB,” according to Panagiotidis and Witt,\textsuperscript{58} takes the angle between the mandibular planum and the Sella-Nasion line into account and by this, the vertical dimension.

To uncouple the anteroposterior jaw relationships completely from the craniofacial reference, Jacobson\textsuperscript{55} introduced Wits appraisal. Here, the functional occlusal plane is used as a reference plane for defining the relation 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 a weak correlation between both variables.\textsuperscript{55–59} When analyzing the geometrical relationship between ANB angle and Wits appraisal, Jarvinen\textsuperscript{60} found that it is difficult to compare measurements based on different reference planes. Therefore, the conjunctive use of ANB angle and Wits appraisal was recommended as an appropriate method for clinical assessment of jaw relationships.\textsuperscript{30,61,62}

The validity of precise landmark identification of Wits appraisal has been questioned because the functional occlusal plane was considered as a major source of error. However, no statistically significant differences were found for repeated intraobserver measurements.\textsuperscript{53} In contrast, interobserver reproducibility was low. In the present study the same investigator traced all radiographs. Therefore, systematic error based on interobserver variance was eliminated.

The question of the stability of the occlusal plane during craniofacial growth has also been raised. Sherman et al\textsuperscript{64} assumed that Wits appraisal is affected by changes in the angulation of the occlusal plane during eruption of the permanent teeth. In contrast, Nanda and Merrill\textsuperscript{65} found that the inclination of the palatal plane was stable throughout the growth period and that the distance between the projections from points A and B on the palatal plane was the best indicator of the sagittal jaw relationship. In the present study, ANB angle, ANB-ANB\textsubscript{nal} angle, and Wits appraisal showed highly significant differences between the nonsurgery and the surgery groups. However, of these variables, only Wits appraisal entered the DA as well as the LogR models. This and the fact that Wits appraisal was the first variable in both models point to its preponderance in separating both patient groups. In a comparable study with a group of 175 adult class III patients, Stellzig-Eisenhauer et al\textsuperscript{17} could also show the decisive character of Wits appraisal in classifying the patients into a group needing either surgery or a nonsurgical treatment approach. The second variable that was extracted into the models was the inclination of the palatal plane relative to the anterior cranial base. Children in the surgery group showed a less steep inclination of the palatal plane than did those in the nonsurgery group. Although this variable did not show a significant
difference in both patient groups in the univariate comparison, it became important for patient selection in multivariate analysis.

In the literature to date, no article discusses the inclination of the palatal plane for further development of class III malocclusion. However, a less steep maxillary occlusal plane in combination with posterior vertical excess of the maxilla was described in adult class III malocclusion patients with an anterior open bite. Consistently, Tsang et al found that the palatal plane inclination correlates significantly with the severity of the anterior open bite. With respect to these findings, the less steep palatal plane before puberty, as seen in surgery patients, possibly constitutes an unfavorable condition for achievement of a stable overbite during adolescence.

The third value that entered the models was the lower inclination of the front teeth after correction for the interbase angle according to Schopf. As mentioned above, Proffit and Ackerman already considered lower incisor inclination as one of the most decisive factors in the choice of orthodontics/orthopedics alone or orthognathic surgery. In the univariate analysis both the inclination of the lower front teeth to the mandibular plane and individualization to the interbase angle tested highly significant. Moreover, Ishikawa et al found that among the compensatory dentoalveolar changes in class III malocclusion, lower incisor inclination was strongly related to the sagittal jaw relationship.

The predictive power of the discriminant model for identification of those class III patients for whom orthodontic treatment was sufficient was high. Only 4.6% of the nonsurgery patients were misclassified. In contrast, the percentage of misjudgment in patients who needed orthognathic surgery was 13.0%. For the LogR the overall classification was even slightly higher. Over 98% of the nonsurgery patients were correctly classified, which is 3.1% higher than for DA. In contrast, the grouping of the surgery patients worsened by −4.4% to 82.6%.

Limitation of growth prediction is based on the fact that huge variation exists in timing, duration, and amount of growth in different components of the face. Also, individual response to orthodontic/orthopedic procedures is different in growing patients. There are cases that do not respond satisfactorily to treatment because of bizarre or unanticipated growth patterns or insufficient patient compliance. Consequently individual growth prediction is limited.

A further explanation for misjudgment of patients is that the cephalometric measurements used here did not encompass all the factors that clinically contribute to treatment outcome. Especially in borderline surgical patients, additional factors have to be considered, such as incisal guidance, soft tissue features, and dentofacial esthetics. Because class III patients also frequently show skeletal deficiencies in the transverse dimension, anteroposterior cephalograms are necessary to analyze this aspect of craniofacial development. If transverse components as well as the aforementioned factors could be included into the analysis, the predictive power of the multivariate model might increase.

Both multivariate statistical procedures yielded nearly the same result. The extracted variables were not only the same but were even selected in the same order. According to Press and Wilson, the two methods do not differ markedly in their results, which also is demonstrated by the data presented. The predictive power of the LogR model was slightly higher (94.3%) than the percentage of correct classification by DA (93.2%). The better result of the LogR procedure was due to a higher sensitivity (0.985). In contrast, the specificity of the LogR model was lesser (0.826) than the specificity resulting from DA (0.87). Because of the more serious consequences, misclassification of nonsurgical patients should be prevented primarily. For that reason the predictive model with the highest sensitivity has to be preferred, which in this study is the model of LogR.

CONCLUSIONS

Both, the LogR and the discriminant models were highly significant ($P < .0001$), classifying 94.3% and 93.2%, respectively, of the prepubertal class III malocclusion children correctly into patients who can be adequately treated by orthopedic/orthodontic therapy alone and those who require orthognathic surgery. The following three cephalometric variables were concordantly selected: Wits appraisal, inclination of the palatal plane, and individualized inclination of the lower incisors.

However, individual growth prediction based on multivariate models is limited because of the diversity and variability of facial growth and the individual response on orthodontic/orthopedic procedures. Moreover, additional factors that might also contribute to clinical treatment outcome, such as transverse components and facial esthetics, have not been considered in the present study.

ACKNOWLEDGMENT

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

REFERENCES