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ORIGINAL ARTICLES

Prediction of mandibular growth rotation evaluated from a longitudinal implant sample

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The aim of this study was to estimate the possibility of predicting the direction and the amount of growth rotation of the mandible on the basis of morphologic criteria observed on a single profile radiograph at pubertal age. The difficulty in such an analysis is due to the fact that the actual growth rotation cannot be evaluated from radiographs by measurements at outer bony contours subjected to remodeling. The sample consisted of twenty-one persons in whom the actual mandibular growth rotation was determined from metallic implants over a 6-year period at around the time of puberty. Morphologic features from the first profile radiograph could therefore be compared with the observed growth changes over the study period and their predicting values calculated. A total of forty-four morphologic variables were employed and the data were analyzed by multivariate statistical methods. For each person, the variables which, alone and in combination, showed the highest predictive value with respect to total mandibular growth rotation are specified. The four variables which, in combination, gave the best prognostic estimate (86%) of mandibular growth rotation in this sample are (1) mandibular inclination, represented by three alternatives—(a) Index I (proportion between posterior and anterior facial height, (b) lower gonial angle (GOL), (c) inclination of lower border (NSL-ML1); (2) intermolar angle (MOLs-MOLi); (3) shape of lower border (ML1-ML2); and (4) inclination of symphysis (CTL-NSL). The statistical analysis was based on a sample of extreme cases. In children with a more normal growth pattern, these features may be less developed. The concordance between the predicted and the observed growth changes is illustrated graphically for each person.

Key words: Prediction, mandibular growth rotation, cephalometrics, metallic implants

With an increased realization of the great individuality in craniofacial growth and development, the need for a predictive system has been imperative in orthodontic treatment planning. In spite of several attempts in recent years, however, there is still doubt as to the extent to which growth of the face as a whole can be predicted from a single profile radiograph.

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In an early attempt to analyze the possibility of predicting growth of a single facial dimension, Björk and Palling[1] correlated linear and angular measurements at prepubertal age with the residual growth of these dimensions up to adulthood. These correlations, however, were found to be very low. The variability of the individual growth changes between the two age levels was remarkably great, between 50% and 80% of the variability at prepubertal age. These findings were confirmed by Meredith,[2] who also found that a single morphologic dimension at an early stage will tell us

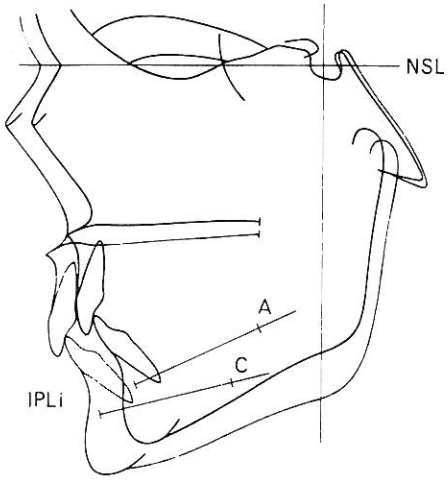

Fig. 1. Growth rotation of the mandibular corpus relative to the anterior cranial base *(NSL)* designated as negative when the implant line *(IPLi)* rotated forward from stage *A* to stage *C*.

little or nothing about the amount and direction of the residual growth of this dimension.

Hixon[3] suggested that the best estimate of an adult facial dimension for a given child is to use the dimension presented by the child and add to that the remaining average growth for the group. This method was adopted by several authors, and Johnston[4] developed his grid method on these premises. As exemplified by Mills,[5] this estimate would fit an average but not an extreme growth pattern, where prediction from a clinical point of view is most important.

In an earlier approach, Johnston[6] applied the multivariate regression method to growth prediction. Bhatia and associates[7] outlined a prediction method based on a cluster analysis. Lavergne[8] tried to individualize the prediction by a subdivision according to morphogenetic types. Ricketts' computerized growth forecasts (short range and long range), his treatment-simulation method, and the commercial Rocky Mountain Data system[9, 10] advocated by him and his coworkers have gained considerable interest. In principle, the arcial method of long-range growth prediction uses geometric procedures to extract information about the previous growth pattern of the mandible and project it to the further development. Statistical tests of these methods have been made by Greenberg and Johnston,[11] Schulhof and Bagha,[12] and Witt and Köran.[13]

A computerized system for short-range facial growth prediction and treatment simulation, based on longitudinal observations of individual growth rate and growth direction over one or more years, has recently been developed by Bjørn-Jørgensen.[14] Since this prediction further is based on skeletal age and includes the actual growth rotations of both mandible and maxilla, the method seems promising.

Cephalometric growth analysis has generally been based on conventional measurement of the facial morphology, without taking into account the remodeling processes at the bony surfaces. The dynamics of the actual growth pattern is therefore often concealed. This applies especially to the vertical development of the face because of the pronounced growth rotations of the maxillary and mandibular bones inside their more stable soft-tissue matrices, as demonstrated in studies with metallic implants.

The present study is limited to an estimate of the possibilities of predicting the amount and the direction of the actual growth rotation of the mandible from prepubertal age during the subsequent growth period. A necessary condition was to analyze a sample, followed longitudinally with metallic implants up to adult age, where the mandibular growth rotation could be exactly determined.

MATERIALS

A sample of twenty-one subjects were chosen. These included nine girls and twelve boys whose dentitional and facial development has been analyzed by the use of metallic implants as references. All the subjects were Danish and in normal physical and mental health. They were selected from the group of children (250), who were enrolled in the implant growth study and who had not undergone orthodontic treatment before or during the 6-year period of observation. Some deciduous and permanent teeth were missing in several cases. The sample was previously described in 1972.[15] The reader is referred to that earlier article for a detailed case description. In order to obtain uniformity regarding physical maturity, the analysis was limited to a period of 6 years encompassing the time of puberty. The first stage A, 3 years before puberty, and the growth change during the period until 3 years after puberty have been used in the present analysis.

METHODS

The profile radiographs were superimposed according to stable structures in the anterior cranial base, and the nasion-sella line (NSL) was transferred from the first to the last film, as described earlier.[15–17]

The observed growth rotation of the mandibular corpus from the first to the last stage was measured as the change in inclination of the implant line in the lower jaw (IPLi) in relation to NSL (Fig. 1). When the im-

Table I.

Independ variable
Index I
GOL
NSL-ML1
NSL-NL
OLs-ML2
NSL-ML2
ML2-RL
MOLs-M(
CTL-NSL
SYMF wi(
Index II
NSL-OLi
OLi-ML2
Y axis
Index III
MOLi-ML
Index IV
ML1-ML2
NSL-MOL
ILi-ML2

Table II. Corr

Index I
GOL
NSL-ML1
NSL-NL
OLs-ML2
NSL-ML2

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P <0.001, r = (

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Table I.

Independent variables	R^2	*Level of significance*	*Definitions of variables*	
Index I	0.6191	$P < 0.001$	Index I	Posterior facial height / Anterior facial height (Fig. 2)
GOL	0.6147		GOL	Lower gonial angle (Fig. 3)
NSL-ML1	0.6081		NSL-ML1	NSL to mandibular line 1 (Fig. 4)
NSL-NL	0.6071		NSL-NL	NSL to nasal line
OLs-ML2	0.5469		OLs-ML2	Upper occlusal line to ML2
NSL-ML2	0.4924		NSL-ML2	NSL to mandibular line 2
ML2-RL	0.3990	$P < 0.005$	ML2-RL	Jaw angle
MOLs-MOLi	0.3884		MOLs-MOLi	Intermolar angle (Fig. 5)
CTL-NSL	0.3759		CTL-NSL	Chin line to NSL (Fig. 7)
SYMF width	0.3712		SYMF width	Width of symphysis
Index II	0.3606		Index II	Ramus height / Corpus length
NSL-OLi	0.3540		NSL-OLi	NSL to lower occlusal line
OLi-ML2	0.3478		OLi-ML2	Lower occlusal line to ML2
Y axis	0.3235	$P < 0.010$	Y axis	NSL to sella prognathion
Index III	0.3052		Index III	Clivus length / Ramus height
MOLi-ML2	0.2967	$P < 0.025$	MOLi-ML2	Lower molar inclination to ML2
Index IV	0.2768		Index IV	Upper face height / Lower face height
ML1-ML2	0.2698		ML1-ML2	Angle between the two mandibular lines (Fig. 6)
NSL-MOLi	0.2294	$P < 0.050$	NSL-MOLi	NSL to lower molar inclination
ILi-ML2	0.2291		ILi-ML2	Lower incisor inclination to ML2

Table II. Correlations at stage A between the six first independent variables in Table I

	Index I	*GOL*	*NSL/ML1*	*NSL-NL*	*OLs-ML2*	*NSL-ML2*
Index I		−0.86	−0.96	−0.96	−0.83	−0.93
GOL	−0.86		0.93	0.93	0.85	0.92
NSL-ML1	−0.96	0.93		0.99	0.83	0.98
NSL-NL	−0.96	0.93	0.99		0.84	0.98
OLs-ML2	−0.83	0.85	0.83	0.84		0.84
NSL-ML2	−0.93	0.92	0.98	0.98	0.84	

$P < 0.05$, $r = 0.43$.
$P < 0.01$, $r = 0.55$.
$P < 0.001$, $r = 0.67$.

plant line showed a forward rotation of the mandibular corpus, the rotation was designated as negative and as positive when the rotation was directed backward.

The mandibular growth rotation during the 6-year observation period was on an average directed −6.0° forward with a range of 21.7° (Table IV) as described for this sample in 1972.[15] The observed rotation was used as the dependent variable in the following multivariate statistical analysis.

In order to find, on a single profile radiograph, the morphologic criteria showing the highest predictive values and expressing as much as possible of the observed rotation, forty-four morphologic variables from the first stage A, taken 3 years prior to maximum pubertal growth in body height (four linear, thirty-five angular, and five indices) were registered. These variables were used as independent variables in the multivariate regression analysis.[18] In the regression analysis between the dependent and the forty-four independent variables, the linear combination of the independent variables that could explain most of the variability of the dependent variable was determined. To characterize

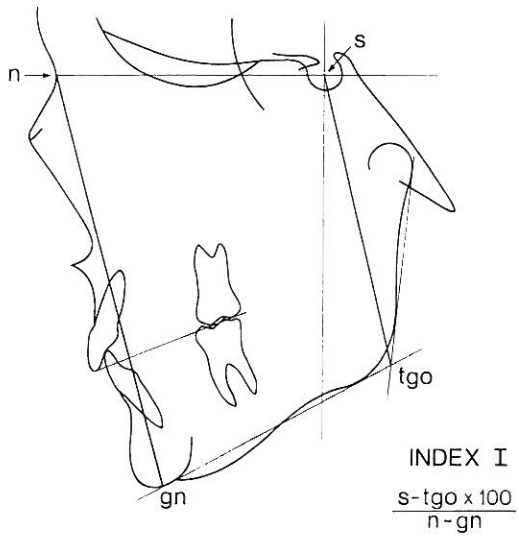

Fig. 2. Mandibular inclination determined by Index I.

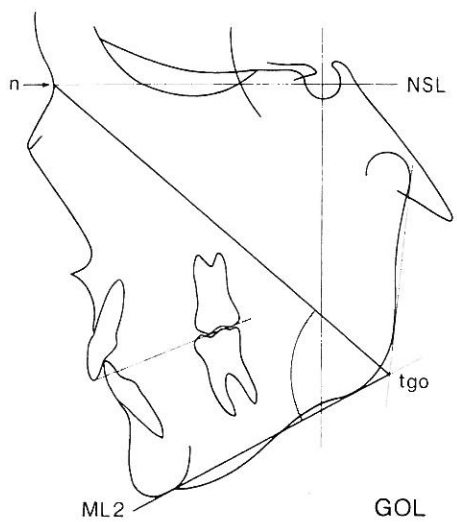

Fig. 3. Mandibular inclination determined by the lower gonial angle.

the regression analysis, the squared multiple correlation coefficient, R^2, was computed, varying between 0 and 1. This value indicated what fraction of the total variation could be explained by the independent variable. The purpose was to select those independent variables which, alone or in combination, could explain as much as possible of the variability of the dependent variable. In this procedure there were two principal purposes: (1) attainment of the greatest possible R^2 values and (2) selection, among morphologic variables with equivalent R^2 values, of those easiest to apply clinically.

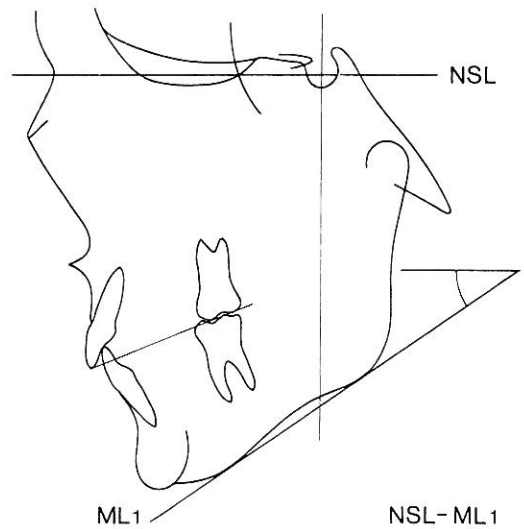

Fig. 4. Mandibular inclination determined by the angle NSL-ML1.

RESULTS

At first a univariate regression analysis for each of the forty-four independent morphologic variables was performed. In Table I, twenty of the forty-four independent variables whose level of significance was less than 5% are listed consecutively according to the R^2 values.

The variable showing the highest R^2 value of 0.6191 was Index I (Fig. 2). This index is an expression of the proportion between the posterior and the anterior facial height calculated as $\frac{\text{s-tgo} \times 100}{\text{n-gn}}$. Thus, 62% of the variability of the mandibular growth rotation in the sample could be explained by Index I, as graphically illustrated in Fig. 8.

The first six morphologic variables in Table I all showed high R^2 values. All of them are associated with the inclination of the upper or lower jaw relative to the anterior cranial base and, consequently, are strongly correlated (Table II). As far as the first four variables are concerned, there was no significant difference in the R^2 values. For clinical use, however, the first three are most relevant. Alternatively to Index I, as an expression of mandibular inclination, the lower gonial angle (GOL) (Fig. 3)[19] and the angle NSL-ML1 could be used (Fig. 4). It may be noted from Table I that the inclination of the mandible showed a considerably lower predicting value when measured as the angle NSL-ML2 (Fig. 3) than when measured as the angle NSL-ML1.

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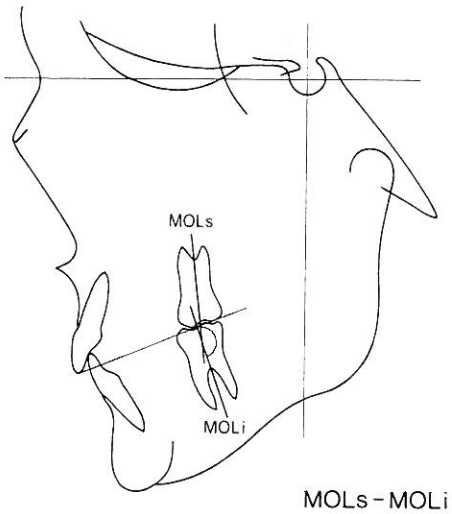

Fig. 5. Intermolar angle.

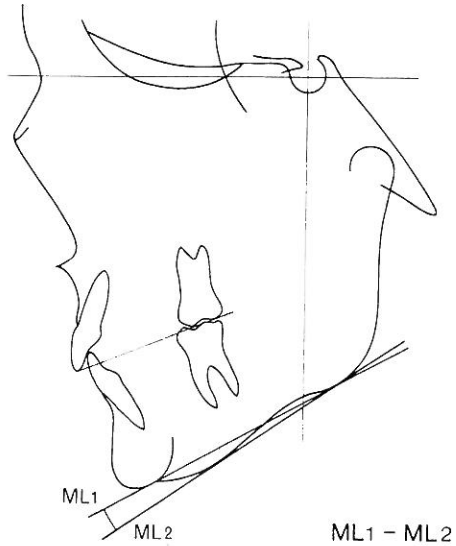

Fig. 6. Shape of the lower border of the mandible.

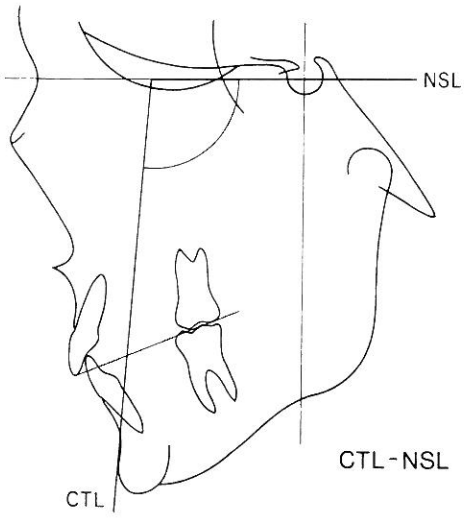

Fig. 7. Inclination of the symphysis.

of the observed mandibular growth rotation during the observation period could be explained by the *mandibular inclination* at the first stage, expressed by Index I or by equivalent measurements.

In the present analysis, Index I was selected as the first independent variable in the multivariate analysis. The next step was to find those variables which, in combination with Index I, could explain as much as possible of the remaining part of the variability of the observed rotation.

Owing to the great number of independent variables, it was practically impossible to investigate all the possible combinations by using a multiple regression analysis in order to find the best combination. Instead, a stepwise regression procedure was used,[18] with a rejection level of $p > 0.1$.

By the use of the regression with two independent variables, it was shown that in combination with Index I the *intermolar angle* (MOLs-MOLi) (Fig. 5) was the most important variable. Together, these two variables could explain 76% of the variability of the mandibular growth rotation (Fig. 8). The variable MOLs-MOLi alone (Table I) explained 39% of the variability of the mandibular growth rotation (Fig. 9). The intermolar angle has only a small topographic association with the mandibular inclination represented by Index I; the correlation is $r = 0.47$ (Table III).

The third variable which, in combination with Index I and MOLs-MOLi, could give a still higher R^2 value and at the same time be clinically applicable was the angle between the two *mandibular lines* (ML1-ML2) expressing the shape of the lower border of the mandible (Fig. 6). Combined, these three variables revealed an R^2 value of 0.8148, thus explaining 81% of the total variability of the mandibular growth rotation (Fig. 8) by which the R^2 value increased by 5%. The angle ML1-ML2 alone (Table I) explained only 27% of the variability of the mandibular growth rotation (Fig. 9). The three variables were only moderately correlated (Table III).

The next procedure in the stepwise selection procedure, the inclination of the *symphysis* relative to NSL, determined by the angle CTL-NSL (Fig. 7), was found to be the fourth variable which, combined with the

Table III. Correlations at stage A between the four independent variables, which in combination gave the best prognostic estimate

	Index I	*MOLs-MOLi*	*ML1-ML2*	*CTL-NSL*
Index I		0.47	0.43	0.85
MOLs-MOLi	0.47		0.21	0.13
ML1-ML2	0.43	0.21		0.56
CTL-NSL	0.85	0.13	0.56	

$P < 0.05$, $r = 0.43$.
$P < 0.01$, $r = 0.55$.
$P < 0.001$, $r = 0.67$.

Table IV. Dependent variable

Dependent variable	*Mean*	*Standard deviation*	*Range*	
			Minimum	*Maximum*
$NSL\text{-}IPLi_{A\text{-}C}$	−6.0°	4.5°	+5.3°	−16.4°

Table V. Independent variables

Independent variables	*Mean*	*Standard deviation*	*Range*	
			Minimum	*Maximum*
Index I	63.6°	6.4°	54.4°	76.8°
GOL	75.8°	6.7°	61.0°	90.0°
NSL-ML1	35.9°	8.2°	19.0°	52.5°
MOLs-MOLi	173.6°	5.6°	159.8°	180.1°
ML1-ML2	2.4°	1.8°	0.0°	5.5°
CTL-NSL	87.4°	12.2°	65.0°	116.0°

three previously mentioned variables, showed the highest R^2 value of 0.8612. Thus, 86% of the total variability of the mandibular growth rotation in this sample could be explained (Fig. 8). The fourth variable, CTL-NSL, taken alone (Table I), explained 38% of the variability of the mandibular growth rotation (Fig. 9). In view of the fact that the inclination of the symphysis relative to NSL correlated more strongly with Index I than did both MOLs-MOLi and ML1-ML2 (Table III), this variable entered as the fourth variable in the stepwise selection procedure.

It was not possible, by a regression analysis, to find a fifth independent variable which could increase the R^2 value to a significantly higher level than that for the four described variables in combination. No further variable was therefore included in this analysis.

The four variables which, in combination, gave the best prognostic estimate (86%) of mandibular growth rotation in this sample are listed below. Mean values and range of variation are given in Table V.

Mandibular inclination, represented by three alternatives:

Index I	Fig. 2
Lower gonial angle, GOL	Fig. 3
Inclination of lower border, NSL-ML1	Fig. 4
Intermolar angle, MOLs-MOLi	Fig. 5
Shape of lower border, ML1-ML2	Fig. 6
Inclination of symphysis, CTL-NSL	Fig. 7

The four regression equations are given with the *caution* that they relate to a sample of extreme cases:

$$29.2 - 0.55 \text{ Index I} \qquad R^2 = 0.6191$$

$$78.2 - 0.32 \text{ (MOLs-MOLi)} - 0.46 \text{ Index I} \qquad R^2 = 0.7580$$

$$71.1 - 0.41 \text{ Index I} -$$

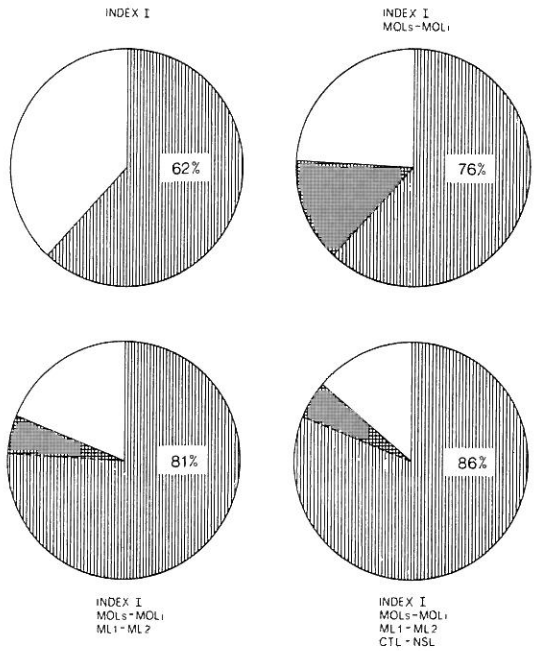

Fig. 8. The fraction (R^2) of the variability in the observed mandibular growth rotation, explained by (a) Index I alone, (b) Index I in combination with one variable, (c) two independent variables, and (d) three independent variables.

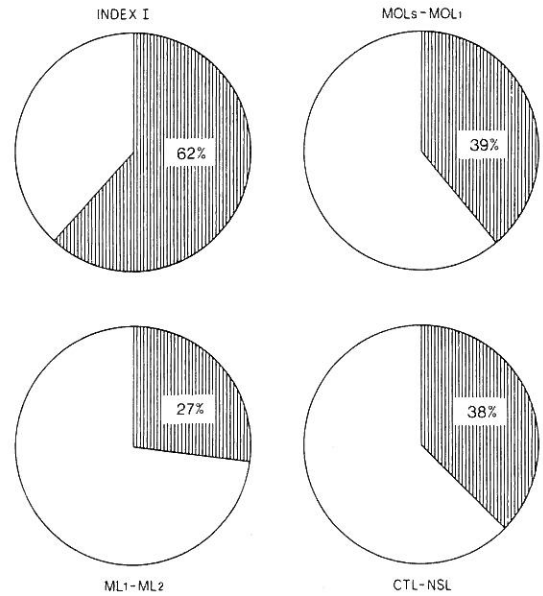

Fig. 9. The fraction (R^2) of the variability in the observed mandibular growth rotation, explained by each of the four independent variables alone.

$$0.28\ (\text{MOLs-MOLi}) - 0.64\ (\text{ML1-ML2}) \qquad R^2 = 0.8149$$

$$75.6 - 0.59\ \text{Index I} - 0.32\ (\text{MOLs-MOLi}) - 0.98\ (\text{ML1-ML2}) + 0.15\ (\text{CTL-NSL}) \qquad R^2 = 0.8612$$

A bivariate scatterplot of the dependent variable versus the best independent variable, Index I, is shown in Fig. 10.

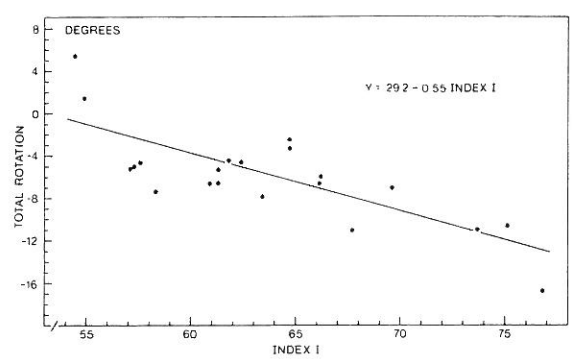

Fig. 10. The bivariate scatterplot of the dependent variable versus the best independent variable, Index I.

Several combinations of variables have been computed. Many of the variables could replace each other, as they are strongly correlated. A replacement of Index I with NSL-ML1 had the following equation:

$$18.3 + 0.44\ (\text{NSL-ML1}) - 0.29\ (\text{MOLs-MOLi}) - 0.94\ (\text{ML1-ML2}) + 0.14\ (\text{CTL-NSL}) \qquad R^2 = 0.8201$$

The observed and the predicted values of the mandibular rotation are illustrated graphically in Figs. 11 to 13 for each of the twenty-one cases.

In all forward-rotation cases the direction of the growth rotation was predicted correctly. Of the two backward-rotating cases (Cases 2 and 4), the direction of rotation was predicted correctly only when two variables in Case 2 (Fig. 12) and three variables in Case 4 (Fig. 13) were combined.

Prediction of the amount of rotation was generally improved by addition of variables. By Index I alone (Fig. 11), the difference between the observed and the predicted values was 3.7°, on an average, for all twenty-one cases, with a range from 0.6° to 6.2°, not taking into account whether the predicted value was higher or lower than the observed value. With the use of all four variables in combination (Fig. 14), the aver-

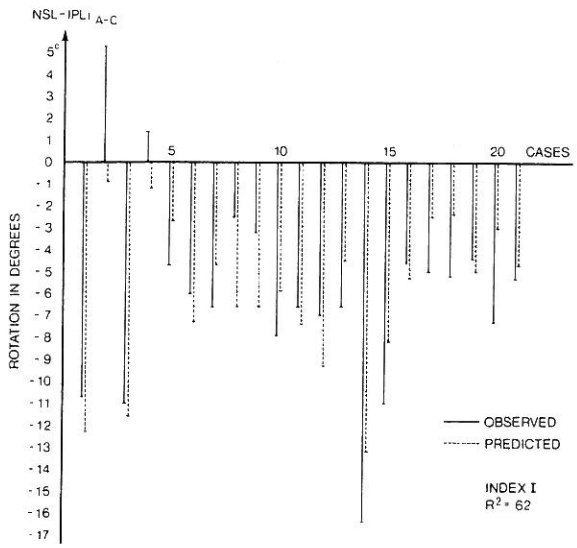

Fig. 11. The observed and predicted values of the mandibular growth rotation in each of the twenty-one cases, using Index I alone for prediction.

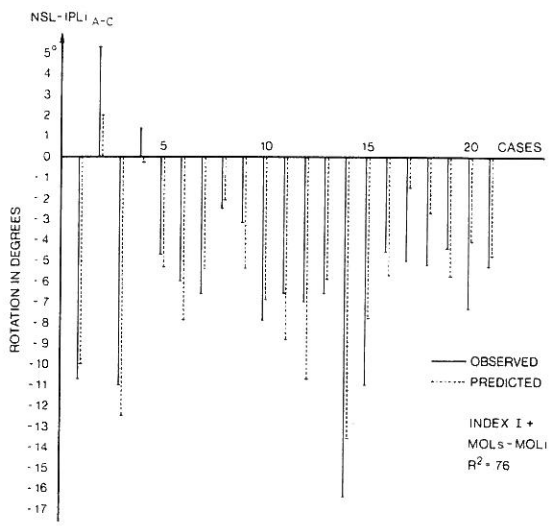

Fig. 12. The observed and predicted values of the mandibular growth rotation in each of the twenty-one cases, using Index I in combination with the angle MOLs-MOLi for prediction.

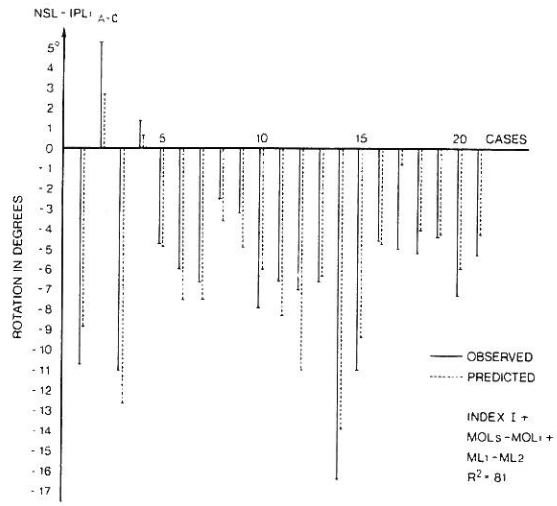

Fig. 13. The observed and predicted values of the mandibular growth rotation in each of the twenty-one cases, using Index I in combination with the angles MOLs-MOLi and ML1-ML2 for prediction.

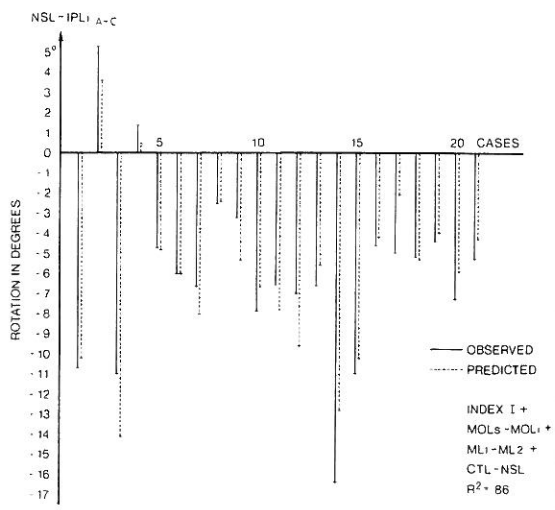

Fig. 14. The observed and predicted values of the mandibular growth rotation in each of the twenty-one cases, using Index I in combination with the angles MOLs-MOLi, ML1-ML2, and CTL-NSL for prediction.

age difference between the observed and the predicted values decreased to 1.3°, with a range from 0° to 3.6°. The prediction was very precise, with a difference of less than 0.5° in Cases 1, 5, 6, 8, 16, 18, and 19. A greater difference than 2.5° was observed in Cases 3, 12, 14, and 17. In more than half of the cases the prediction was progressively improved with the increase of variables, but it varied inconsistently in others.

It is of interest to compare the growth tracings of the cases described in 1972 with the graphs in Figs. 11 to 14. In Case 3, for instance, where all signs of an extreme forward growth rotation were pronounced, the predicted rotation was overestimated. In Case 12 with

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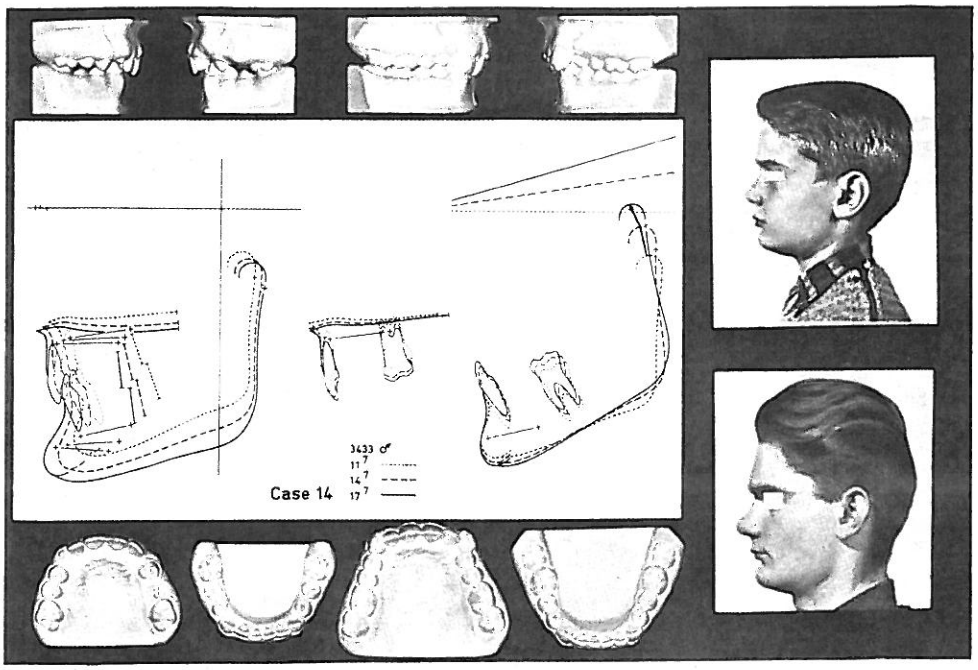


Fig. 15. Reproduction of Case 14 from the description of the twenty-one cases given by Björk and Skieller.[15]

an extreme malocclusion, prediction was underestimated, possibly because the predicting signs were influenced by dysfunction.

The greatest forward rotation of 14.4° was observed in Case 14 (Fig. 15). By Index I alone, the rotation was predicted to 13.2° forward. In combination with the second variable, the prediction improved to 13.6°, and it improved to 13.9° forward when the third variable was included. With all four variables combined, the prediction, however, decreased to 12.8° forward, probably because of the high correlation between the first and the fourth variables.

The case showing the greatest observed backward rotation of 5.3° (Case 2) is seen in Fig. 16. Index I alone gave a prediction of 0.9° forward, indicating a small forward instead of backward rotation. However, the direction of a backward growth rotation was correctly predicted in the continued analysis. With the use of two variables in combination, the predicted value was 2.0° backward; with three variables together, it was 2.7°; and finally, when all four variables were included, it was 3.6° backward.

The other cases might be studied in the same way.

DISCUSSION

When a sample involves many extreme variations, the biologic relations may be easier to find. However, it may imply that the correlations found will give an over- or underestimate of the actual magnitude of the relations.

In other words, the high level of prediction reached in this study by the four variables in combination may be explained by the fact that this sample included more cases with extreme growth patterns and severe malocclusions than a random sample. A certain reservation may therefore be made on the magnitude of the multivariate regression coefficients. The multivariate statistical analysis, however, has given an indication of significant morphologic features to be observed clinically in cases with extreme mandibular growth rotation and has made it easier to understand the interaction between different morphologic features. In children with a more normal growth pattern, these features in many cases may be less developed.

By a *univariate* regression analysis, twenty out of forty-four morphologic variables from the first stage were found at a significant level to contribute to the variability of the mandibular growth rotation taking place over the pubertal period in a selected sample (Table I). The prognostication of these twenty morphologic variables varied between 23% and 62%. All variables were more or less correlated. By the *stepwise* regression procedure, a combination of four variables was found to increase the prognostication to a level of

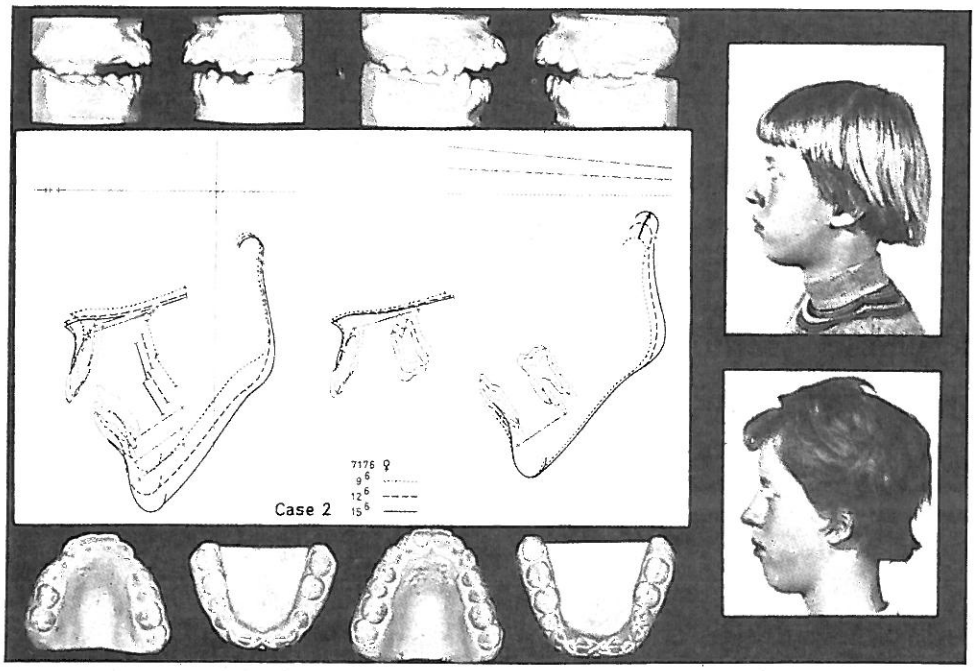


Fig. 16. Reproduction of Case 2 from the description of the twenty-one cases given by Björk and Skieller.[15]

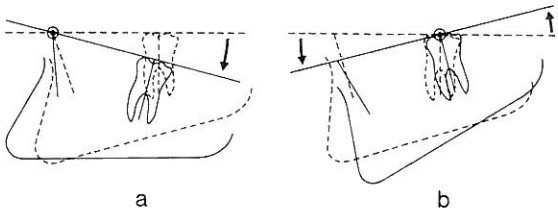


Fig. 17. Molar inclination. Change in inclination of the lower first molar in forward rotation *(a)* and in backward rotation *(b)* of the mandible. (See Fig. 5.)

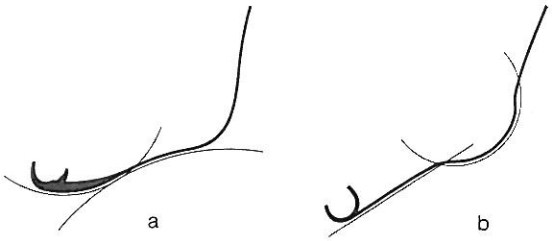


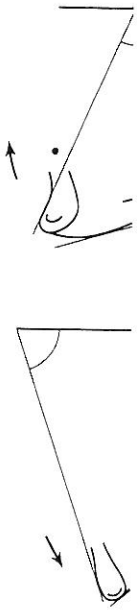
Fig. 18. Shape of the lower border of the mandible characterizing forward *(a)* and backward *(b)* growth rotation. (See Fig. 6.)

86% in this sample. This level did not increase significantly by further increasing the number of combined variables.

The inclination of the mandible, expressed by Index I or by alternative variables GOL or NSL-ML1, all gave the same prediction values, nearly 60% by a *univariate* regression analysis. Thus, around 40% of the variability of the observed rotation was still unexplained. This implies that the mandibular inclination in relation to the anterior cranial base at a given developmental stage may be considered as a morphogenetic feature which only to a moderate degree reflects the actual growth rotation pattern of the mandible. This finding is illustrated by Fig. 19.

Obviously, it was necessary to search for variables which, apart from the mandibular inclination, could explain as much as possible of the residual variability of the growth rotation. That the intermolar angle MOLs-MOLi (Fig. 5) was essential for the purpose of prediction is in accordance with the observation that the intermolar angle tends to increase in forward rotation of the mandible and decrease when the rotation is directed backward (Fig. 17). The change in the intermolar angle during growth is even more distinct in backward-rotating cases where eruption of the molars often is impeded.

For prediction, the importance of the shape of the lower border of the mandible, expressed by the angle ML1-ML2 (Fig. 6), is obvious when one is looking at a mandibular growth tracing, as in Fig. 15. The apposi-



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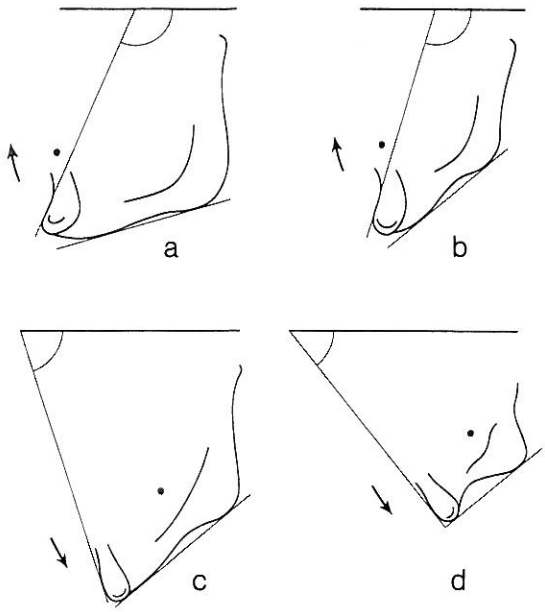

Fig. 19. Inclination of the symphysis. Forward growth rotation of the mandible (*a* and *b*) characterized by retroclination of the symphysis, irrespective of small *(a)* or great *(b)* mandibular inclination. Backward growth rotation *(c)* characterized by proclination of the symphysis and great inclination of the mandible. *d*, Pathologic form. (See Figs. 4 and 7.)

tion below the anterior part of the mandible was great because of the extreme forward rotation, giving rise to a convex shape of the lower anterior border (Fig. 18, *a*). In contrast, this apposition anteriorly at the lower border does not take place in backward rotation of the mandible, as in Fig. 16, resulting in an almost linear shape of the anterior lower border (Fig. 18, *b*). Furthermore, in backward-rotating cases the shape of the lower border of the mandible is characterized by apposition below the angular part, resulting in a convex shape, especially in pathologic cases (Fig. 19, *d*).

The inclination of the mandibular symphysis, measured as the angle between the tangent to the anterior surface of the mandible and the anterior cranial base (Fig. 7), is an important feature in prognostication of rotation of the mandible in view of the fact that this surface normally is practically free from remodeling, except when alveolar prognathism is increased or reduced. However, the determination of the inclination of the symphysis in extreme backward-rotating cases may be biased by apposition at the anterior surface of the chin, occurring especially in association with aberrant condylar growth.[17] Significant correlations with the inclination of the symphysis were not obtained when measured relative to the occlusal plane of the lower jaw or to the mandibular border.

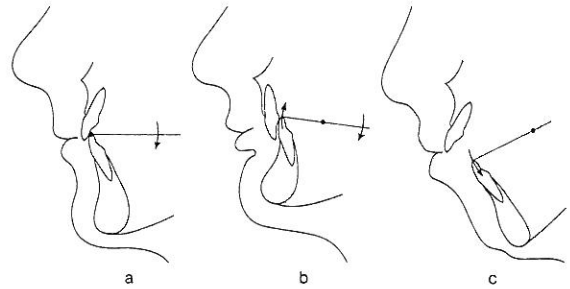

Fig. 20. Lower face height. Forward growth rotation of the mandible with normal incisal occlusion *(a)* and with deep overbite and reduced lower face height *(b)*. Backward growth rotation *(c)* with increased lower face height and "double chin."

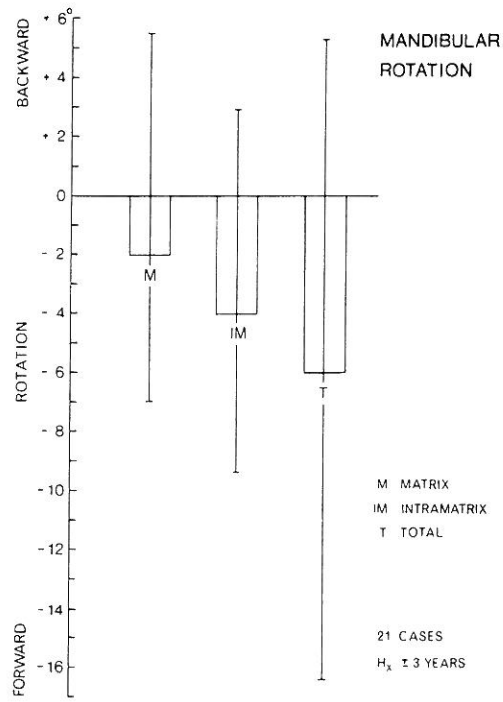

Fig. 21. Mean values and ranges for the three rotation components.

The four selected variables which, in combination, gave the highest level of prediction confirm the clinical observations described by Björk[20] in 1969. Common for the variables not discussed in Table I was a more or less strong correlation with the mandibular inclination: the jaw angle, the thickness of the symphysis, the inclination of the Y axis, the inclination of the lower incisors to ML2, and the lower face height represented by Index IV. Whether the Y axis defined by Ricketts would yield correlations different from the Y axis used in the present study cannot be inferred from the present

study. Because of its topographic position, a facial diagonal, it is presumed to give the same information about mandibular growth rotation as the Y axis. The lower face height is, to some extent, dependent on the incisal occlusion (Fig. 20, *b*). An evaluation of size and shape of the condylar head was not included in this study.

The mandibular growth rotation is composed of a complex system of movements. In a recent report by Björk and Skieller[17] the bony mandibular corpus and its soft-tissue covering, the matrix, have been considered as independent tissue systems capable of independent rotation. Both forward and backward rotation was divided into three components: *total rotation,* referring to the rotation of the mandibular corpus (implant line or reference line) relative to the anterior cranial base; *matrix rotation,* referring to the rotation of the soft-tissue matrix of the mandible (tangential line to lower mandibular border) relative to the anterior cranial base; and *intramatrix rotation,* referring to the rotation of the mandibular corpus within its soft-tissue matrix (or the difference between reference lines), expressing the amount of remodeling at the lower border of the mandible. Analyzed from longitudinal samples, the total rotation, which is the sum of matrix and intramatrix rotation, generally showed a steady increase with age, forward or backward, dependent on the case. The matrix rotation, on the contrary, displayed a pendulum movement, forward or backward, in the same person during development. The intramatrix rotation, like the total rotation, increased steadily during growth, but with fluctuations counteracting the pendulum movements of the matrix.

In the present study the observed mandibular rotation is a *total* rotation by definition. In this sample (Fig. 21) the matrix rotation comprised, on an average, nearly one third of the total rotation and the intramatrix rotation around two thirds, both with ranges about 50% of that for the total rotation. The four morphologic features discussed above in relation to prediction are undoubtedly influenced by both the matrix and the intramatrix rotation components, the shape of the lower border of the mandible apparently mainly by the latter.

As pointed out before, our statistical analysis was based on a sample that included several extreme cases. In a normal sample moderate rotation may be difficult to classify according to the discussed features for prediction of mandibular growth. However, if one or more of these features are strongly developed in individual cases, they indicate that an extreme growth rotation of the mandible is going on.

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