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GRADUATE STUDIES

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Date MAY 24, 1972

Dr Neuger -
Thank you very
much for everything.
Larry

# COMPUTERIZED GROWTH PREDICTION: A STATISTICAL EVALUATION OF THE RICKETTS SYNTHESIS

by

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Submitted in partial fulfillment of the requirements

for the Degree of Master of Science

School of Dentistry

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CASE WESTERN RESERVE UNIVERSITY

June, 1972

COMPUTERIZED GROWTH PREDICTION: A STATISTICAL EVALUATION OF THE RICKETTS SYNTHESIS

Abstract

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The purpose of this investigation was to evaluate the predictive accuracy of the Ricketts Synthesis of growth prediction as prepared two ways:

(1) commercially by computer, and

(2) hand-prepared by the author.

A sample of one hundred orthodontically untreated individuals (fifty males and fifty females), each represented by two lateral cephalograms taken at ten and fifteen years of age, was selected at random from the records of the Bolton-Brush Growth Study. Of the one hundred individuals, twenty (ten males and ten females) were randomly selected for non-treatment computerized five-year growth predictions according to the as-yet-unpublished Ricketts Arcial Method utilized by Rocky Mountain Data Systems Inc., Sherman Oaks, California. In essence the sample consisted of three groups of cases:

(1) one hundred author-predicted cases

(2) twenty author-predicted cases, sub-sample of 1 (above)

(3) same twenty cases predicted by computer

A scheme of cephalometric analysis was chosen on the basis of its independence from the prediction scheme and for its descriptive utility. The cephalometric data were reduced to measurements of change (predicted and actual) and error. Statistical methods were chosen to compare the accuracy of three specific approaches to prediction:

(1) the somewhat unlikely assumption that no change would occur over a five-year period

(2) the assumption that an estimate of the mean change provides the best forecast

(3) the assumption that one or both of the Ricketts methods provides the best forecast.

For predictions of linear dimension, the Ricketts methods were found to be minimally more efficient than an assumption of no change and less efficient than an assumption of mean change. For the more complex predictions of relationship, the Ricketts forecasts were consistently less efficient thanboth alternate methods. Measurements of maxillomandibular relationship, or particular interest to the orthodontist, were plagued with negative predictive efficiencies.

An error study was conducted between tracings executed commercially and by the author. Statistical analysis revealed that the magnitude of the cephalometric error was sufficient to vitiate the prediction of growth changes occurring over a five-year interval.

Although unexamined by this study, it was proposed that changes effected in the craniofacial complex as a result of orthodontic treatment are of such a magnitude as to render the prediction of slight growth changes meaningless.

The following conclusions were drawn with regard to the specific sample employed:

(1) The use of the Ricketts Synthesis for the prediction of changes attributable only to growth is somewhat more accurate than an assumption of no change and less accurate than adding an estimate of the five-year mean change.

(2) For any non-trivial prediction (craniofacial relationship), the Ricketts synthesis, executed by hand or by computer, can not be shown to be of sufficient efficiency to be of clinical significance.

(3) The magnitude of inherent cephalometric error is sufficient to mask changes attributable only to growth.

(4) A decision to employ the Rocky Mountain Data Systems Inc. prediction scheme must be based on factors other than its prediction efficiency; namely, its undoubted heuristic significance and its considerable utility in patient education.

ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude to the following individuals:

Dr. Lysle E. Johnston, Associate Professor and Chairman of the Department of Orthodontics, School of Dentistry, Case Western Reserve University, who, in addition to suggesting the thesis topic, provided countless hours of much needed advice and consultation in every aspect of its preparation.

Dr. B. Holly Broadbent, Jr., Associate Professor of Dento-facial Morphology, School of Dentistry, Case Western Reserve University, for his consultation and generous use of the records and facilities of the Bolton Study.

Dr. Sanford Neuger, Associate Professor of Orthodontics, Department of Orthodontics, School of Dentistry, Case Western Reserve University, for his interest and consultation.

Dr. Joel Wisotzky, Professor of Oral Biology and Medicine and Director of Dental Research, School of Dentistry, Case Western Reserve University, for the use of his electronic calculator.

Mr. William Golden, Research Associate, School of Dentistry, Case Western Reserve University, for his kind assistance in the technical facets of the study.

Mrs. Idy Morrison, Technical Secretary, Case Western Reserve University, for her assistance in obtaining the records of the Bolton Study.

Mr. Robert Schulhof, General Manager, Rocky Mountain Data Systems Inc., for his helpful correspondence during the course of this investigation.

This Thesis is Lovingly

Dedicated to My Wife

Lois

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# INTRODUCTION

In the conduct of a clinical practice, the contemporary orthodontist is faced with the problem of estimating the magnitude of growth and treatment changes in the face of each patient. By successfully doing so, he can plan to take advantage of, or counteract, growth changes and hopefully minimize the duration of his mechanotherapy. Schemes for the prediction of individual changes in growth pattern have commonly been developed through years of trial-and-error practice and usually consist of a system of procedures which cannot be operationally defined and which are of unknown predictive significance.

To date, no intuitive method of facial growth prediction has survived the rigors of controlled validation. Recently, however, computer technology has been employed in an effort to evolve a practical method. One such approach, (that of Ricketts), has been made commercially available and, it is claimed, serves as a diagnostic adjunct which, among other benefits, will forecast craniofacial changes as measured by cephalometric radiographs. Unfortunately, the accuracy of this method has never been adequately characterized.

Inasmuch as Ricketts approach to growth prediction is currently gaining acceptance, it will be the purpose of this paper to validate statistically its predictive accuracy. The present study will examine two versions of the Ricketts approach:

(1) The so-called "short-range method" which can be done by the orthodontist himself.

(2) The "arcial" method, which is computer-executed by a commercial firm.

Specifically, it will be the purpose of this investigation to determine the accuracy with which individual changes may be forecast by means of the methods devised by Ricketts.

## REVIEW OF THE LITERATURE

Recently, much has been written about facial growth prediction. Although the cephalometric method is over forty years old, only for the last fifteen years or so, has the word "prediction" had other than a trivial meaning.

Perhaps the first by-product of the cephalometric era was the so-called "pattern concept," according to which facial proportions remain independent of time during childhood and adolescence. Although this idea owes much to one of Broadbent's (1937) diagrams (Figure 9), it was truly made flesh by Brodie (1941). In a now classic investigation based upon longitudinal data derived from a sample of twenty-one males, he concluded that any facial growth accomplished by eight years of age preserves the proportion that existed three months subsequent to birth. The establishment of the original pattern was later (1949) amended to a time "prior to birth." In 1946, Brodie doubted the existence of any individual variability in the pattern and emphasized that disharmonies remain unaltered by growth and "cannot be changed by treatment." Finally, in 1953, although he noted a few individual changes in pattern between ages eight and seventeen, Brodie generally adhered to his original concept. Obviously, there can be no need for growth prediction if an individual patient's craniofacial architecture remains stable throughout his growth period and cannot be altered by treatment.

The first reevaluation of Brodie's rather static interpretation was fostered by Björk's massive (1947) cross-sectional roentgenographic study of adolescent growth changes in a large sample of Swedish males--three hundred twenty two boys, twelve years of age, and two hundred eighty one army conscripts, twenty-one years of age. He concluded that, on the average, there is a progressive straightening of the facial profile. Later (1951), in a study of one hundred fifty one males from twelve to twenty years, Björk confirmed his earlier findings, this time on a longitudinal sample. Metallic implant studies on five human subjects in 1955 and on one hundred ten subjects in 1963 allowed Björk to be even more detailed in the description of changes in individual pattern.

Other investigators concurred. Lande (1952) concluded that facial convexity usually decreased because of an increase in mandibular prognathism. Pelton and Elsasser (1955) studied (cross-sectionally) soft tissue profile changes in six thousand eight hundred twenty nine subjects. Although the specific conclusions of their study are somewhat at variance with Björk and Lande, they concluded that ". . . the basic facial pattern does change between the ages of six and twenty-four years." Longitudinal studies by Nanda (1955) and Merow (1962) also showed changes in the pattern of craniofacial growth. The current concept of craniofacial growth involves the recognition that the pattern does change with time, both on the average and even more so for individuals.

Hirschfeld and Moyers have recently (1971) reviewed growth prediction methods and have classified them according to the basis of the underlying mathematical model, a classification which will be employed here.

## Regression Methods

Regression schemes are based upon a statistical treatment of growth data by means of correlation coefficients and regression equations, linear algebraic descriptions of the relationship of a dependent variable to one or more independent variables obtained from the same individual at two different time intervals.

Björk (1953), in a longitudinal study of two hundred forty three Swedish males from twelve to twenty years of age, concluded from the negligable magnitude of his correlation coefficients that: "The degree of prognathy in either jaw does not. . . provide any clue to the future prognathic development."

Meredith (1959) has published a compilation of correlation coefficients obtained in a series of studies dealing with the prediction of changes in certain craniofacial dimensions in a sample of boys ranging from five to eleven years of age. He summarized his findings by concluding that:

> ...the size of the child at four or five years gives no clinically useful information regarding the rate at which he will grow during the ensuing years of childhood.

Undaunted, Harvold (1963), investigated predictability of both the rate and amount of mandibular growth from six to twelve

years in fifty-five boys. He obtained coefficients of linear correlation which were neither statistically nor clinically significant. Harvold concurred with Meredith that the size of a structure at one age offers no basis for the prediction of future growth.

Johnston (1968) used the multivariable approach to generate regression equations for males and females. In spite of the apparent sophistication of the method, the prediction of change was only ten to thirty percent efficient and was of minimal clinical significance.

On measurements gathered from serial study casts of the deciduous dentition, Savin and associates (1970) applied discriminant analysis and various forms of correlation to devise a method for predicting "acceptable" occlusion of the permanent dentition. However, upon validation by the authors, the method was found to have little clinical value.

Ballrick (1971), in an unpublished thesis, validated the regression equations and correlation coefficients derived from the studies of Björk and Palling (1955), Meredith (1958), Maj and Luzi (1964), and Johnston (1968). He concluded that the published regression schemes, by virtue of their complicated mathematics, low correlation coefficients, and relatively poor prediction efficiency, are not clinically useful in the prediction of individual growth pattern changes.

In describing the regression methods, Hirschfeld and Moyers listed the following pitfalls:

(1) The regression equation might be based on a population sample of which the individual patient is not a member.

(2) The assumption that the coefficients of the independent and dependent variables remain constant over the growth period is erroneous.

## Time-Series Methods

Since growth data can be thought of as a "Time-Series," time-series analyses may be used "to extract in mathematical form the fundamental nature of the process." This establishes a framework within which "Exponential Smoothing" methods produce current estimates of a parameter by means of estimates of past values of that same parameter. These smoothing methods are as follows:

(1) trend or long-term movement

(2) oscillations about a trend

(3) cyclic or periodic events

(4) random components

This allows predictions to be made based on coefficients derived from the smoothed parameters. Hirschfeld and Moyers feel that this method offers the most promise for growth prediction primarily because it is designed to deal with random changes in the parameters of the mathematical model. One of the limitations of time-series analysis is that, similar to the regression method, predictions may be less accurate if mean values from an appropriate population are not available.

Hirschfeld and Moyers have reported the application of "Time-Series" methods of craniofacial prediction to a small sample of ten children from six to sixteen years of age. They show evidence (Student's t-test and Chi square test) for substantially greater predictive

accuracy in comparison to the "Regression" method; nevertheless, it must be realized that the "Time-Series" method has not been validated on a large sample, nor has its accuracy been adequately characterized.

M. J. Moroney, an English statistician, has likened (1962) time series to fortune telling. He has described its use in the commercial world to detect seasonal variation and long term trends:

> This is the sort of thing that any competent ice-cream manufacturer does in a flash without statistics. Only where the effect is very marked is it worth the doing [italics mine].

The question, then, would seem to be, "how big are the effects?"

## Hereditary Methods of Growth Prediction

The inheritance of the craniofacial complex in like-sexed siblings has been examined from the standpoint of multiple linear regression (Pelle, 1971). Interestingly enough, Pelle showed that the addition of an estimate of the mean change had approximately the same efficiency as did multiple linear regression equations containing information from both the individual and a sibling.

The hereditary methods of Wylie (1944), Curtner (1953), and Wasson (1963) may be described as non-mathematical approaches to growth prediction. In general, these workers compared lateral headfilms of parents and siblings in an effort to predetermine the adult faces of the children. Wylie, working within the framework of Brodie's pattern concept, was unable to explain the lack of resemblance among the angles composing the facial polygons of parents and offspring. Curtner claimed

"It appears possible to predetermine the adult face in most children . . ." and showed similarity of anatomical parts in five families; however, there was no attempt made to quantify the accuracy of the method. Wasson, on the other hand, claimed to be accurate 58.9 percent of the time when he employed a Sassouni arcial analysis to find structural similarities and differences in facial pattern. Unfortunately, the meaning of the word "accurate" is not altogether clear. The hereditary approach to growth prediction has failed to gain clinical acclaim even though it might be regarded as an initial attempt to construct a picture of the adult face.

## Intuitive Methods

This scheme of growth prediction is usually an attempt by an individual to codify his clinical observations for use by others in the profession.

Tweed (1963) stressed the need for classifying the "Growth Trend" of the individual pattern in the mixed dentition. During an eighteen month preorthodontic observation period, serial lateral cephalograms are taken to analyze the size and magnitude of change in the angle A-Na-B. Growth is subsequently categorized into three types with various subdivisions depending upon the anteroposterior relationship of the mandible to the maxilla. It is then assumed that the growth pattern identified during the deciduous dentition would prevail in the permanent dentition and treatment is planned accordingly.

Reukema (1971), in an unpublished thesis, recently examined the reliability of Tweed's growth trend classification theory on a longitudinal sample of eighty-four children. He found the theory to be statistically unreliable as a predictor of the individual growth pattern and concluded that it was only of questionable value as a diagnostic aid for treatment planning in the mixed dentition. Reukema also concurred with Johnston's earlier statement (1968) that:

> . . .it would seem highly improbable that any one measure could ever contain enough information to be of predictive significance.

Ricketts, in a series of articles from 1957 to 1961 presented the orthodontic profession with the "dynamic synthesis"--a method designed to forecast, one to three years in advance, the combined effects of growth and treatment on the growing child. He strongly contended that orthodontic treatment should be tailored to the individual patient with definite objectives in mind rather than ". . . one fixed idea of tooth arrangement for all individuals." He even went so far as to imply that failure to do an individual prediction is tantamount to malpractice.

The scheme functions under the premise that facial form is influenced greatly by the morphology of the mandible in general and the location of the chin in particular. The amount and direction of chin growth are dependent on ten anatomical characteristics of the mandible which can be employed in its prediction.

Average treatment effects were derived from a study of one

hundred fifty orthodontically treated cases which were compared with one hundred non-treated controls. In the maxilla he reported distal movement of the maxillary molars, changes in the amount and direction of maxillary growth, and as much as eight millimeters of distal movement of A-point in the course of maxillary incisor retraction with lingual root torque, headgear, and Class II elastics. In the mandible, his treatment effects were limited to a rotation of the mandible to change the direction of growth and the inclination of the occlusal plane.

In the construction of a prediction, the "expected change" for growth and treatment effects are added to the original facial structure in such a manner that the prediction of successive parts is dependent upon the accuracy of the previous estimate. Growth changes were obtained in an exhaustive study of one thousand consecutively treated clinical cases from his private practice.

With regard to the accuracy of his forecast technique, Ricketts (1957), perhaps facetiously, claimed accuracy ". . . within the width of a pencil line." Later, in the same article, he amended his estimate to "sensibly accurate in ninety percent of the cases." Three years later, in a paper entitled "A Foundation for Cephalometric Communication," he cautioned against the use of vague terminology in the cephalometric technique since, in his words, ". . . the primary purpose of tracing and measuring is to permit a critical description . . . ." Later that same year, while discussing the accuracy of his synthesis, he stated, "At the clinical level this procedure yields a rough estimate of conditions most likely to occur." Finally, in the last article

of the series, Ricketts (1961) admitted that additional statistical data should be compiled on his scheme to make it "simpler and more foolproof."

Johnston (1968), in a multivariate examination of cephalometric prediction, questioned the biologic and statistical significance of the clinical estimation procedures advocated by Ricketts. He noted that the accuracy of the method, as applied to a non-orthodontic sample, had not been established and that the inherent error in cephalometric technique imposed a limit on the accuracy of cephalometric prediction, in general.

Johnston also advanced the concept that growth changes, by virtue of their small size in comparison to the changes wrought by orthodontic treatment, need not necessarily be considered in the post-treatment forecast. He maintained that the two most important factors to be considered in growth prediction were:

> . . .the extent to which the individual pattern remains stable, and the extent to which the individual orthodontist is capable of predetermining the effects of his own treatment procedures.

Balbach (1969), in a study of the predictive significance of the various mandibular morphologic characteristics advocated by Ricketts, was unable to verify their utility in forecasting individual changes.

Ødegaard (1970), from an implant study conducted on an orthodontically mixed sample of twenty-five patients, arrived at a similar conclusion. By means of regression analysis of the data, he found that condylar growth varies with gonial angle and concluded that mandibular growth prediction ". . . must be based upon mandibular morphology and not upon the position of the mandible in space."

Other investigators have emphasized the importance of other factors effecting craniofacial growth. Burstone (1963) stressed the need to determine the rate and level of maturation of the individual in terms of factors such as sex, body type, dental age, skeletal age, sexual development, and genetic factors. Gianelly (1970) did not concur. In a study of a large sample of children between eight and thirteen years of age, he found little age and sex variation in facial proportions. Hunter and Garn (1969) reported another variable that might effect growth prediction--a secular trend toward an increase in face size, which they postulated might require a revamping of current orthodontic norms.

In spite of the lack of scientific support for growth prediction schemes in general, the Ricketts method has survived and is being used by an increasing number of orthodontists. If for no reason other than its clinical popularity, it must be examined further.

Ricketts and associates (1972) recently summarized their application of computer technology to the field of cephalometric growth prediction.

The basic framework is similar to that published in 1957, except that the computer is programmed to add increments which are "individualized" according to the patient's race, age, sex, and size of facial proportions.

Two types of predictions are currently available:

(1) short-range projection of from one to four years

(2) long-range projection of from five to fifteen years

In the short-range forecast, methods published by Ricketts and associates are carried out by the computer; it can, however, be done by hand. In the long-range forecast, the mandible is located by Ricketts Arcial Method--a technique which has not yet been described in the literature and which can only be obtained from the commercial computer service.

The computerized scheme of growth prediction is specifically designed to minimize measurement error related to the construction of growth forecasts. Once programmed with key cephalometric points, the computer accurately analyzes the data in the form of linear and angular measurements which are summarized on print-out sheets. Using a sophisticated "polar-grid" coordinate system, the computer also advances these key cephalometric points the predetermined magnitude and direction to form an outline to which the technician adds the anatomy for the prediction.

In order to program the computer, the authors selected from among 400,000 coefficients of correlation to determine the best cephalometric procedure. Treatment effects were estimated from a sample of two thousand treated cases.

With regard to the predictive accuracy of the computerized method, Ricketts and associates have, as yet, failed to characterize it in meaningful terms. Statements range from:

(1) a conservative, "No claim for positive dependability has even been made."

(2) to ". . . as accurately as this can be accomplished with current scientific data."

(3) to the tantalizing vague,

". . . at least ninety percent accurate, eighty-five percent of the time for maxillomandibular relations," and

". . . at least ninety percent accurate, seventy-five percent of the time in upper face height."

The time has come for a quantitative estimation of the prediction accuracy of the Ricketts scheme.

The preceding literature review demonstrates some of the diversity of opinion regarding the predetermination of growth and treatment changes for the individual patient. If natural growth changes are significantly large enough to effect orthodontic treatment, then there is justification in searching for a method of determining that which changes.

Ricketts has proposed such a method which, in spite of its unspecified theoretical basis, has evolved to a state of computerized sophistication that is rapidly gaining in acceptance by the profession as an adjunct to successful treatment planning.

It will be the purpose of the present investigation to examine the predictive efficiency of two versions of the Ricketts synthesis:

(1) The so-called "short-range method" which can be done by the orthodontist himself.

(2) The "arcial" method, which is computer executed by a commercial firm.

# METHODS AND MATERIALS

## Source

The cephalograms analyzed in this investigation were obtained from the files of the Bolton-Brush Growth Study Center at Case Western Reserve University, Cleveland, Ohio.

## Sample

A sample of one hundred orthodontically untreated subjects (fifty males and fifty females) each having a lateral cephalogram taken in occlusion at ten and fifteen years of age was selected at random. For this study, "random" meant that selection of the sample was in no way based on any characteristic of the craniofacial skeleton before, during, or after the period of growth for which the prediction was intended.

An orthodontically untreated sample was secured to avoid unnecessary and uninterpretable confounding of growth and treatment effects.

According to Gugino (1971), the two major changes in orthodontic treatment philosophy which are directly responsible for popularizing growth forecast are:

(1) planning treatment to the anticipated skeletal structure and face not only at the end of active treatment, but also to adulthood.

(2) beginning treatment at an earlier age in order to enjoy the benefit of pubertal growth.

In view of the fact that precise methods for the determination of the initiation of pubertal growth are still unavailable, it is generally accepted that such growth occurs in females in the age range of ten to twelve years and from twelve to fourteen years in males (Beattie, 1963; Broadbent, Jr. and Golden (1971).The upper and lower age limits of the present sample were determined on the likelihood of including pubertal growth. In addition, a five-year growth forecast was chosen in preference to a two-year forecast because the additional three-year increment of growth would generally serve to increase the size of a structure. Since technical error is roughly a constant, its percentage decreases if the dimension is larger.

## Technical Details

The lateral cephalograms were obtained with a Broadbent-Bolton roentgenographic cephalometer using a source-film distance of sixty inches. The tracings and growth forecasts were made in pencil (4H) on .003 inch frosted acetate. Angular and linear measurements were read to the nearest tenth of a degree and a tenth of a millimeter, respectively. Angular measurements were obtained through the use of a drafting machine[1] and linear determinations were secured with pointed dial vernier calipers[2].

---

[1]Vemco--Model 3300, V. and E. Manufacturing Co., Pasadena, California.

[2]Helios Dial Calipers.

## Growth Forecasts

Each of the ten-year cephalograms was traced by the author and a five-year growth forecast was constructed according to the procedure outlined by Gugino (pp. 77-78, 1971). The definition of anatomical landmarks and planes particular to this study may be found in Appendix I. (See Figures 1 and 2) Details concerning specific growth increments utilized by the computer in the construction of a five-year forecast were obtained through the courtesy of Mr. Robert J. Schulhof, General Manager of Rocky Mountain Data Systems Inc., Sherman Oaks, California (1972a). (See Appendix II) The fifteen-year cephalograms were traced for later comparison with the growth forecasts.

## Computer Prediction

Of the one hundred subjects comprising the original sample, twenty individuals (ten males and ten females) were selected at random; the original Bolton ten-year films were duplicated and sent to Rocky Mountain Data Systems Inc. for five-year predictions (see Figures 3 and 4). After the films and forecasts had been returned, duplicated fifteen-year films of the same individuals were sent for tracing, only. Essentially, the three groups of cases comprising the author's sample were:

(1) one hundred author-predicted cases

(2) twenty author-predicted cases, a sub-sample of 1 (above)

(3) same twenty cases predicted by computer

Figure 1

Ricketts Landmarks and Measuring Planes

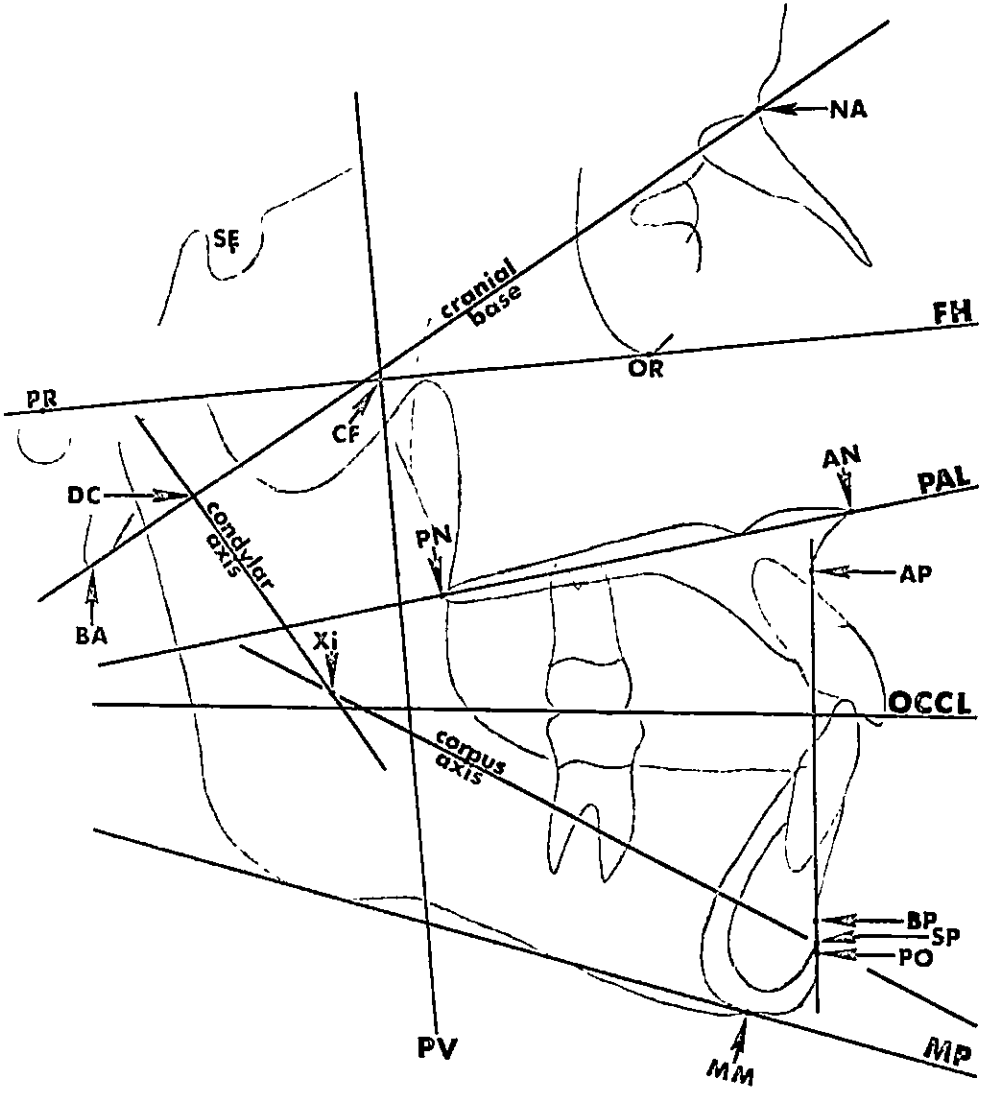

NA
SE
cranial base
FH
OR
PR
CF
AN
PAL
DC
condylar axis
PN
AP
BA
Xi
OCCL
corpus axis
BP
SP
PO
PV
MM
MP

Figure 2

Ricketts Xi Point: Author's Standardization

of A-Point, B-Point, and Pogonion

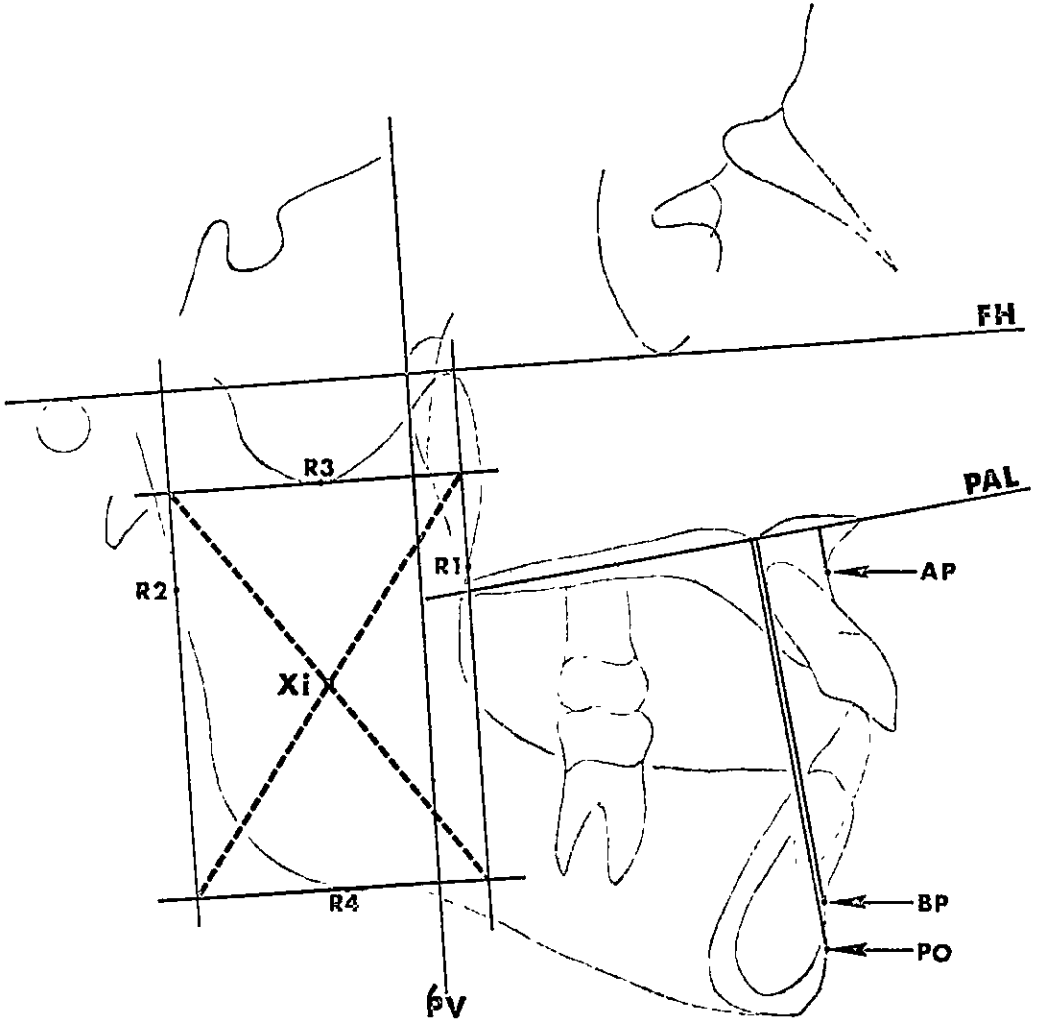

FH
PAL
R3
R1
R2
Xi
R4
AP
BP
PO
PV

Figure 3

A Typical Commercial Tracing

DR GREENBERG

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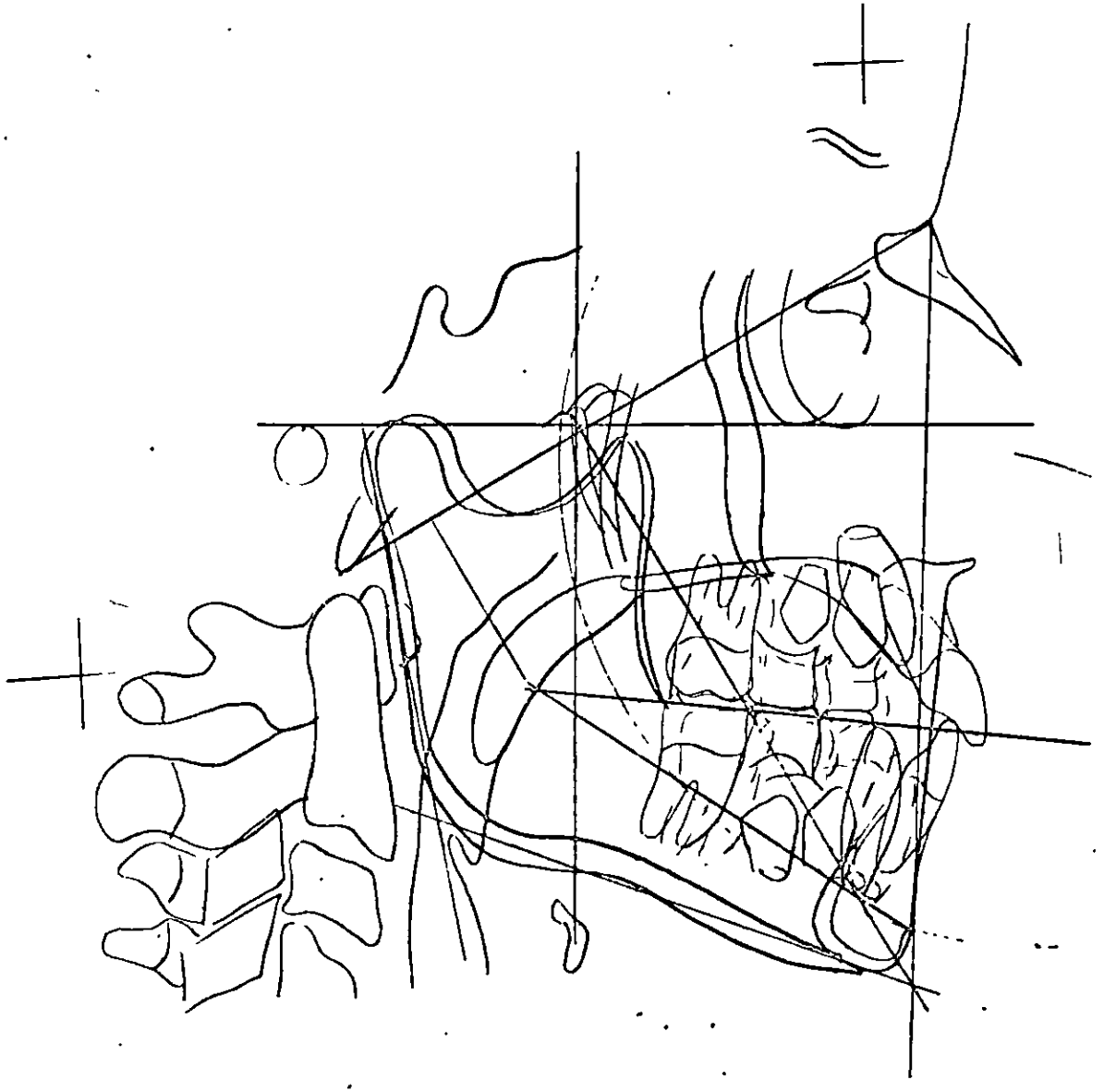
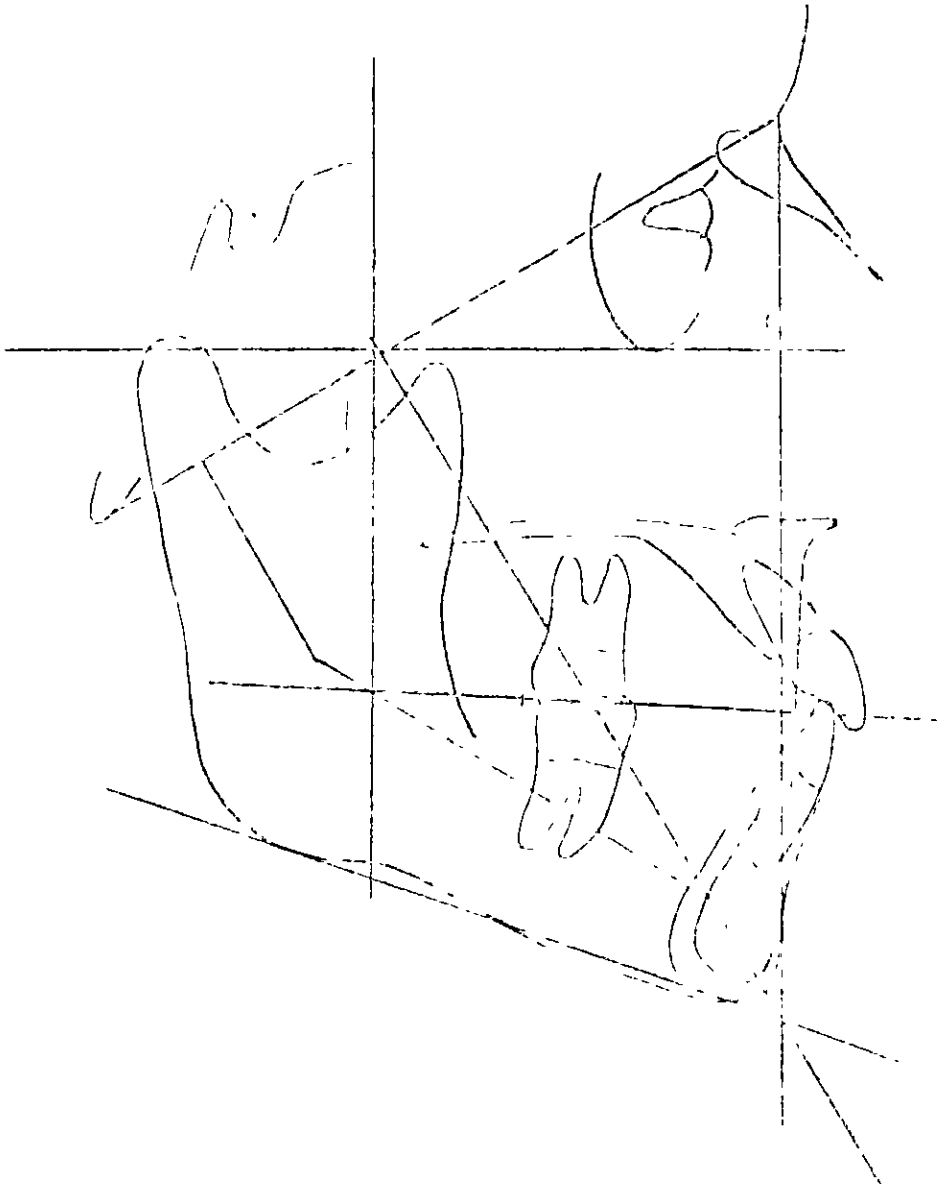


Figure 4

A Typical Commercial Five-Year Growth Forecast



## Measurements

In order to assess the accuracy of a prediction scheme it is necessary to measure the actual outcome. A scheme of cephalometric analysis was chosen that would accurately describe, in terms that would be meaningful to the clinical orthodontist, the craniofacial skeleton depicted in the original and final cephalograms as well as the predicted configuration. In addition, this validation analysis was chosen on the basis of its independence from the prediction scheme and on its ability to reduce the tracings to data which could be analyzed statistically.

### Linear Measurements (see Figure 5)

1. Max O ($\underline{6}$D-A): Sagittal maxillary dental arch length measured from the distal of the maxillary first permanent molar parallel to the natural occlusal plane.

2. Mand O ($\overline{6}$D-B): Sagittal mandibular dental arch length measured from the distal of the mandibular first permanent molar parallel to the natural occlusal plane.

3. A/B (A point-B point): The position of A point relative to B point measured parallel to the natural occlusal plane.

4. Max. P ($\underline{6}$D-B): Sagittal maxillary dental arch length measured parallel to the palatal plane.

5. Mand. P ($\overline{6}$D-B): Sagittal mandibular dental arch length measured parallel to the palatal plane.

6. $\underline{A/B}$ (A point-B point): The position of A point relative to B point measured parallel to the palatal plane.

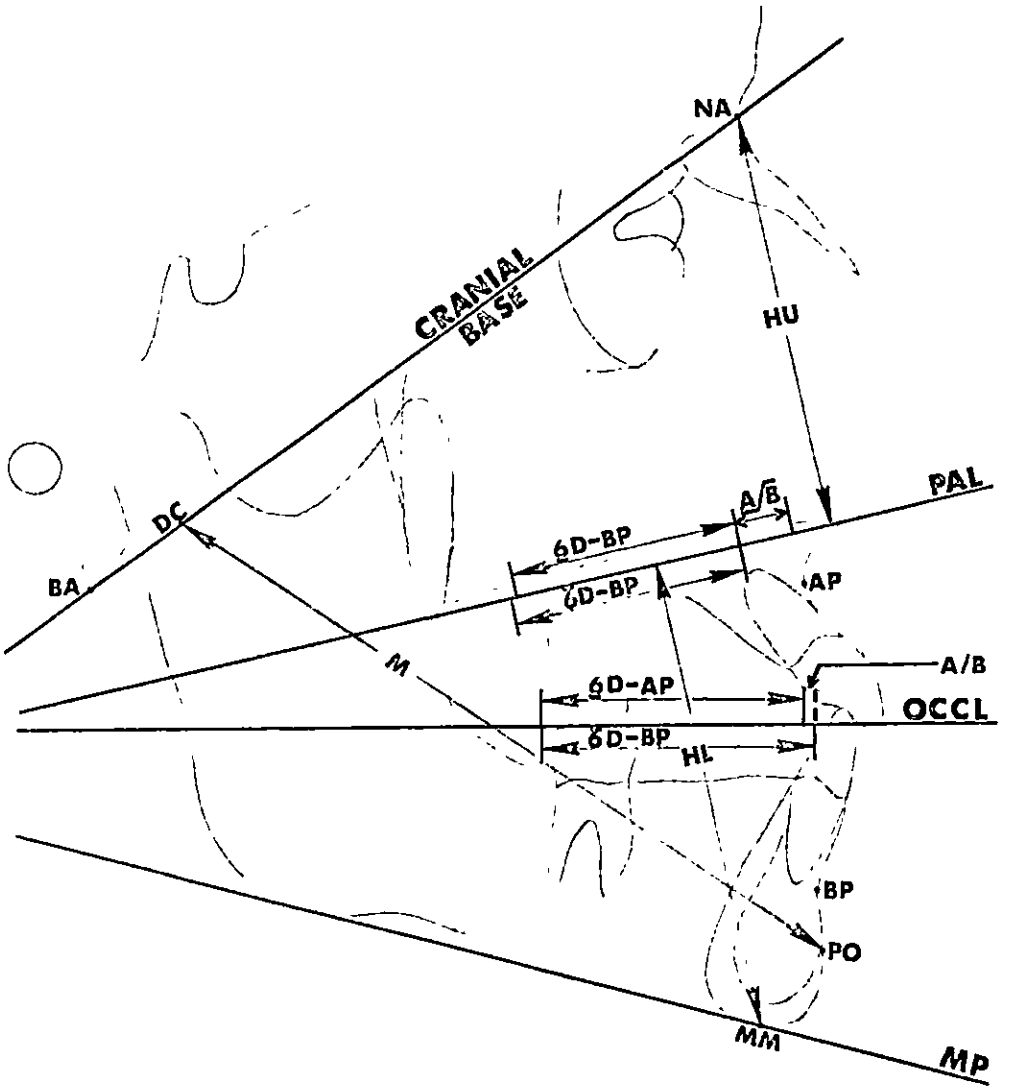
7. M (DC-PO): Effective mandibular length measured directly.

8. Hu (NA-Palatal plane): Upper face height measured perpendicular to the palatal plane.

9. Hl (Palatal plane-MM): Lower face height measured perpendicular to the palatal plane.

Figure 5

Author's Linear Measures


NA
CRANIAL BASE
HU
PAL
A/B
DC
BA
6D-BP
6D-BP
AP
M
A/B
6D-AP
OCCL
6D-BP
HL
BP
PO
MM
MP

Angular Measurements (See Figure 6)

1. ∠ Convx. (NA-A-Po): A measurement of facial skeletal convexity.

2. ∠ ANB (A-NA-B): An angular measurement of maxillomandibular relationship.

3. ∠ Occl. (Occlusal plane-Palatal plane): The angulation of the natural occlusal plane relative to the palatal plane.

4. ∠ Mand. (Mandibular plane-Palatal plane): The angulation of the mandibular plane relative to the palatal plane.

## Statistical Methods

The following descriptive statistics were calculated for each of the measurements:

(1) The Actual Change ($\Delta Y$): Fifteen-year measurement minus ten-year measurement.

(2) The Mean and Standard Deviation of the actual changes (Mean $\Delta Y$, S.D.$\Delta Y$).

(3) The Predicted Change: Predicted fifteen-year measurement minus ten-year measurement.

As mentioned in the Introduction, the present study represents an attempt to determine if the Ricketts method can be utilized as a "dynamic" synthesis in the sense that it is capable of forecasting individual variation in growth pattern, and whether it is better than other methods which are available to the orthodontist.

Specifically, three approaches to prediction will be examined:

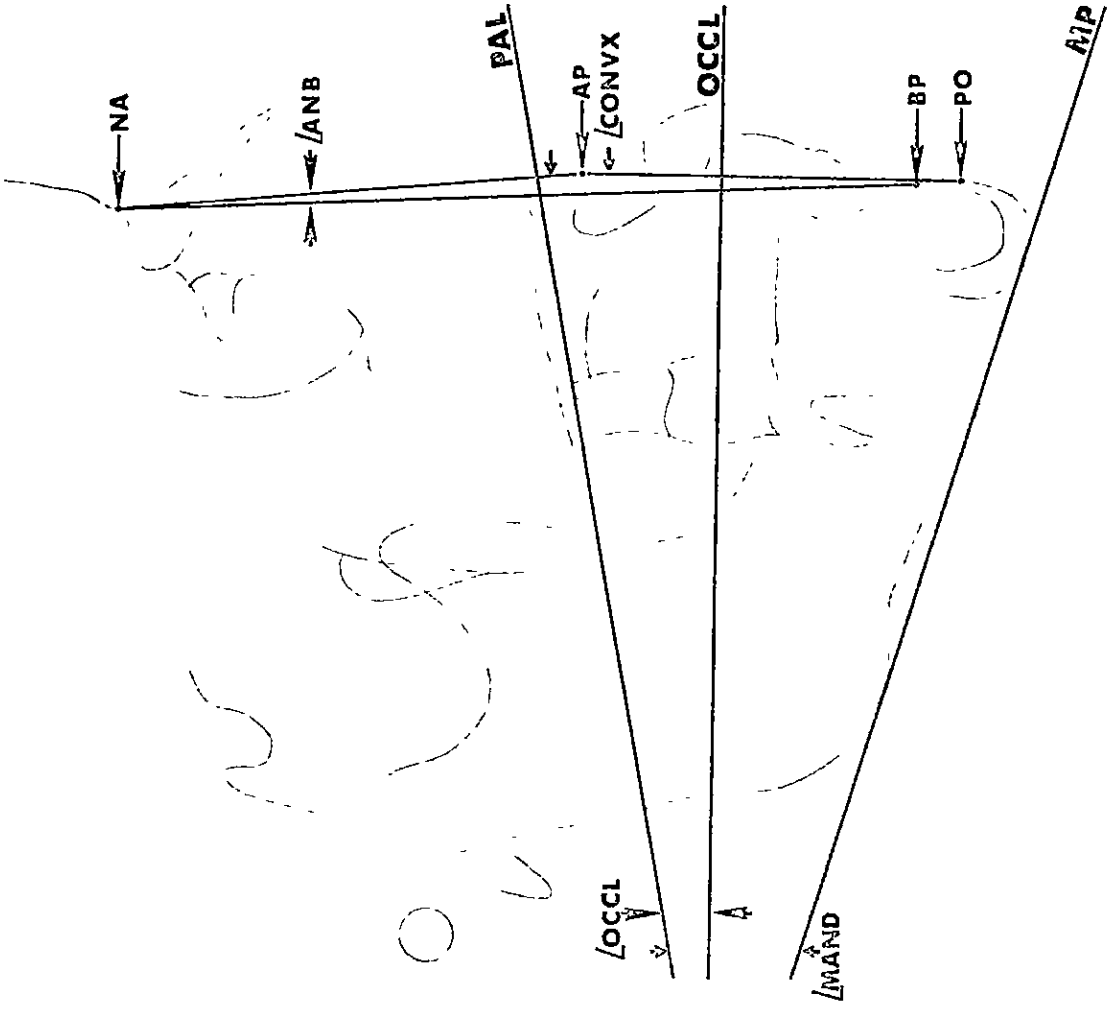
(1) The somewhat unlikely assumption ($H_0$) that no changes will occur over a five-year period.

(2) The assumption ($H_1$) that an estimate of the mean changes provides the best forecast.

(3) The assumption that one or both of the Ricketts methods provides an efficient estimate of future growth.

Figure 6

Author's Angular Measures


NA
ANB
PAL
AP
CONVX
OCCL
BP
PO
RIP
OCCL
MAND

For purposes of statistical evaluation, the root mean squared error (RMSE) of predictions be each of these methods were calculated:

(1) $H_o$: no change

$$RMSE_o = \sqrt{\frac{\Sigma(\text{five-year change})^2}{N}}$$

$$= \sqrt{\frac{N-1}{N}(S.D.\Delta Y)^2 + (\overline{\Delta Y})^2}$$

(2) $H_1$: mean change

$$RMSE_1 = \sqrt{\frac{\Sigma(\text{Mean}\Delta Y - \Delta Y)^2}{N-1}}$$

$$= S.D.\Delta Y$$

(3) Ricketts:

$$RMSE_R = \sqrt{\frac{\Sigma(\text{Predicted change} - \text{Actual change})^2}{N}}$$

$$= \sqrt{\frac{N-1}{N}(S.D.\text{error})^2 + (\text{Mean Error})^2}$$

To estimate the percentage reduction in error achieved by the Ricketts methods, a coefficient of prediction efficiency (E) was calculated:

$$E = \frac{RMSE_{o \text{ or } 1} - RMSE_R}{RMSE_{o \text{ or } 1}} \cdot 100$$

A positive value for E signifies an improvement in accuracy; a negative value, a decrement.

To test the statistical importance of the reductions--or increases--in error described by the various values of E, use was made of variance ratios (F):

$$F = \frac{(RMSE_{o \text{ or } 1})^2}{(RMSE_R)^2}$$

If the variances (mean squared error) are equal, the ratio has an F distribution, and should be approximately one. Ratios significantly less than unity indicate that the Ricketts method is not as accurate as the method with which it is being compared ($H_o$ or $H_1$); values significantly greater than one imply the opposite. These rejection areas may be listed:

$F \geq F_{1-\frac{\alpha}{2}}(\nu_1,\nu_2)$ --Ricketts method significantly better

$F \leq F_{\frac{\alpha}{2}}(\nu_1,\nu_2)$—Ricketts method significantly worse

To estimate the reliability of the particular cephalometric method employed, all measurements from the twenty tracings executed by both the author and Rocky Mountain Data Systems Inc. were correlated. The resulting coefficient of linear correlation ($r_{xx}$) is, therefore, a measure of the reliability of the method, and as such can be used as an error study. The coefficients of reliability were calculated for two sets of variables: the original ten-year measurement and the actual change (fifteen-year minus ten-year). A perfect direct or inverse relationship would be indicated by a +1 or -1, respectively, while a value of zero would denote relative independence of the measurements.

Certain of the data were examined from the standpoint of binomial probability (sign-test; Dixson and Massey, 1969). All

calculations were performed with the aid of a programmable electronic calculator (Model 9100A; Hewlett-Packard Company; P. O. Box 301; Loveland, Colorado).

## FINDINGS

### Means and Standard Deviations

Means and standard deviations for the actual change and Ricketts-prediction of the five-year change, as well as for the error of the prediction, for the various craniofacial dimensions ($\Delta Y$, $\Delta X$, and error, respectively) are shown in Tables I, II and III. It may be noted that the means and standard deviations of the actual and predicted changes are, in most cases, quite similar, especially for the author-prepared sample. For any dimension, the standard deviations of the error of the three predictions are very similar. In some instances, the standard deviation of the error exceeded that of the change and vice versa. As judged by the sign test, however, there was no significant trend.

### Variance

Table IV contains variance ratios for estimates of the error of the Ricketts methods as compared to two alternative prediction schemes: the hypothetical situation of stability of the craniofacial architecture ($H_o$) and the more realistic addition of an estimate of the mean five-year change ($H_1$).

Patterns can be observed among the three samples for significant measurements for $H_o$ and $H_1$. It can also be noted that the null hypothesis failed to be rejected for twenty-one measures (of thirty-

TABLE I

MEANS, STANDARD DEVIATIONS AND ERRORS

FOR ONE HUNDRED AUTHOR PREDICTIONS

| | Actual Change (ΔY) | | Predicted Change (ΔX) | | Error | |
|---|---|---|---|---|---|---|
| Measure | S.D. | Mean | S.D. | Mean | S.D. | Mean |
| Max. O | 1.62 | -1.54 | 0.72 | 0.49 | 1.61 | -2.03 |
| Mand. O | 1.47 | -2.82 | 0.54 | -1.34 | 1.58 | -1.47 |
| A/B | 1.95 | 0.68 | 1.76 | 0.89 | 2.19 | -0.24 |
| Max. P | 3.63 | -1.17 | 0.92 | 0.02 | 1.78 | -0.96 |
| Mand. P | 1.51 | -1.75 | 0.75 | -0.49 | 1.54 | -1.26 |
| $\underline{A}/\overline{B}$ | 1.94 | -0.84 | 0.43 | 0.37 | 1.95 | -1.19 |
| M | 3.07 | 11.33 | 1.78 | 11.65 | 3.07 | -0.47 |
| Hu | 2.07 | 4.77 | 1.71 | 3.91 | 2.08 | 0.86 |
| H1 | 2.67 | 6.46 | 1.35 | 7.11 | 2.33 | -0.66 |
| $\angle$Convx. | 3.23 | -1.06 | 0.95 | -0.74 | 2.98 | -0.31 |
| $\angle$ANB | 1.23 | -0.25 | 0.77 | -0.30 | 1.47 | 0.06 |
| $\angle$Occl. | 2.83 | -3.33 | 1.49 | -3.46 | 2.80 | 0.27 |
| $\angle$Mand. | 2.61 | -1.95 | 1.18 | 1.92 | 2.59 | -3.88 |

TABLE II

MEANS, STANDARD DEVIATIONS AND ERRORS

FOR TWENTY AUTHOR PREDICTIONS

| | Actual Change (ΔY) | | Predicted Change (ΔX) | | Error | |
|---|---|---|---|---|---|---|
| Measure | S.D. | Mean | S.D. | Mean | S.D. | Mean |
| Max. O | 1.71 | -1.89 | 0.74 | 0.46 | 1.82 | -2.35 |
| Mand. O | 1.19 | -2.84 | 0.55 | -1.50 | 1.28 | -1.33 |
| A/B | 1.99 | 0.83 | 1.66 | 0.44 | 2.07 | 0.40 |
| Max. P | 2.13 | -1.35 | 0.64 | -0.01 | 2.10 | -1.35 |
| Mand. P | 1.39 | -1.63 | 0.57 | -0.45 | 1.30 | -1.19 |
| $\underline{A}/\overline{B}$ | 2.40 | -0.79 | 0.38 | 0.48 | 2.42 | -1.08 |
| M | 3.69 | 11.18 | 2.38 | 12.00 | 2.80 | -0.82 |
| Hu | 2.23 | 4.33 | 0.46 | 3.73 | 2.08 | 0.61 |
| Hl | 2.52 | 7.00 | 1.02 | 7.42 | 1.87 | -0.41 |
| ∠Convx. | 3.66 | -0.24 | 0.69 | -0.61 | 3.42 | 0.37 |
| ∠ANB | 1.60 | 0.06 | 0.28 | -0.39 | 1.60 | 0.45 |
| ∠Occl. | 2.75 | -3.16 | 1.70 | -3.05 | 2.91 | 0.15 |
| ∠Mand. | 2.34 | -1.51 | 1.25 | 1.95 | 2.75 | -3.46 |

TABLE III

MEANS, STANDARD DEVIATIONS AND ERRORS
FOR TWENTY COMPUTER PREDICTIONS

| | Actual Change (ΔY) | | Predicted Change (ΔX) | | Error | |
|---|---|---|---|---|---|---|
| Measure | S.D. | Mean | S.D. | Mean | S.D. | Mean |
| Max. O | 1.60 | -1.43 | 1.16 | -3.53 | 2.02 | 2.10 |
| Mand. O | 1.25 | -3.28 | 0.96 | -2.16 | 1.28 | -1.13 |
| A/B | 1.92 | 0.13 | 1.30 | 0.88 | 2.50 | -0.75 |
| Max. P | 2.40 | -1.10 | 1.41 | -1.21 | 2.32 | 0.12 |
| Mand. P | 3.34 | -2.03 | 1.22 | -1.66 | 1.78 | -0.37 |
| $\underline{A}/\overline{B}$ | 2.27 | -1.54 | 0.93 | -2.44 | 2.46 | 0.90 |
| M | 3.93 | 11.53 | 2.60 | 12.44 | 3.66 | -0.91 |
| Hu | 2.48 | 5.07 | 1.02 | 5.78 | 1.86 | -0.71 |
| Hl | 2.15 | 7.21 | 1.52 | 5.71 | 2.65 | 1.50 |
| /Conx. | 3.75 | -0.50 | 2.65 | -1.99 | 2.75 | 1.49 |
| /ANB | 1.47 | -0.17 | 0.93 | -1.28 | 1.40 | 1.11 |
| /Occl. | 4.12 | -3.39 | 1.51 | -2.08 | 3.59 | -1.31 |
| /Mand. | 3.25 | -0.25 | 3.69 | -1.49 | 2.70 | 1.24 |

TABLE IV

VARIANCE RATIOS[a]

| Measure | One Hundred Author | | Twenty Author | | Twenty Computer | |
|---|---|---|---|---|---|---|
| | $H_o$[b] | $H_1$[c] | $H_o$[b] | $H_1$[c] | $H_o$[b] | $H_1$[c] |
| Max. O | 0.742 | 0.392* | 0.732 | 0.337* | 0.540 | 0.309* |
| Mand. O | 2.184* | 0.466* | 2.833* | 0.426 | 4.320* | 0.551 |
| A/B | 0.881 | 0.791 | 1.051 | 0.936 | 0.539 | 0.567 |
| Max. P | 3.546* | 3.250* | 1.018 | 0.755 | 1.305 | 1.123 |
| Mand. P | 1.352 | 0.579 | 1.487 | 0.639 | 2.957* | 3.545* |
| $\underline{A}/\overline{B}$ | 0.854 | 0.726 | 0.367* | 0.856 | 1.105 | 0.786 |
| M | 14.413* | 0.987 | 16.972* | 1.677 | 10.882* | 1.140 |
| Hu | 5.366* | 0.853 | 5.238* | 1.109 | 8.320* | 1.622 |
| H1 | 8.314* | 1.216 | 15.746* | 1.867 | 6.312* | 0.518 |
| ∠ Convx. | 1.289 | 1.174 | 1.079 | 1.132 | 1.445 | 1.495 |
| ∠ ANB | 0.725 | 0.706 | 0.929 | 0.972 | 0.672 | 0.698 |
| ∠ Occl. | 2.423* | 1.022 | 2.127 | 0.937 | 1.974 | 1.216 |
| ∠ Mand. | 0.486* | 0.314* | 0.390* | 0.286* | 1.195 | 1.248 |

[a] $F_{(100,99).025} = .67$ $F_{(20,19).025} = .406$

$F_{(100.99).975} = 1.50$ $F_{(20,19).975} = 2.46$

[b] $H_o$: compared to no change

[c] $H_1$: compared to the addition of an estimate of the mean five-year change

nine) for $H_o$ and for thirty-one measures (of thirty-nine) for $H_1$.

## Prediction Efficiency

Estimates of prediction efficiency for the Ricketts synthesis as opposed to alternate methods of prediction ($H_o$ and $H_1$) are presented in Table V. In this investigation, the total range in prediction efficiency among the three samples tested was found to vary from -60.1% to 75.7% for $H_o$ and from -87.1% to 44.4% for $H_1$. In addition, the overall average efficiencies can be determined (from the means) and were found to be 18.2% and -13.8%, respectively, for the Ricketts method compared to $H_o$ and $H_1$.

## Cephalometric Error

As may be seen in Table VI, the values of $r_{xx}$ for the ten-year measurements were quite large and, as might be expected, statistically significant at the ninety-five percent level. Two notable exceptions to this generalization are A/B and $\angle$Occl., measurements associated with the occlusal plane. In marked contrast, measurements of change were relatively independent, none of the values of $r_{xx}$ differing significantly from zero.

TABLE V

COEFFICIENTS OF PREDICTION EFFICIENCY

| Measure | One Hundred Author | | Twenty Author | | Twenty Computer | |
|---|---|---|---|---|---|---|
| | $H_o$ [a] | $H_1$ [b] | $H_o$ [a] | $H_1$ [b] | $H_o$ [a] | $H_1$ [b] |
| Max. O | -16.2% | -59.9% | -16.8% | -72.0% | -36.1% | -79.5% |
| Mand. O | 32.4% | -46.1% | 40.6% | -52.3% | 51.9% | -34.3% |
| A/B | - 6.4% | -12.1% | 2.3% | - 3.5% | -36.2% | -32.9% |
| Max. P | 46.9% | 44.4% | 0.9% | -15.1% | 12.5% | 6.0% |
| Mand. P | 13.9% | -31.5% | 18.0% | -24.6% | 41.8% | 24.1% |
| $\underline{A}/\overline{B}$ | - 8.1% | -17.3% | - 5.0% | - 8.2% | 4.7% | -12.8% |
| M | 73.7% | - 0.8% | 75.7% | 22.7% | 69.7% | 6.3% |
| Hu | 56.8% | - 8.5% | 35.4% | 5.3% | 65.3% | 21.5% |
| H1 | 65.5% | 9.8% | 74.8% | 25.8% | 60.2% | -38.8% |
| ∠ Convx. | 12.0% | 7.8% | 3.7% | 8.4% | 16.8% | 18.1% |
| ∠ ANB | -17.3% | -19.2% | - 3.7% | - 1.1% | -22.0% | -19.8% |
| ∠ Occl. | 35.7 | 1.0% | 31.4% | - 3.3% | 28.8% | 9.3% |
| ∠ Mand. | -43.2% | -78.3% | -60.1% | -87.1% | 8.5% | 10.5% |
| Means: $H_o$ [a] | 18.9% | | 15.2% | | 20.5% | |
| Means: $H_1$ [b] | | -16.2% | | -15.8% | | - 9.4% |

[a] compared to no change

[b] compared to the addition of an estimate of the mean five-year change

TABLE VI

COEFFICIENTS OF RELIABILITY[a]

($r_{xx}$)

| Measure | Y (10yr) | ΔY (10-15 yr) |
|---|---|---|
| Max. O | .85 | .03* |
| Mand. O | .74 | .28* |
| A/B | .45* | .18* |
| Max. P | .84 | .23* |
| Mand. P | .80 | .02* |
| A/B | .91 | .31* |
| M | .98 | -.08* |
| Hu | .95 | .18* |
| Hl | .99 | .02* |
| ∠Conx. | .92 | .04* |
| ∠ANB | .93 | .36* |
| ∠Occl. | .47* | -.19* |
| ∠Mand. | .94 | .19* |

[a] $r_{.95} = .55$; $r_{.99} = .68$

## DISCUSSION

The purpose of a facial-growth prediction would seem to be the predetermination of the magnitude of an event which has not yet occurred. For the orthodontist, this event is the change in size and form of an individual face. Obviously, there must be some uncertainty as to the outcome of the event, otherwise there would be nothing to predict. A measure of this uncertainty is the mean squared deviation of the change in the various craniofacial dimensions. The success of a prediction scheme, then, may be measured by the extent to which this uncertainty is reduced. Practically speaking, the reduction should be both statistically and clinically significant.

### Means and Standard Deviations

From Tables I, II, and III it may be seen that the standard deviations of the predicted change were consistently smaller than the standard deviations of the actual change. In order to determine the probability that all thirty-nine standard deviations for predicted change could be smaller than the standard deviations of the actual change, a sign test was used; the result was highly significant ($P<.01$).

From these results one can infer that for the present samples, the computerized and author-prepared versions of the Ricketts scheme tended to add increments whose dispersion was less than that of the

actual change.

Theoretically, however, the standard deviations of the predicted change within each of the two groups of author-predicted cases should be equal to zero since the growth increments were added to each ten-year tracing by similar prediction procedures, and were, in most instances, estimates of the population five-year mean change (Schulhof, 1972b). The standard deviations of the predicted change, however, were not zero, as had been shown, although they were usually of lesser magnitude than the standard deviations of the actual change. The opportunity for error in the prediction is, therefore, a prime consideration.

The sequential nature of the Ricketts predictions would have a cumulative effect on error since the forecast of size and form would, then, be dependent upon the cumulative inaccuracy of all previously-determined structures. The fact that the Ricketts scheme is not geometrically unique may be another contributing factor. Consideration must also be given to the fact that, in addition to anatomical dimensions, growth forecasts involve relationships which are only measured indirectly.

Thus, although the estimated increments are themselves relatively constant, they may have varying effects on relationships (A/B, $\angle$ANB), depending upon craniofacial architecture.

To a considerable extent, the previously mentioned sources of variability would also apply to the computerized predictions. One of the advantages, however, of using a computerized scheme is to

reduce the technical error characteristic of hand-prepared predictions. Why, then, do the standard deviations of the predicted changes for the computer cases also differ from zero? As previously mentioned in the Review of the Literature, the computer is programmed to "individualize" the increments according to the patient's age, sex, race, and facial proportions, etc. It is apparent that the standard deviations of these custom-tailored growth changes, in the majority of instances, exhibit wider dispersion than those of the author-predicted cases.

The question now arises whether this individualization is, in fact, an estimate of the future individual change. It can be established mathematically that, in the absence of additional information, the best estimate (least error) of the future change of a structure is an estimate of the population mean change.

## Variance Ratios

Variance ratios, in general, are important because they attach a level of statistical significance to the relationship between two measures of dispersion--in this case, the mean squared error of the Ricketts forecast versus the mean squared error of an alternate prediction scheme. One can infer, therefore, that the significantly large (ninety-five percent level) variance ratios for Mand. 0, M, Hu, and Hl indicate less error for the Ricketts method as compared to the alternate assumptions ($H_o$). On the other hand, the Ricketts predictions for $\angle$ Mand. ($H_o$ and $H_1$) and Max. 0 ($H_1$) were significantly less accurate. For measurements in which the F ratios approach unity

(A/B, ∠ANB, and $\underline{A}/\overline{B}$), it can be inferred that the error of the Ricketts methods is generally neither larger nor smaller than that of alternative prediction schemes.

Upon further examination of Table IV, it becomes evident that for measures where there is an established population trend toward an increase (M, Hu, Hl) or decrease (Mand. O) in linear dimension, the Ricketts forecast is, generally, more accurate than assumption $H_o$. Conversely, measures of relationship (∠ ANB, A/B, $\underline{A}/\overline{B}$), which undergo considerable individual change in pattern, but no marked population trend (mean change is approximately zero), proved no more accurate than assumption $H_o$.

An overall comparison of the Ricketts scheme with the two alternate methods reveals slightly less error than the assumption of no change ($H_o$) and slightly greater error, in two samples of author-predicted cases, than an alternate method of mean change ($H_1$).

## Prediction Efficiency

Coefficients of prediction efficiency are estimates of the level of clinical significance that can be attained using the Ricketts synthesis as opposed to the alternate method of prediction.

Considerable variability for this statistic was noted (Table V) within and among the three groups.

A comparison of Tables IV and V will demonstrate that measures of known trend (Mand. O, M, Hu, and Hl) are generally easier to predict; therefore, they will have greater variance ratios and prediction

efficiencies. Measures of maxillomandibular relationship (∠ANB, A/B, and $\underline{A}/\overline{B}$) which, as a group, remain fairly constant but, which are characterized by considerable (individual) variability, are found to have smaller variance ratios and negative coefficients of efficiency.

A comparison of the mean efficiencies revealed that the Ricketts methods were only 18.2 percent more efficient when compared to relative stability of the pattern ($H_o$) and 13.8 percent less efficient when compared to an estimate of the five-year mean change.

Since the Ricketts synthesis was, generally, found to be more efficient than a forecast of no change (linear dimensions; not for relationships) and less efficient (in both respects) than a method of mean change, forecasts utilizing mean changes would seem promising. Perhaps; but consideration must be given to the fact that mean changes are obtained from a sample, as an estimate of the population mean change, and as such, they can not be expected to fit any other sample as well. Nevertheless, there is evidence (Pelle, 1971) that, for large samples, there is not that much between sample variance. Therefore, one could infer that validated estimates of population mean changes should suffice except in the more variable measures for craniofacial relationship.

Inasmuch as some of the same measures (A/B, $\underline{A}/\overline{B}$, and ∠ANB) were employed, the prediction efficiency of the Ricketts scheme can be compared to that of the regression method by referring to Ballrick's validation of the equations proposed by Johnston (1968) and Björk

and Palling (1955). Ballrick obtained values of 24.6 percent (A/B) and 8.1 percent (A/B) for maxillomandibular relationship on a longitudinal sample of fifty males at seven and twelve years of age. Johnston reported values of thirty-six percent (A/B) and thirty-nine percent (A/B) for these same variables on the sample from which they were derived. Using the simple linear regression equations of Björk and Palling on a sample of fifty males ages twelve to twenty, Ballrick obtained an E of 18.3 percent for ∠ ANB (ss-n-sm). Although these validated efficiencies were higher than could be obtained with the Ricketts schemes, no claims of clinical utility were advanced. Rather, Ballrick concluded that predictions obtained from regression equations were no more accurate than an estimate of mean change.

## Cephalometric Error

The major source of cephalometric error in the Ricketts computerized scheme is associated with the technician related duties of tracing cephalograms, and specifically for the five-year prediction, locating the mandible according to the Arcial Method. Ricketts (1972) has recently introduced a multitude of new landmarks and planes that are utilized in the computerized scheme (Xi, SP, PT, Mu, Eva, Foramen Rotundum, Ptergyoid Vertical, Corpus Axis); however, a biologic rationale for, and rigorous definition of many of these are lacking. Baumrind and Frantz (1971), in an extensive study of the reliability of head film measurements, cautioned the profession against the use of ill-defined and poorly reproducible landmarks.

From Table VI it can be observed that the measurements for A/B and ∠ Occl. (ten-year) demonstrated very low values for the coefficient of reliability ($r_{xx}$). This can be explained by considering that errors in determining the occlusal plane have a marked projectional effect on points and planes not intimately related to it. The dentition, on the other hand, is more closely associated with the occlusal plane and similarly exhibited a diminished $r_{xx}$ because all commercial tracings of teeth are rendered from the same template. Mention should be made of the fact that reliability coefficients $\underline{A}/\overline{B}$ and ∠ Mand. which utilize a more easily identifiable palatal plane were consistently higher in value.

From the coefficients of reliability it can be inferred that the tracing accuracy was consistent for eleven out of thirteen original (ten-year) measurements. If this consistency persists, and there is no reason to doubt that it would, then the low $r_{xx}$ values obtained for the actual change (fifteen-year minus ten-year) must be intimately associated with the relationship between the size of the actual change and the magnitude of the technical cephalometric error. If the five-year growth change being measured cephalometrically is so slight in comparison to the magnitude of an inherent constant error, accumulated from four tracings, then the future of any cephalometric prediction scheme is questionable since a dimension cannot be predicted any more accurately than it can be identified.

## Treatment Effects

There is yet another facet to consider with respect to cephalometric prediction--the ability of the orthodontist to predetermine the effects of his treatment on the skeletal structures of the individual patient. Orthodontically induced changes are difficult to forecast since they depend upon the mechanical prowess of the clinician and the cooperation of the patient; nevertheless, skeletal and dental changes have been reported in the literature and include an eight millimeter distal movement of A point, palatal expansion, and early treatment with orthopedic forces to retard or redirect growth. Perhaps as Johnston (1968) states, the success of growth prediction is dependent upon ". . . the individual clinician's ability to estimate in advance the effects of treatment. . . ."

## SUMMARY AND CONCLUSIONS

The purpose of this investigation was to evaluate the predictive accuracy of the Ricketts Synthesis of growth prediction as prepared two ways:

(1) commercially by computer, and

(2) hand-prepared by the author

A sample of one hundred orthodontically untreated individuals (fifty males and fifty females), each represented by two lateral cephalograms taken at ten and fifteen years of age, was selected at random from the records of the Bolton-Brush Growth Study. Of the one hundred individuals, twenty (ten males and ten females) were also randomly selected for five-year computerized growth predictions.

The cephalometric data were reduced to measurements of change (predicted and actual) and error.

Statistical methods were chosen to compare the accuracy of three specific approaches to prediction:

(1) the somewhat unlikely assumption that no change would occur over a five-year period.

(2) the assumption that an estimate of the mean change provides the best forecast.

(3) the assumption that one or both of the Ricketts methods provides the best forecast.

For predictions of linear dimension, the Ricketts methods were found to be minimally more efficient than an assumption of no

change and less efficient than an assumption of mean change. For the more complex predictions of relationship, the Ricketts forecasts were consistently less efficient than the alternate methods. Measurements of maxillomandibular relationship, of particular interest to the orthodontist, were plagued with negative predictive efficiencies.

An error study revealed that the magnitude of the inherent cephalometric error was sufficient to vitiate the prediction of growth changes occurring over a five-year interval.

Although unexamined by this study, it was proposed that changes effected in the craniofacial complex as a result of orthodontic treatment are of such a magnitude as to render the prediction of slight growth changes meaningless.

The following conclusions were drawn with regard to the specific sample employed:

(1) The use of the Ricketts synthesis for the prediction of changes attributable only to growth is somewhat more accurate than an assumption of no change and less accurate than an estimate of the five-year mean change.

(2) For any non-trivial prediction (craniofacial relationships), the Ricketts synthesis, executed by hand or by computer, can not be shown to be of sufficient efficiency to be of clinical significance.

(3) The magnitude of inherent cephalometric error is sufficient to mask changes attributable only to growth.

(4) A decision to employ the Rocky Mountain Data Systems Inc. prediction scheme must be based on factors other than its prediction efficiency; namely, its undoubted heuristic significance and its considerable utility in patient education.

## APPENDIX I

### LATERAL CEPHALOMETRIC POINTS AND PLANES EMPLOYED IN SHORT-RANGE GROWTH FORECASTING (After Gugino, 1971, p. 49)

Cephalometric points:

A POINT (AP): the deepest point on the curve of the maxilla between the anterior nasal spine and the dental alveolus

UPPER MOLAR (A6): a point on the occlusal plane perpendicular to the distal surface of the crown of the upper first molar

MAXILLA (ANS): the tip of the anterior nasal spine

LOWER MOLAR (B6): a point on the occlusal plane perpendicular to the distal surface of the crown of the lower first permanent molar

B POINT (BP): the deepest point on the anterior curve of the mid-sagittal symphysis

BASION (BA): the most inferior posterior point of the occipital bone

PTERYGOID (CC): a point on Basion-Nasion plane at a perpendicular from PT Point

PTERYGOID (CF): the intersection of Pterygoid Root Vertical with Frankfort horizontal plane

CONDYLE (DC): a point selected in the center of the condyle neck on the BA-NA plane

GNATHION (GN): a point at the intersection of the facial and mandibular planes (Cephalometric GN)

MENTON (MM): a point located at the lowest point on the midline curve of the symphysis

NASION (NA): a point at the anterior limit of the nasofrontal suture

ORBITALE (OR): a point located at the lowest point on the external border of the orbital cavity, tangent to the Frankfort plane

MAXILLA (PNS): the tip of the posterior nasal spine

POGONION (PO): the most anterior point on the midsagittal symphysis

PORION (PR): a point located at the most superior point of the external auditory meatus, tangent to the Frankfort plane

SELLA (SE): the center of the sella turcica, selected by inspection

MANDIBLE (Xi): a point located by constructing four planes: two perpendicular planes from Frankfort horizontal through Points R1 and R2 and two parallel horizontal planes to Frankfort through Points R3 and R4--then locating a center point (Xi) within the rectangle

PT POINT (PT): the intersection of inferior border of Foramen. Rotundum with posterior wall of pterygo-maxillary fossa as viewed in lateral head film

SUPRAPOGONION (SP): a point selected at the anterior border of the symphysis between point B and Pogonion

MANDIBLE (R1): the deepest point on the curve of the anterior border of the ramus, one-half the distance between the inferior and superior curves

MANDIBLE (R2): a point located on the posterior border of the ramus of the mandible opposite R1

MANDIBLE (R3): a point located at the center and most inferior aspect of the sigmoid notch of the ramus of the mandible

MANDIBLE (R4): a point on the lower border of the mandible directly inferior to the center of the sigmoid notch of the ramus

Cephalometric planes:

APO PLANE: (AP-PO)

CONDYLAR AXIS: (Xi-DC)

CORPUS AXIS: (Xi-SP)

CRANIAL BASE: (BA-NA)

FACIAL AXIS: (CC-GN)

FACIAL PLANE: (NA-PO)

FRANKFORT PLANE (FH): (PR-OR)

MANDIBULAR PLANE (MP): a line tangent to the lower border of the mandible and passing through Menton

OCCLUSAL PLANE (OCCL): a line passing through first molars and canines without bisecting incisors

PTERYGOID VERTICAL (PV): a perpendicular to the Frankfort Plane passing through the distal of the Pterygopalatine Fossa

PALATAL PLANE (PAL): (ANS-PNS)

## APPENDIX II

### THE STEPWISE MECHANICS OF THE RICKETTS SHORT-RANGE GROWTH PREDICTION TECHNIQUE AS MODIFIED FOR THE FIVE YEAR UNTREATED FORECAST (Schulhof, 1972a)

CRANIAL BASE PREDICTION

(1) Trace the Basion-Nasion plane, making it longer at each end by the following increments:

Basion
3.9 mm for males
3.0 mm for females

Nasion
4.5 mm for males
3.4 mm for females

(2) Trace Nasion

(3) Trace Basion

MANDIBULAR GROWTH PREDICTION

(4) Superimpose at Basion along the Basion-Nasion planes

Trace: Condylar Axis
Coronoid Process
Condyle

(5) From point DC, move the prediction superiorly along the Condylar Axis 4.5 millimeters for males and 3.4 millimeters for females

Trace: Corpus Axis, extending it 9.0 millimeters for males and 6.8 millimeters for females
Posterior border of the ramus
Angle and lower border of the mandible

(6) Superimpose at SP points along the Corpus Axis and:

Trace: Symphysis

Draw: Facial Plane
Mandibular Plane
Facial Axis

MAXILLARY GROWTH PREDICTION

(7) Superimpose at Nasion along the Facial planes and divide the distance between the original and predicted Mentons into thirds by drawing two marks

(8) Superimpose the original Menton and the superior mark along the Facial planes

Trace: Maxilla

OCCLUSAL PLANE POSITION

(9) Posteriorly, the Occlusal plane will drop two and one-half millimeters when superimposing at Xi point-- Anteriorly, it will rise one-half the total increase in lower face height from the Anterior Nasal Spine to Pogonion

Trace: new Occlusal plane

Draw: new APo plane

DENTITION

(10) Use the original incisor relationship to the Occlusal and APo planes as a template

Trace: upper and lower central incisors

(11) Superimpose at the symphysis--Project a perpendicular from the mesial of the lower first molar to the new Occlusal plane

(12) Superimpose the Occlusal planes with the perpendicular at the mesial of the lower first molar

Trace: the original upper and lower molar relationship

## LITERATURE CITED


Balbach, D. R. 1969. The cephalometric relationship between the morphology of the mandible and its future occlusal position. Angle Orthod., 39: 29-41.

Ballrick, J. W. 1971. A statistical validation of cephalometric prediction. Unpublished M.S. thesis. Department of Orthodontics, Case Western Reserve University, Cleveland. vii+76p.

Baumrind, Sheldon, and Frantz, R. C. 1971. The reliability of head film measurements. 1. Landmark identification. Am. J. Orthod., 60: 111-127.

Beattie, J. R. 1963. Serial radiographic cephalometric study of mandibular growth and its relationship to height, weight, and skeletal age. Unpublished M.S. thesis. Department of Orthodontics, Western Reserve University, Cleveland. vii+91p.

Björk, Arne. 1947. The face in profile. Svensk Tandl. Tidskrift, 40(Suppl. 5B), Lund.

Björk, Arne. 1951. The significance of growth changes in facial pattern and their relationship to changes in occlusion. D. Rec., 71: 197-208.

Björk, Arne. 1953. Estimation of age changes in overjet and sagittal jaw relation. Europ. Ortho. Soc. Trans., 29: 240-256.

Björk, Arne and Palling, Morgens. 1955. Adolescent age changes in sagittal jaw relation, alveolar prognathy and incisal inclinations. Acta Odont. Scand., 12: 201-232.

Björk, Arne. 1955. Facial growth in man, studied with the aid of metallic implants. Acta Odont. Scand., 13: 9-34.

Björk, Arne. 1963. Variations in the growth pattern of the human mandible. Longitudinal radiographic study by the implant method. J. Dent. Res., 42: 400-411.

Broadbent, B. H. 1937. The face of the normal child. Angle Orthod., 7: 183-208.

Broadbent, B. H., Jr., and Golden, W. H. 1971. The value of an assessment of skeletal maturity in orthodontic diagnosis. Am. J. Phys. Anthrop. (N.S.), 35: 409-410.

Brodie, A. G. 1941. On the growth pattern of the human head from the third month to the eighth year of life. Am. J. Anat., 68: 209-262.

Brodie, A. G. 1946. Facial patterns--a theme on variation. Angle Orthod., 16: 75-87.

Brodie, A. G. 1953. Late growth changes in the human face. Angle Orthod., 23: 146-157.

Burstone, C. J. 1963. Process of maturation and growth prediction. Am. J. Orthod., 49: 907-919.

Curtner, R. M. 1953. Predetermination of the adult face. Am. J. Orthod., 39: 201-217.

Dixon, W. J. and Massey, F. J. 1969. Introduction to Statistical Analysis, third edition, New York, McGraw-Hill. vii+638p.

Gianelly, A. A. 1970. Age and sex cephalometric norms. Am. J. Orthod., 57: 497-501.

Gugino, C. F. 1971. An Orthodontic Philosophy, fifth edition, Denver, Colorado, EDCO Associates. ii+122p.

Harvold, Egil. 1963. Some biologic aspects of orthodontic treatment in the transitional dentition. Am. J. Orthod., 49: 1-14.

Hirschfeld, W. J. and Moyers, R. E. 1971. Prediction of craniofacial growth: the state of the art. Am. J. Orthod., 60: 435-444.

Hunter, W. S. and Garn, S. M. 1969. Evidence for a secular trend in face size. Angle Orthod., 39: 320-323.

Johnston, L. E. 1968. A statistical evaluation of cephalometric prediction. Angle Orthod., 38: 284-304.

Lande, M. J. 1952. Growth behavior of the human bony facial profile as revealed by serial cephalometric roentgenology. Angle Orthod., 22: 78-89.

Maj, Giorgio, and Luzi, Cesare. 1964. Longitudinal study of mandibular growth between nine and thirteen years as a basis for an attempt of its prediction. Angle Orthod., 34: 220-230.

Meredith, H. V., Knott, V. B. and Hixon, E. H. 1958. Relation of the nasal and subnasal components of facial height in childhood. Am. J. Orthod., 44: 285-294.

Meredith, H. V. 1959. Recent studies on growth of the body and face. Am. J. Orthod., 45: 110-124.

Merrow, W. M. 1962. A cephalometric statistical appraisal of dentofacial growth. Angle Orthod., 32: 205-213.

Moroney, M. J. 1962. Facts from Figures. Baltimore, Penguin Books.viii+472p.

Nanda, R. S. 1955. The rates of growth of several facial components measured from serial cephalometric roentgenograms. Am. J. Orthod., 41: 658-673.

Ødegaard, Jan. 1970. Growth of the mandible studied with the aid of metal implant. Am. J. Orthod., 57: 145-157.

Pelle, J. M. 1971. Inheritance of craniofacial morphology in like-sexed siblings. Unpublished M.S. thesis. Department of Orthodontics, Case Western Reserve University, Cleveland. xii+108p.

Pelton, W. J. and Elsasser, W. A. 1955. Studies of dentofacial morphology. IV. Profile changes among 6,829 white individuals according to age and sex. Angle Orthod., 25: 199-207.

Reukema, K. R. 1971. An evaluation of the reliability of the facial growth trend classification theory of Dr. Charles Tweed. Unpublished M.S. thesis, St. Louis University, School of Graduate Dentistry, St. Louis. vi+48p.

Ricketts, R. M. 1957. Planning treatment on the basis of the facial pattern and an estimate of its growth. Angle Orthod., 27: 14-37.

Ricketts, R. M. 1960. The influence of orthodontic treatment on facial growth and development. Angle Orthod., 30: 103-131.

Ricketts, R. M. 1960. Foundations for cephalometric communication. Am. J. Orthod., 46: 330-357.

Ricketts, R. M. 1960. Cephalometric synthesis--an exercise in stating objectives and planning treatment with tracings of the head roentgenogram. Am. J. Orthod., 46: 647-673.

Ricketts, R. M. 1961. Cephalometric analysis and synthesis. Angle Orthod., 31: 141-156.

Ricketts, R. M., Bench, R. W., Hilgers, J. J. and Schulhof, R. 1972. An overview of computerized cephalometrics. Am. J. Orthod., 61: 1-28.

Sanin, Carlos, Savara, B. S., Clarkson, Q. C., and Thomas, D. R. 1970. Prediction of occlusion by measurements of the deciduous dentition. Am. J. Orthod., 57: 561-572.

Schulhof, R. J. 1972a. Personal communication, January.

Schulhof, R. J. 1972b. Personal communication, March.

Tweed, C. H. 1963. Treatment planning and therapy in the mixed dentition. Am. J. Orthod., 49: 881-906.

Wasson, J. L. 1963. Evaluation of a method of predicting craniofacial growth that compares cephalometric roentgenograms of children and parents. Abstract. Am. J. Orthod., 49: 864.

Wylie, W. L. 1944. A quantitative method for the comparison of cranio-facial patterns in different individuals: its application to a study of parents and offspring. Am. J. Anat., 73: 39-60.