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A Linear Cephalometric Analysis: Its Description and Application in Assessing Changes in the Mandible After Orthodontic Treatment

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A LINEAR CEPHALOMETRIC ANALYSIS: ITS DESCRIPTION AND APPLICATION IN ASSESSING CHANGES IN THE MANDIBLE AFTER ORTHODONTIC TREATMENT

by

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LIFE

J. Keith Grimson was born in Evanston, Illinois, on January 24, 1936. He was graduated from Evanston Township High School in June, 1953.

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CHAPTER I

INTRODUCTION AND GENERAL CONSIDERATIONS

A. Introduction

In the past 34 years, orthodontists have seen cephalometric roentgenography develop from its infancy as an implement of the researcher to its maturity as a valuable instrument for the clinician. At its beginning cephalometry was employed primarily to provide comparative data for studies of normal and abnormal growth. There is still a vast field open for additional research in this area, but in routine clinical practice there is also a definite need for easily applicable methods of diagnosis, treatment planning, and assessing changes occurring concomitant with orthodontic treatment.

Some degree of success has been achieved in the clinical application of cephalometrics, but many practitioners still refuse to avail themselves of its benefits. There are many reasons for this reluctance to accept cephalometrics as a diagnostic aid instead of merely a research instrument. A lack of appreciation due to a lack of education in the subject is undoubtedly a major factor, plus a natural resistance to adopting something new, without which they feel they have been successful.

Investigations in cephalometrics may be placed into five general classes: appraisals of growth and development, investigations of abnormal growth, studies of general facial and skeletal types, function analyses, and the use of cephalometrics as an aid in case analysis and treatment planning. Various investigators have assessed changes occurring concomitant with the orthodontic treatment of different types of malocclusion. Of these, most studies have concerned themselves with treatment changes in Class II malocclusion. Comparatively little work has been done in assessing changes in the correction of the Class I malocclusion. One of the purposes of this study is to assess the changes which have occurred after the treatment of malocclusions of this type.

Most work in cephalometrics has concerned itself with the facial profile rather than the frontal aspect of the face for the reason that cephalometry, at least in its present state of development, lends itself more readily to the techniques used in profile analysis. Most discussed among the current methods of assessing skeletal and dental disharmonies are those by Wylie, Downs, Tweed, and Steiner. European influence has been felt through the work of Björk in his study of the human profile. All of these studies have in common the concept of measuring spatial relationships using angular measurements. In addition to the use of angles, several studies have employed linear measurements to supplement the angular observations. Except for Wylie's studies on the assessment of anteroposterior dysplasia and Steiner's linear measurements of the relationships of the central incisors to the NA and NB planes, the use of linear measurement in the most popular methods of faciodental assessment has been very much neglected.

This study is concerned with the investigation of changes in the morphology of the mandible and in the positions of dental structures after orthodontic treatment. All changes will be assessed exclusively by the use of linear cephalometric measurements. Earlier major investigations in this area of craniofacial appraisal used angular or combined angular and linear measurements. This study will provide a simple clinical method of assessing changes occurring after the orthodontic treatment of 26 Class I malocclusions using analytic functions in rectangular coordinates. This method of appraisal is unique insofar as it will show not only changes in the horizontal and vertical directions, but also angles and intersection points without the use of a protractor.

B. Statement of the Problem

The purpose of this thesis is twofold:

1. To devise and demonstrate the versatility of a linear system of measurements using analytic functions in rectangular coordinates.
2. To utilize this system of measurements in assessing the changes occurring in the morphology of the mandible and in the positions

of associated dental structures after the treatment of 26 Class I (Angle) extraction malocclusions.

CHAPTER II

REVIEW OF THE LITERATURE

A. Evolution of Cephalometrics

The speciality of orthodontics has advanced rapidly in its brief history and it is gradually being elevated to a science through the medium of research. In attaining a more scientific foundation, orthodontics has to some extent looked to the pure sciences of mathematics and geometry. These have been used to evaluate numerous angular and linear measurements accumulated by the use of various mechanical devices from living subjects, wet and dry skull material, and cephalometric radiographs.

Anthropologists and craniologists have done extensive work in taking linear measurements between various skull landmarks made with head spanners, calipers, and other measuring devices on dry skull material. These investigators used the comparative method, arbitrarily choosing "fixed" points from which to make their measurements, and then comparing dimensions of different skulls. This work had some orthodontic implications, but was chiefly a study of racial types.

In 1922 Keith and Campion reported a study of growth and development of the skull in which they superimposed disarticulated bones from the skull of a five year old child upon those of an adult skull. Then by observations and linear measurements, they attempted to determine the amount of growth that would be necessary for each of the child's bones to grow into adult proportions. They demonstrated forward growth of the face by measuring from the transmeatal axis.

Hellman published in 1927 the results of a systematic anthropologic study on the development of the human face. He made angular and linear measurements from a collection of 78 American Indian skulls that represented every age group from infancy to old age. He classified the skulls according to the stages of development of the dentition, and then made a comparative and quantitative analysis. He established anthropometric measurepoints and made over 70 measurements for each skull. Hellman's evaluation of these data contributed considerable knowledge on the dimensions and form of the face.

Krogman in 1926 used methods similar to Hellman's in a comparative anatomy study on the growth of the face in anthropoids.

In 1929, T. Wingate Todd and his associates in the Department of Anatomy at Western Reserve University published work on their development of the craniostat from a craniometric instrument known as the head spanner. The craniostat orients the mounted skull to certain definite planes:

a. Frankfort Horizontal plane which passes through right and left Porion and Orbitale.

b. Transverse Vertical Plane which passes through right and left Porion, perpendicular to the Frankfort Horizontal plane.

c. The Median Saggital plane which passes through Nasion and is perpendicular to both of the other planes.

The craniostat is then used to make careful measurements on the mounted skull. This is accomplished by means of pointers mounted on metal blocks that slide along scales which are related to the above three planes. These measurements are then plotted on graph paper, the points connected by lines, and thus craniostatic drawings of the skull in frontal and profile views are obtained. From these drawings the exact linear distance of any point on the skull from any of the three planes of reference can be determined.

All of this research on skeletal material has been important in laying a foundation, but it definitely had its limitations. This type of material is static, it is subject to warpage and shrinkage, and it is subject to racial as well as individual differences. Todd pointed out the important fact that "a dead child is a defective child in whom there has occurred an interruption or a prohibition of developmental growth for some time before death, unless, of course, death is due to an acute disease or to an accident such as injury or burns. If we are to investigate healthy skulls we must do it in the living."

Another approach that should be mentioned is the application of anthropometrics to living material. Simon's gnathostatic diagnosis reported in 1926 was foremost of this group. He used anthropometric landmarks and combined them with an oriented scale photograph for serial observation. He related his gnathostatic casts through linear measurements with the median and orbital planes and his photognathostatic photos with the eye-ear, orbital, and mandibular planes.

Andresen also in 1926 related his casts to Camper's plane (a line from the external auditory meatus to a point just below the nasal spine) by means of a gnathophor.

Rubbrecht in 1930, according to Logan, constructed a facial diagram by means of external linear measurements and subsequent graphs.

In 1932 Smyth and Young conducted an extensive study of facial growth in children with special reference to the dentition. They recorded linear measurements of numerous facial and dental characters in about 1400 children under 14 years of age that were selected as having "morphologically normal occlusion." The results were published in an 80 page pamphlet which included complete descriptions of the prosopometer, various types of calipers, and other measuring devices used. They presented a statistical analysis of the data and established mean values and variabilities for facial and dental linear dimensions.

The primary disadvantage to these methods is the difficulty of locating the points of reference through the overlying soft tissues without error. In addition, it is obvious that many of the internal landmarks that are used in anthropology are inaccessible in the living subject.

In order to overcome the shortcomings of craniometric and gnathostatic techniques, a more accurate method of measurement of living subjects was needed. Also a more accurate delineation of the bony points themselves was necessary, and this could only be accomplished by roentgenography. Krogman summed up the situation when he stated:

> With the introduction of the X-ray, we witness a merging of two major techniques, the purely craniometric, based on skulls alone, and the purely cephalometric or gnathostatic, based on the head and soft parts alone. Each has its limitations, but each surrenders its best to the X-ray. We are able finally to correlate the earlier craniometric and the later cephalometric into the all-inclusive roentgenographic.

One of the initial attempts at cephalometric roentgenography was made by Pacini in 1922. Pacini oriented the skull in accepted craniometric planes and immobilized it by strapping it with bandages. He developed a formula of proportion thus allowing for correction of enlargement.

Following Pacini's work several men reported using radiographs of the head for diagnostic purposes, but they did not mention their techniques or any statistical evaluations. Phillips in 1927 examined a number of orthodontic cases taking their history, models, and also anteroposterior radiographs of a few cases with full occlusions in good relation. These comparisons revealed any marked distortion or asymmetries of the bony structures of his cases under examination. Riesner in 1928 advocated taking skull radiographs with the standard dental X-ray machine. He desired a radiograph that would show the profile of the soft tissues and their relation to the hard tissues beneath, but he did not make any measurements or try to locate anthropometric points.

In 1931, Hofrath in Germany and Broadbent in Cleveland, working independently, published techniques for taking oriented lateral roentgenograms. Hofrath's method consisted of placing the head between two pairs of crossed wires so that the intersection of wires on each side lay opposite the tragia of the ears. The X-ray tube was placed at one end of the long lead tube, with one set of crossed wires being at the other end, using a two meter target distance.

Broadbent, using the principles of the Todd craniostat in designing his apparatus, constructed an instrument much more elaborate and accurate than the Hofrath device. The Hofrath technique never gained popularity, but Broadbent, under the auspices of the Bolton Research Foundation, developed the technique and laid the basis for subsequent growth and development research.

Briefly, Broadbent's apparatus consisted of two X-ray tubes directed at right angles to each other and positioned so that one central ray passes through the ear rods of the craniostat or head positioner, which is built around a dental chair. The head positioner, which had a fixed base, orients the head so that there is a constant relation between the source and path of the rays to the head and the film. Both lateral and frontal views are taken at a target distance of five feet, giving the same degree of enlargement for both. With the exception of the X-ray tube and mechanism used to produce the frontal view, the apparatus most commonly used today is essentially the same as that developed by Broadbent. The front view has generally been discarded in routine office use because clinical interest lies in changes measured in the anteroposterior plane.

Since the introduction of the Broadbent-Bolton cephalometer, as it is known today, many others such as Higley, Margolis, Weingart, Strauss, Hooper, Graber, Thurow, and Björk have devised modifications of the head holder. All fulfill the same requirements and are of the same basic design as Broadbent's but are used with some variation in technique.

B. Methods of Cephalometric Appraisal

The foregoing discussion has been limited to a description of the various methods of taking records of the skull or living head; now for a review of various methods used to appraise these records. In regard to the study or comparison of successive radiographs, several different methods, employing various different planes - both cranial and facial - have been used and are in use today.

Broadbent concluded that neither Orbitale nor Porion were stable enough to use as landmarks for superimposing tracings and thus he never used the Frankfort Horizontal plane. Knowing that the sphenoid area was considered one of the most stable points in the skull, he constructed a base point called Registration point (R), and superimposed the tracings on this point, keeping the Bolton planes parallel to each other. Describing the Bolton plane and the construction of point R, Broadbent wrote:

> This plane is determined at its anterior end by the craniometric landmark known as Nasion, i.e., the junction of the frontal and the nasal bones in the midplane; its posterior termination is the highest point in the profile of the notches at the posterior end of the condyles on the occipital bone. The right and left condyles on the occipital bone are close enough to the midplane and to the path of the central ray that the X-ray shadow of their outlines is registered on the film as a single image. From this Bolton-Nasion plane there is erected a perpendicular from the Bolton-Nasion plane to sella turcica, designated as R, is used as the registration point for registering tracings of subsequent pictures of the same individual and of different individuals as well.

Brodie in 1941 conducted an extensive study on the growth pattern of the human head from the third month to the eighth year of life. His ideas on the selection of a plane of orientation differed from Broadbent's. He wrote:

> The Bolton plane has been shown to be very stable and is an excellent plane of reference for successive roentgenograms of the same patient over certain age ranges. However, as the mastoid process

> grows downward it tends to obscure the Bolton point and make its accurate location difficult. For this reason, I prefer the line Sella-Nasion (center of sella turcica to nasion) with Sella as the registration point. A series of roentgenograms of the same growing individual covering a span of ten to fifteen years reveals that Sella-Nasion and Bolton planes maintain a constant angular relation to each other in the individual and hence, one is equal to the other in accuracy. The Sella-Nasion points can be located easily at any age.

The use of linear observations in the evaluation of cephalograms is certainly not a new concept of appraisal. Linear measurements have been employed as far back as 1939 when Adams, in studying the possible association of variations in mandibular form with specific malocclusions, used a linear measurement to assess the length of the body of the mandible. What is significant is the fact that very few studies have limited themselves to assessment by linear observations alone. The following paragraphs will briefly review in chronological order some of the most popular methods of appraisal with special emphasis given to those methods employing linear measurements.

Björk, in his investigation in 1947 of the effects of variations in jaw growth on the mechanics of facial prognathism, devised a facial diagram, the linear and the angular configurations of which, he showed, determine the amount and distribution of facial prognathism. The linear measurements were recorded between the landmarks used in his study such as Sella, Nasion, Articulare, etc. These distances when used with the angular readings determined the location and degree of facial prognathism.

In 1947, Wylie advocated a method of assessing anteroposterior dysplasia by an analysis of the degree to which certain facial disharmonies were compensated for or reinforced by variations in the area of the affected parts. He measured distances between various landmarks by erecting perpendiculars from the Frankfort Horizontal plane to the points of interest. The distances along this plane formed by the intersecting perpendiculars were then used in his assessment of anteroposterior dysplasia. Wylie also assessed the length of the mandible by measuring the distances between perpendiculars erected from the mandibular plane to Gnathion and to the most posterior surface of the condyle (point Glenoid Fossa).

Downs in 1948 introduced a method of recording the skeletal and denture pattern by which the facial form may be measured. This analysis which has attained great popularity among orthodontists is based on five angular measurements for analyzing the skeletal pattern and five angular measurements for analyzing the relationship of the denture to skeletal pattern.

It is interesting to note that Downs, like Wylie and many other investigators, has used the Frankfort Horizontal plane to which most structures are referred. This plane is drawn through the upper periphery of the two ear holes, and the lowest point of the left infraorbital margin. It was introduced in 1872 by Von Ihering and accepted by the Anthropological Congress in Frankfort, Germany in 1884, and so given its name. In 1924, Simon stated: "The eye-ear plane (Frankfort) is preferable to the other horizontal planes because in holding the head erect, it is more frequently parallel with the horizontal plane of the earth's surface."

Downs stated:

> Our own results would indicate an almost identical degree of stability in the Sella-Nasion, Bolton, and Frankfort planes. It should be recalled, however, that both Sella-Nasion and Bolton constitute dividing lines between the face and cranium and therefore are measures of craniofacial relations. The Frankfort plane, on the other hand, cuts across the face and, hence, would be a more logical choice for a study of relationships involving only the face. It is in these relationships that the interest of the orthodontist lies. In an examination of a large number of individuals, I have yet to find a facial angle (inferior inside angle of FH-NPo) that was not a good expression of the facial type of the individual as appraised by his profile radiograph.

Many investigators are of the opinion that the Frankfort plane is too difficult to pick up accurately and that this error overrules any of the advantages claimed for it. There has been found considerable variability of the inferior orbital margin among various races, and the orbit is not always clearly discernible. In addition, if mechanical Porion is used as Björk points out, the upward pressure of the ear rods may vary from case to case, thus making the point indicated also slightly variable. On the other hand, if anatomical Porion is used, its accurate location is often difficult. It is for these reasons that the Sella-Nasion plane has been selected for use in this study.

In 1951, Craig in an investigation comparing skeletal patterns of Class I and Class II, Division I malocclusions used a "grid system of horizontal and vertical lines." Serial tracings of lateral headfilms were placed over a sheet of millimeter graph paper so that the center of sella turcica was superimposed at the intersection of the vertical and horizontal axes and with the Porion-Orbitale (Frankfort) line parallel to the horizontal axis. Each anatomical landmark on the superimposed tracings was recorded in terms of its distance from the vertical and horizontal reference axes.

Steiner's analysis, developed in 1953, is primarily angular with the exception of the relation of the upper incisor to the NA line and the lower incisor to the NB line. These measurements are linear and are also included in the method advocated by Holdaway for properly locating the lower incisor with relation to Pogonion.

Williams in 1953, in a study investigating craniofacial proportionality in a horizontal and vertical plane before and after the onset of puberty, superimposed lateral headfilms on the Sella-Nasion plane using Sella as registration point. After locating anatomical landmarks in the usual manner, tracings were made on graph paper in such a way that the paper was divided into four quadrants by the Sella-Nasion plane, which was designated the horizontal reference axis, and a perpendicular to Sella-Nasion erected at Sella as the vertical reference axis. Positions for each anatomical point could then be established in relation to the two reference axes. Distances were recorded in millimeters and were subject to statistical analysis to establish a mean distance, mean proportion, standard deviation and range for each measurement.

Swann in 1954 in studying the etiology of Class II, Division I malocclusions, used linear measurements. He related structures to each other by using Frankfort as a horizontal reference axis and a perpendicular erected to Sella as the vertical reference axis. Landmarks were then related to each other in a horizontal direction only.

In 1955, Altemus in an investigation of mandibular morphology of two groups of females in which one group had "normal" occlusion while the other had Class II, Division I malocclusion, used a linear method of analysis similar to Wylie's. Linear measurements included over-all mandibular length, ramal height, and corpal length. He used projections dropped from Frankfort to the various landmarks. The distances from Frankfort and along Frankfort were then recorded.

In an analysis of the integration of facial skeletal variants, Coben in 1955 used linear measurements with a line parallel to Frankfort as the horizontal axis of reference and lines perpendicular to it as vertical axes of reference. Middle facial prognathism was evaluated antero-posteriorly by measuring various landmarks along the horizontal axis (a line from Nasion parallel to Frankfort which intersects a projection from Basion) as percentages of the face depth, Basion to Nasion. All vertical measurements were expressed as a percentage of the anterior face height, Nasion to Menton. An index of the relationship of face height, to face depth was then established by expressing anterior face height as a percentage of the cranial base depth, Basion to Nasion. The coordinate method of analysis permitted the appraisal of the integration of the actual size and relative proportions of the various craniofacial structures of each face at the two age periods studies.

Elsasser in 1957 devised a coordinate analysis using graph paper in which all points were related to the same planes of reference. He used the Frankfort Horizontal plane for the abscissa and a line perpendicular to Frankfort erected 20 mm. anterior to Nasion as the ordinate. Various landmarks were spotted and the horizontal and vertical distances from these points to the reference axes were recorded. Three angular measurements were obtained from the linear readings to determine the relationships of the upper incisor to Frankfort, the relationship of the lower incisor to Frankfort, and the relationship of Frankfort to the mandibular plane. Elsasser compiled in table form a mean, standard deviation, and range for each observation from a "normal" sample obtained from Tweed.

Kean, working in New Zealand in 1958, compared the faces of two groups of children, one with "normal" occlusion and the other with Class II Division I malocclusion, to study the variations in facial depth in relation to the type of occlusion. He used a coordinate system in which a plane from Nasion parallel to the Frankfort Horizontal plane was the horizontal reference axis, and a perpendicular from this plane to Basion was the vertical reference axis. The author employed a specially constructed glass scale to read the linear measurements from each tracing directly in true millimeters. In order to construct this scale, millimeter graph paper with accentuated centimeter lines was drymounted on a piece of thick cardboard which in turn was firmly attached to a bench. Fine stainless steel wires were stretched along the horizontal and vertical centimeter lines and kept in place with "Scotch" tape. The resulting stainless steel wire mesh was placed in the midline of the Margolis cephalostat used in the study, corresponding to the position of the midsaggital plane of the head, and radiographed. On the radiograph of enlarged centimeter squares, a standard series of squares having 10 divisions was "fitted" by image projection. By removing the radiograph and in its place exposing a photographic glass plate to the fitted image, a permanent scale duplicating the enlarged millimeter scale was obtained. Thus, a millimeter on the scale was enlarged to the same extent as a given distance in the midsaggital plane is enlarged on a radiographic film since the midsaggital film-plane distance is constant on the Margolis cephalostat.

Any distance between two landmarks in the midsaggital plane of the subject could nowbe read directly from a tracing placed on the glass scale. All readings were in actual millimeters and the error incurred was "less than one per cent."

Merow in 1962 employed linear observation in a study of the horizontal and vertical dentofacial proportions of 25 "normal or ideal" occlusions before and after puberty. He oriented serial cephalograms in much the same manner as Broadbent except that successive headplates were oriented parallel to the Frankfort Horizontal plane rather than to the Bolton plane. Frankfort was used as the horizontal reference axis and a perpendicular to Frankfort was erected from Registration point as the vertical reference axis. Facial height and depth were then measured to these axes and the absolute and proportional changes calculated.

Harris, Johnston, and Moyers in 1963 developed a cephalometric template to indicate the degree of harmony of the craniofacial complex and the site of any disharmony which underlies a given malocclusion. The derivation of the template was based on craniofacial constructions used by the University of Toronto in the study of a population of Burlington, Ontario, children. The construction of the template involved two planes: Bolton-Nasion and the mean occlusal plane. Growth vectors were obtained by regression analysis of scattergrams of three selected landmarks. This provided information with which it was possible to construct rectangular areas for each specific landmark at each age. These rectangles were designed to delineate the area within which the specific landmark found in 68% of the sample would lie. Vinyl plastic templates were then fabricated for boys and girls of ages 4-16. These templates could then be used for the comparison of individual cases to a cross-sectional sample of children of the same age and sex.

Wallis in 1963 investigated the integration of certain variants of the facial skeleton in Class II, Division II malocclusion. His tracings were oriented in a rectangular coordinate system using the method advocated by Coben. Measurements of height, depth, and angularity were taken, and their means and standard deviations were calculated.

Wieslander, also in 1963, attempted to evaluate the effect of occipital anchorage on the dentofacial area in the mixed dentition period. He used tracings superimposed on the sphenoethmoidal plane and the midline point of the two great wings of the sphenoid bone as it intersects this plane. This permitted registration of changes due to both growth and orthodontic treatment. He felt that this area was most stable or unchanging during growth. A coordinate system composed of the Frankfort Horizontal plane and a line perpendicular to this plane through the midline point of the great wings of the sphenoid bone was the method of appraisal. Changes in position of certain anatomical landmarks were assessed in horizontal and vertical directions by relating the structures to this coordinate system.

Huggins and Birch in 1964, in a study of the position of the upper incisors before and after their retraction following bilateral extraction of dental units, employed a transparent measuring grid scribed with 1 mm. squares. The upper margin of this grid was oriented on the plane formed by joining the anterior and posterior nasal spines. The authors took Anterior Nasal Spine as a stable point from which to measure the antero-posterior change in position of the upper incisor. The vertical change was measured from the incisal tip of the upper incisor directly to the ANS-PNS plane. All measurements recorded in millimeters were analyzed to determine the mean and range of the change in pretreatment and posttreatment upper incisor positions.

This review has traced the evolution of cephalometrics from its origins in physical anthropology and craniometrics to its methods of use today. It can be easily seen that the application of cephalometrics has taken many varied paths from simple angular and linear observations to ingenious systems involving templates and grids. The method for this present study is similar to those of Craig, Williams, Kean, and Elsasser. None of these investigators used the method to evaluate changes resulting from orthodontic treatment, and none demonstrated the versatility of the method by showing how angles could be easily calculated if desired. By using a sample of pre- and posttreatment cephalograms of Class II (Angle) four first premolar extraction malocclusions, co-worker F. Peter Wall, D. D. S., and I will show the versatility of this method. In addition, this method will be employed in a study of changes occurring in the morphology of the mandible and associated dental structures after the orthodontic treatment of this study sample of 26 children.

CHAPTER III

METHODS AND MATERIALS

A. Introduction

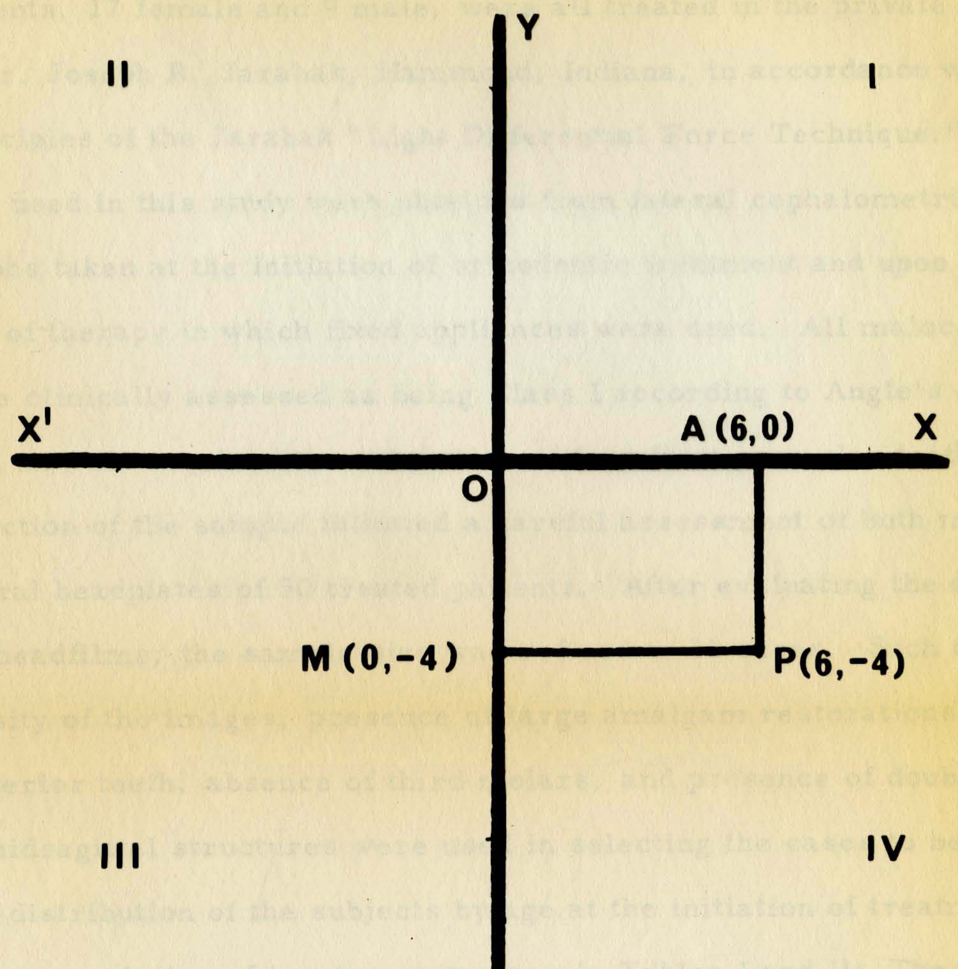
The purpose of this and a similar study by F. Peter Wall, D. D. S., is to introduce and demonstrate the use of a rectangular coordinate system in the evaluation of a cephalogram. This linear system of analysis is ideally suited for application to large, high speed computers. It is hoped that this method of appraising lateral headplates will eventually be refined sufficiently to allow its use in computer systems in evaluating growth and development, general skeletal and facial types, and finally, as an aid in case analysis and treatment planning.

B. The Rectangular Coordinate System

The invention of a system of rectangular coordinates is usually attributed to René Descartes, a French mathematician and philosopher, whose La Géométrie, appeared in 1637. It was from this source that the mathematical world learned the value of the methods of analytic geometry. Because of this work of Descartes, rectangular coordinates are sometimes called "Cartesian Coordinates."

In order to create a rectangular coordinate system, two mutually perpendicular lines (X'X and Y'Y) must be drawn intersecting at 0 (Figure 1). These reference lines, called axes, divide the plane into four parts, or quadrants. The quadrants are numbered I, II, III, and IV, starting with the upper righthand quandrant and reading counter-clockwise. The point of intersection of the axes is called the origin. The line X'X is called the axis of abscissas, or x-axis, and is generally taken to be the horizontal. The line Y'Y is called the axis of ordinates, or y-axis, and is generally taken to be vertical. All distances measured horizontally to the right or vertically upward are considered positive, and all distances measured horizontally to the left or vertically downward are considered negative. Positive distances are represented by positive numbers, and negative distances are represented by negative numbers. A landmark is an undefined object which is represented in this study by a point on a drawing paper. Every landmark is located by two numbers which represent the distances of the landmarks from the axis of ordinates and the axis of abscissas. These two numbers are called the coordinates of the point. In analytic geometry, these two numbers are written in pairs separated by a comma and are enclosed in parentheses, as (7, -5). The first number is called the abscissa and the second number is called the ordinate. Points of the plane located by these ordered pairs, have been related to a rectangular frame of reference and the numbers X and Y for the point P are termed its coordinates relative to this reference frame. Figure 1 locates three points in relation to their axes of reference.

FIGURE 1



THE RECTANGULAR COORDINATE SYSTEM

C. Selection of the Sample

The sample in this study comprised pre- and posttreatment lateral cephalometric radiographs of 26 orthodontically treated children. The patients, 17 female and 9 male, were all treated in the private practice of Dr. Joseph R. Jarabak, Hammond, Indiana, in accordance with the principles of the Jarabak "Light Differential Force Technique." The data used in this study were obtained from lateral cephalometric radiographs taken at the initiation of orthodontic treatment and upon completion of therapy in which fixed appliances were used. All malocclusions were clinically assessed as being Class I according to Angle's classification, and all required the extraction of four first premolar teeth. The selection of the sample followed a careful assessment of both models and lateral headplates of 50 treated patients. After evaluating the quality of the headfilms, the sample size was refined to 26 cases. Such criteria as density of the images, presence of large amalgam restorations in the posterior teeth, absence of third molars, and presence of double images of midsagittal structures were used in selecting the cases to be studied. The distribution of the subjects by age at the initiation of treatment and at the completion of treatment is given in Tables I and II. The mean treatment time is found in Table III.

D. Roentgenographic Technique

The roentgenographic method used in this study utilized a standard cephalometric apparatus similar in design to that shown in Figure 2. The tube housing incorporated a fixed anode and a high voltage generator providing a machine setting of 90 KVP and 45 ma. The exposure time for all films was 3/4 seconds.

The cephalostat (head-holder) provided a fixed distance of 48 inches from the focal point of the roentgen tube to the midsagittal plane. This device, shown in Figure 2, was necessary in order to prevent distortion errors due to movements of the patient's head, and to allow the operator to replace the patient into the head-holder in the same spatial relation to the roentgen-ray tube each successive time a film was exposed. The midsagittal plane-to-film distance was held constant at 15 centimeters.

Each subject was oriented in the cephalostat in the manner described by Broadbent. The ear rods and an Orbitale marker were used to orient the head on the Frankfort Horizontal plane. All patients were instructed to maintain their teeth in full occlusion and to avoid any movement during the exposure of the film.

The radiographic film used in this study was 8 x 10 inch, high speed, blue brand, Kodak Medical X-Ray Film. Each cassette was equipped with double high speed intensifying screens to eliminate some secondary radiation and to provide greater contrast. The standard development procedure,

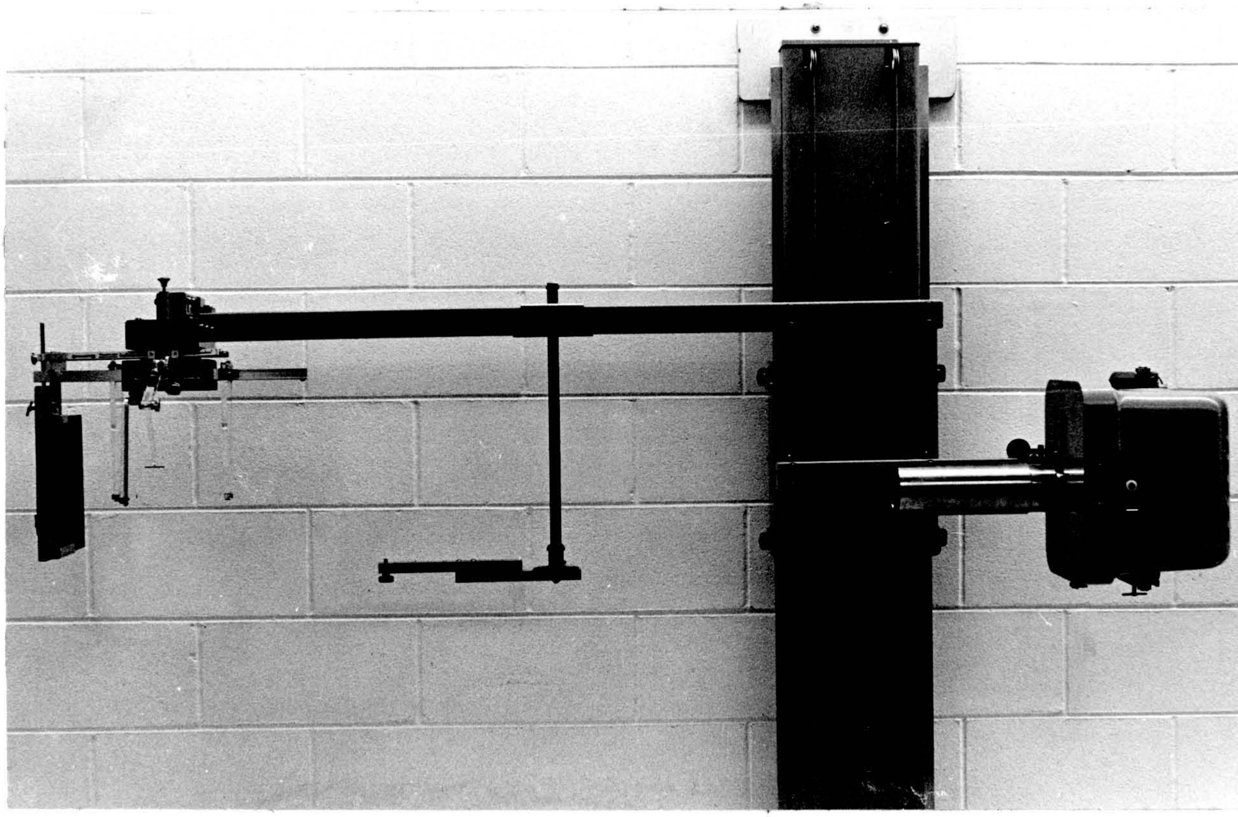


FIGURE 2

THE CEPHALOMETRIC APPARATUS

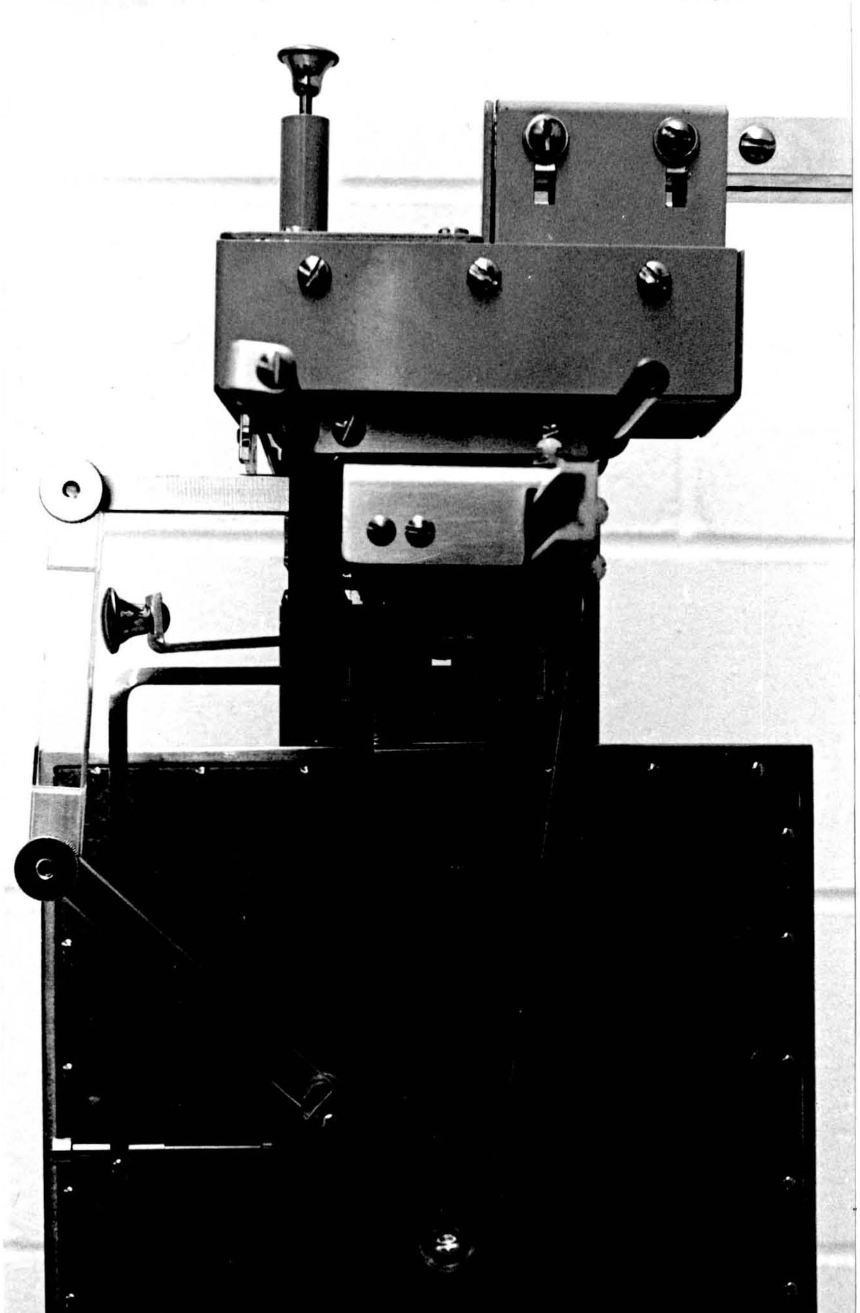


FIGURE 3

THE CEPHALOSTAT

following the usual time-temperature method recommended by Eastman Kodak Company, was adhered to for all films.

E. Spotting Technique

The rationale of this study was that everything could be measured with reference to the focal point, Sella Turcica. In referring to Sella, however, it was necessary to make use of oriented planes or reference axes, namely, Sella-Nasion as the horizontal reference axis, and a perpendicular to Sella-Nasion erected at Sella as the vertical reference axis. Any point on the lateral headplate could then be located in relation to Sella. The vertical distance from Sella could be found by measuring the distance from the point of interest to the horizontal reference axis. The same point was then related to Sella in a horizontal direction by measuring the distance from that point to the vertical reference axis.

For this study, thirteen landmarks were accurately spotted on each lateral headplate and a small pin hole was made directly through the film at each point. To accomplish this spotting with precision, a transilluminated tracing table was used in a darkened room. The pinholes were made with a phonograph needle test probe of the type commonly used in radio and electronic work (Figure 4). Phonograph needles were replaced after puncturing points on ten lateral headfilms to insure uniformly small perforations. A sheet of cellulose acetate was placed between the film and tracing table to aid in maintaining a uniform size of perforation and to

TABLE I

DISTRIBUTION OF THE SUBJECTS BY AGE

(PRETREATMENT)

AGE (YEARS)	TOTAL
10	2
11	10
12	9
13	3
14	0
15	2

MEAN 11.08 TOTAL 26

TABLE II

DISTRIBUTION OF THE SUBJECTS BY AGE

(POSTTREATMENT)

AGE (YEARS)	TOTAL
11	1
12	5
13	9
14	4
15	5
16	0
17	2

MEAN 13.57 TOTAL 26

TABLE III

TREATMENT TIME

TREATMENT TIME (YEARS)	TOTAL
0.5	1
1.0	4
1.5	11
2.0	5
2.5	3
3.0	1
3.5	1

MEAN 1.21 TOTAL 26

prevent damage to the tracing table. Spotting sessions were limited to 30 minute intervals with 15 minute rest periods to reduce errors in spotting due to eye fatigue.

To eliminate errors between investigators in locating Sella and Nasion, the points orienting the horizontal reference axis, one individual located these points on all lateral headfilms after which their locations were corroborated by two other individuals. Disputed landmarks were located by a two-out-of-three vote basis with the original spotter and the two corroborators participating.

Referring the spotted points to the reference axes required the use of a grid system. This was provided by a coordinate paper laid off in major divisions of centimeters and minor divisions of millimeters. Drawing paper fulfilling these requirements was obtained from Keuffel and Esser Company (#46-1510). Their sheets were 8 1/2 x 11 inches in size and provided one major centimeter line for every ten minor millimeter lines.

Each spotted lateral headfilm was again returned to the tracing table, this time with a sheet of the drawing paper placed between the sheet of cellulose acetate and the film. Under the same conditions used in the spotting procedure, the graph paper was carefully oriented so that the point identifying Sella was located at the intersection of two major centimeter lines. For this study, Sella was located at the intersection of the

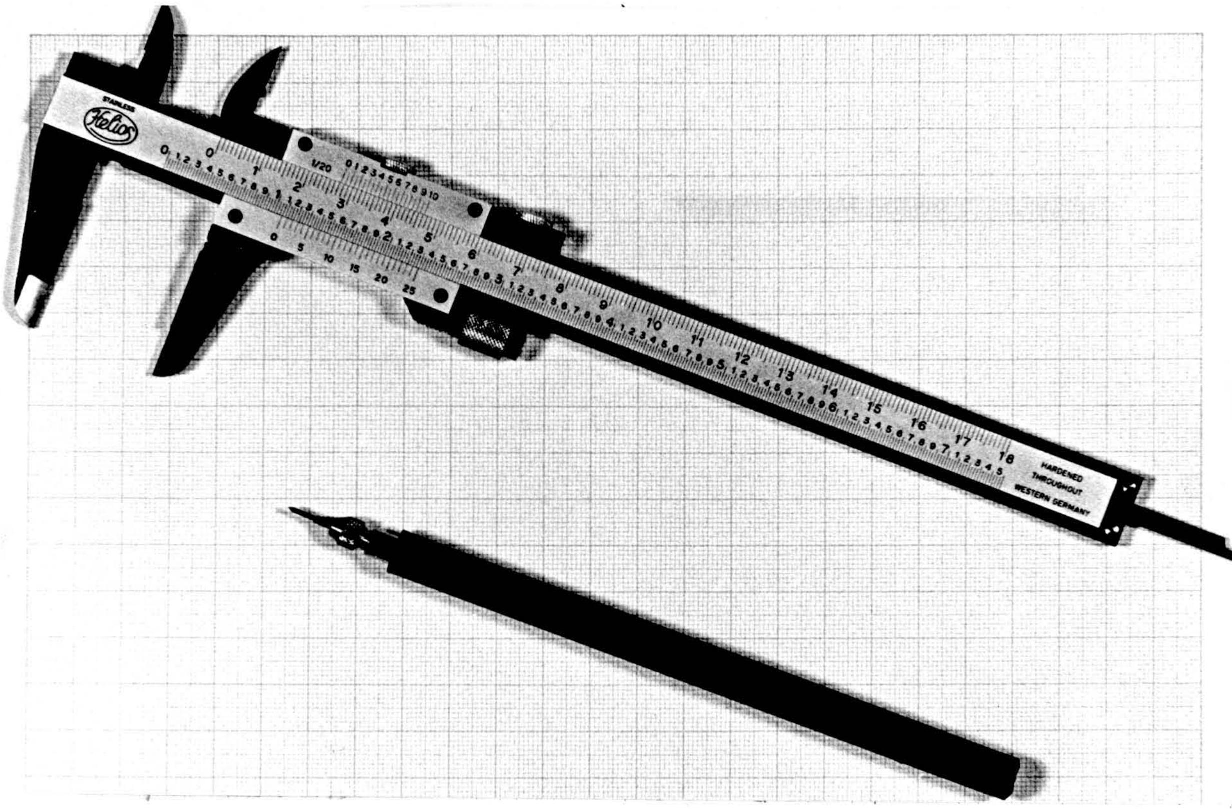


FIGURE 4

TEST PROBE, CALIPERS, AND DRAWING PAPER

tenth major vertical line from the left-hand (8 1/2 inch) side of the graph sheet with the third major horizontal line from the top (11 inch) edge of the sheet. This provided a uniformity in the location of Sella on all sheets. When Sella was placed at its correct intersection, the graph sheet was rotated so that Nasion was located on the same horizontal major centimeter line (third from the top). With these two points correctly located on the grid, the film and graph sheet were fixed together with "Scotch" tape.

The phonograph needle test probe was again used to re-enter the perforations in the film and to puncture the drawing paper at the precise location of each landmark. The same conditions and procedure were followed in marking the graph sheets as were used in the original spotting operation. After each graph sheet was perforated, the film was removed and each pinhole was carefully circled with a sharp pencil in order to easily locate all points. The axes of reference were marked for easy identification by placing pencil lines in segments in which no measurements from the axes to the landmarks would be made (Figure 5).

F. Description of Selected Landmarks

The landmarks used in this study were selected because of the ease and accuracy with which they were located and spotted, and their clinical interest. When possible, midsagittal plane structures were used and the midpoint of the two images was selected when a double projection occurred. All points were located by observation except Gonion and Posterior Sym-

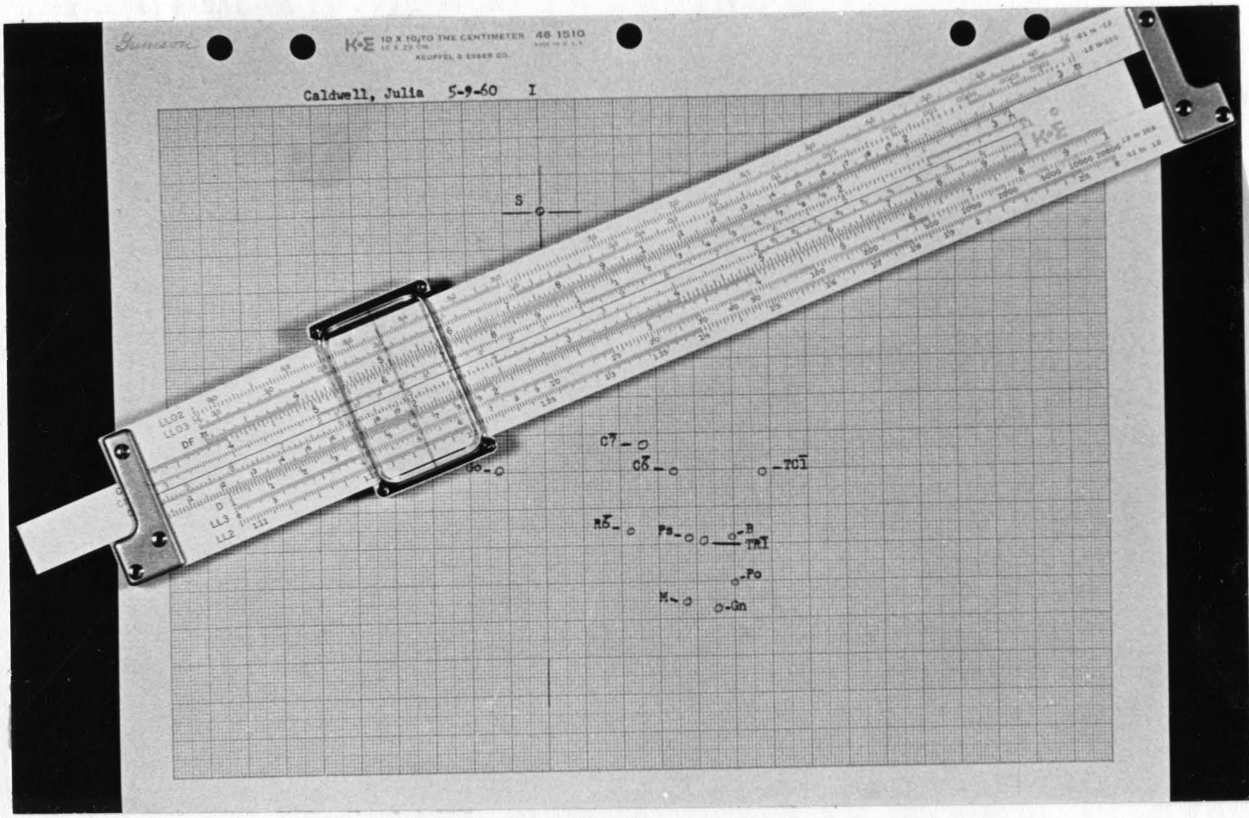


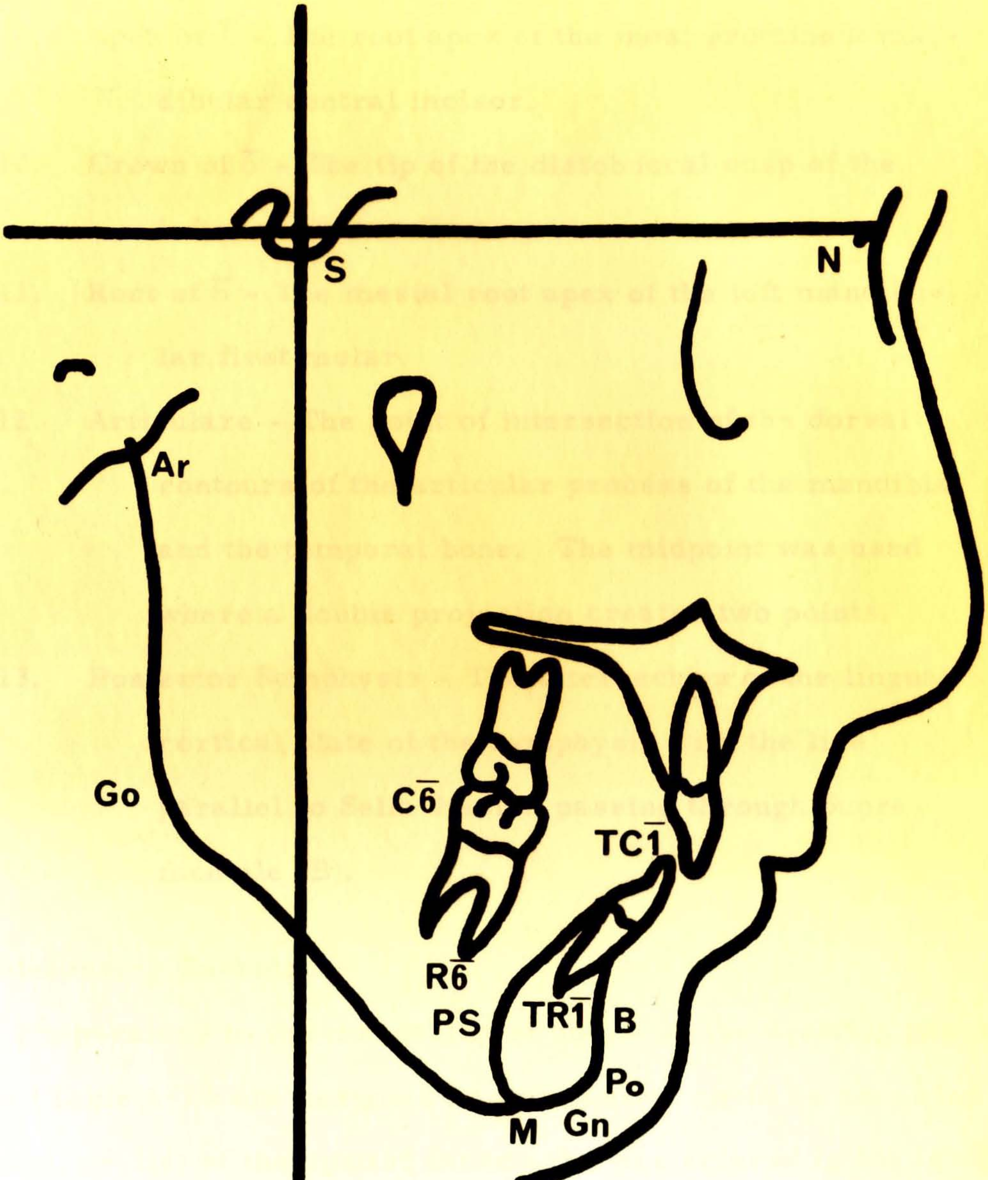
FIGURE 5

SLIDE RULE AND SPOTTED DRAWING PAPER

physis whose locating necessitated construction lines. The selected landmarks are shown in Figure 6.

1. Sella Turcica - The geometric center of the pituitary fossa of the sphenoid bone.
2. Nasion - The middle point on the frontonasal suture.
3. Gonion - The lowest, posterior, and most outward point of the angle of the mandible. Obtained by bisecting the angle formed by tangents to the lower and the posterior borders of the mandible. When both angles appeared on the profile roentgenogram, the point midway between the right and left side was taken.
4. Gnathion - The lowest point of the median plane in the lower border of the chin.
5. Pogonion - The most anterior, prominent point on the chin.
6. Supramentale (B point-Downs) - The deepest point on the contour of the alveolar projection, between infradentale and pogonion.
7. Menton - The intersection of the inferior border of the mandible with the lingual cortical plate of the symphysis.
8. Incision Inferius - The incisal point of the most promi-

FIGURE 6



SELECTED LANDMARKS

nent mandibular central incisor.

9. Apex of $\overline{1}$ - The root apex of the most prominent mandibular central incisor.

10. Crown of $\overline{6}$ - The tip of the distobuccal cusp of the left mandibular first molar.

11. Root of $\overline{6}$ - The mesial root apex of the left mandibular first molar.

12. Articulare - The point of intersection of the dorsal contours of the articular process of the mandible and the temporal bone. The midpoint was used where a double projection created two points.

13. Posterior Symphysis - The intersection of the lingual cortical plate of the symphysis with the line parallel to Sella-Nasion passing through Supramentale (B).

G. Measuring Technique

Preparatory to the measuring of points on the drawing paper, data sheets (Table IV) were designed so information could be recorded in tabular form. A list of the spotted landmarks was entered in the left-hand column of each data sheet. Two sets of paired columns were placed to the right of the column of landmarks. These were labeled I and II for pretreatment and posttreatment readings respectively. Each of these was

TABLE IV

DATA SHEET

NAME: PATIENT #1

ALL MEASUREMENTS ARE IN MILLIMETERS

NAME OF POINT	I X	I Y	II X	II Y
"S" Sella	0	0	0	0
"N" Nasion	73.1	0	73.4	0
"Go" Gonion	-12.4	-69.9	-13.8	-70.0
"Gn" Gnathion	45.5	-107.6	45.0	-110.4
"Po" Pogonion	50.0	-100.6	50.0	-103.2
"B" Supramentale	49.5	-88.4	49.0	-89.2
"M" Menton	37.4	-105.8	37.0	-107.8
$\overline{TCI}$ Incision Inferius	57.9	-70.9	56.5	-74.5
$\overline{TRI}$ Apex	42.0	-89.5	40.3	-92.8
$\overline{C6}$ Crown	26.0	-63.1	29.6	-65.2
$\overline{R6}$ Root	22.5	-86.5	25.1	-88.5
"Ar" Articulare	-13.2	-24.5	-13.8	-23.7
"PS" Posterior Symphysis	37.9	-88.4	38.8	-89.2

NOTE: FOR ANALYTICAL WORK, ALL VERTICAL DIMENSIONS MUST BE CONSIDERED NEGATIVE.

divided into an X and Y column to represent the abscissa and ordinate of each point. Since all vertical readings were below the axis of abscissas, all would be negative values. To avoid entering each vertical measurement as negative, all were considered positive for this procedure and a note stating this fact was entered at the bottom of each data sheet.

A vernier caliper measuring to 0.1 millimeter was used to obtain the readings for each point on the graph sheets. A systematic procedure of measuring was achieved by first reading all horizontal measurements and then rotating the graph sheet 90 degrees to read all vertical measurements. Great care was taken so that the beaks of the caliper were accurately located over each pinhole and were correctly oriented with respect to the reference axis. For this procedure, the lined graph paper was essential to accurately align the caliper beaks on the reference axis and on the point to be measured. As each reading was made on the vernier scale, it was recorded in the correct row and column on the data sheet by an assistant. This eliminated any fatigue resulting from alternately measuring and then recording the data for each point. Measuring procedures were conducted under the same conditions as the two spotting sessions.

H. Testing the Precision of Measurement

In order to evaluate the ability of individuals to measure accurately with the vernier caliper and rectangular coordinate system, a study of the precision of measurement was undertaken. Six graduate students from the Orthodontic Department, Loyola University, Chicago, Illinois, using the same vernier caliper measured five landmarks on each of two different patients. Prior to the experiment, another graduate student located and spotted all landmarks in the manner previously described. This was necessary as the ability of the six students to accurately locate the landmarks was not to be a part of the test. Each individual made measurements in both horizontal and vertical directions for both the pretreatment and posttreatment lateral headplates of each patient.

The 120 horizontal and 96 vertical measurements were analyzed statistically by Fisher's analysis of variance (Tables V and VI). These analyses were of interest because they demonstrated the degree of precision obtained using this type of measurement technique.

The results of the precision of measurement test in Table V show that there was a statistically significant amount of variation introduced into the horizontal measurements by the "students," but that there was nothing of practical importance since their sum of squares was less than 1 part in 142000. It was known that the other main sources of variation would contribute largely to the total variation and hence they are not important to this study. None of the interactions that include "students" as one of the factors was significantly large and hence their sums of squares can be added together to yield a very reliable measure of the experimental error incurred in this much of the measuring process. The standard

TABLE V

ANALYSIS OF VARIANCE

(HORIZONTAL MEASUREMENTS)

Sources	D. F.	S. S.	M. S.	V. Ratio	Significance
Students	5	.60	.12	4.06	5% 2.71 1% x 4.10
Treatments	1	59.50	59.50	2016.94	5% 3.96 1% xxx 6.96
Landmarks	4	140921.02	35230.25	1194245.75	5% 2.48 1% xxx 3.56
Patients	1	834.77	834.77	27958.30	5% 3.96 1% xxx 6.96
S x T	5	.13	.026		N. S.
S x L	20	.80	.040		N. S.
S x P	5	.17	.034		N. S.
T x L	4	370.28	92.57	3137.96	5% 2.48 1% xxx 3.56
T x P	1	19.12	19.12	648.13	5% 3.96 1% xxx 6.96
L x P	4	382.02	95.50	3237.28	5% 2.48 1% xxx 3.56
S x T x L	20	.70	.035		N. S.
S x T x P	5	.08	.016		N. S.
T x L x P	4	45.56	11.39	386.10	5% 2.48 1% xxx 3.56
S x L x P	20	.47	.024		N. S.
SxTxLxP	20	.46	.023		
Total	119	142635.68			

Standard Deviation of Error = ± 0.172 mm. and the 99%

Confidence Limits Are = (2.63 x 0.172) = ± 0.4523 mm.

XXX = Highly Significant Variance Ratio

N. S. = Non-Significant Variance Ratio

TABLE VI

ANALYSIS OF VARIANCE

(VERTICAL MEASUREMENTS)

Sources	D. F.	S. S.	M. S.	V. Ratio	Significance
Students	5	1.26	.252	7.28	5% 2.71 1% xx 4.10
Treatments	1	241.12	241.12	6968.78	5% 3.96 1% xxx 6.96
Landmarks	4	116171.05	29042.76	839386.12	5% 2.48 1% xxx 3.56
Patients	1	218.97	218.97	6326.58	5% 3.96 1% xxx 6.96
S x T	5	.05	.010		N. S.
S x L	20	1.12	.056		N. S.
S x P	5	.13	.026		N. S.
T x L	4	98.89	24.72	717.45	5% 2.48 1% xxx 3.56
T x P	1	45.51	45.51	1315.31	5% 3.96 1% xxx 6.96
L x P	4	310.15	77.54	2241.04	5% 2.48 1% xxx 3.56
S x T x L	20	.58	.029		N. S.
S x T x P	5	.06	.012		N. S.
T x L x P	4	26.36	6.59	190.46	5% 2.48 1% xxx 3.56
S x L x P	20	.35	.018		N. S.
SxTxLxP	20	1.00	.05		
Total	119	117116.60			

Standard Deviation of Error = ± 0.186 mm. and the 99%

Confidence Limits Are = (2.63 x 0.186) = ± 0.490 mm.

XXX = Highly Significant Variance Ratio

N. S. = Non-Significant Variance Ratio

error of measurement or the standard deviation of the distribution of errors was ± 0.172 mm. based on 95 degrees of freedom. The 99% confidence limits become ± 0.4523 mm. or nearly 1/2 mm.

Table VI shows the results of analyzing the whole set of vertical measurements, and again there was a statistically significant amount of variation in the measurements due to the "students". The "treatments," "landmarks," and "patients" were expected to contribute most of the variation but they were necessary in the design of the experiment to provide all of the opportunities for making measurements. The seven interactions containing "students" as one factor were not large enough to be significant either practically or statistically and hence they provided a valid estimate of the experimental error from 95 degrees of freedom. The standard deviation of the distribution of errors was ± 0.186 mm. and the 99% confidence limits were ± 0.490 mm. or just about 1/2 mm.

There was no statistically significant difference between the two estimates of error variance and therefore, the two sets of measurements were alike as far as their precision was concerned. The vernier caliper was read to the nearest tenth of a millimeter which was about one-fifth of the confidence limit. This is an acceptable ratio. The caliper was accurate to closer than one mil which is about one-twentieth of the confidence limit. This means that the accuracy of any reading is determined by the precision of the measuring process and not by the calibration of the instrument.

I. Mandibular Changes Selected for Study

Eight changes were selected for study: four in mandibular morphology, and four in the positions of associated dental structures. Each required a series of mathematical computations which were calculated using mathematical tables and a slide rule. Data sheets for each change were designed so all calculations could be recorded in tabular form. Since there were variations in the method of calculating each change, they will be listed individually and a sample calculation demonstrated. Table IV shows a sample data sheet and contains the figures from which the sample calculations were derived.

1. Change in the position of Gonion. (For this and succeeding computations, "I" indicates the beginning headplate and "II" the finish headplate. All measurements are in millimeters.)

	I		II	
	X	Y	X	Y
Gonion	-12.4	-69.9	-13.8	-70.0

$$Y_{II} - Y_I = -70.0-(69.9) = -0.1$$

$$X_{II} - X_I = -13.8-(12.4) = -1.4$$

$$\arctan\left(\frac{-0.1}{-1.4}\right) = \arctan\ (0.7143) = 4.1^{\circ}$$

In a coordinate system all angles are measured from a common reference line. This locates the angle in a particular quadrant.

$$\measuredangle = 180^\circ + 4.1^\circ = 184.1^\circ$$

This tells us that Gonion moved along a path directed at 184.1°. To find the distance Gonion moved, the trigonemetric Cosine function is used.

$$\text{Cos } 4.1^\circ = 0.99744$$

$$\text{Cos} = \frac{\text{adjacent}}{\text{hypotenuse}} \quad \text{or} \quad \text{Hypotenuse} = \frac{\text{adjacent}}{\text{Cos}}$$

$$\text{Hypotenuse} = \frac{-1.4}{0.99744} = -1.4+$$

Therefore Gonion moved posteriorly a distance of 1.4 millimeters along a path located at 184.1°.

2. Change in the height of the ascending ramus.

	I		II	
	X	Y	X	Y
Gonion	-12.4	-69.9	-13.8	-70.0
Articulare	-13.2	-24.5	-13.8	-23.7

$$\text{Height I} = Yg - Ya = -69.9-(-24.5) = -45.4$$

$$\text{Height II} = Yg - Ya = -70.0-(-23.7) = -46.3$$

$$\text{II-I} = -46.3-(-45.4) = -0.9$$

Therefore, the height of the ascending ramus increased 0.9 millimeters during treatment. Since Gonion and Articulare were on or close to the same vertical axis, a direct subtraction was possible to determine the change in height. If they had not been close to the same vertical axis, the actual change in height would be calculated trigonometrically. The angularity of Gonion and Articulare was ignored if the following relationship was true:

$$|Xa - Xg| < .03 \quad |Ya - Yg|$$

3. <u>Change in the alveolar height of $\overline{6}$: apex $\overline{6}$ to Go-Gn line</u>

This calculation required the writing of two equations and the solving of the resulting equations simultaneously.

	I		II	
	X	Y	X	Y
Gonion	-12.4	-69.9	-13.8	-70.0
Gnathion	45.5	-107.6	45.0	-110.4
Root $\overline{6}$	22.5	-86.5	25.1	-88.5

I $$(Y - Ygo) = \frac{Ygn - Ygo}{Xgn - Xgo} (X - Xgo)$$

$$(y + 69.9) = \frac{-107.6 + 69.9}{45.5 + 12.4} (X + 12.4)$$

$$Y + 69.9 = \frac{-37.7}{57.9} (X + 12.4) = -.6511X - 8.0736$$

(a) $$Y = -.6511X - 77.97$$

$$-\left(\frac{1}{-.6511}\right) = 1.5359 = m$$ (negative reciprocal of slope)

$$(Y-Yr) = m(X-Xr)$$

$$(Y+86.5) = 1.5359(X-22.5)$$

$$(Y+86.5) = 1.5359X-34.558$$

(b) $$Y = 1.5359X-121.058$$

Equating (a) and (b) gives

$$-.6511X-77.97 = 1.536X-121.06$$

$$43.09 = 2.187X$$

$$19.70 = X$$

$$\arctan 1.536 = 56.9^{\circ} \qquad \cos 56.9^{\circ} = .54561$$

$$\frac{22.5-19.7}{.54561} = \frac{2.8}{.54561} = 5.14$$

Therefore, alveolar height of the mandibular first molar before treatment was 5.14 millimeters.

II

$$(Y+70.0) = \frac{-110.4+70.0}{45.0+13.8} (X+13.8)$$

$$Y+70.0 = \frac{-40.4}{58.8} (X+13.8) = -.68706X-9.4814$$

(a) $$Y = -.68706X-79.4814$$

$$-\left(\frac{1}{-.68706}\right) = 1.45548 = m$$

$$Y+88.5 = 1.45548(X-25.1) = 1.45548X-36.53$$

(b) $$Y = 1.4555X-125.03$$

Equating (a) and (b) gives

$$-.68706X-79.4814 = 1.4555X-125.03$$

$$45.549 = 2.1426X$$

$$21.259 = X$$

$$\arctan 1.45548 = 55.5^{\circ} \quad \cos 55.5^{\circ} = .56617$$

$$\frac{25.1-21.26}{.56617} = \frac{3.84}{.56617} = 6.78$$

Therefore, alveolar height of the mandibular first molar after treatment was 6.78 millimeters.

$$6.78-5.14 = 1.68 \text{ millimeters}$$

Alveolar height of the mandibular first molar has increased 1.68 millimeters during treatment.

4. Change in the angle of the occlusal plane.

	I X	I Y	II X	II Y
Incision Inferius	57.9	-70.9	56.5	-74.5
Crown $\overline{6}$	26.0	-63.1	29.6	-65.2

I

$$Y_6 - Y_1 = -63.1 - (-70.9) = 7.8$$

$$X_6 - X_1 = 26.0 - 57.9 = -31.9$$

$$\arctan\left(\frac{7.8}{-31.9}\right) = \arctan(-0.244514) = -13.7^\circ$$

II

$$Y_6 - Y_1 = -65.2 - (-74.5) = 9.3$$

$$X_6 - X_1 = 29.6 - 56.5 = -26.9$$

$$\arctan\left(\frac{9.3}{-26.9}\right) = \arctan(-0.345725) = -19.1^\circ$$

$$\text{II} - \text{I} = -19.1 - (-13.7) = -5.4^\circ$$

This angle is measured from the horizontal and indicates that the occlusal plane angle increased 5.4 degrees during treatment.

5. Change in the width of the symphysis.

	I X	I Y	II X	II Y
Supramentale(B)	49.5	-88.4	49.0	-89.2
Posterior Symphysis	37.9	-88.4	38.8	-89.2

I   Xb-Xps = 49.5 - 37.9 = 11.6

II   Xb-Xps = 49.0 - 38.8 = 10.2

II - I = 10.2 - 11.6 = -1.4

This indicates that the width of the symphysis at the level of Supramentale (B) decreased 1.4 millimeters during treatment.

6. Change in the height of the symphysis.

	I X	I Y	II X	II Y
Root Apex $\overline{I}$	42.0	-89.5	40.3	-92.8
Menton	37.4	-105.8	37.0	-107.8

I   Xr-Xm = 42.0-37.4 = 4.6

$\Delta^2 = (4.6)^2 = 21.16$

Yr-Ym = -89.5-(-105.8) = 16.3

$\Delta^2 = (16.3)^2 = 265.69$

$\Delta^2 + \Delta^2 = 21.16 + 265.69 = 286.85$

$\sqrt{\Delta^2 + \Delta^2} = 286.85 = 16.935$

II $Xr-Xm = 40.3-37.0 = 3.3$

$\Delta^2 = (3.3)^2 = 10.89$

$Yr-Ym = -92.8-(-107.8) = 15.0$

$\Delta^2 = (15.0)^2 = 225.00$

$\Delta^2 + \Delta^2 = 10.89 + 225.00 = 235.89$

$\sqrt{\Delta^2 + \Delta^2} = 235.89 = 15.359$

II - I = 15.359 - 16.935 = -1.576

Therefore, there was a decrease in the height of the symphysis (alveolar height) of 1.576 millimeters.

7. Location of the axis of tipping of $\overline{1}$.

	I X	I Y	II X	II Y
Incision Inferius	57.9	-70.9	56.5	-74.5
Root Apex $\overline{1}$	42.0	-89.5	40.3	-92.8

This computation required the writing of two equations and the solving of the resulting two simultaneous equations.

I $(Y-Yc) = \frac{Yr-Yc}{Xr-Xc} (X-Xc)$

$(Y+70.9) = \frac{-89.5+70.9}{42.0-57.9} (X-57.9)$

$Y+70.9 = \frac{-18.6}{-15.9} (X-57.9) = 1.1698X-67.73$

(a) $Y = 1.1698X-138.63$

II $$Y+74.5 = \frac{-92.8+74.5}{40.3-56.5}(X-56.5) = \frac{-18.3}{-16.2}(X-56.5)$$

$$Y+74.5 = 112.96X-63.8224$$

(b) $$Y = 1.296X-138.3224$$

Equating (a) and (b) gives

$$1.1698X-138.63 = 1.1296X-138.32$$

$$.0402X = .31$$

$$X = 7.711 \text{ millimeters}$$

$$Y = 1.1698(7.711)-138.63$$

$$Y = 9.0203-138.63 = -129.61 \text{ millimeters}$$

This point is far down near the vertical axis. It indicates that the tooth tipped very little, but experienced mostly translation.

8. <u>Relation of the central axis of the lower central incisor to the anteroposterior width of the symphysis.</u>

	I		II	
	X	Y	X	Y
Supramentale(B)	49.5	-88.4	49.0	-89.2
Posterior Symphysis	37.9	-88.4	38.8	-89.2

This calculation required the use of the two equations obtained in the previous computation (#7).

I. $Y = 1.1698X - 138.63$ (from #7-I)

$-88.4 = 1.1698X - 138.63$

$50.23 = 1.1698X$

$42.94 = X$

$37.90 = PS$

$X - PS = 42.94 - 37.90 = 5.04$ millimeters

This intersection is at a point 5.04 millimeters anterior to Posterior Symphysis.

II. $Y = 1.1296X - 138.32$

$-89.2 = 1.1296X - 138.32$

$49.12 = 1.1296X$

$43.48 = X$

$38.80 = PS$

$X - PS = 43.48 - 38.80 = 4.68$ millimeters

This intersection is at a point 4.68 millimeters anterior to Posterior Symphysis.

$II - I = 4.68 - 5.04 = -0.36$ millimeters

Therefore, the central axis of the lower central incisor moved posteriorly 0.36 millimeters during treatment.

CHAPTER IV

FINDINGS

Changes in mandibular morphology and in the positions of associated dental structures will be presented with the aid of line graphs. The graphic method of reporting the findings of this study was included because it provided a manner of presenting statistical data in visual form. The results of all pertinent calculations for each change were plotted as histograms or rectangular frequency polygons. These represented frequency distributions.[1] After plotting the findings for each change, the resulting distributions were evaluated. If the distribution was found to be symmetrical and tapered to each end, the measurements were analyzed statistically to find the average (mean) and the degree of dispersion about the mean (standard deviation). For those changes that did not yield a tapering distribution, the calculation of the mean and standard deviation was omitted since these statistical measures could be misinterpreted in such cases. The statistical measures used in this study are defined as follows:

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[1]A frequency distribution is a graph showing the frequency of occurrence of an observation plotted against the magnitude of the observation.

TABLE VII

MEANS, STANDARD DEVIATIONS, AND t-RATIOS

Change	Mean	Standard Deviation	N	Standard Error	t Ratio	Significance
Gonion (mm.)	3.81	2.03	26	0.40	9.52	*
Gonion (degs.)	244.1	32.8	26	6.43	37.9	*
Ascending Ramus	2.00	1.96	25	0.39	5.13	*
Alveolar Height $\overline{6}$ to Go-Gn	3.12	1.50	23	0.31	10.0	*
Width of Symphysis	-1.25	1.73	26	0.34	3.67	*
Angle of Occlusal Plane	-2.24	2.94	26	0.57	3.93	*
Height of Symphysis	-0.48	1.79	25	0.36	1.33	
Axis of Tipping of $\overline{1}$. (Vertical)	-84.64	12.19	23	2.54	33.3	*
Axis of Tipping of $\overline{1}$. (Horizontal)	52.47	10.42	23	2.17	24.1	*
Central Axis of $\overline{1}$ to A-P Width of Symphysis	0.32	1.52	25	0.34	0.94	

* Significant at .05 level.

1. Mean - the arithmetic average. Designated by $\overline{X}$.
2. Standard Deviation - an index of how the measurements are "scattered" or "dispersed" about the mean. Designated by σ.
3. Sample Size - the number of measurements included in a given distribution. Designated by N.

Six of the histograms contain measurements from all 26 patients. The sample size of the remaining four distributions was reduced slightly by omitting extreme values. All values were tested for significance by applying principles of Student's t-distribution. The results are shown in Table VII.

CHANGES IN MANDIBULAR MORPHOLOGY AND IN ASSOCIATED DENTAL STRUCTURES.

1. Change in the Location of Gonion.

The change in the location of Gonion was assessed both lineally and angularly. Figure 7 shows that Gonion moved within a range of 1.0 mm. to 8.2 mm. Since the change in the location of Gonion is a vector quantity and has both magnitude and direction, the linear quantities must be associated with angular measurements. This is indicated by Figure 8 which reveals that Gonion moved within a range of 180 degrees to 300 degrees from the plane of reference.[2]

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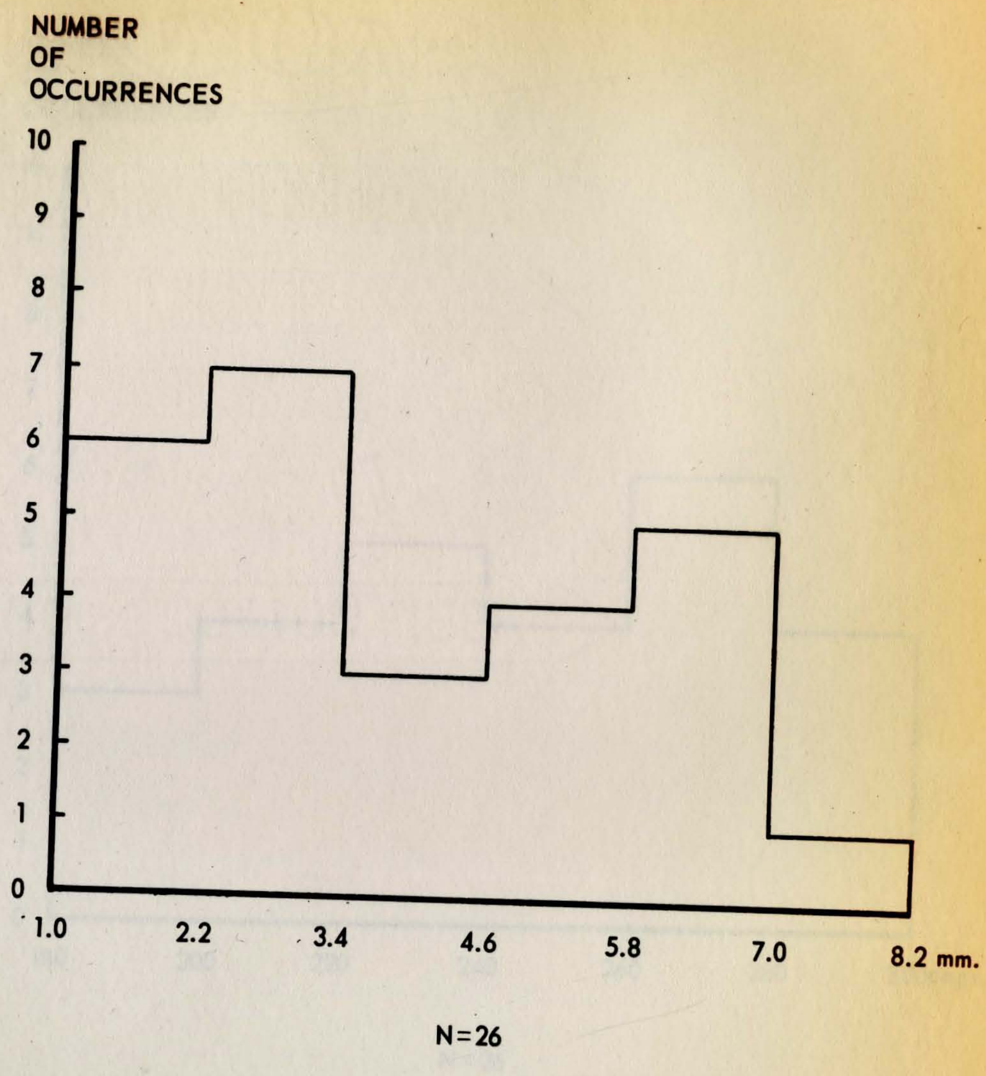
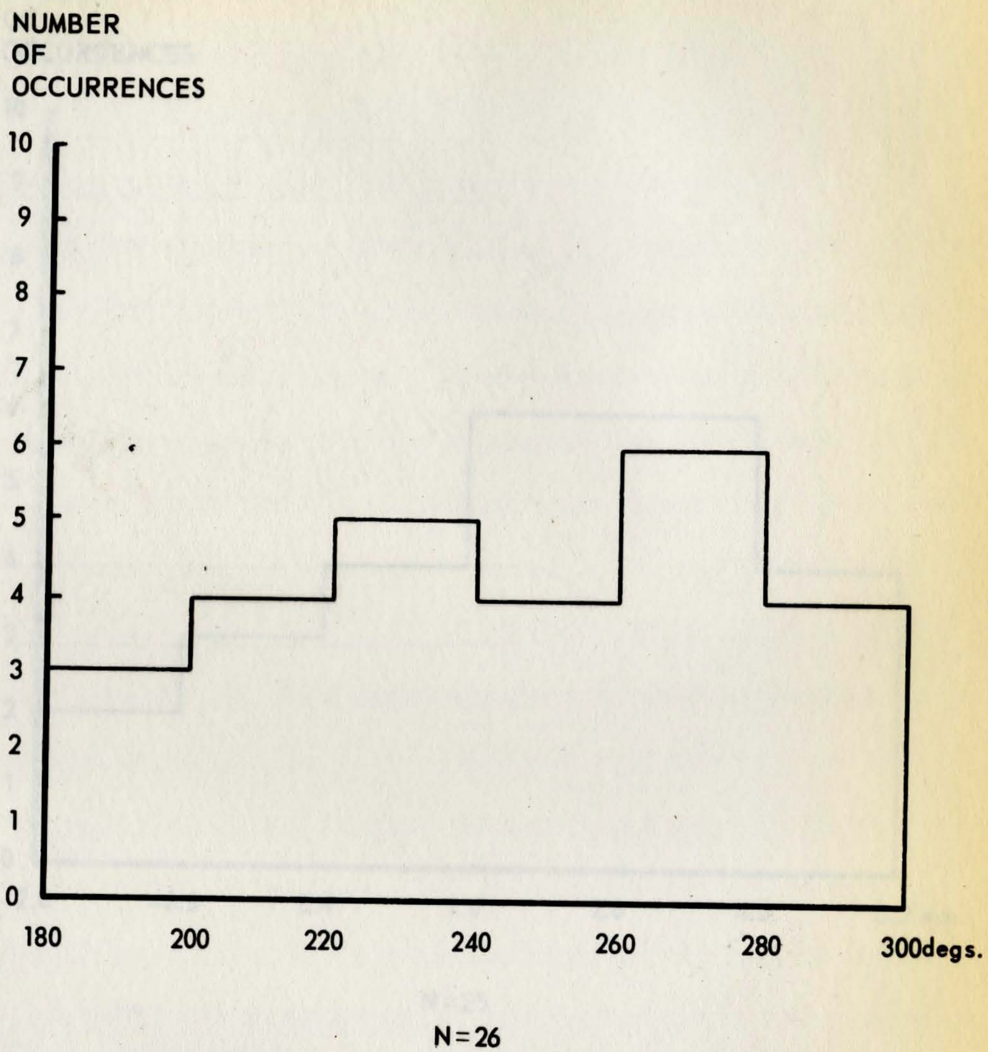
[2] In a coordinate system, angles are usually read in a counter-clockwise direction starting from the horizontal reference axis to the right of point O, or in this study, Sella.



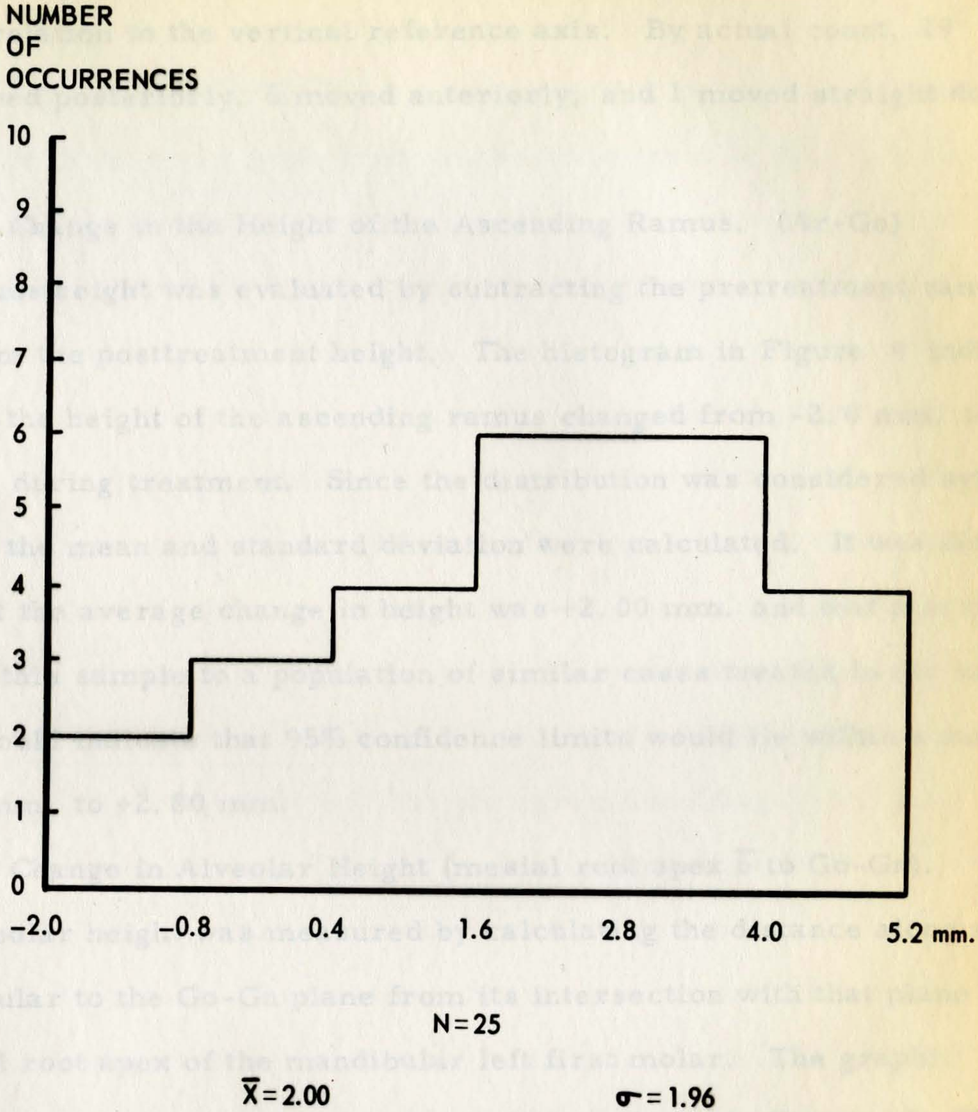
CHANGE IN THE LOCATION OF GONION

FIGURE 7



CHANGE IN THE LOCATION OF GONION

FIGURE 8



CHANGE IN HEIGHT OF THE ASCENDING RAMUS

FIGURE 9

It is interesting to observe that Gonion moved either posteriorly or anteriorly in relation to the vertical reference axis. By actual count, 19 cases moved posteriorly, 6 moved anteriorly, and 1 moved straight downward.

2. Change in the Height of the Ascending Ramus. (Ar-Go)

Ramus height was evaluated by subtracting the pretreatment ramus height from the posttreatment height. The histogram in Figure 9 indicates that the height of the ascending ramus changed from -2.0 mm. to +5.2 mm. during treatment. Since the distribution was considered symmetrical, the mean and standard deviation were calculated. It was determined that the average change in height was +2.00 mm. and that a projection from this sample to a population of similar cases treated in the same manner would indicate that 95% confidence limits would lie within a range of +1.20 mm. to +2.80 mm.

3. Change in Alveolar Height (mesial root apex $\overline{6}$ to Go-Gn).

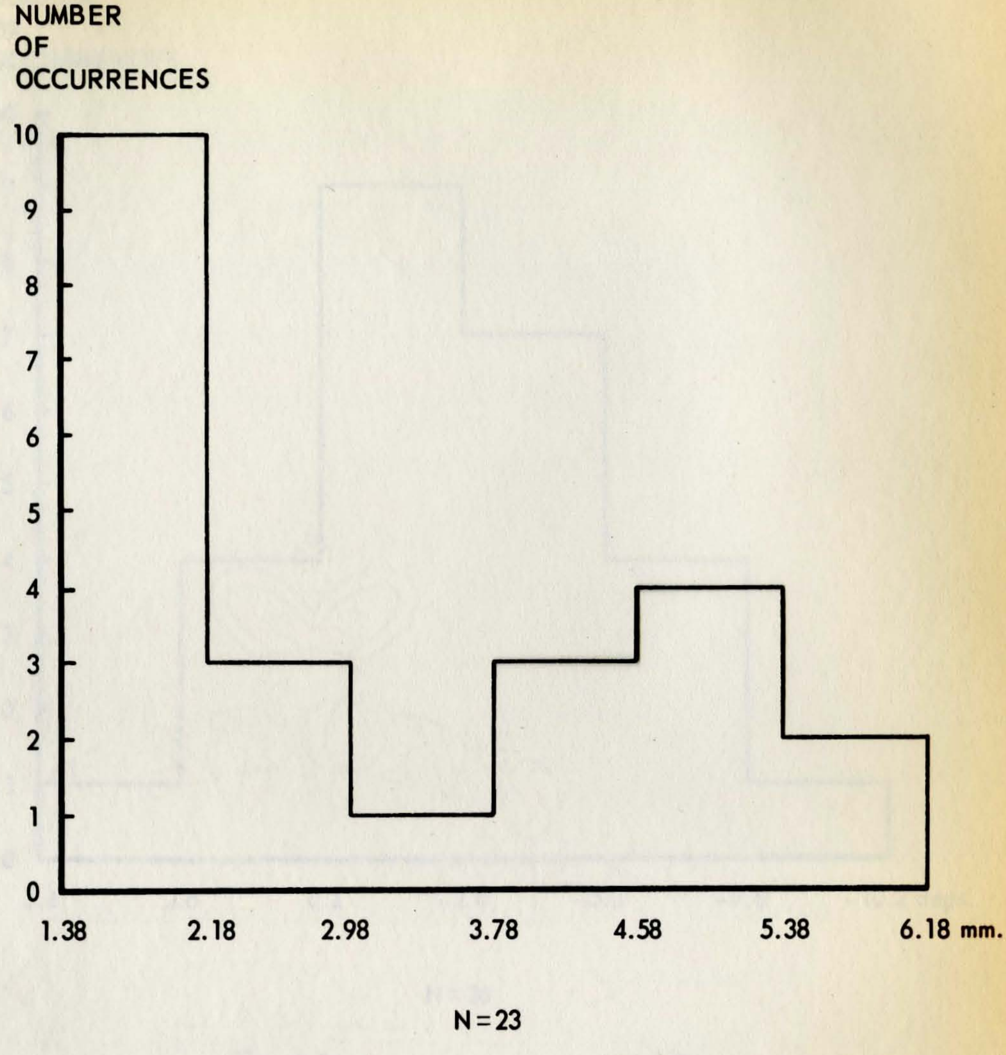
Alveolar height was measured by calculating the distance along a perpendicular to the Go-Gn plane from its intersection with that plane to the mesial root apex of the mandibular left first molar. The graphic presentation of the actual changes in height are shown in Figure 10. Three cases of extreme values were omitted from the histogram. The change in alveolar height ranged from +1.38 mm. to +6.18 mm. Due to the unsymmetric grouping, the calculation of an average and an index of dispersion were omitted.

4. Change in the Angle of the Occlusal Plane.

The angle of the occlusal plane was computed by subtracting the pretreatment occlusal plane angle from the posttreatment angle. In calculating these changes, a departure was made from the customary method of reading angles in the coordinate system as described in footnote 2. These angles were read from the same origin (the horizontal axis of reference to the right of Sella) in a clockwise direction and given negative values. The change in angularity obtained by subtracting the pretreatment from the posttreatment angle, required the maintaining of the correct polarity. A negative angular difference indicated that the occlusal plane moved away from the horizontal axis of reference (Sella-Nasion) while a positive angle indicated that the occlusal plane moved to a position more nearly parallel to Sella-Nasion. The histogram resulting from these calculations may be seen in Figure 11. It was found that the change in the occlusal plane angle for all 26 cases was within a range of +5.4 degrees to -10.2 degrees. The average change was calculated to be -2.24 degrees and a projection of the sample to a similar population would suggest that 95% of the cases in a similar population would present a change in the occlusal plane angle from -1.05 degrees to -3.43 degrees.

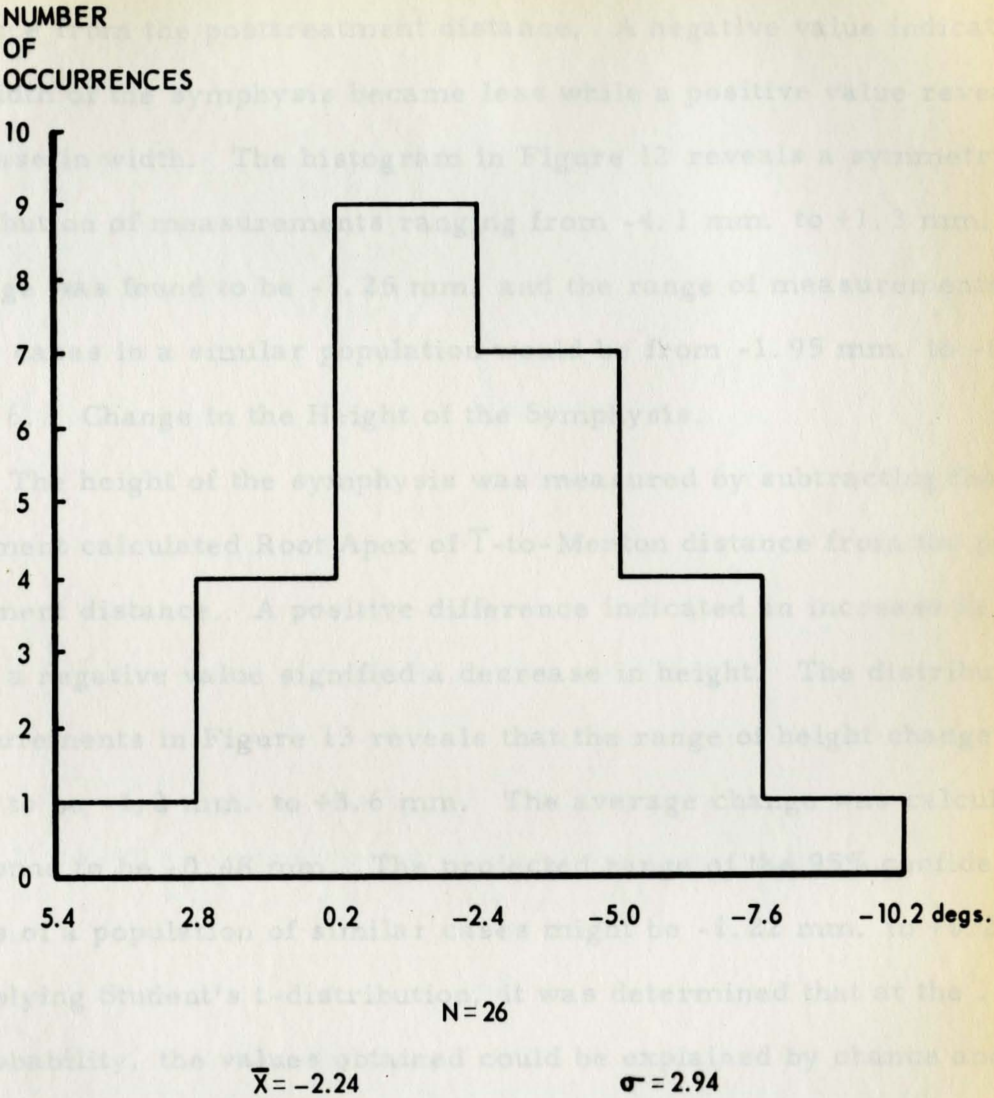
5. Change in the Width of the Symphysis.

The change in the width of the symphysis was calculated by sub-



CHANGE IN ALVEOLAR HEIGHT
(MESIAL ROOT APEX $\overline{6}$ TO Go-Gn)

FIGURE 10



CHANGE IN THE ANGLE OF THE OCCLUSAL PLANE

FIGURE 11

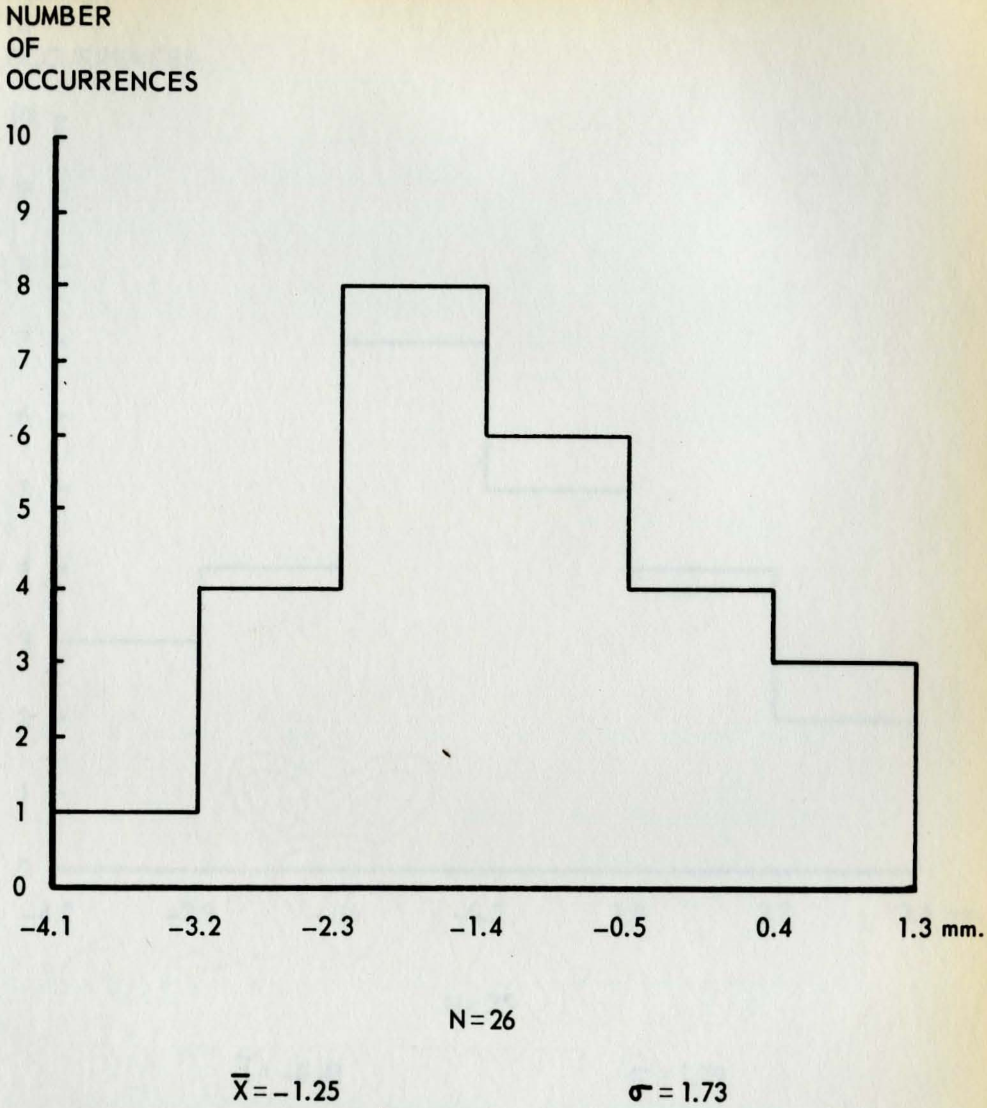
tracting the pretreatment horizontal Supramentale-to-Posterior Symphysis distance from the posttreatment distance. A negative value indicated that the width of the symphysis became less while a positive value revealed an increase in width. The histogram in Figure 12 reveals a symmetrical distribution of measurements ranging from -4.1 mm. to +1.3 mm. The average was found to be -1.25 mm. and the range of measurements in 95% of the cases in a similar population would be from -1.95 mm. to -0.55 mm.

6. Change in the Height of the Symphysis.

The height of the symphysis was measured by subtracting the pretreatment calculated Root Apex of $\overline{1}$-to-Menton distance from the posttreatment distance. A positive difference indicated an increase in height while a negative value signified a decrease in height. The distribution of measurements in Figure 13 reveals that the range of height change was found to be -4.2 mm. to +3.6 mm. The average change was calculated and found to be -0.48 mm. The projected range of the 95% confidence limits of a population of similar cases might be -1.22 mm. to +0.26 mm. In applying Student's t-distribution, it was determined that at the .05 level of probability, the values obtained could be explained by chance and, hence, could not be established as real changes.

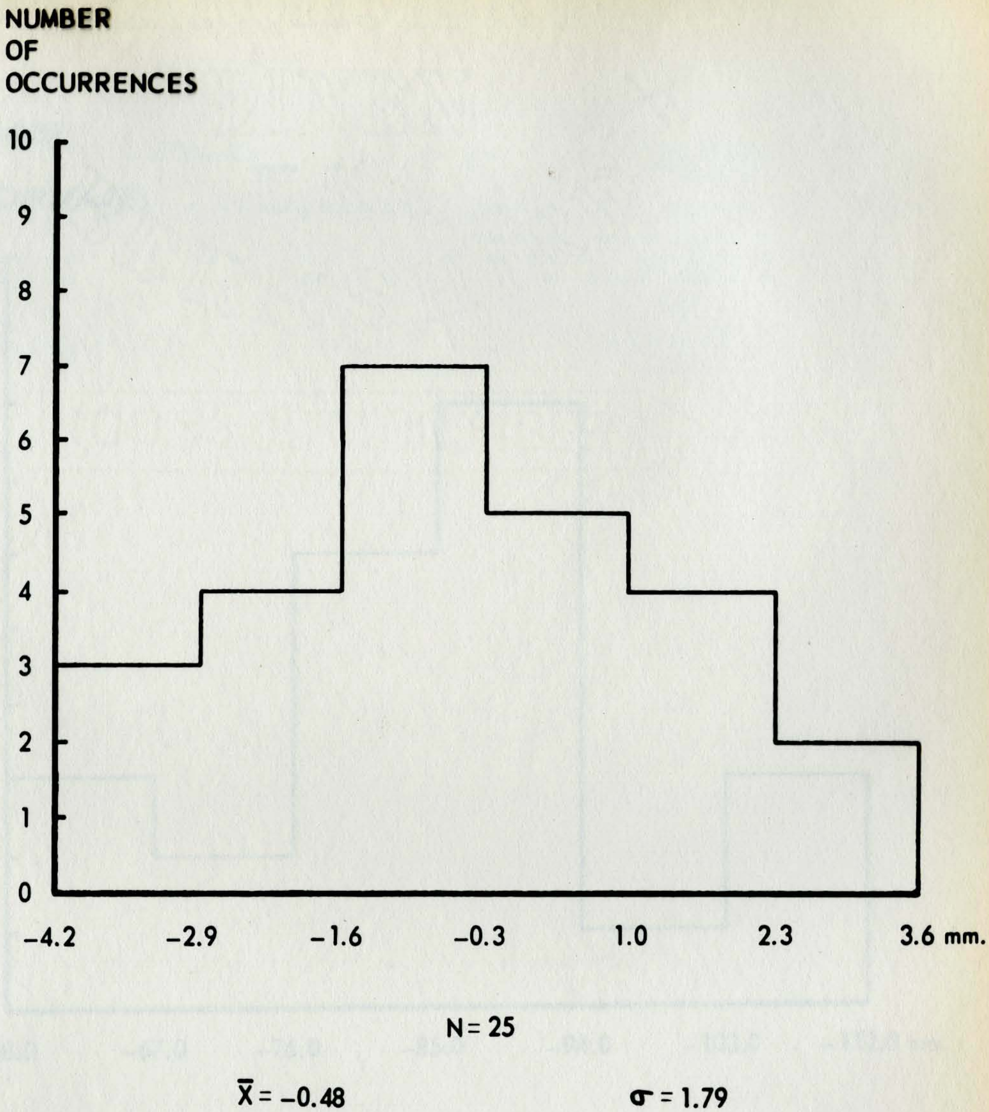
7. Location of the Axis of Tipping $\overline{1}$.

The axis of tipping of $\overline{1}$ was calculated by determining where the central axis of $\overline{1}$ in its pretreatment position intersected with the central



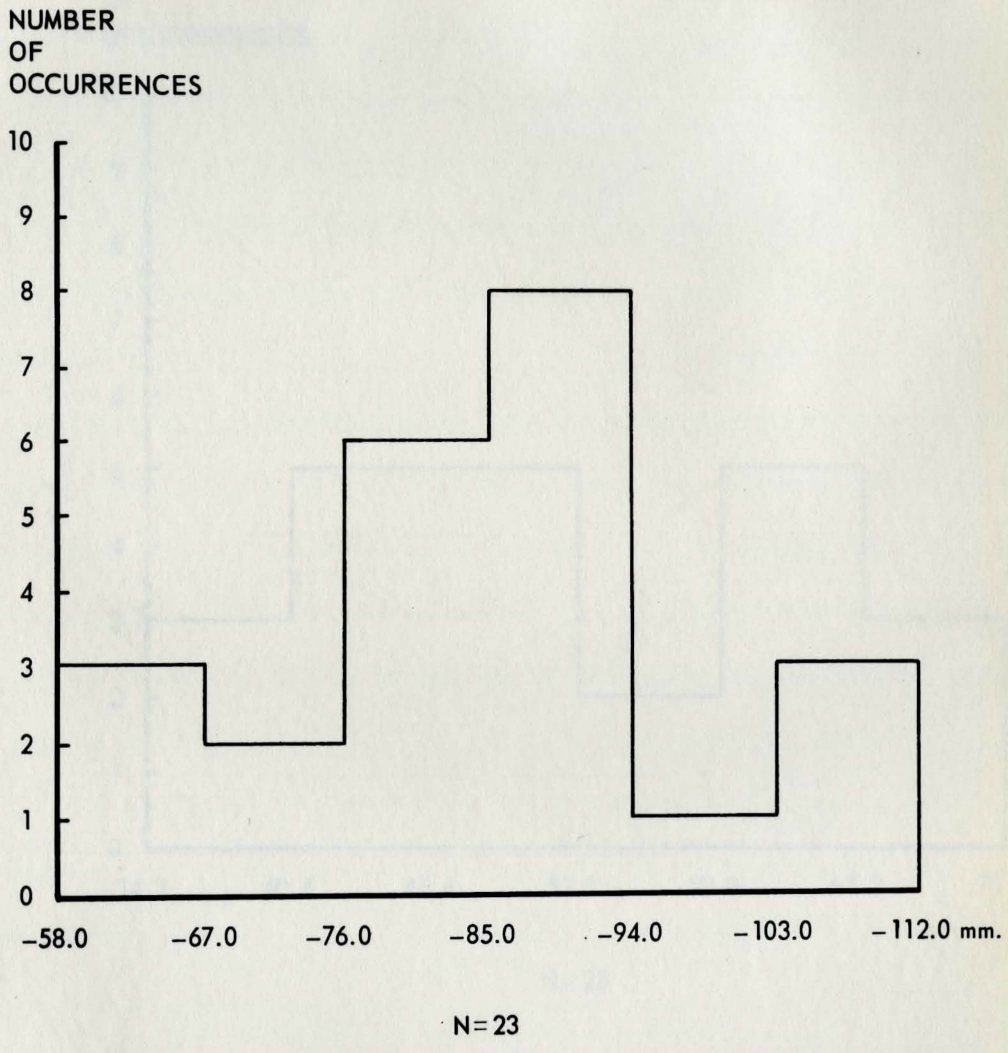
CHANGE IN THE WIDTH OF THE SYMPHYSIS

FIGURE 12



CHANGE IN THE HEIGHT OF THE SYMPHYSIS
(ROOT APEX $\bar{1}$ TO MENTON)

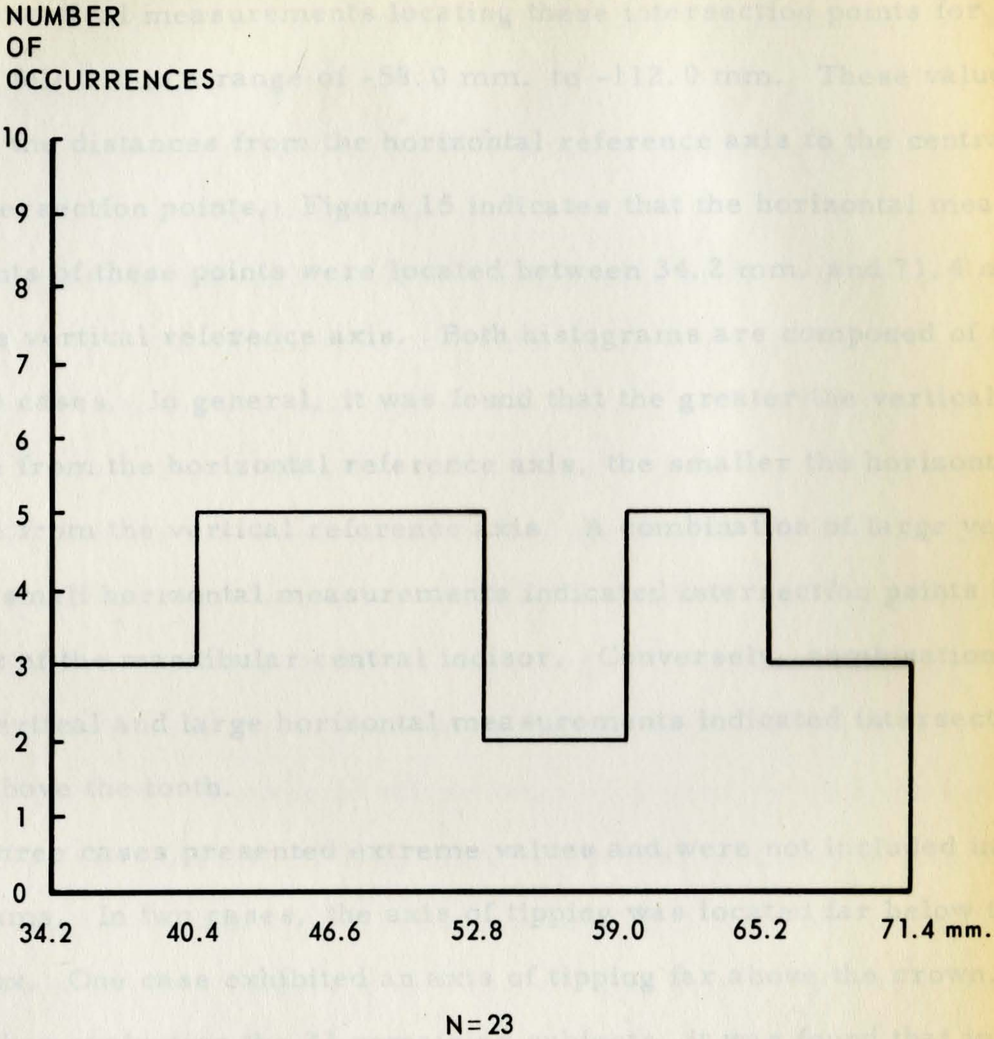
FIGURE 13



LOCATION OF THE AXIS OF TIPPING OF $\bar{1}$

(VERTICAL MEASUREMENTS)

FIGURE 14



LOCATION OF THE AXIS OF TIPPING OF 1̄

(HORIZONTAL MEASUREMENTS)

FIGURE 15

axis in its posttreatment position. The histogram in Figure 14 reveals that the vertical measurements locating these intersection points for 23 patients fell within a range of -58.0 mm. to -112.0 mm. These values indicate the distances from the horizontal reference axis to the central axes intersection points. Figure 15 indicates that the horizontal measurements of these points were located between 34.2 mm. and 71.4 mm. from the vertical reference axis. Both histograms are composed of the same 23 cases. In general, it was found that the greater the vertical distance from the horizontal reference axis, the smaller the horizontal distance from the vertical reference axis. A combination of large vertical and small horizontal measurements indicated intersection points below the apex of the mandibular central incisor. Conversely, combinations of small vertical and large horizontal measurements indicated intersection points above the tooth.

Three cases presented extreme values and were not included in the histograms. In two cases, the axis of tipping was located far below the root apex. One case exhibited an axis of tipping far above the crown.

When evaluating the 23 remaining subjects, it was found that in 16 cases the axis of tipping was located within the tooth itself. The location of the axes of these 16 cases was as follows: 9 were located in the coronal one-third of the tooth, 6 were located in the middle one-third of the tooth, and 1 was located in the apical one-third of the tooth. Of the remaining

7 cases, the axis of tipping was located above the crown in 4, and below the apex in the remaining 3. Table VIII indicates the location of the axes of tipping of $\overline{1}$ in the sample subjects.

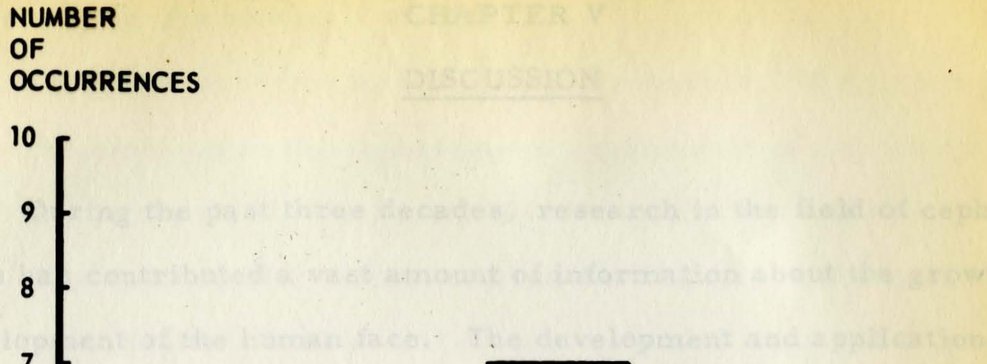
8. Relation of Central Axis of $\overline{1}$ to the Anteroposterior Width (PS-B) of the Symphysis.

The point of intersection of the central axis of the mandibular central incisor with the anteroposterior width of the symphysis (PS-B) was calculated to determine if the apex of the central incisor had moved posteriorly or anteriorly in relation to the symphysis during orthodontic treatment. A negative value indicated that the central axis moved closer to the lingual cortical plate of the symphysis, while a positive value indicated that the central axis moved in an anterior direction. The calculated changes in position of the central axis along the width of the symphysis are seen in Figure 16. A range of values from -3.0 mm. to +4.6 mm. was found. The distribution was considered to be symmetrical and was subjected to statistical analysis. The mean was found to be +0.32 mm. and the projected range of values in 95% of a similar population would fall within -0.30 mm. and +0.94 mm. At the .05 level of probability, chance could account for the changes in the relation of the central axis of the lower incisor to the anteroposterior width of the symphysis.

TABLE VIII

LOCATION OF THE AXIS OF TIPPING OF $\overline{1}$

LOCATION	NUMBER OF OCCURRENCES
Above Tooth	5
Coronal One-third	9
Middle One-third	6
Apical One-third	1
Below Tooth	5
TOTAL	26



N = 25

$\bar{X} = 0.32$ $\sigma = 1.52$

RELATION OF THE CENTRAL AXIS OF $\bar{1}$ TO THE ANTEROPOSTERIOR WIDTH (PS-B) OF THE SYMPHYSIS

FIGURE 16

CHAPTER V

DISCUSSION

During the past three decades, research in the field of cephalometrics has contributed a vast amount of information about the growth and development of the human face. The development and application of cephalometry has provided not only those associated with research, but also the clinical orthodontist with data on normal and abnormal facial growth, general facial and skeletal types, the dynamics of function, and case analysis and treatment planning. Most of this information has been obtained by using angular measurements to assess spatial relationships. Methods of assessment incorporating linear measurements (Wylie, 1947, and Björk, 1947) have been proposed; but, for one reason or another, have never become popular with the everyday practitioner. Most current cephalometric discussions are centered around the more popular angular methods, proposed by Downs (1948), Tweed (1946, 1953, 1954), and Steiner (1953), for evaluating skeletal and dental disharmonies. Discussing linear relationships with orthodontists is much like speaking in a foreign language--most orthodontists today can only understand the angular "language." In spite of this lack of interest in linear relationships, methods employing these types of measurements when coupled with a rectangular coordinate system do provide a unique versatility not found in the angular evaluations.

The purpose of this investigation was twofold. The first was to devise and demonstrate the cephalometric application of a system of rectangular coordinates. The second was to test the versatility of this method by applying it to an appraisal of the changes in mandibular morphology and in associated dental structures which occurred after the orthodontic treatment of 26 Class I premolar extraction malocclusions. Each of these two purposes will be discussed separately.

A system of rectangular coordinates is predicated on the fact that all points are referred to the intersection of a set of perpendicular axes. Since 1637, these axes have been popularly known as "Cartesian Coordinates" and have been applied to many mathematical and engineering situations. Their use makes possible the locating of any point in a coordinate system if the distances to each reference axis are known. Not only may points be located to the reference axes, but they may be functionally related to each other. One of the few investigators who applied a rectangular coordinate system to cephalometrics (Elsasser, 1957) used a geographical analogy to illustrate that two points on a lateral headplate may be related to each other by relating each to the same axes of reference. He said that if one would want to relate Chicago to New York, he could do so by relating both cities to Cleveland. This would be much less confusing than to relate New York to Cleveland, and Chicago to San Francisco. In this case, he still would not know where Chicago and New York were in relation to each other. While this simile is unrelated to cephalometrics, it clearly illustrates the value of a rectangular coordinate system.

Before commencing this study, it was decided to evaluate carefully the radiographic technique used in exposing the lateral head films of the 26 subjects. One of the primary faults that critics of linear analyses point to is that the method of measurement is highly susceptible to errors arising in the radiographic technique. In essence, they say that when a three-dimensional object (the head) is projected onto a two-dimensional plane (the film), the problems of magnification and distortion are more critical when assessed lineally than when evaluated angularly. Actually, these two factors are problems on all cephalograms, but it is the method in which the images are assessed that makes linear measurements more susceptible to errors due to magnification and distortion. Angular measurements, being a relationship between two lines, will not change in value due to a magnification or a reduction in image size since the spatial relation between these two lines is unaltered. Linear measurements, however, are highly susceptible to error introduced by an enlargement or a reduction of the image size. Error is also more apparent in linear dimensions when distortion due to a twisting of the head has occurred. With these points in mind, the selected films were carefully chosen from a sample of over fifty subjects. All cephalograms were taken on the same apparatus, by the same two individuals. In future studies of this type, precautions should be taken in maintaining a constant film-to-midsagittal plane distance and in preventing any distortion due to movement of the patient's head in the cephalostat. If adequate care is taken in reducing errors arising from these two sources, the results of investigations such as linear studies of normal or abnormal growth will have scientific merit.

A phonograph needle test probe, used to puncture the film and coordinate paper, was necessary in order to provide a uniformly small size of perforation. Any sharp, pointed instrument which produced a small pinhole could have been used. One advantage of the test probe was that the phonograph needles could be changed allowing their replacement as they became dull.

The use of the cellulose acetate sheet to "back up" the film and coordinate paper was successfully employed to prevent any damage to the surface of the tracing box. In addition, its use provided a more uniform size of perforation since the phonograph needle always penetrated the graph paper to the same depth.

It was essential in using the coordinate system that the measurements for each point be made perpendicular to the reference axes. The lined drawing paper was employed especially to provide an easy way of aligning the caliper beaks on the particular line which intersected the point and the reference axis. The use of unlined paper would have presented a problem in correctly orienting the beaks to the point and the axes from which the measurement was to be made. It must be emphasized that no measurements were read directly from the coordinate paper. This method of using the graph paper is not objectionable for crude measurements, but it did not provide sufficient accuracy for use in this investigation. Any type of coordinate paper could be used in a study of this type as it is only used for correctly aligning the vernier caliper. It is a definite advantage, however, to select a kind with small divisions in order to have numerous axes, one of which will almost certainly intersect the points to be measured.

A vernier caliper was used to provide an accuracy of measurement which could not have been obtained in any other manner. While its use may seem cumbersome to the casual observer, the accuracy with which measurements were read clearly demonstrated its value. Any type of caliper could have been used, but one reading to an accuracy of 0.1 mm. was sufficient to meet the requirement of this cephalometric study. Error introduced by other sources would obscure any increase in caliper accuracy.

The selection of landmarks was predicated on the ease and accuracy with which they were located and on their clinical interest. The particular purpose to which this method of assessment is to be applied will govern which landmarks are to be spotted. In general, midline structures were selected for use in this study. This eliminated the problem of determining the location of the midpoint between the two superimposed images. When non-midline structures were used, definite methods of point selection were exercised.

The two reference axes selected for use in this study were Sella-Nasion as the horizontal axis of reference (axis of abscissa) and a perpendicular to Sella-Nasion erected at Sella as the vertical axis of reference (axis of ordinates). As mentioned previously, Craig and Williams were the only two investigators to use coordinate systems with Sella as the focal point. Three investigators (Craig, Elsasser, and Kean) used the Frankfort Horizontal as the axis of abscissas. Williams selected Sella-Nasion as the horizontal axis of reference. Because of the inability to locate Porion and Orbitale with a high degree of accuracy, the Sella-Nasion plane was substituted in this study for Frankfort. It was believed, as Brodie stated in 1941, that Sella and Nasion could be located more easily at any age than could Porion and Orbitale. Some early investigators used the Frankfort plane as the cranial reference axis because they believed it to be more stable in position than other reference planes. Downs, however, in 1948, found that there was almost an identical degree of stability in the Sella-Nasion, Bolton and Frankfort planes. Since many cephalometricians used both Sella-Nasion and Frankfort the selection of a horizontal reference plane was dictated largely by its ease of location. In this respect, Sella-Nasion was the plane of choice.

The advantages of using linear measurements in association with a rectangular coordinate system are numerous. Probably the most obvious is its versatility. The casual observer will look at a perforated sheet of coordinate paper and fail to see the almost infinite number of measurements, both linear and angular, that could be derived from the spotted landmarks. Clinicians think only in terms of a few stereotyped angular measurements. With today's popular methods of analyses, the practitioner is unable to learn of spatial relationships other than those listed in that particular analysis. More than likely, the clinician looking at a sample graph sheet from this study would be surprised that the particular changes selected for investigation could have been obtained without using a protractor or millimeter rule. The findings provided by this study could only have been obtained with a high degree of accuracy through the application of mathematics. The mere mention of this word, much less trigonometry or analytic geometry, usually is enough to discourage most clinicians. The fact is that the principles of trigonometry and analytic geometry enable one to obtain almost any measurement he could desire from a spotted graph sheet.

The application of engineering and mathematical principles has caused a revolution in the field of biophysics and its application to orthodontics. By the same token, the principles of analytic geometry when applied to cephalometry, can provide information for the orthodontist in an accurate and concise manner. The complex mathematical calculations shown in Chapter III are nothing more than the application of simple trigonometry, algebra, and analytic geometry. All mathematical functions could be programmed in a computer. Then what might seem to be complex mathematics may be easily resolved by a series of punch cards containing useful information on selected landmarks. Angular changes can also be accurately assessed by employing rectangular coordinates. The protractor, commonly used for measuring angles, may be eliminated and angular changes may be calculated directly from the spotted graph paper without returning the graph sheet to the cephalogram. Hence the graph paper becomes a permanent record of the landmarks in a particular headplate and may be recalled for additional information without the need for locating and retracing the film.

In future studies the use and refinement of this method of assessment will provide a limitless amount of important data on skeletal and dental disharmonies as well as on all phases of orthodontic treatment.

Today with the impact of the computer being felt in nearly all phases of business and science, its application to orthodontics and more specifically cephalometrics is imminent. This linear method of assessment in association with "Cartesian Coordinates" will provide a workable instrument which can be programmed for use in a computer. With this a reality, it will be possible for investigators to process vast amounts of data on all types of malocclusion, treatment, and even case analysis. The types of application will be almost infinite and the amount of knowledge obtained may greatly increase the orthodontist's ability to provide the best service possible for his patients. In essence, the application of computer systems to cephalometry may have the same effect that the automobile had on mass transportation.

The second part of this discussion will deal with the changes which occurred during the orthodontic treatment of the sample subjects. Since this thesis was primarily a study of a method of linear analysis, no attempt will be made to discuss in detail the cephalometric ramifications of each investigated change. Rather, the findings will be discussed with the purpose of demonstrating how this method is applied to an evaluation of treatment changes.

A basic and most important factor in the evaluation of these changes must be mentioned before the individual changes are discussed. That is that there was no provision in this investigation for actually determining how much of each change was due to growth, and how much was due to the orthodontic treatment. There was no possible way to divorce these two factors from one another. While this, at first, may seem to be a factor which was overlooked in the design of this investigation, it was decided that the actual interest was in the resulting changes that occurred because of both growth and orthodontic therapy working simultaneously. The overall effect of both factors was of interest to the investigators. It was felt that there would be no practical advantage in separating growth from treatment changes since the orthodontist will also encounter a certain amount of growth occurring during the treatment of his patient. In most cases of the type assessed in this investigation, growth changes will aid his therapy and should be evaluated in his case analysis and treatment planning. In other words, the clinician cannot eliminate a consideration of growth changes when he is planning the particular type of treatment to be employed. It seemed to this investigator that a knowledge of the overall change occurring due to both growth and treatment would be of value in the correction of Class I premolar extraction malocclusions. If desired, future studies of growth in children of the same age and skeletal characteristics could be made using this linear method. This would then enable those changes due to growth to be separated from those changes resulting from the orthodontic treatment. Thus, the reader must keep in mind that growth has been an unknown factor in the findings of this investigation.

Before proceeding with a discussion of each change, a brief description of the treatment employed to correct these malocclusions will be presented. The treatment of a Class I premolar extraction malocclusion, as described by Jarabak and Fizzell (1963), consists of three objectives:

1. Simultaneous canine distal-driving
2. Space consolidation

3. Correct seating of inclined planes and establishment of a functional overbite - overjet relationship.

The first objective, that of distal-driving the canines into the premolar extraction sites, has two parts which are performed simultaneously:

1. Distal-drive the four canines into the extraction sites, and correct the axial deviations and rotations of the four anteriors in each arch.
2. Upright the mandibular molars to reduce the anterior overbite.

Force systems, both intrinsic and extrinsic, are used to accomplish all three objectives. The resulting effect is one in which the canines have been moved distally into the premolar extraction sites, the mandibular molars and Curve of Spee reduced to decrease the overbite, the four incisors in each arch retracted and any remaining spaces closed, and finally, the teeth aligned in their ideal functional relationships. Keeping this treatment plan in mind will aid in an understanding of the findings of this investigation. An enumeration of the evaluated changes follows.

1. Change in the Location of Gonion

As seen in the graph in Figure 7, Gonion moved within a range of +1.0 mm. to +8.2 mm. in the 26 cases. In order to determine the direction in which Gonion moved, it was necessary to calculate the angles shown in Figure 8. As explained in Chapter IV, Gonion moved posteriorly (away from the axis of ordinates) in 19 cases, and forward (toward the axis of ordinates) in 9 subjects. In one patient, Gonion moved vertically downward (parallel to the axis of ordinates).

It has been shown by Brodie (1941) and others that if the condyle were held in a fixed position, growth would move Gonion in an anterior and downward direction. When the growth of the mandible is assessed in relation to the posterior cranial base, to which it is articulated, the direction of growth moves Gonion in a downward and posterior direction. Since these two factors, in addition to appositional growth at the posterior border of the ramus, largely control the direction in which Gonion moves, one would expect to find that the landmark has moved in any of three directions - posteriorly, anteriorly, or vertically downward. Which of these three will prevail will depend on the magnitude of growth at each of the contributing growth sites.

Schudy (1965) observed that the rotation of the mandible involves primarily the vertical growth of the dentofacial complex. His paper, dealing essentially with the mandible, found that variation in growth at the condyles and at the molar area is responsible for the rotation of the mandible. Although he did not assess the change in position of Gonion, it can be surmised from his cephalometric drawings that even with unfavorable condylar growth and an overall vertical pattern of facial growth, Gonion moved in a downward or posterior direction.

Treatment would also be expected to alter the position of Gonion. As described earlier, the mandibular molars were uprighted to reduce the overbite usually found in Class I arch length discrepancy malocclusions. This molar uprighting would be expected to alter the position of Gonion. Since the mandible is a hinged structure attached to the cranium in the region of the posterior cranial base, an opening of the bite caused by the molar uprighting would cause the mandible to rotate in a clockwise direction (as viewed from the patient's right) and would be expected to move Gonion in a posterior direction. This fact was confirmed by the results seen in Figure 8. In general, Gonion moved along a path in a posterior or vertically downward direction. Some cases did, however, show that Gonion moved anteriorly, and it can only be speculated that either the overbite was not excessive and little correction was required, or that growth moved Gonion anteriorly offsetting the effect produced by the bite opening.

The actual distance that Gonion moved, seen in Figure 7, varied greatly. In one-half of the cases, Gonion appeared to have moved from +1.0 mm. to +3.4 mm. during the orthodontic therapy. Since these findings present no clear picture of the direction and distance in which Gonion moved, no definite conclusions may be reached as to how it would have moved in a similar population. The direction and distance that Gonion moved are the result of treatment and individual variations in growth.

2. Change in the Height of the Ascending Ramus.

Ramus height increased an average of +2.00 mm. during the time of orthodontic treatment. It was interesting to observe that the ramus height actually decreased in 5 cases. This fact was probably due to the presence of superimposed images necessitating the location of their mid-point as the selected point to be evaluated. Since Gonion is often selected as the midpoint of the two constructed points locating Gonion on both rami, its location is variable even in correctly oriented lateral headplates. The projection of the two rami on a correctly positioned film is dictated by the morphology of the mandible (one ramus being closer to the film than the other) and the projection of the roentgen rays and is unavoidable in many cases.

Ricketts in 1955 reported a study of facial and dental changes due to orthodontic treatment in Class II malocclusions. He found that the average increase in height of the ascending ramus was +4.5 mm. during the 25 month average treatment time. This he attributed largely to growth expressed at the condyle. Since his sample was composed of Class II malocclusions which for the most part exhibited a vertical facial growth pattern, no direct comparison may be made with the results of this study of Class I extraction malocclusions. It is interesting, however, to note that the average growth increment of the Class I subjects was about one-half that of the Class II cases over the approximately equal treatment periods. No linear investigations of the ascending ramus in Class I extraction malocclusions during orthodontic treatment were available.

Twelve cases or almost 50% of the sample indicated a ramus height increase of from +1.6 mm. to +4.0 mm. It is difficult to correctly assess whether this increase was due to growth, orthodontic treatment, or both. Since treatment would have had little effect on the distance from Articulare to Gonion, most of the changes were probably a result of growth at the head of the condyle as Ricketts observed, and along the posterior border of the ascending ramus. Condylar growth alone would project the ascending ramus further away from Articulare and would contribute most to the increase in ramus height.

3. Change in Alveolar Height (mesial root apex of $\overline{6}$ to Go-Gn).

Alveolar height in the region of the left mandibular first molar was found to increase in all 26 subjects with the largest number of cases exhibiting an increase of +1.38 mm. to +2.18 mm. These distances were all measured from the root apex of the mesial root of the molar to the Go-Gn (mandibular) plane. Measuring from this root apex to the Go-Gn plane provides a measure of the amount of uprighting accomplished during orthodontic treatment. It also reveals any increase in height resulting from growth either of the alveolar process or from apposition on the points locating the inferior border of the mandible (Gonion and Gnathion).

Recent work by Björk (1963) has a definite relationship to this subject. By the use of metallic implants, he has shown that the inclination of the inferior border of the mandible (Go-Gn) may change considerably by resorption in the gonial region and deposition in the region of the symphysis. Thus it may be surmised that the extremities of the inferior border of the corpus undergo a change which alters the mandibular plane relationship to the root of the first molar. This effect would be one of increasing the distance between the plane and apex.

The distal tipping or uprighting of the mandibular molar teeth accomplished by applying a posterior force to these teeth in association with angulated brackets may also change the mandibular plane-to-root apex distance. This combination of bracket angulation-induced second-order bends and light resilient forces tipped these teeth on an axis located near their distal root apexes. Gantt (1960) and Kemp (1961) found that in about 50% of the cases in their sample, the axis of tipping was in the middle of the distal root. In the remainder of their subjects, it was in the apical one-third of the distal root.

If the distal root apex is near the axis of tipping and no intrusive movement of that root has occurred, it can be assumed that the mesial root apex has been extruded. The amount of extrusion and subsequent alveolar compensation that has occurred is shown by this change. The increase in height due to growth of alveolar process and the change due to uprighting of the molar are impossible to separate in this study. What is established, however, is the fact that there is an increase in alveolar height due to one or a combination of the following factors: alveolar apposition, growth changes at Gnathion or Gonion, and the uprighting of the mandibular first molar. Since none of these possibilities can be definitely established as effecting the increase in alveolar height, neither the work by Björk, Gantt, or Kemp could be corroborated nor refuted by the results of this study.

4. Change in the Angle of the Occlusal Plane.

The occlusal plane in this study was established by a line connecting the tip of the distobuccal cusp of the mandibular left first molar to the tip of the most prominent central incisor. The pretreatment and posttreatment angles were calculated and the change was obtained by subtracting the pretreatment from the posttreatment angle. The average change was found to be -2.24 degrees. This means that the occlusal plane moved 2.24 degrees away from the horizontal (Sella-Nasion) in a downward direction.

In discussing the plane of occlusion, one is involved in an area in which it is difficult to communicate. Care must be exercised not to refer to this plane as though it were a tangible entity. It is not an anatomical part but a boundary between two parts. To achieve optimum accuracy, one should refer not only to the mandibular occlusal plane, but also to the maxillary occlusal plane. Ideally, a discussion of the changes in angular relation of the mandibular occlusal plane should be qualified by indicating that a given segment of teeth moved a specific number of millimeters vertically to cause this change. If anterior and posterior segments of teeth are always related to their respective bases, confusion about occlusal plane changes will be minimized.

The results of the change in alveolar height of the mandibular molar described before (#3), indicated that there was an increase in the distance from the Go-Gn (mandibular) plane to the mesial root apex of that tooth. Since the molars are located near the apex of the angle formed by the occlusal and Sella-Nasion planes, any uprighting or extrusion of the molar teeth would profoundly affect the angular relationship between the two planes. It was observed in assessing the changes in alveolar height of the mandibular left first molar (#3) that there was a noticeable amount of molar uprighting. The relocation of Gonion (#1) was also affected by this molar uprighting and the resulting bite opening. This change in the occlusal plane angle may be another indication that the bite was opened thus reducing the overbite.

There is also the possibility that a change in position of the lower central could have had an effect on the occlusal plane angle. If the tooth were tipped lingually about an axis near its apex, the result would be a reduction in the occlusal plane angle. Tipping the tooth about an axis near the center of the tooth would not have had an appreciable effect on the angle.

Schudy, in a paper published in 1963, states that in untreated cases condylar growth is the key to changes of the occlusal plane. By assessing the changes in alveolar height in both the anterior and posterior areas, and the vertically expressed growth of the condyles, he has concluded that it is the amount of condylar growth that profoundly affects the occlusal plane relationship with the Sella-Nasion plane.

It is impossible to definitely conclude from this study if one or any combination of the three possibilities (increase in alveolar height in the molar region, the incisor region, or an increment of growth of the condyle) caused the increase in divergence of the occlusal plane. Since Schudy only studied untreated cases, the changes in position of the molar and incisor and the resulting alveolar compensation may have had more influence on the occlusal plane angle than did condylar growth.

5. Change in the Width of the Symphysis.

The width of the symphysis was found to decrease an average of 1.25 mm. during treatment. The measurement for the width was taken as the distance between Supramentale and Posterior Symphysis.

In evaluating this change, we are again faced with the problem of separating the effects of growth from those of orthodontic treatment. Ever since Downs (1948) described "B" point as a landmark indicating the arbitrary division of apical base and alveolar process, clinicians have formulated various methods of assessing this point.

In 1955 Björk, in a study of mandibular growth in untreated cases using metallic implants, found that there was actual resorption of bone occurring in the area of point "B" as the lower incisors shifted vertically with growth. His study in 1963 stated that there was an increase in thickness of the symphysis. This seemed to be the result of appositional growth on the posterior and inferior borders of the symphysis.

Ricketts in 1964 stated that during orthodontic treatment point "B" tends to follow the lower incisor. He observed clinically that after forward movement of the lower incisor, a ledge of bone in the alveolar process appeared on the lingual side; this was retained for a time but gradually disappeared. He observed, however, that no such shelf appeared on the labial side after lingual movement of the teeth. He concluded that the heavy, slow-resorbing bone is located on the lingual surface of the symphysis.

This study evaluates the width of the symphysis by using point "B" as the anterior border of the symphysis. Posterior Symphysis, a point on the lingual cortical plate of the symphysis on the same horizontal axis as point "B", is used as the posterior reference landmark. Since two points were used in establishing the width, it is difficult to assess whether one or both were responsible for the change. The results of this investigation would indicate that there was a definite resorption of bone at one or both points. If the findings of both Björk and Ricketts are taken into consideration, it may be surmised that in the 26 sample cases there was not only a resorption in the area of point "B" as Björk observed, but also in the region of Posterior Symphysis, as Ricketts noted during orthodontic treatment. This study does not confirm or refute either of these investigations since the points of measurement, type of treatment, age of the subjects, and methods of assessment varied. It does, however, indicate that this method of evaluation may be used in association with other investigations to provide an understanding of various cephalometric phenomena.

6. Change in the Height of the Symphysis.

The height of the symphysis, being measured from the root apex of the most prominent mandibular central incisor to Menton, will be subject not only to the effects of growth, but also to any changes in alveolar height. In the treatment of these malocclusions, the first premolars were extracted to provide space for the normal alignment of the anterior teeth. This, in most cases, allowed some retraction of the incisors.

There was found to be no significant change in the height of the symphysis. There was, however, a range of values from -4.2 mm. to +3.6 mm. Ordinarily one would expect some alveolar compensation due to a stimulation of growth in the mandibular anterior region.

Using metallic implants, Björk (1963) determined that there was a deposition of bone at the inferior border of the symphysis (Menton). This fact would tend to refute the findings obtained using the rectangular coordinate system. A possible explanation of the phenomenon observed is that through uprighting of the lower incisor, the root apex-to-Menton distance decreased. The fact that there was found to be no significant change in the height of the symphysis may have been the result of two factors cancelling each other. Any factor causing a decrease in symphyseal height such as the uprighting of the lower anteriors, may have masked the factors causing an increase in symphyseal height such as alveolar growth or a deposition of bone at Menton.

Garn, Lewis, and Vicinus in 1963, in an evaluation of the inheritance of symphyseal size during growth, found that the main dimensions of the mandibular symphysis are largely independent, not only of each other, but also of related facial and dental structures. They determined symphyseal height as its maximum vertical diameter. The width (thickness) was assessed as the maximum anteroposterior distance at right angles to the above. Since their study measured these changes in dimension independent of the lower incisor teeth and in a slightly different manner, no direct comparisons may be made with this investigation.

7. Location of the Axis of Tipping of $\overline{1}$.

An assessment was made of the location of the axis of tipping of the lower central incisor. The results of the calculations located the position of the axes of tipping on the coordinate system. It was found that in the majority of cases, the axis was located within a range of 76.0 mm. to 94.0 mm. below the horizontal reference axis, and from 40.4 mm. to 65.2 mm. to the right of the vertical reference axis. As explained in Chapter IV, the significance of the measurements is that they not only located the axis of tipping, but that they also provided information as to the type of movement that occurred. In general, the findings indicated that in most cases, the tooth experienced a combination tipping and translation (bodily movement) during orthodontic treatment. In two of the 26 cases, the axis of tipping was located far below the root apex, and in one case, the axis was far above the crown. These three cases demonstrated mainly a translatory type of tooth movement even though it is readily admitted that a "pure" translation did not occur. A "pure" translatory type of movement would be one in which the pretreatment and posttreatment long axes were parallel and intersected only at infinity. Since the lower incisor in 16 cases tipped about an axis within the tooth itself, it may be assumed that the crown and root moved in opposite directions.

8. Relation of the Central Axis of $\overline{1}$ to the Anteroposterior Width (PS-B) of the Symphysis.

The lower incisor has long been a favorite of cephalometricians. Almost every analysis heretofore presented has in some way evaluated the position of the lower central incisor. Such terms as incisor-mandibular plane angle, Holdaway ratio, and "trough" are commonly used jargon within cephalometric circles. Practically all investigators from 1945 to 1955 were measuring the angulation of the lower incisor rather than its spatial relationship to the symphysis or profile. For the most part, the orthodontist was trying to avoid the movement of the apex of the incisor for fear of root resorption or destruction of the alveolar bone or gingival tissue. Only one investigator, Ricketts, using the A-Po plane has measured the relationship of the lower incisor to the symphysis.

This study has determined that there was no significant change in the position of the long axis of that tooth along the anteroposterior width of the symphysis. In view of the findings determining the location of the axis of tipping of the lower incisor (#7) which indicated that the axis in most cases was within the tooth itself, and the findings determining that the width of the symphysis (#5) decreased during treatment, it is impossible to accurately conclude in which direction the tipping occurred.

Since there was found to be no significant change in the position of the long axis along the anteroposterior width of the symphysis, the results of this study cast some doubt on the commonly accepted theories of tooth stability which say that the lower incisor must be 90 degrees to the mandibular plane. These 26 cases having been completed for some time were evaluated during the retention period. The majority of cases have maintained a high degree of stability both in the mandibular incisor region and in the buccal segments. The fact that these teeth were uprighted and placed over denture base during treatment suggests that the future stability of the lower incisor may in some way be associated with the post-treatment position of the long axis within the symphysis. Additional studies of this relationship of the lower incisor to the symphysis may provide a clue to the stability of the mandibular anterior teeth.

The precision with which these changes were evaluated demonstrated that this linear method in association with a rectangular coordinate system and "Cartesian Coordinates" has a definite place in cephalometry. As demonstrated in the assessment of these changes, a high degree of accuracy may be obtained with this method. The accuracy is limited only by the investigator's precision in his method of exposing the cephalograms, locating and spotting the landmarks, measuring the various distances, and calculating the desired measurements, both linear and angular. As mentioned previously, with further refinement and modification, this method of assessment used in association with computers, will provide an unlimited source from which information in many areas of cephalometry may be obtained.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The purpose of this investigation was twofold: the first was to devise and demonstrate the versatility of a linear system of measurements using analytic functions in rectangular coordinates, and the second was to utilize this system of measurements in assessing the changes occurring in the morphology of the mandible and in the positions of the associated dental structures after orthodontic treatment.

Pretreatment and posttreatment lateral headplates for each of the 26 sample patients were evaluated using "Cartesian Coordinates" in association with a system of rectangular coordinates. Precision techniques were employed to locate and spot the desired mandibular landmarks. The distances from these points to the coordinate axes were measured and tabulated on data sheets on a pretreatment-posttreatment basis. Principles of trigonometry, algebra, and analytic geometry were employed to calculate the change in positions of the various spotted landmarks. The investigated changes in dimension were as follows:

1. Change in the position of Gonion.
2. Change in the height of the ascending ramus.
3. Change in the alveolar height (mesial root apex of $\overline{6}$ to Go-Gn).

4. Change in the angle of the occlusal plane.
5. Change in the width of the symphysis.
6. Change in the height of the symphysis.
7. Location of the axis of tipping of $\overline{1}$.
8. Relation of the central axis of $\overline{1}$ to the anteroposterior width (PS-B) of the symphysis.

The information obtained from each group of computations was plotted in graphic form to enable a visualization of the distribution. Those distributions that were judged to be symmetrical were analyzed statistically to obtain a mean and standard deviation. The calculation of these statistical measures was omitted in those distributions that were judged to be unsymmetrical. These evaluations provided an interpretation of the orthodontic therapy and the accompanying growth which occurred during the treatment period. All calculations were tested for significance by applying Student's t-ratio.

The sample in this study comprised 26 patients treated in the office of Dr. Joseph R. Jarabak, Hammond, Indiana. All patients were assessed clinically as Class I (Angle) malocclusions and all required the extraction of the four first premolar teeth prior to the initiation of treatment. These patients were treated according to the principles of the Jarabak "Light Differential Force Technique."

This method of applying the rectangular coordinate system and associated "Cartesian Coordinates" is the first to employ the following innovations:

1. The use of a precision instrument (vernier caliper) to measure linear distances with a high degree of accuracy.
2. The incorporation of principles of analytic geometry to cephalometrics to obtain accurate measurements heretofore impossible with existing methods of analysis.
3. The use of a simple, uniform procedure of manipulation to obtain the measurements. Only two movements of the vernier caliper are required to obtain all measurements.
4. The elimination of the need to trace and construct lines to obtain various measurements. Any measurements may be calculated without necessitating the construction of lines and the use of a protractor.

During the orthodontic therapy of the 26 Class I malocclusions it may be concluded that:

1. Gonion moved posteriorly in the largest number of subjects. There were, however, a significant number of patients in which Gonion moved anteriorly. The distances that Gonion moved exhibited a high degree of individual variation. The method of assessment was able to show both magnitude and direction of all changes.

2. The height of the ascending ramus increased an average of 2.00 mm. during the treatment period. The height of the ramus was calculated by this method as a true diagonal length, not just a vertical height.
3. The alveolar height in the molar region increased in all but three cases. This measurement required extensive use of analytical methods but no construction lines.
4. The divergence of the occlusal plane to Sella-Nasion increased an average of 2.24 degrees.
5. The width of the symphysis decreased an average of 1.25 mm. during treatment.
6. There was no significant change in the height of the symphysis during the time of orthodontic correction.
7. In sixteen cases, the axis of tipping of the lower incisor was located within the tooth itself. The axes of the remaining ten cases were equally divided between locations above and below the tooth indicating that these teeth were moved bodily. The positions of the axes of tipping of the lower incisors would be difficult to locate accurately by the method of superimposing two lateral headplates. As demonstrated by this investigation, their location is not difficult when analytical methods are employed.

8. The relationship of the central axis of the lower incisor to the anteroposterior width of the symphysis did not change significantly during the period of orthodontic correction. This calculation is easily made by the analytical method used in this study.

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APPROVAL SHEET

The thesis submitted by Dr. J. Keith Grimson has been read and approved by members of the Department of Oral Biology.

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form, and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

May 12-65
DATE

Joseph R Jaralak
Signature of Adviser