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A Cephalometric Evaluation of Young Adult Caucasian Males with Normal Occlusion: Its Application to Orthodontic Assessment by an Electronic Computer

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A CEPHALOMETRIC EVALUATION OF YOUNG ADULT CAUCASIAN MALES WITH NORMAL OCCLUSION: ITS APPLICATION TO ORTHODONTIC ASSESSMENT BY AN ELECTRONIC COMPUTER

BY

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LIFE

Gerald L. Ashley was born in Rockford, Illinois on February 24, 1932.

He was graduated from East Rockford High School in June 1949. After attending Beloit College, he entered Northwestern University Dental School receiving the degree of Doctor of Dental Surgery in June 1957. During the following year, he served as an intern at the Veterans Administration Research Hospital in Chicago, Illinois.

Upon completion of his internship, he practiced general dentistry in Chicago until June 1964. He began graduate study in the Department of Oral Biology at Loyola University, Chicago, Illinois in June 1964.

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CHAPTER I

INTRODUCTION AND STATEMENT OF THE PROBLEM

A. Introductory Remarks:

The high-speed electronic computer is a new tool, different from any ever created, for extending the scientist's mental activity in problem analysis. Small signals effect large outputs of information involving extensive data, multitudinal factors and mathematical manipulations. Accumulated knowledge is stored electrically, correlated promptly and analyzed automatically by planned programming to provide prompt solutions to complex problems. They have been characterized in various contexts as "mechanical brains", "hardware" and "high-speed data processors". More exactly, an electronic computer is a tool for analysis and simultation of activity systems. It can be used in designing such systems and as an aid to the decision process in a system already in being.

All computing automata fall into two great classes: The digital, which counts electric pulses like beads on an abacus, and the analog. The modern analog computer is an expansion of original computational schemes, such as the slide rule, but is capable of a greater variety of uses and can solve extremely more complex problems. It is more versatile by virtue of electronic parts instead of mechanical parts.

The modern digital computer has shown the greatest development and most promise of all computing machines because of the concept of a stored program. This stored information may be parts of tables, data that is as yet unprocessed, statistical data that has resulted from partial or complete analysis, or instructional material that is part of the stored computer program. The machine is programmed to talk to itself, shift data around, work with it in a prescribed manner, and at various points along the way, to report out intermediate results until at the end of the program the final answers are ready.

The analog computer, as its name indicates, uses an electrical signal such as voltage which is measured by an analog of some physical or measurable quantity under study. For addition and multiplication, a circuit is designed with adding units which feed in the appropriate additional amount of voltage or an amplifier which multiplies the voltage by the required amount. Capacitors are used to accumulate the voltage over a period of time as an analog of integration. If several equations are to be solved simultaneously, the circuits can be so arranged.

The requirements of efficient computer use are (1) the presence and recognition of the problem, (2) an approach to solution of the problem, including certain stated hypotheses and methods of testing these hypotheses, and (3) translation of the testing procedure into machine language. Computers do not replace thinking. They demand deeper thought. They permit the thoughtful detailed sequence of logical steps used in the solution of a problem to be used repeatedly without repeating the same human expenditure of effort. Many different problems require parts of the same thinking. Problem solving has repetitious aspects at all levels, and this is what allows the use of programmed machines.

The secret to success rests in having a well-formulated, concise, answerable question in the first place. Automatic data processing without this leads to expensive processed data and nothing more. Large amounts of data can be reduced into precise answers only to the extent that there has been considerable logical thinking about the problem. There is a direct relationship between time spent on the statement of the problem and time saved in data reduction.

Electronic computers are rapidly achieving a place as a recognized tool in the field of medicine. They are used extensively in medical and biological research to aid in solving, for example, statistical problems, biological simulation problems, and for pattern recognition and analysis. The computers have also been geared for clinical use in epidemiologic studies, electroencephalography and electrocardiology, psychological testing and differential diagnosis, to name but a few. Their use in all branches of dentistry has been quite limited. As a clinical tool, they have been employed primarily in growth studies and in epidemiologic studies of malocclusion.

B. Statement of the Problem:

The purpose of this thesis is twofold:

To investigate craniofaciodental characteristics of clinically excellent occlusion in young adult Caucasian males.

To collect data from this investigation as the initial phase in developing a program of orthodontic diagnosis applicable to automatic electronic computers.

CHAPTER II

REVIEW OF THE LITERATURE

A. Computers in Medical Diagnosis:

The earliest analog and digital computers were mechanical. Lord Kelvin worked on an analog integrator. Later both types became electromechanical. Gears, shafts and electric motors were used in analog computers and relays in digital computers.

For a number of years prior to 1951, Brodman and his co-workers attempted to develop a numerical system which would automatically place data taken from medical histories in a disease category. This system became known as the Cornell Medical Index-Health Questionnaire.

In 1953, Dr. Vannevar Bush delivered an address to the medical society of the District of Columbia and compared the utilization of medical information to the construction of the tower of Babel. The tower was never completed for the workmen found that each was speaking a special language, and no man understood what the other was saying. Bush observed that too much was required of memory and not enough time was left for thought. He suggested that electronic means be exploited to take over the data storage and retrieval areas in medicine.

Nash (1954), working in England, discussed the inadequacies of textbooks in making the many comparisons required in differential diagnosis. He experimented with a special ruler with about 300 diseases or diagnoses listed on the side. Into this ruler multiple inserts, each labeled as a sign or symptom, were inserted. Marked lines on these moveable inserts would lie opposite the disease when that sign or symptom was present in that disease. The diagnostician would then use this aid by selecting those inserts corresponding to the observed positive signs and symptoms. When some disease, or diseases, were present with the lines across all or most of the inserts, a diagnosis could then be narrowed to a few choices.

This comparator, or "logoscope", as Nash called it, is illustrative and instructive. It is a landmark in a shift of thinking from books on differential diagnosis to automatic data processing and storage equipment.

In 1955, a study was reported in which marginal punched cards were used to correlate data in the differential diagnosis of hematological diseases. In this study, by Lipkin and Hardy, data which characterized twenty-six hematological diseases were recorded. From the data which had been listed for each disease, a master code was made containing all the information, and the data were then assigned to spaces on the periphery of marginal-punched cards. Since the cards were identical, a given space on the margin of all cards represented the same information.

A single card was chosen to represent each of the hematological diseases. When a given finding was characteristically present in a disease, a triangular wedge was punched in the appropriate space on the disease card. In addition, those items of information which were definitive diagnostic criteria in each disease were noted by placing arrows to their appropriate spaces. Findings in a patient could then be compared with the characteristic findings in each disease as noted by the punched card. Although it was possible to end this correlation procedure with no diagnosis, it was impossible to end with the wrong diagnosis, if the data from the patient and the disease description on the card were correct.

An analog method was used in 1955 by these same workers to measure the probability of a diagnosis and to correlate data automatically in the differential diagnosis of hematological diseases. A numerical value was assigned to each of the twenty-six diseases studied. If the presence of an item contributed to the establishment of the diagnosis, it was given a positive value in that disease. If its presence would not be compatible with the given diagnosis, the item was given a negative value. If its presence would in no way affect the diagnosis, it was given the value of zero. Thus each item might carry different weight in each disease. Each disease description contained all the data of the master code, and each item in each disease carried an individual numerical positive or negative number.

In 1957, Lipkin and his fellow workers transferred this problem to a digital computer employing the use of three magnetic tapes. Tape A contains the case history of each patient. This is first compared to the material on Tape B which carries the definitions of classes of diseases. Tape C contains the definitions of each disease within a class. After the comparison has been made between Tape A and Tape B, the appropriately suspicious classes are selected from Tape C. Then further comparison with the patient and further differentiation of the diagnosis from class to specific disease results.

Lipkin has indicated that it is desirable to list the diseases in the differential diagnosis in sequence of decreasing probability. He suggested that a program of this sort could be employed as an aid in teaching differential diagnosis. Also its use in medical practice might contribute to an increasingly analytical basis for diagnosis.

In 1959, Lusted and Ledley analyzed the reasoning foundations of diagnosis. They indicated that to use a computer effectively for diagnosis one must know how a clinician thinks or arrives at a diagnosis. They believed a diagnosis was made, in general, in four steps which are: (1) Facts are obtained from the history, physical examinations and laboratory tests; (2) the relative importance of each of the different signs and symptoms are evaluated, some data being of first order importance, other less important; (3) all diseases which can reasonably resemble the specific case are listed or considered; (4) one disease after another is excluded from the list until it becomes apparent that the case can be fitted into a definite disease category, or it may be one of several possible diseases, or else the exact nature cannot be determined.

Although they admitted to oversimplification and there was always the clinician's "feeling about the case", they believed that a medical diagnosis involves a process that can be systematically analyzed. They concluded that three factors are involved in the logical analysis of a medical diagnosis. These are: (1) Medical knowledge that relates disease complexes to symptom complexes; (2) the particular symptom complex presented by the patient; and (3) the disease complexes that are the final diagnosis. The effect of medical knowledge is to eliminate from consideration the disease complexes that are not related to the symptom complexes presented. The resulting diagnosis computed by means of logic is essentially a list of all the possible disease complexes that the patient can have that are consistent with medical knowledge and the patient's symptoms. Lusted suggests that the final mathematical model of medical diagnosis may involve a sequence of a number of different approaches including symbolic logic, probabilistic analysis, and theory value.

Brodman, van Woerkman, Erdman, and Goldstein (1959) reported on a study with the Cornell Medical Index (CMI). They collected data from nearly 6,000 consecutive male patients as an initial sample. Some sixty diseases were then studied and the pattern or score on the CMI was computed for each disease. Data were then collected from 2,745 consecutive patients, and on the previously computed probabilities of each complaint for each disease, the new patients were assigned likelihood indices for each of the sixty diseases studied. A diagnosis was considered or made when the index reached a certain level. The computer diagnosed forty-four per cent of patients having the sixty diseases and identified the organ system in fifty-five per cent. When a random sample of 350 questionnaires were examined by both computer and physician, there was no statistically significant difference in the results except that physicians tended to diagnose psychoneurosis more accurately than did the machine.

Schenthal and Sweeny, in 1960, reported a method of clinically applying large-scale electronic data processing machines. They also evaluated and described analog and digital computers and concluded, that for this study, the digital computer fitted their needs best. They used 138 medical records which were coded with the help of the Cornell Medical Index and other aids. It was found possible to punch a history of 195 questions on IBM cards within forty seconds. It was pointed out that manual card punching can be eliminated by a procedure (mark-sensing) whereby information recorded by electrographic lead pencils can be transferred directly to the punch cards by machine. Data in this form can then be easily stored and quickly retrieved. The study demonstrated the possibility of locating rapidly, in a very large collection of records, a group of charts meeting any desired combination of requirements.

In 1960, Warner, Toronto, Veasey and Stephenson prepared a matrix of probabilities based on a study of 1,035 patients with suspected congenital heart disease. They listed fifty symptoms and signs and thirty-three diagnoses. The incidence of each symptom was transferred to punched cards and stored in the computer along with the program for carrying out the analysis. For each subsequent diagnostic problem analyzed, the symptoms from a check list were punched on a card which was run through the computer. A conditional probability equation was then worked out automatically with the appropriate probabilities from the table. Then the diseases with probabilities greater than one per cent were printed out together with their respective probabilities.

These workers plan to use the computer to recalculate the probabilities periodically as additional data accumulate in the further use of the program. In a sense, then, the program will "learn" from experience by virtue of refinements of the table based on the accumulating data.

Newall and Simon, in the following year, suggested a means to study human thinking which is somewhat analogous to simulation experiments. In a very general program, they suggested we observe how a human subject and the problem-solving analog called GPS (The General Problem-Solving Program) solve the same problem. To watch man and a programmed machine work on the same problem would have the virtue of developing a specific diagnosis program useful in medicine while, at the same time, exploring the ways in which an experienced diagnostician functions in arriving at a diagnosis.

In 1961, Warner and his associates presented a mathematical approach to medical diagnosis. They stated that diagnosis from clinical data is a subtle art which may be mastered only after years of careful study and extensive personal experience. The purpose of their study was to find an explicit mathematical expression for analyzing and improving the logical process by which a diagnosis is deduced from information given by the patient. They felt such an expression might improve the accuracy of diagnosis, lead to a more scientific approach to the teaching of medical diagnosis and provide a means, with the help of electronic computers, for relieving the physician the task of storing and recalling for practical use in diagnosis an ever increasing mass of statistical data.

Swenson and others, in 1962, reported on their initial experience with a personality inventory test which could be used alone or in combination with the Cornell Medical Index. This copyrighted text which was developed by Hathaway and McKinley at the University of Minnesota, and called the Minnesota Multiphasic Personality Inventory (MMPI) consists of 550 yes-no questions which were originally standardized on a group of normal persons.

Patients were then selected who demonstrated rather clearcut psychiatric problems which could be classified in one of eleven different groups. Grading the test consists of determining whether an individual patient answers the questions in a way consistent with the original normal group or with one of the psychiatric group categories.

In 1962, Freidman, writing an editorial in the New York State Dental Journal, reported that dentists are now aware of "that marvelous prodigy of the marriage of electronics and business management, the computers". He pointed out what the computer could do and could not do in the field of diagnosis, and suggested dentists should now begin to explore its possibilities.

Rome (1962) defending the automation technique of diagnosis said:

> "The entire process is a data organizing and matching operation. The categorical facts of medical art and science are reshaped and altered to provide the patient with a tailor-made diagnosis and treatment which, ideally, fits him perfectly. This requires some condensation and alteration with the tacit recognition of a basic assumption that, in the most significant particulars of health and disease, people by and large are more alike in their reactions than they are different. If a more expert clinical evaluation is to be had for a larger number of persons than are receiving at the present, and if the necessary experts are in short supply, the logical thing to do is to augment the number of experts and accelerate what they do. Alternatively, there is the theoretical possibility that the experts' operations can be speeded beyond the limitations of his individual capacities, if they can be standardized and instrumentated. Moreover, the standardization of his operation minimizes the idiosyncratic errors to which all human experts are liable. This is the rationale which underlies the application of high speed data processing to medical diagnosis."

He further stated that computers have a happy faculty of a slavish adherence to whatever they are programmed to do, they are immune to distraction and incapable of boredom, preoccupation, forgetfulness, and the rest of the long list of idiosyncrasies to which the human expert is susceptible. The price for this zeal comes high, he added, "for machines also lack inspiration, capacity to improve and, in the accepted sense of the term, creative ability. Furthermore, they are expensive, sessile, and require highly skilled nursing care to keep fit".

Lusted, 1962, stated that medical information at the present time is not in a form which is easily usable by a computer. A great deal of careful data collection and analysis must be done by physicians in cooperation with mathematicians. The attention of the physicians should be directed to two tasks: (1) defining symptom-disease complexes; and (2) determining the probabilities of these symptom-disease complexes.

Mathematical logic (propositional calculus) is employed in order to make a computer list diagnostic possibilities for the symptoms presented by a patient. The use of logic for this purpose is closely related to the concept of symptom-disease complexes (SDC's). A symptom complex is a list of the symptoms that a patient does or does not have; a disease complex is a similar list of diseases. A symptom-disease complex is a list of both symptoms and diseases that a patient does and does not have.

Lipkin and his associates continuing their work with computers in hematological diseases, reported in 1962, that the most efficient data analyses have resulted from the use of a combination of digital and analog methods involving probability calculations and matching procedures. The development of more sophisticated computer programs and the development of methods to assist in the translation of medical data into computer systems should further test the usefulness of computers in this area.

Discussing the integration of data in diagnosis, Caceres (1962) said:

> "Like the physicians' reasoning process, computer statistical programs are based on the use of many bits of data that separately would not differentiate one disease from another. We know from medical practice that values which themselves are not different enough to allow for differentiation or separability between groups play an important role in the differentiating process. The problem is learning how to relate the variables. Neither the physicians nor the computer--in the absence of specific programming--is capable of assigning correct weights to data or of discarding irrelevant or confusing data."

Woodbury, in the same year, in an article discussing the use of computers in solving statistical problems, biological simulation problems, pattern analysis and the use of computers in diagnosis concluded that, at the present time, the great area of potential applications of computers in medicine is for the most part untouched. In several relatively narrow areas, deep penetration of some problems has been made; but, by and large, the areas of greatest potential await the availability of data in computer-accessible form. For some time, he believes, most applications will be concerned with relatively simple applications of computers.

One must use some form of language to write instructions to the computer. Cady discussed communication with a computer in an article by that title in 1962. He explained that the language is a direct and comparatively easy means for instructing the computer, once the overall thinking is done. The complete instructions that enable the computer to solve a problem are called the program. These programs are written using a basic set of letters, numbers, arithmetic operations and punctuation marks. He noted, however, that the sophistication of programming languages is continuously increasing. At the lowest level are the machine-oriented languages, by means of which each step of a machine operation is executed. The symbolic languages are in a one-to-one correspondence with the machine language and replace numeric instructions with conventional, mnemonic alphabetic symbols. Next in sophistication are the problem-oriented languages, which require special compilers to translate the terms into symbolic and machine language. This compiler itself is a computer program that gives the computer the instructions required to convert the initial instructions into the numeric language of the computer. The problem-oriented languages require different compilers for each type of machine with which the program is to be run. One such problem-oriented language that is in general use is FORTRAN, which is a general mathematical, or formula-translating, language. Another problem-oriented language is COBOL, which is used in business calculations. From one program statement in COBOL or FORTRAN, he explained, a compiler will generate several machine instructions by which that segment of the program can be carried out. When the entire program has been written on cards or tape, it can then be fed into the computer, for which a compiler has also been written.

Best, in 1962, discussed the potential role of computers in medical practice. In this article he presented an example of a computer program using the program languages of ALGOL-60 and FORTRAN. He also pointed out reasons for delay in medical uses of computers among which are: (1) the expense of the hardware; (2) the general practicability in medicine of the more involved programs; and (3) the lack of well-developed suitable software or programs.

The possibility of every hospital or clinic having a computer is obviously prohibitive. However, Mason and Bulgren (1964) have pointed out there is no reason why a group of physicians in small hospitals without computer facilities could not participate in a study as a "satellite" with very little local investment in equipment. This would have the added advantage for the central study of adding to the size of their sample as well as broadening the base from which the sample is obtained.

The dental literature contains but few articles concerning computers. There is a complete paucity of literature dealing with the automata and dental diagnosis. Significant as it may be, most references to the use of computers in dentistry is in the field of orthodontics. Their application, however, was not in the realm of orthodontic diagnosis, but rather in the incidence of malocclusion.

Telle, in 1951, studied the frequency of malocclusion in Hedmark, Norway. He used a card-index or punched card system which carried the personal particulars of each observed child. The edge of the cards are punched-hole perforated and each hole is numbered. In this manner, each hole or number indicates a definite single symptom. Telle recorded eighty-one different symptoms, all of which are "closely defined and describes a single simple detail of the jaws and teeth".

No attempt was made to classify malocclusion according to an established system. "Each malocclusion consists of a complex of symptoms, and these symptoms taken together can be used to determine which of the larger groups it shall belong."

The results are subsequently transferred to another punched card system of the kind used in the so-called "Power System" or "Hollerith System" where computation is done mechanically. Using this, it is possible to select a single number or symptom, in the course of ten minutes, from all the 2,349 cards collected.

Bjork, Krebs, and Solov, in 1964, described a method of epidemiological registration of malocclusion. The study was designed to use detailed definitions of the recorded symptoms which makes it possible to analyze the data by electronic computers.

Their registration of malocclusion was divided into three parts: (1) anomalies in the dentition, i.e., tooth anomalies, abnormal eruption patterns and malalignment of individual teeth; (2) occlusal anomalies or deviations in the positional relationship between the two dental arches and (3) deviations in space conditions, i.e., spacing or crowding of the teeth.

The data collected are transferred to punched cards or tape, and it is then possible to obtain, with respect to age, sex, and stage of dental development, the prevalence of any anomaly or the combinations of anomalies. At the same time any particular symptom may be excluded.

Jonsgar (1964) used this same method in an epidemiologic study of malposition of teeth of school children in Bergen, Norway. The collected data were transferred to tapes and placed in a programmed electronic computer.

Any review would be incomplete without the mention of Norbert Wiener and the expression cybernetics. The term, coined by Dr. Wiener in 1947, is derived from the Greek word steersman. By definition, it is the science of "the entire field of control and communication theory, whether in the machine or in the animal".

Quoting Dr. Wiener from his book, <u>Cybernetics</u>:

"At this point there enters an element which occurs repeatedly in the history of cybernetics--the influence of mathematical logic. If I were to choose a patron saint for cybernetics out of the history of science, I should have to choose Leibnitz. The philosophy of Leibnitz centers about two closely related concepts--that of a universal symbolism and that of a calculus of reasoning. From these are descended the mathematical notation and the symbolic logic of the present day. Now, just as the calculus of arithmetic lends itself to a mechanization progressing through the abacus and the desk computer machine to the ultra-rapid computing machines of the present day, so the "calculus ratiocinator" of Leibnitz contains the germs of the "machina ratioinatrix", the reasoning machine. Indeed, Leibnitz himself, like his predecessor Pascal, was interested in the construction of computing machines in the metal. It is therefore, not in the least surprising, that the same intellectual impulse which has led to the development of mathematical logic has at the same time led to the idea or actual mechanization of processes of thought."

B. Cephalometric Assessment Methods:

The era of roentgenographic cephalometrics began in the year 1931. In the United States, Broadbent developed his precision instrument, the Bolton-Broadbent cephalometer. Hofrath in Germany--independent of Broadbent--published techniques for taking oriented lateral roentgenograms. Hofrath's method never gained popularity, but Broadbent's contributions laid the foundation for a new approach of scientific investigation in the field of orthodontics.

Broadbent (1937) questioned the reliability of cranial landmarks used in anthropometric methods of measurement. From a study of skulls housed in the Western Reserve Anatomical Laboratory and the American Museum of Natural History, he found that landmarks above the face, in the cranial base, are more stable and fixed than those located in the rapidly growing lower face.

Realizing that the sphenodial area was one of the most stable of points, he established the Bolton-nasion plane of orientation and the "R" or registration point. This point is located midway on a perpendicular line erected from the Bolton-nasion plane to the center of sella turcica. These references were then used for superposition and orientation for subsequent roentgenograms of the same individual. By including the Frankfort horizontal plane and a perpendicular to this at orbitale, dental and facial changes were noted in relation to these two planes as well as the Bolton-nasion plane.

Wylie, in 1947, developed a method of analyzing cephalometric X-rays by which discrepancies in the size of facial bones in the anteroposterior plane could be assessed. Wylie's analysis is based upon linear measurements in millimeters. All measurements are projected to the Frankfort horizontal plane with the exception of the mandibular length. The measurements of his analysis are: The most posterior point on the mandibular condyle to sella turcica, sella to the center of the pterygomaxillary fissure, the pterygomaxillary fissure to the buccal groove of the maxillary first molar, the pterygomaxillary fissure to the anterior nasal spine, and the mandibular length.

Wylie has shown with this method a very important principal: "It is not the absolute dimensions of each part which are important, but the way they add to each other."

It seemed a foregone conclusion that subsequent to the tremendous amount of research being done on oriented lateral headplate films, someone would evolve a method of appraisal that was concise and not too complex for clinical use. It remained for William B. Downs to do this in 1948.

The Downs analysis provides a method of determining how the dentoskeletal pattern of the individual compares to the norms he established in his sample. His sample consisted of ten males and ten females, twelve to seventeen years of age, each having excellent dental occlusion, balance, and harmony of facial musculature.

Downs divided his analysis into (1) the Skeletal Pattern, and (2) Relationship of Denture to Skeletal Pattern, and employed five different measurements in each of the headings. Downs emphasized the importance of using the analysis in its entirety rather than depending upon just a few of the ten measurements.

In 1951, Craig compared the facial patterns of Class I and Class II, division 1 malocclusion. The method involved measuring tracings of oriented head films related to a grid system of horizontal and vertical lines. Each tracing was placed over millimeter graph paper that was divided into four quadrants by two coordinates, one horizontal, one vertical, which intersect each other in the center of the paper.

Serial tracings of lateral head films were placed so that the center of sella turcica was superposed at the intersection of the horizontal and vertical axes with the Frankfort horizontal plane parallel to the horizontal axis. Thus, the location of any anatomical point could be recorded as its distance (nearest 0.5 mm) from each of the vertical and horizontal coordinates. The reading for any point then gave its location in relation to all other points.

Steiner published his cephalometric analysis in 1953. It was his desire to produce an assessment that would be of value to the clinical orthodontist and also could be "more easily understood by parents with whom we discuss them".

In all, the Steiner analysis involves thirteen measurements which include the angular measurements of SNA, SNB, the ANB difference, Go-Gn-SN, occlusal plane to SN, interincisal angle, angle formed by the mandibular incisor with the mandibular plane, maxillary first molar to the NA line and the mandibular first molar to the NB line.

Sassouni, in a study of 100 lateral headfilms, developed an analysis for studying the structural organization of the skull, using as a cranial base the anterior fossa. He sought to find some acceptable constant relationships to use in diagnosis and treatment planning. The four main horizontal planes used for reference are anterior cranial base plane, occlusal plane, palatal plane, and mandibular base plane. In a well-proportioned face, these four planes meet in a single common point 0 which lies posterior to the occipital contour. With point 0 as a center, anterior and posterior arcs are established using 0-ANS and 0-S as radii.

Williams (1953) investigated craniofacial proportions in the horizontal and vertical planes before and after the onset of puberty. He superposed the lateral headfilms on the sella-nasion plane using sella as the registration point. Tracings were made on graph paper so that the paper was divided into four quadrants by the S-N lines and a perpendicular to this line erected at sella as the vertical reference axis. The position of each landmark could then be established to two reference axes. The distances were recorded in millimeters and subjected to statistical analysis to establish a mean distance, mean proportion, standard deviation and range for each measurement.

Moorrees (1953) presented the results of a study on the range of variation in the dentofacial complex in individuals with normal occlusion.

In his study he employed a mesh diagram similar to the one introduced to orthodontics by de Coster. Unlike de Coster, he oriented his mesh to the skull base (N-S line) and the lowest border of the body chin. The mesh consists of sixteen squares within the frame that is constructed by a line that joins nasion to the midpoint of sella, a line passing downward from nasion at eighty-five degrees to the N-S line, and two lines perpendicular to A, and one through N (line B) and the other passing through the lowest point of the bony chin (line C). The vertical posterior boundary is determined by dividing the N-S distance into three equal parts, and adding the length of one part to the occipital end of line B. From this point a perpendicular is drawn downward to meet line C. The basic rectangle is then divided so that sixteen equal rectangles result.

Moorrees used eight basic landmarks and superposed individual tracings on the mesh constructed as outlined above. The proportionate differences between the individual and the average facial pattern was thus illustrated.

Bjork (1955) investigated the effects of posterior cranial anatomy on facial prognathism as well as the relationship of facial build to occlusion. He devised a facial diagram to determine facial prognathism by means of linear and angular measurements. These measurements are assessed individually, in relation to one another, and as interrelated parts of the total facial diagram.

His diagram was constructed as follows: A line drawn from the apex of the anterior nasal spine to nasion, to the center of sella turcica, to articulare to the point of intersection between lines tangent to the base and the ramus of the mandible, to a point between lines tangent to the base of the mandible to pogonion, and from there to infradentale.

Bjork used the S-N line as a reference plane and measured points on the facial profile to this plane. This facilitates the orientation of the facial profile to the cranial base by using nasion as a constant point of reference.

In the same year, Altemus published a report on the dentofacial relationships in normal and Class II, division 1 malocclusions. He selected landmarks on the mandible and upper face and analyzed anteroposterior dysplasia of the upper face using a linear system similar to Wylie's. Fifteen linear and four angular measurements were made to assess mandibular morphology. Perpendiculars were constructed from the reference line, the Frankfort horizontal plane, to the selected landmarks in the mandible and the measurements were recorded.

In 1958, Kean presented a cephalometric study to determine the variations in facial depth relative to the type of occlusion. He used a coordinate system in the analysis of two groups of children, one with Class II, division 1 malocclusion, the other group with normal occlusion. The Frankfort plane and a perpendicular to this erected at nasion were the axes of references. Measurement of facial height were measured to the horizontal axis (F-H plane); facial depth was measured to the perpendicular. The linear measurements were read with a specially constructed glass scale calibrated in millimeters.

The scale was constructed by taping fine stainless steel wire along the horizontal and vertical centimeter lines of the graph paper mounted on stiff cardboard. This wire mesh was then radiographed. Onto this film of enlarged centimeter squares, a standard series of squares having ten divisions per side was "fitted" by image projection. The film was then removed and a photographic glass plate was exposed to the fitted image. Thus, a permanent scale duplicating the enlarged millimeter squares was obtained which was enlarged exactly as the original headplate. Distances between landmarks in the midsagittal plane could now be read directly from the tracing placed on the glass slide.

Harris, Johnston and Moyers (1963) constructed a template to indicate the degree of harmony of disharmony of the craniofacial complex. The template was patterned after craniofacial construction used by the University of Toronto in a study of children in Burlington, Ontario.

The Bolton-nasion plane was used for orienting the headfilms along with the mean occlusal plane. Growth vectors were obtained by a regression analysis of scattergrams of three selected landmarks. This provided information to construct rectangular areas for each landmark at each age investigated. The rectangles were designed to delineate the area within which each measured landmark would fall in sixty-eight per cent of the sample. Plastic templates were then constructed for boys and girls in the age range of four to sixteen years old. The templates could then be used for comparison of individuals to a cross-sectional sample of children of the same age and sex.

Huggins and Burch (1964) studied the position of procumbent maxillary incisors before and after their retraction in malocclusions requiring bilateral extraction of teeth. They employed a transparent grid scribed with one millimeter squares oriented on the plane formed by joining the anterior and posterior nasal spines. The authors took the anterior nasal spine as a stable point from which to measure anteroposterior changes in position of the maxillary incisors. The vertical changes were measured from the incisal tip of the tooth directly to the ANS-PNS plane. All the measurements were recorded in millimeters and analyzed to determine the mean and range of change in positions of the maxillary incisors before and after the treatment.

In 1965, Wall used a rectangular coordinate system to assess changes in the maxilla and positions of the teeth during, or as a result of, orthodontic treatment.

The sella-nasion plane was chosen as the horizontal plane of reference and the mid-point of sella turcica as the registration point. Landmarks on lateral headfilms were spotted by perforating a small hole through the film. Each spotted headplate was returned to the illuminating table with a sheet of millimeter paper under the film. The graph paper was oriented to the horizontal reference line (S-N), and a needle, as used to spot the headplates, was employed to perforate the graph paper from the previously spotted film. Measurements from the selected landmarks to the vertical and horizontal axes were then recorded before and after treatment.

Since 1931, cephalometric roentgenography has developed into a valuable diagnostic aid for the clinical orthodontist. Its technique has been refined; landmarks, measuring points, reference planes and angles, along with nomenclature, have been standardized.

Interest in the employment of electronic computers for medical diagnosis has developed in the last decade. The automata have been used extensively for the diagnosis, among others, of hematological diseases, psychological disorders, and cardiovascular problems.

Computers have not as yet been applied to dentistry for diagnosis. It is proposed that these high-speed data processing machines be applied to orthodontics with the aim of developing a method of diagnosis.

CHAPTER III

METHODS AND MATERIALS

A. Selection of the Sample:

Fifty young adult Caucasian males were selected for this study. These subjects were chosen on the basis of their excellent occlusions. The arrangement and functional occlusion of their dentition satisfied, as nearly as possible, the concepts and standards of ideal occlusion. None of those selected had undergone, nor was undergoing, orthodontic treatment.

Approximately 500 potential subjects were screened and examined. The examination consisted of three parts:

1. Extraoral evaluation of the face and jaws.
2. Functional analysis of the temporomandibular joint and mandibular excursions.
3. Intraoral examination of the hard and soft tissues.

Candidates were eliminated if any facial asymmetry or pathology was noted. No subject was accepted if functional or pathological disorders of the temporomandibular joints were discovered or if mandibular deviations were detected during jaw movements.

In addition to the aforementioned requirements, examinees were excluded from the study if any of the following conditions were disclosed:

1. Pathology of the hard or soft oral structures.
2. Missing teeth (except third molars).
3. Occlusion of any of the teeth in a position other than neutroclusion, in both the anteroposterior and medio-lateral directions, when the teeth were in centric occlusion.
4. Pronounced arch constriction and/or asymmetry in either of the arches.
5. Excessive procumbency of the maxillary and/or mandibular anterior teeth.
6. Overjet and/or overbite of more than four and one-half millimeters.
7. Rotation of any tooth of more than twenty degrees.
8. Broken contacts displacing any tooth more than two millimeters from the arch.
9. Spacing between any two adjacent teeth of more than two millimeters.
10. Teeth in poor repair or repaired with extremely large restorations.

Fifty-five candidates were chosen from the examined population. Records consisting of lateral cephalograms, intraoral roentgenograms, facial photographs and dental impressions were taken on each of the fifty-five subjects. After reevaluation and review of their diagnostic records, a final sample of fifty was selected.

At the time of record procurement, each subject was assigned an identification number. This not only assisted in brevity of identification, but also eliminated bias that might have arisen if the material being investigated was not so coded.

The subjects' dates of birth were also recorded. The mean age of the final sample was 25 years, 6.3 months. Their ages ranged from 20 years, 11 months to 36 years, 3 months.

B. Cephalometric Technique:

The lateral headplate radiographs employed in this study were taken on a standard cephalometric machine (Universal). The tube housing of this machine incorporates a rotating anode and a high voltage generator providing a machine setting of 90 KVP and 45 milliamperes. The exposure time for all films was one second.

The cephalostat provided a fixed distance of sixty inches from the focal point of the roentgen tube to the midsagittal planes. The use of the head-holder was necessary to prevent distortion errors due to movement of the subject's head and to allow the operator to place each successive participant in the same spatial relationship to the roentgen-ray tube. The midsagittal plane to film distance was kept constant at fifteen centimeters.

Each subject was oriented in the cephalostat so that his projected Frankfort horizontal plane was parallel to the floor. The ear rods and orbitale marker were used to aid fixing the head in this position. The subjects were instructed to maintain their teeth in full occlusion and to avoid any movement during the exposure of the film.

The radiographic film used was 8 by 10 inch high speed, Blue Brand, Kodak medical X-ray film. Each cassette was equipped with double high-speed intensifying screens to eliminate secondary radiation and to provide greater contrast. Development following the usual time-temperature method recommended by the Eastman Kodak Company was adhered to for all films.

C. Description of the Rectangular Coordinate System:

Rectangular coordinates were employed in the evaluation of the cephalograms. This method of assessment is extremely versatile; not only are landmarks precisely located, but angles are evaluated, linear distances measured and points of intersection located.

This system of measurements is readily adaptable to the process of data reduction. Thus, this inquiry explored the possibilities of combining rectangular coordinate measurements obtained from the cephalograms with electronic computers so a program of computerized orthodontic diagnosis can be developed.

Through further investigation, it is hoped that orthodontic diagnosis and treatment planning, as well as the assessment of growth and treatment can be programmed to electronic computers.

Sella turcica was selected as the point of origin to which all other points were related. Orthogonal reference axes were constructed to sella and all points were then measured to these axes. A line from sella turcica to nasion represented the horizontal reference axis, and a perpendicular to this line at sella represented the vertical reference axis. Thus, a system of rectangular or Cartesian coordinates was developed.

D. Spotting Technique:

Selected landmarks were spotted on each of the lateral cephalometric headplates. The spotting was accomplished by piercing a small hole through the cephalogram where the landmark was determined to be. A definite sequence was followed throughout all spotting procedure.

All work was performed in a darkened room. No one spotting session lasted longer than thirty minutes. At the end of this time, the investigator entered an adequately lighted room for at least ten minutes, after which time the work was again resumed. These precautions were necessary to prevent eye strain and to reduce error due to fatigue.

The procedure was to place a sheet of cellulose acetate paper 0.002 of an inch thick on a transilluminated tracing table. Each headplate to be spotted was then placed on top of the acetate. The acetate paper not only provided a uniform thickness between the headplate and plastic surface of the tracing table, but also aided in producing pinhole perforations of uniform diameter. The perforations were made by a phonograph needle test probe. The point of the probe was placed at the selected landmark and forced through the film into the underlying acetate paper. The phonograph needles were replaced after spotting ten headplates in order to have a consistently sharp point with which to make uniformly small perforations.

To eliminate errors in locating sella turcica and nasion, the points orienting the horizontal reference axis, this investigator located these landmarks on all films after which their locations were corroborated by the original spotter and the author of the companion thesis. All other landmarks, if not readily identified by this investigator, were located by two others, and their locations were determined on a two-out-of-three vote basis with this investigator and the two corroborators participating.

To locate the spotted points in the rectangular coordinate system it was necessary to establish a rectangular grid system.

This was provided by coordinate paper laid off in major divisions of centimeters and minor divisions of millimeters. Engineering paper fulfilling these requirements were obtained (Clearprint Paper Co. #C39). These sheets were 8-1/2 by 11 inches in size and provided one major centimeter line for every ten minor millimeter lines.

Each spotted headplate was returned to the tracing table with a sheet of the graph paper placed between it and the cellulose acetate paper. The graph paper was oriented so that sella turcica was located at the intersection of two major centimeter lines. Sella was located at the intersection of the twelfth major vertical line from the left (8-1/2 inch) side of the graph sheet with the second major horizontal line from the top (11 inch) edge of the paper. These reference axes were then marked for easy identification by drawing over them with a fine, sharp, hard lead pencil. Sella turcica was then uniformly located on all sheets. When sella was placed in its correct position to the graph paper, the sheet was rotated so that nasion was located on the same horizontal major centimeter line (second from the top). With these two points correctly located on the grid, the film and graph sheet were fixed together with transparent cellulose tape (Figure 1).

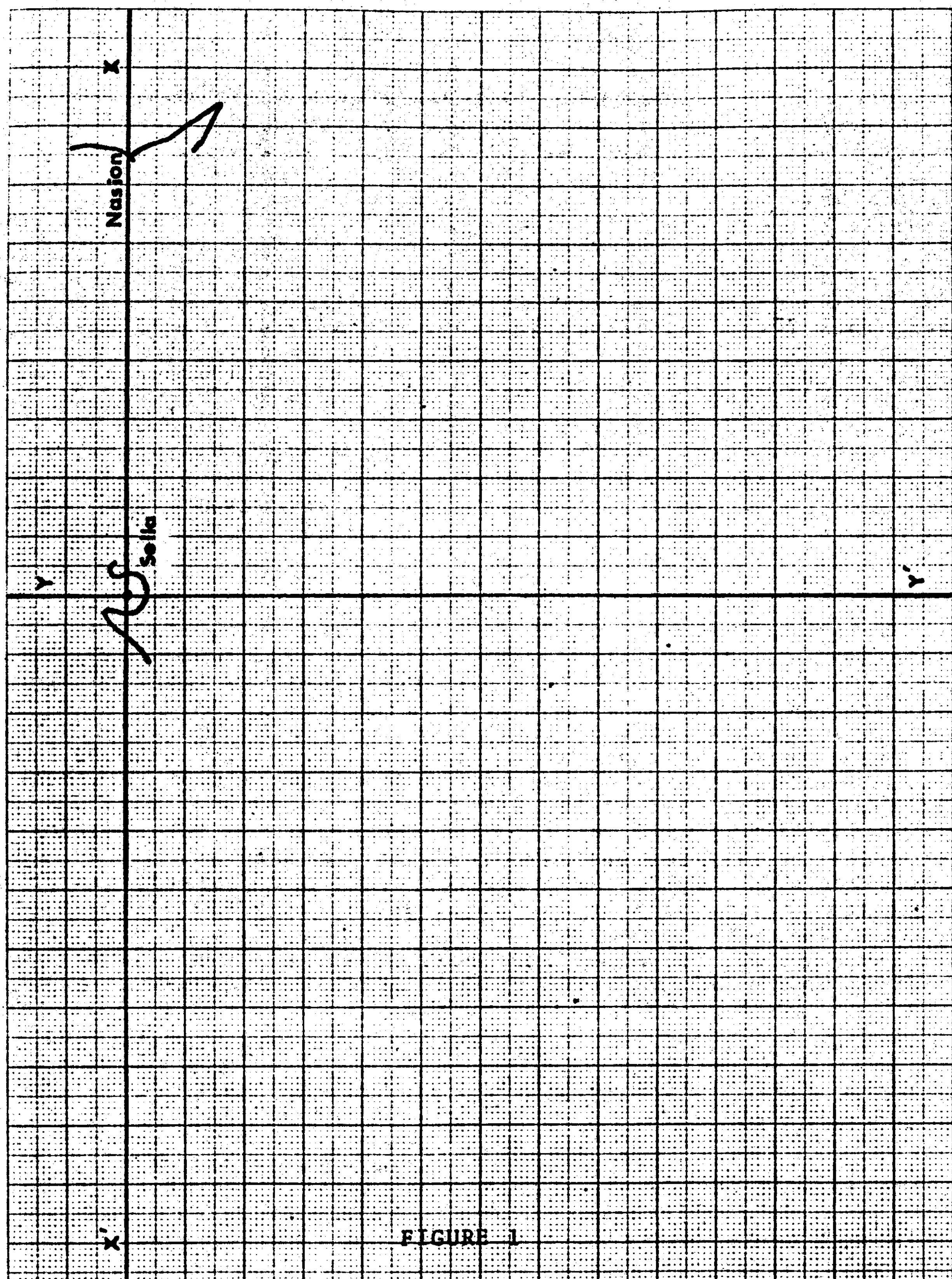


FIGURE 1

LOCATION OF SELLA AND NASION ON HORIZONTAL AXIS

The phonograph needle was then used to reenter the perforations made previously in the headfilms to pierce the graph paper at the precise location of each landmark. The same conditions and procedures were followed in spotting the graph sheets as were adhered to in the original spotting sessions. After each graph sheet was spotted, the graph paper was correctly oriented on top of the headplate. Each pinhole was carefully located and circled with a hard, sharp pencil and marked with a previously assigned identification number.

E. Description of Selected Landmarks:

The landmarks used in this investigation were selected because of their clinical interest, diagnostic importance and ease and accuracy of identification. When possible, midsagittal plane structures were used. Most of the points were identified by inspection. The method involved to fix the location of points that required construction lines is described with each so established landmark. In their description, the landmarks are numbered and appear in the same order as they appeared on the recording sheet (Figure 2).

1. Anterior Nasal Spine (ANS) - The most anterior point on the hard palate.
2. A Point (Jarabak) - A point measured two millimeters anterior to the intersection of a line drawn from the

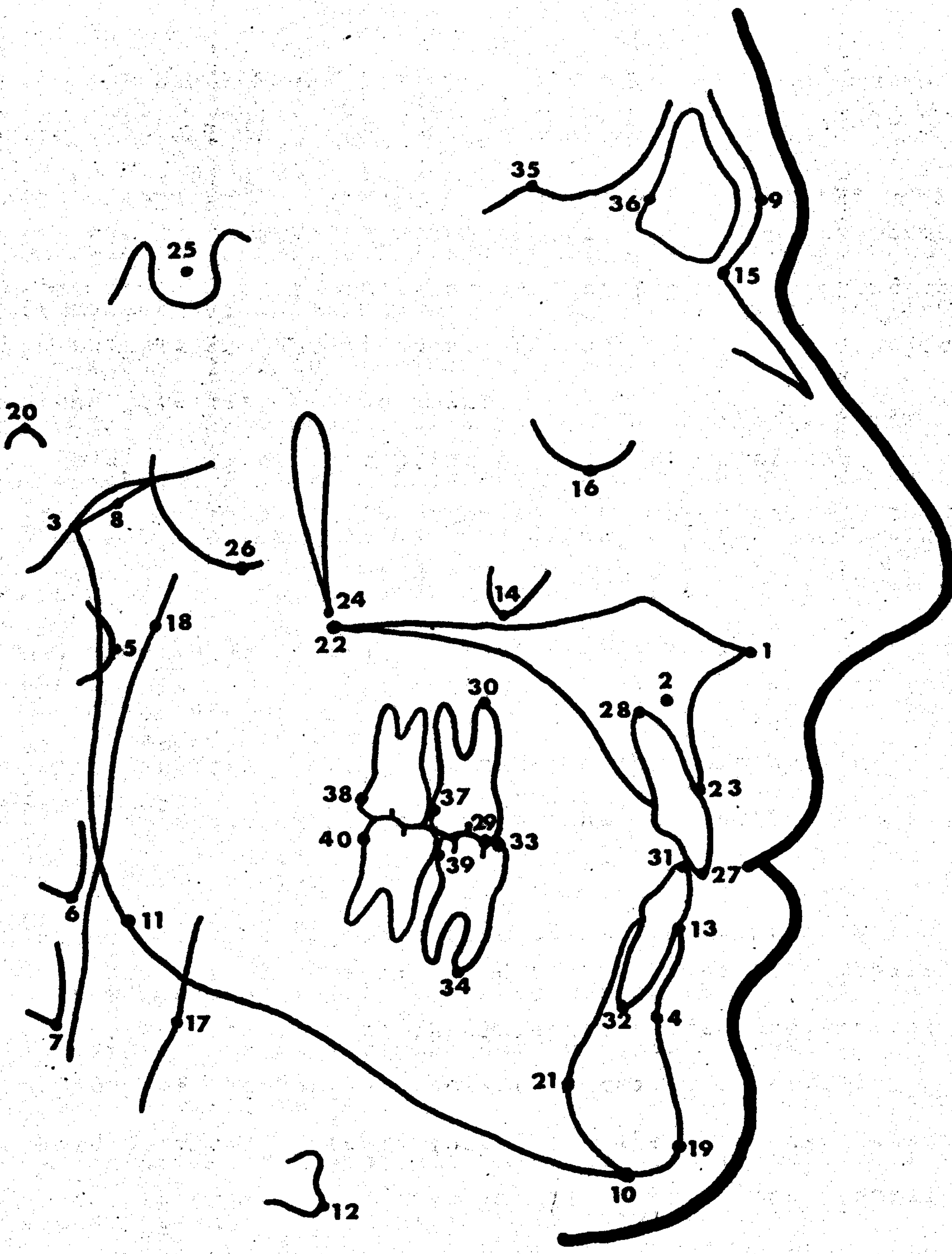


FIGURE 2

LOCATION OF CEPHALOMETRIC LANDMARKS

apex perpendicular to a line tangent to the root and parallel to the long axis of the tooth.

3. Articulare (Ar) - The point of intersection of the dorsal contour of the articular process of the mandible and the os temporale. The midpoint was used when double projections gave rise to two points.
4. B Point - The deepest point on the contour of the alveolar projection, between infradentale and pogonion. If this landmark was represented by a plane, a point on that plane established by a perpendicular drawn from the long axis of the mandibular central incisor at its apex, was designated as "B" Point.
5. First Cervical Vertebra (1st CV) - The most prominent point on the ventral contour of the body of the first cervical vertebra.
6. Second Cervical Vertebra (2nd CV) - The point established by the intersection of the inferior border and ventral boundry of the body of the second cervical vertebra.
7. Third Cervical Vertebra (3rd CV) - The point established by the intersection of the inferior border and ventral boundry of the body of the third cervical vertebra.
8. Condyle (Co) - The midpoint of a line drawn from articulare to the intersection of the ventral contour of the

articular process of the mandible and the os temporale.

9. Gladbella (Gl) - The most prominent point in the mid-sagittal plane of the bony prominence joining the supraorbital ridges.

10. Gnathion (Gn) - The lowest point of the median plane in the lower border of the chin.

11. Gonion (Go) - The lowest, posterior and most outward point of the angle of the mandible. This was established by bisecting the angle formed by tangents to the lower and posterior borders of the mandible. When both angles appeared on the roentgenogram, the point midway between the right and left side was used.

12. Hyoid Bone (HB) - The most prominent point on the ventral contour of the body of the hyoid bone.

13. Infrandentale (In) - The point of transition from the crown of the most prominent mandibular central incisor to the alveolar projection.

14. Key Ridge (KR) - The most inferior point of the zygomaticomaxillary ridge. When both points appeared on the radiograph, the point midway between the right and left side was used.

15. Nasion (N) - The anterior limit of the frontonasal suture.

16. Orbitale (Or) - The deepest point on the infraorbital margin. The midpoint was used when double projections gave rise to two points.

17. Anterior Pharynx (Ant Phar) - The most ventral point of the pharynx on a horizontal line passing through the point of identification for the third cervical vertebra.

18. Posterior Pharynx (Post Phar) - The most dorsal point of the pharynx on a horizontal line passing through the point of identification representing the posterior nasal spine.

19. Pogonion (Po) - The most anterior prominent point on the chin.

20. Porion (Por) - The midpoint on the superior margin of the external auditory meatus.

21. Posterior Cortical Plate of the Symphysis (PCP) - The most prominent point on the dorsal contour of the posterior plate of the mandibular symphysis.

22. Posterior Nasal Spine (PNS) - The most posterior point on the hard palate.

23. Prosthion (Pr) - The transition point between the crown of the most prominent maxillary central incisor and the alveolar projection.

24. Pterygomaxillary Fissure (PTM) - The most inferior

point of the pterygomaxillary fissure.

25. Sella Turcica (S) - The midpoint of the horizontal axis of sella turcica.

26. Sigmoid Notch (Sig Not) - The deepest point on the contour of the sigmoid notch.

27. Tip of Crown of $\underline{1}$ (TC $\underline{1}$) - The incisal point of the most prominent maxillary central incisor.

28. Apex of $\underline{1}$ (TR $\underline{1}$) - The apex of the root of the most prominent maxillary central incisor.

29. Tip of Crown of $\underline{6}$ (TC $\underline{6}$) - The most mesiocclusal point of the maxillary left first molar.

30. Apex of $\underline{6}$ (TR $\underline{6}$) - The apex of the mesial root of the maxillary left first molar.

31. Tip of Crown of $\overline{1}$ (TC $\overline{1}$) - The incisal point of the most prominent mandibular central incisor.

32. Apex of $\overline{1}$ (TR $\overline{1}$) - The apex of the most prominent mandibular central incisor.

33. Tip of Crown of $\overline{6}$ (TC $\overline{6}$) - The most mesiocclusal point of the mandibular left first molar.

34. Apex of $\overline{6}$ (TR $\overline{6}$) - The apex of the mesial root of the mandibular left first molar.

35. Interplate of the Frontal Bone (FB) - A point on the frontal bone bordering the posterior boundry of the

frontal sinus on the horizontal plane passing through glabella.

36. Crista Galli (CG) - The most superior tip of the crista galli of the ethmoid bone.

37. Distal of Crown of $\underline{6}$ (DC $\underline{6}$) - The most prominent point on the distal curvature of the maxillary left first molar.

38. Distal of Crown of $\underline{7}$ (DC $\underline{7}$) - The most prominent point on the distal curvature of the maxillary left second molar.

39. Distal of Crown of $\overline{6}$ (DC $\overline{6}$) - The most prominent point on the distal curvature of the mandibular left first molar.

40. Distal of Crown of $\overline{7}$ (DC $\overline{7}$) - The most prominent point on the distal curvature of the mandibular left second molar.

F. Measuring Techniques:

Data sheets were designed so that information acquired during spotting of the headplates could be recorded in tabular form. A list of the landmarks measured was entered in the left hand vertical column of each data sheet. A set of vertical columns were placed to the right of the column of landmarks. This set was divided into an x and y column to represent the abscissa and ordinate of each recorded point. The readings were marked positive or negative corresponding to the quadrant within which they were located.

A vernier caliper measuring to 0.1 millimeter was used in obtaining the readings for each point on the graph sheet. A systematic procedure of measuring was carried out by first reading all the horizontal measurements and then rotating the graph sheet ninety degrees to read all vertical measurements. Care was taken to insure that the beaks of the calipers were accurately placed over each pinhold and were correctly oriented with respect to the reference axis. As each reading was made on the vernier scale, it was recorded in the correct column on the data sheet. Measuring procedures were conducted under the same conditions as employed in the spotting techniques.

This method of measurement has been shown to be precise and accurate. Wall (1965) has demonstrated that the ninety-five percent confidence limits of this technique are plus or minus one-half millimeter.

This means, ranges, standard deviations and ninety-five percent confidence limits of all the x and y readings were then computed and recorded.

G. Selection of Diagnostic Cephalometric Measurements:

The forty cephalometric landmarks selected for this study gave rise to numerous linear distances, angles, and combinations thereof worthy of investigation. It is not within the scope of this inquiry to examine all the possibilities, but rather to study cephalometric values that were of vital diagnostic importance and clinical interest. Many of the distances and angles studied are presently accepted. The merit of these measurements in cephalometric assessment and diagnosis has been demonstrated. Other measurements used had not been previously investigated, but their values appeared to be of clinical and diagnostic significance. Whether the angles and distances investigated were familiar or not studied previously, means and normal ranges for them were determined for the young adult male population.

The angles or distances used in a cephalometric analysis can aid in assessing either the skeletal or dentoalveolar arrangement of the cranium, teeth, and jaws. Therefore, any cephalometric measurement can be placed arbitrarily into one of two broad groups: the category that assesses the skeletal parts and the portion that evaluates the teeth and surrounding alveolar bone. The skeletal assessment can in turn be subdivided. For the purpose of this inquiry, it was separated into three parts: the posterior cranial assessment, the anterior cranial assessment, and the facial and growth axis assessment. The measurements evaluating the dentoalveolar relationships were placed into one of two groups:

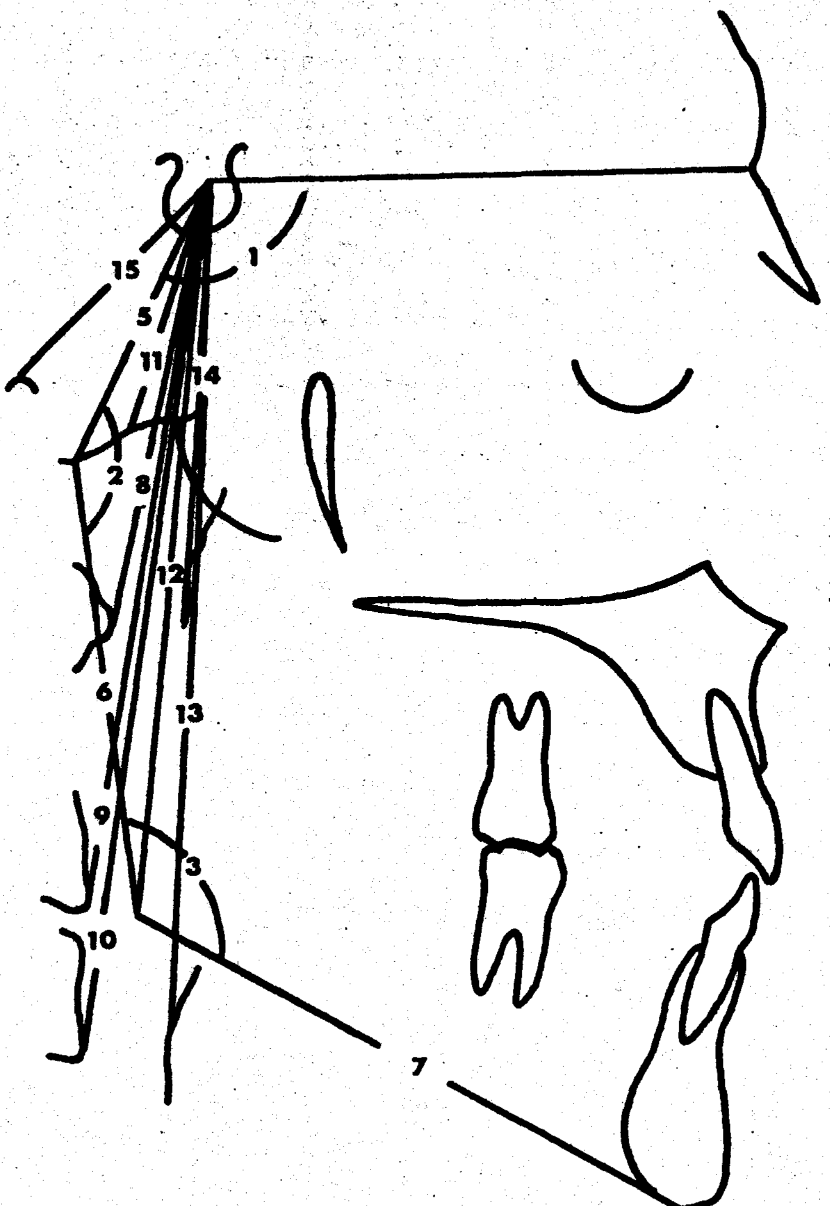
maxillary or mandibular assessment. With the development of a cephalometric diagnosis applicable to an electronic computer in mind, this plan of approach appeared to be the most logical and reasonable. Therefore, in the listing and description of the various cephalometric measurements investigated, each appears within the group to which it contributes.

Cephalometric Measurements:

I. Skeletal Assessment:

A. Posterior Cranial Assessment (Figure 3):

1. Saddle Angle - measurement of the angle at sella turcica formed by the lines nasion - sella - articulare.
2. Articulare Angle - measurement of the angle at articulare formed by the lines sella - articulare - gonion.
3. Gonial Angle - measurement of the angle at gonion formed by the lines articulare - gonion - gnathion.
4. Sum of the Three Angles - the total of the three above angles.
5. Posterior Cranial Base Length - the distance of a line drawn from sella turcica to articulare.



KEY

1. Saddle Angle
2. Articulare Angle
3. Gonial Angle
4. Sum
5. PCB Length
6. Ramus Height
7. Body Length
8. S - 1st CV
9. S - 2nd CV
10. S - 3rd CV
11. S - Co
12. S - Go
13. S - Ant Phar
14. S - Post Phar
15. S - Por

FIGURE 3

CEPHALOMETRIC MEASUREMENTS - POSTERIOR CRANIAL ASSESSMENT

6. Ramus Height - the distance of a line drawn from articulare to gonion.
7. Mandibular Body Length - the distance of a line drawn from gonion to gnathion.
8. Sella to First Cervical Vertebra - the linear distance from sella to the point identifying the first cervical vertebra and the angle formed by the line and the horizontal reference axis (abscissa).
9. Sella to Second Cervical Vertebra - the linear distance from sella to the point identifying the second cervical vertebra and the angle formed by that line and the abscissa.
10. Sella to Third Cervical Vertebra - the linear distance from sella to the point identifying the third cervical vertebra and the angle formed by that line and the abscissa.
11. Sella to Condyle - the linear distance from sella to the point identifying the condyle and the angle formed by that line and the abscissa.
12. Sella to Gonion - the linear distance from sella to the point identifying gonion and the angle formed by that line and the abscissa.

13. Sella to Anterior Border of the Pharynx - the linear distance from sella to the point identifying the anterior border of the pharynx and the angle formed by that line and the abscissa.

14. Sella to Posterior Border of the Pharynx - the linear distance from sella to the point identifying the posterior border of the pharynx and the angle formed by that line and the abscissa.

15. Sella to Porion - the distance from sella to the point identifying porion and the angle formed by that line and the abscissa.

B. Anterior Cranial Assessment (Figure 4):

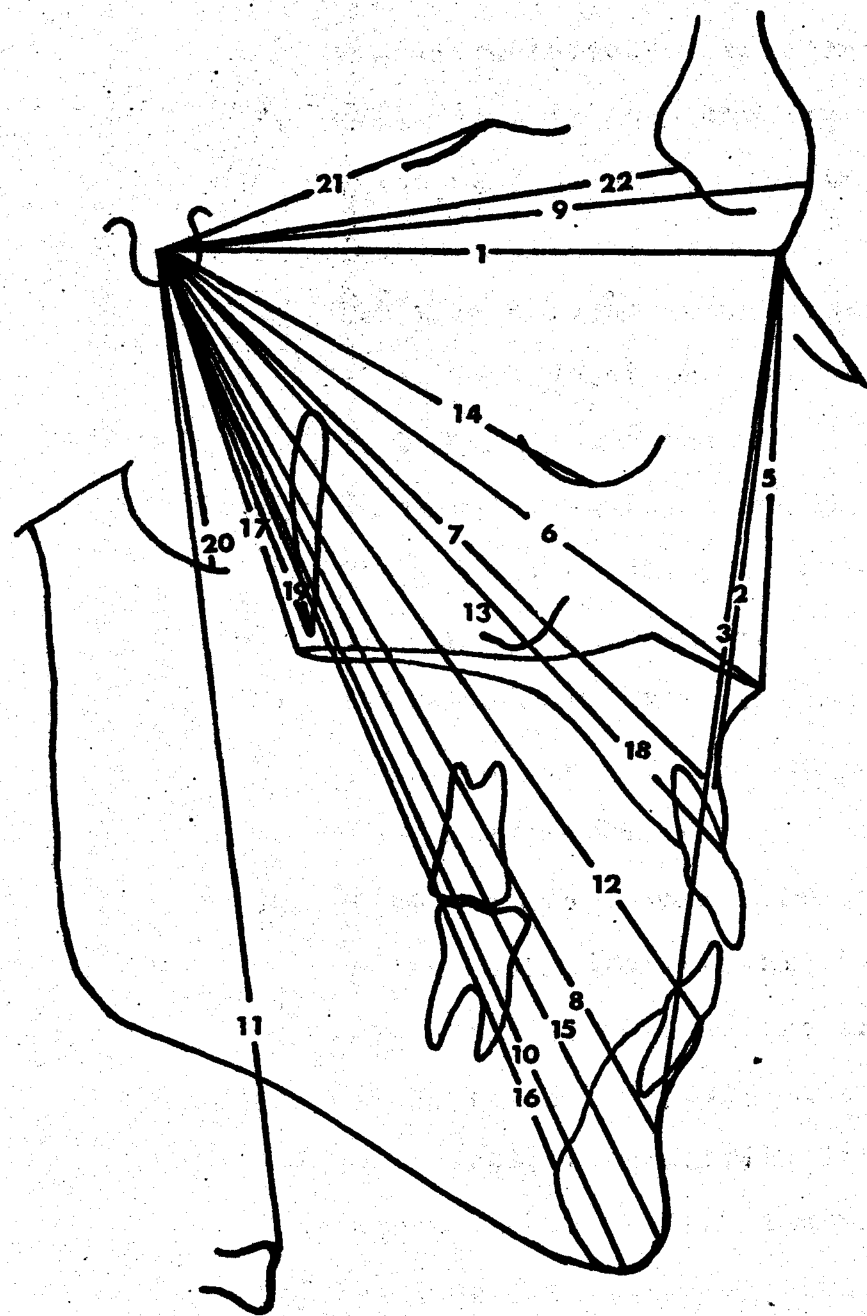
1. Anterior Cranial Base Length - the linear distance from sella turcica to nasion.

2. Angle SNA - measurement of the angle at nasion formed by the lines sella - nasion - A point.

3. Angle SNB - measurement of the angle at nasion formed by the lines sella - nasion - B point.

4. ANB Difference - the difference in degrees obtained by subtracting SNB from SNA.

5. Nasion to Anterior Nasal Spine - the linear distance from nasion to anterior nasal spine.



KEY

1. ACB Length
2. SNA
3. SNB
4. ANB
5. N - ANS
6. S - ANS
7. S - A Point
8. S - B Point
9. S - Gl
10. S - Gn
11. S - HB
12. S - In
13. S - KR
14. S - Or
15. S - Po
16. S - PCP Sym
17. S - PNS
18. S - Pr
19. S - PTM
20. S - Sig Not
21. S - CG
22. S - FB

FIGURE 4

CEPHALOMETRIC MEASUREMENTS - ANTERIOR CRANIAL ASSESSMENT

6. Sella to Anterior Nasal Spine - the linear distance from sella to anterior nasal spine and the angle formed by that line and the abscissa.
7. Sella to A Point - the linear distance from sella to A point and the angle formed by that line and the abscissa.
8. Sella to B Point - the linear distance from sella to B point and the angle formed by that line and the abscissa.
9. Sella to Glabella - the linear distance from sella to glabella and the angle formed by that line and the abscissa.
10. Sella to Gnathion - the linear distance from sella to gnathion and the angle formed by that line and the abscissa.
11. Sella to Hyoid Bone - the distance from sella to the point identifying the hyoid bone and the angle formed by that line and the abscissa.
12. Sella to Infradentale - the distance from sella to the point identifying infradentale and the angle formed by that line and the abscissa.
13. Sella to Key Ridge - the distance from sella to the point identifying the key ridge and the

angle formed by that line and the abscissa.

14. Sella to Orbitale - the linear distance from sella to orbitale and the angle formed by that line and the abscissa.

15. Sella to Pogonion - the linear distance from sella to pogonion and the angle formed by that line and the abscissa.

16. Sella to the Posterior Plate of the Symphysis - the linear distance from sella to the point identifying the posterior plate of the symphysis and the angle formed by that line and the abscissa.

17. Sella to Posterior Nasal Spine - the linear distance from sella to posterior nasal spine and the angle formed by that line and the abscissa.

18. Sella to Prosthion - the linear distance from sella to prosthion and the angle formed by that line and the abscissa.

19. Sella to Pterygomaxillary Fissure - the linear distance from sella to the point identifying the pterygomaxillary fissure and the angle formed by that line and the abscissa.

20. Sella to Sigmoid Notch - the linear distance

from sella to the point identifying the sigmoid notch and the angle formed by that line and the abscissa.

21. Sella to Crista Galli - the linear distance from sella to the point identifying crista galli and the angle formed by that line and the abscissa.

22. Sella to Intertable of the Frontal Bone - the linear distance from sella to the point identifying the intertable of the frontal bone and the angle formed by that line and the abscissa.

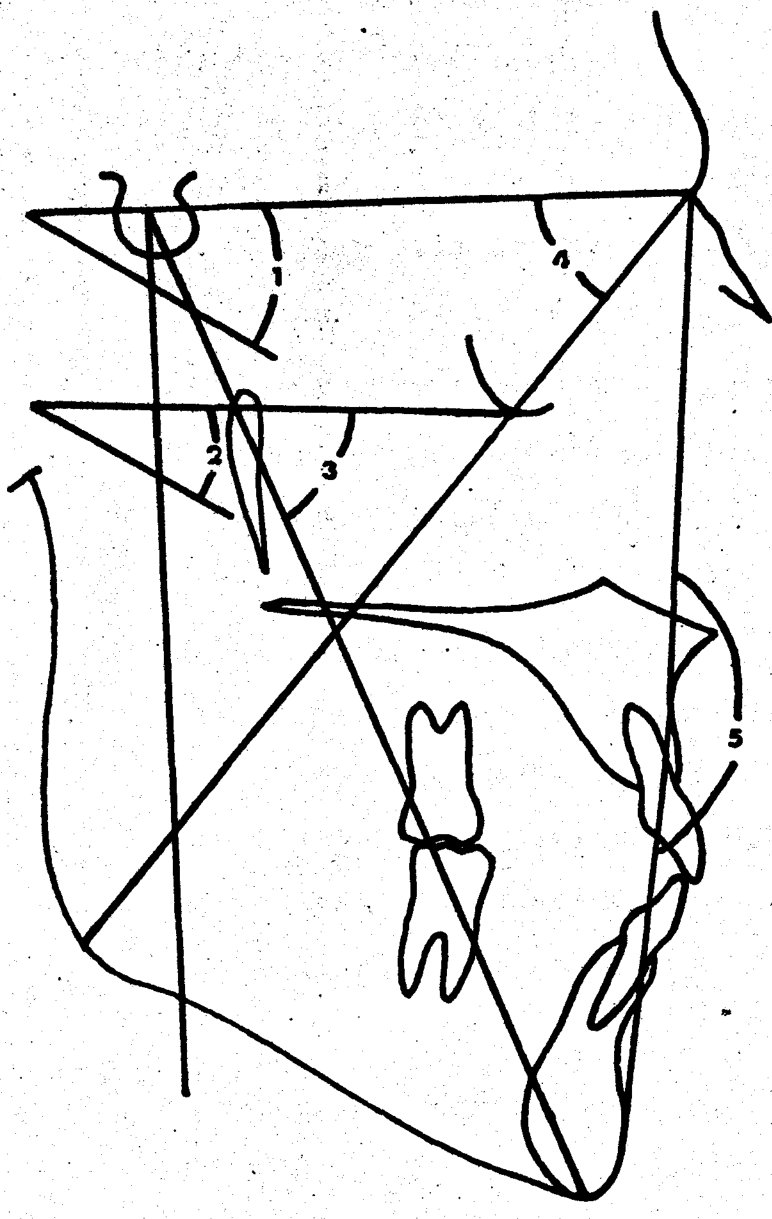
C. Facial and Growth Axis Assessment (Figure 5):

1. Angle Go-Gn-SN - the angle measured at the intersection of the lines drawn from gonion - gnathion and sella - nasion.

2. Angle FMA - the angle measured at the intersection of the lines drawn from orbitale - porion and gnathion - gonion.

3. Y- Axis - the angle measured at the intersection of the lines drawn from orbitale - porion and sella - gnathion.

4. Facial Depth Angle - the angle measured at nasion formed by the lines sella - nasion and nasion - gonion.



KEY

1. Go-Gn-SN
2. FMA
3. Y-Axis
4. Facial Depth Angle
5. Angle of Facial Convexity

FIGURE 5

FACIAL AND GROWTH AXIS ASSESSMENT

5. Angle of Facial Convexity - the angle measured at A point formed by the lines nasion - A point and A point - pogonion.

II. Dentoalveolar Assessment:

A. Maxillary Assessment (Figure 6):

1. Maxillary One to SN - the angle formed by the long axis of the maxillary central incisor and the line drawn from sella to nasion.

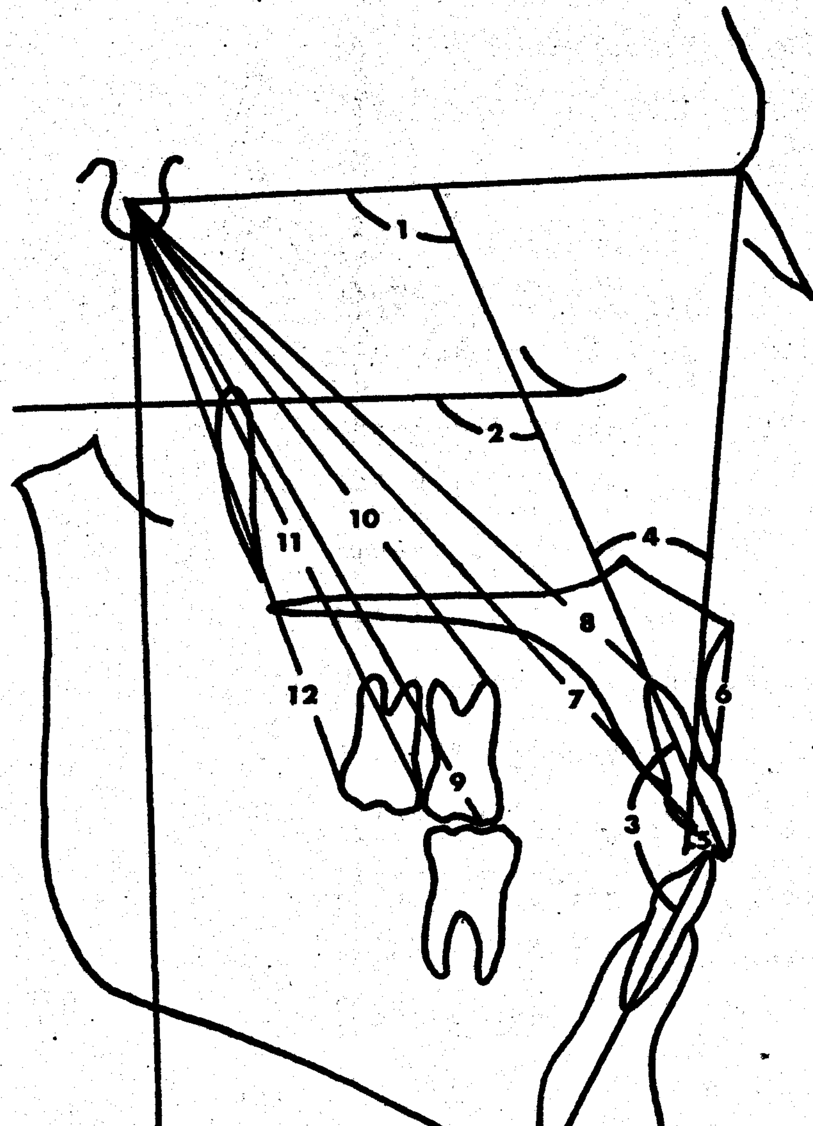
2. Maxillary One to FH - the angle formed by the long axis of the maxillary central incisor and the Frankfort horizontal plane.

3. Maxillary One to Mandibular One - the angle formed by the intersection of the long axes of the maxillary and mandibular central incisors.

4. Maxillary One to NA - the angle formed by the intersection of the long axis of the maxillary central incisor and the line drawn from nasion to A point.

5. Maxillary One to NA (mm) - the length of the line drawn from the tip of the crown of the maxillary central incisor perpendicular to the line drawn from nasion to A point.

6. Anterior Nasal Spine to Prosthion - the linear



KEY

1. $\underline{1}$ - SN
2. $\underline{1}$ - FH
3. $\underline{1}$ - $\overline{1}$
4. $\underline{1}$ - NA
5. $\underline{1}$ - NA (mm)
6. ANS - Pr
7. S - TC$\underline{1}$
8. S - TR$\underline{1}$
9. S - TC$\underline{6}$
10. S - TR$\underline{6}$
11. S - DC$\underline{6}$
12. S - DC$\underline{7}$

FIGURE 6

MAXILLARY DENTOALVEOLAR ASSESSMENT

distance from anterior nasal spine to prosthion.

7. Sella to Tip of Crown of Maxillary One - the distance from sella to the tip of the crown of the maxillary central incisor and the angle formed by that line and the abscissa.

8. Sella to Tip of Root of Maxillary One - the linear distance from sella to the tip of the root of the maxillary central incisor and the angle formed by that line and the abscissa.

9. Sella to Tip of Crown of Maxillary Six - the linear distance from sella to the point identifying the tip of the crown of the maxillary first molar and the angle formed by that line and the abscissa.

10. Sella to Tip of Root of Maxillary Six - the linear distance from sella to the point identifying the tip of the root of the maxillary first molar and the angle formed by that line and the abscissa.

11. Sella to Distal of Crown of Maxillary Six - the linear distance from sella to the point identifying the distal contour of the crown of the maxillary first molar and the angle formed by

that line and the abscissa.

12. Sella to Distal of Crown of Maxillary Seven - the linear distance from sella to the point identifying the distal contour of the crown of the maxillary second molar and the angle formed by that line and the abscissa.

B. Mandibular Assessment (Figure 7):

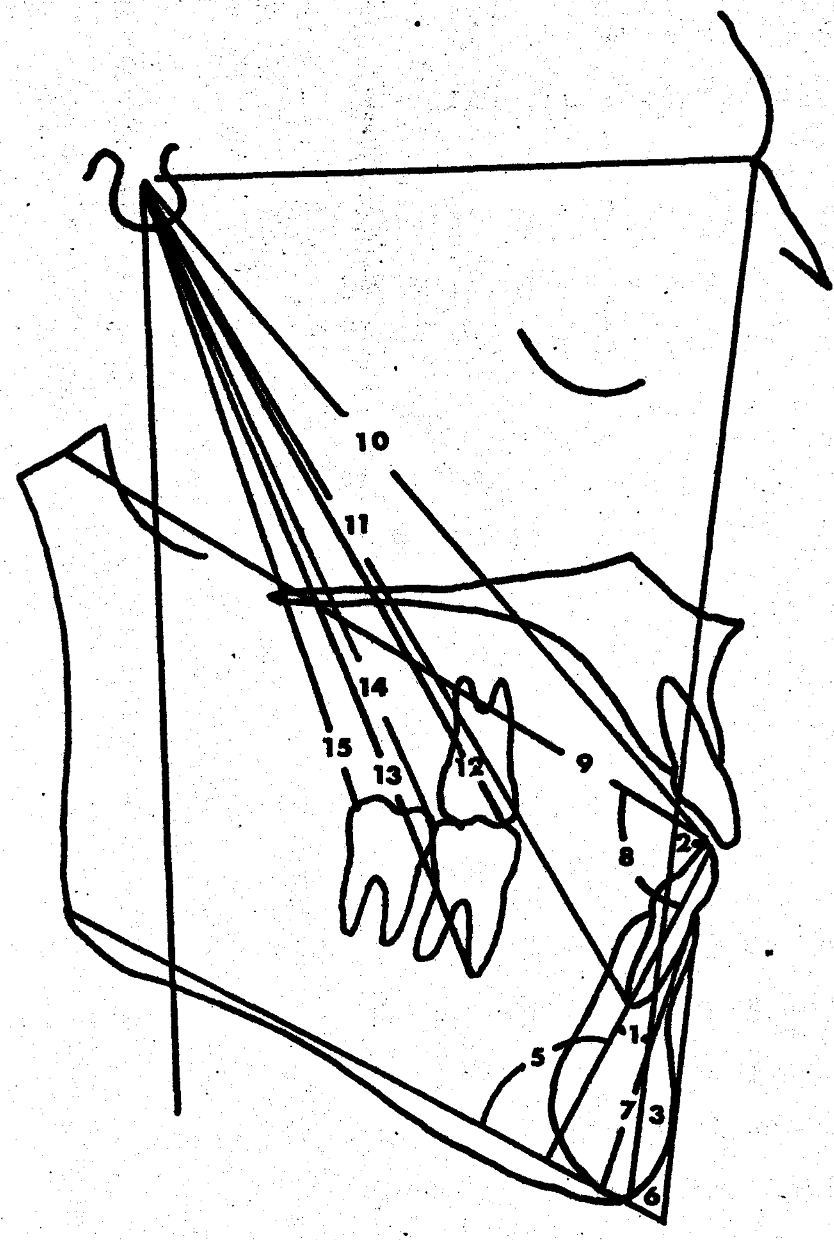
1. Mandibular One to NB - the angle formed by the intersection of the long axis of the mandibular central incisor and the line drawn from nasion to B point.

2. Mandibular One to NB (mm) - the linear distance of a line drawn from the tip of the mandibular central incisor perpendicular to the line drawn from nasion to B point.

3. Pogonion to NB - the linear distance of a line drawn from pogonion perpendicular to the line drawn from nasion to B point.

4. Mandibular One to Pogonion - the ratio of the distances of mandibular one to NB and pogonion to NB.

5. Angle IMPA - the angle formed by the intersection of the long axis of the mandibular



KEY

1. $\overline{1}$ - NB
2. $\overline{1}$ - NB (mm)
3. Po - NB
4. $\overline{1}$ - Po
5. IMPA
6. Chin Angle
7. Gn - In
8. Co - $\overline{1}$
9. Co - $\overline{1}$ (mm)
10. S - TC $\overline{1}$
11. S - TR $\overline{1}$
12. S - TC $\overline{6}$
13. S - TR $\overline{6}$
14. S - DC $\overline{6}$
15. S - DC $\overline{7}$

FIGURE 7

MANDIBULAR DENTOALVEOLAR ASSESSMENT

central incisor and a line drawn from gnathion to gonion.

6. Chin Angle - the angle formed by the intersection of the lines drawn from infradentale - pogonion and gnathion - gonion.

7. Gnathion to Infradentale - the linear distance from gnathion to infradentale.

8. Condyle to Tip of Crown of Mandibular Central Incisor - the angle formed by the intersection of the long axis of the mandibular central incisor and the line drawn from the point identifying the condyle to the tip of the mandibular central incisor.

9. Condyle to Tip of Mandibular Central Incisor (mm) - the linear distance from the point identifying the condyle to the tip of the mandibular central incisor.

10. Sella to the Tip of Crown of Mandibular One - the linear distance from sella to the tip of the crown of the mandibular central incisor and the angle formed by that line and the abscissa.

11. Sella to the Tip of Root of Mandibular One - the linear distance from sella to the tip of

the root of the mandibular central incisor and the angle formed by that line and the abscissa.

12. Sella to Tip of Crown of Mandibular Six - the linear distance from sella to the point identifying the tip of the crown of the mandibular first molar and the angle formed by that line and the abscissa.

13. Sella to Tip of Root of Mandibular Six - the linear distance from sella to the point identifying the tip of the root of the mandibular first molar and the angle formed by that line and the abscissa.

14. Sella to Distal of Crown of Mandibular Six - the linear distance from sella to the point identifying the distal contour of the crown of the mandibular first molar and the angle formed by that line and the abscissa.

15. Sella to Distal of Crown of Mandibular Seven - the linear distance from sella to the point identifying the distal contour of the crown of the mandibular second molar and the angle formed by that line and the abscissa.

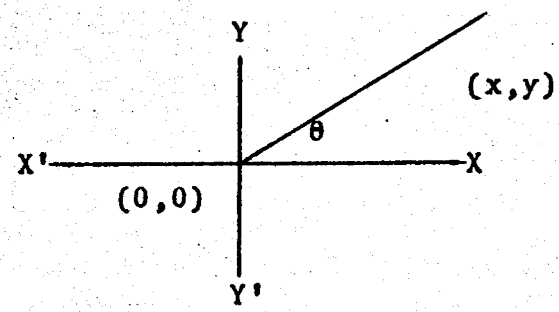
H. Description of Required Mathematical Equations to Compute Cephalometric Measurements by an Electronic Computer:

For an electronic computer to be effective in the solution of a scientific problem, the problem-solving procedure must be presented to the computer in a language it can "understand". The computer's basic language consists of elementary instructions such as add, subtract, shift a number right or left, or punch a card. The problem-solving procedure therefore must be translated into simple instructions the computer is capable of obeying.

The mathematical problems in this undertaking were to read linear distances or angles from a system of coordinates. Given a set of coordinates it was mathematically feasible to determine the length of a line dictated by these number pairs. Likewise it was possible to compute angles from three or four sets of coordinates. The problems must be stated to the computer without vagueness or ambiguity. Mathematical solutions to the problems must first be worked out by the investigator, then a set of directions written, and finally a computer program formulated which in turn can be fed to the machine. Only then can the computer perform the calculations. The selected diagnostic cephalometric measurements can be solved by one of four mathematical equations. The mathematical solutions and examples of each of the four types of problems follows:

Problem and Solution 1.

The first mathematical problem was to determine the distance of a landmark from sella turcica and the angle that that line representing that distance made with the horizontal reference line or abscissa. All thirty-nine landmarks were measured from the fortieth (sella) in this manner. For example, the distance sella to gonion and the angle that line formed with the abscissa was calculated. Since one of the landmarks in this example was always the origin (sella), one set of coordinates was always (0,0).

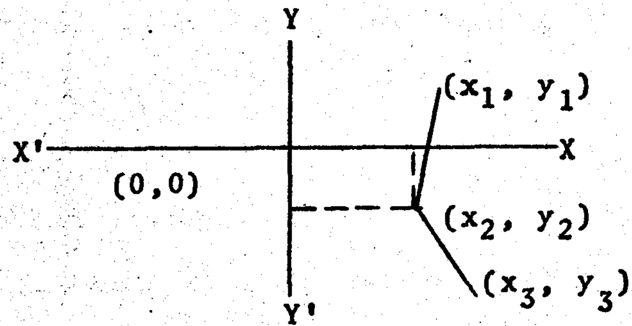


$$\text{Distance} = \sqrt{x^2 + y^2}$$

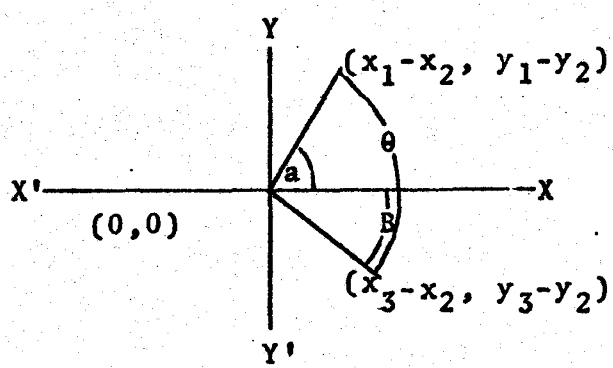
$$\theta = (y/x).$$

Problem and Solution 2.

The second type of problem dealt with finding the value of an angle when the coordinates of three points were given. In this case it was necessary to translate the coordinates so that the vertex (x_2, y_2) was at the origin, i.e., x_2 was subtracted from every x value and y_2 was subtracted from every y value. An example of such a problem was the determination of the size of the gonial angle.

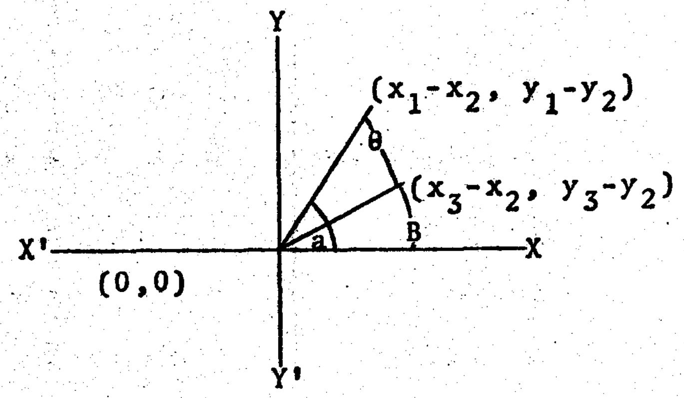


Translate coordinates so the vertex is located at the origin.



$$\theta = a + B$$

or

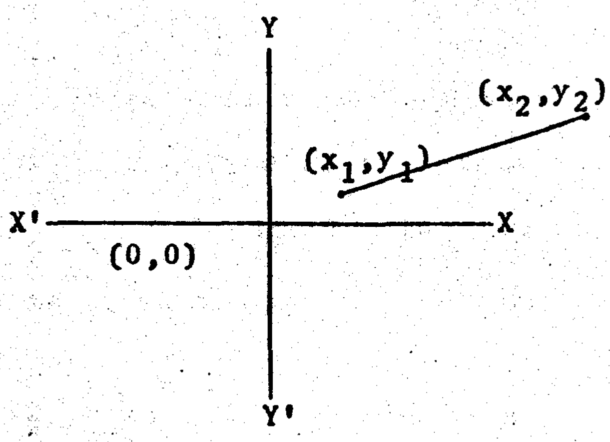


$$\theta = a - B$$

The angle θ in the first instance is made up in part of a negative angle, B. In the second example θ = a-B. Since the absolute value was not taken into account, the general equation for solution to the angles in all cases was: $\theta = \arctan\left(\frac{y_1 - y_2}{x_1 - x_2}\right) - \left(\arctan\right)\frac{y_3 - y_2}{x_3 - x_2}$.

Problem and Solution 3.

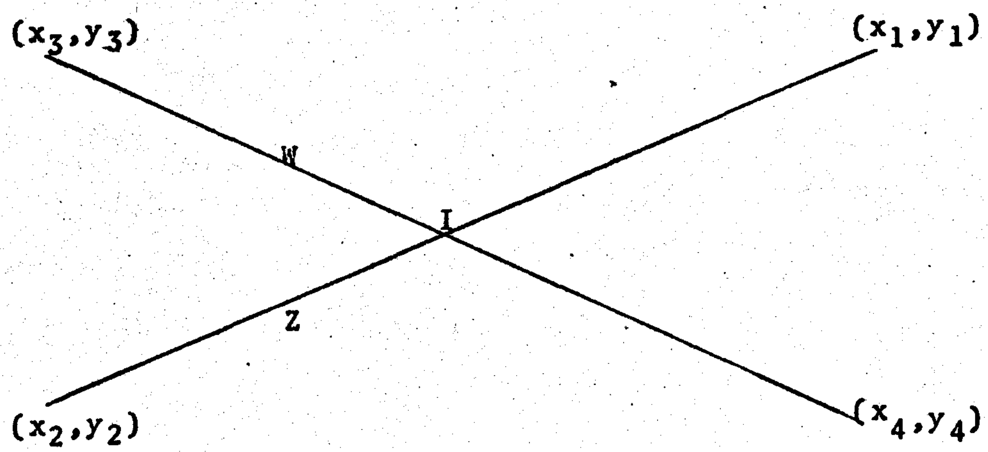
The third type of problem dealt with determining the linear distance between two points one of which was not the origin. This was actually a variation or special case of the first example problem and solution. An example of this type of problem was the determination of mandibular body length.



$$\text{Distance} = \sqrt{(x_1-x_2)^2 + (y_1-y_2)^2}$$

Problem and Solution 4.

In the fourth type of problem it was necessary to find the value of an angle when the coordinates for four points were given. Each set of coordinates determined a line, and it was necessary to find the value of that angle formed at the point of intersection of the two lines. An example of such a problem was the determination of the value of the angle Go-Gn-SN.



Line W has the general formula $y = mx + b$, where m is its slope and b its y - intercept. Since the slope m can be expressed as $\left(\frac{y_1 - y_2}{x_1 - x_2}\right)$ and using the coordinates of point 1 for x and y, we have:

$$y_1 = \left(\frac{y_1 - y_2}{x_1 - x_2}\right) x_1 + b.$$

Solving for b, we have:

$$b = y_1 - \left(\frac{y_1 - y_2}{x_1 - x_2}\right) x_1.$$

Line Z has its own unique m and b producing its own general equation:

$$y = m_z x + b_z.$$

The x and y values common to both lines or common to their equations are the coordinates of I, the point of intersection. This is solved by the solution of simultaneous equations:

i) $y = m_w x + b_w$

ii) $y = m_z x + b_z$

where m_w, m_z, and b_z are just calculated. Subtraction of i from ii yields: $y - y = m_w x - m_z x + b_w - b_z$.

Solving for x, we have:

$$x = \frac{b_z - b_w}{m_w - m_z} \quad .$$

Knowing x we can now solve for y:

$$y = m_w x + b_w .$$

The problem is now the same as that shown in problem and solution 2, since the coordinates of I, the intersection, are now known.

The angle is calculated from one point on W, to the intersection, to one point on Z. If the obtuse angle is calculated, for example 1 to I to 3, it is simple to determine its supplement.

I. Electronic Computer Program to Establish Means and Normal Ranges of the Cephalometric Measurements:

1. Data Preparation:

Means and normal ranges (ninety-five percent confidence limits) of the x and y coordinates for the forty landmarks investigated, as previously noted, had been recorded. The mathematical solutions necessary for measuring linear distances and angles have also been explained and demonstrated. It was then necessary to create a program, applicable for the electronic computer that would calculate the means and normal ranges of all

106 cephalometric measurements investigated in this study.

The x and y coordinates representing the mean values, high and low ninety-five percent confidence limits for each of the forty landmarks were recorded. These values were written on the layout sheet in a sequence that would determine a specific angle or linear distance. For example, the saddle angle was formed by the landmarks 15, 25, 3 (nasion, sella, articulare), and it was necessary to record the x and y readings of each point on the layout sheet in exactly that order. This information was then punched onto cards, and it was necessary to punch one or more cards for each of the 106 measurements.

The layout sheet was divided so that the first six columns contained a code number which corresponded to the landmarks making up the cephalometric measurement. In the example, saddle angle, the code columns contained the number 152503, thus indicating the landmarks and their sequence. Columns seven through thirty-four were allotted for the name of the measurement, and "SADDLE ANGLE" was printed in those columns. The next ten columns contained the x and y readings of the high ninety-five percent confidence limits for the first landmark stated in the code number. The next ten columns were allotted for the x and y values of the high ninety-five percent confidence limits of the next number in the code, while the next ten columns recorded the same for the last number in the code. The final fifteen columns on the sheet (66-80) contained the x and y coordinates of the low ninety-five percent confidence limits for the first landmark and the x readings for the second landmark. This filled the entire eighty spaces of the layout sheet so another line, representing a continuation card, was used to record the remaining data. The y coordinate readings of the low ninety-five percent confidence limits of the second landmark in the code were placed in columns thirty-five through thirty-nine of the second line. The readings of the low confidence limits for the last number in the code were written into the next ten spaces. The last thirty spaces on the second line contained the mean values of the x and y coordinates of the three landmarks in the order dictated by the code number. (Figure 8.)

After recording the information for each cephalometric measurement onto the layout sheet, the data contained thereon was punched onto IBM cards. For convenience the layout sheets are arranged and printed in a form exactly as the punch cards, thus making the transcribing of the

M

INTERNATIONAL BUSINESS MACHINES CORPORATION

Form X24-6599-0
Printed in U. S. A.

MULTIPLE-CARD LAYOUT FORM

ny ______________________

ation ______________________ by ______________________ Date ____________ Job No. ____________ Sheet No. ____________

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data from the sheets to the cards a routine task.

After the IBM cards were key-punched, they were verified to detect errors in punching. At the completion of this step each card contained, in the correct sequence, the x and y values (means and ninety-five percent confidence limits) constructing an angle or linear distance which represented a cephalometric measurement under investigation.

2. FORTRAN Program and the Computer:

The mathematic equations explained previously were written into a program which would direct the computer to calculate the means and normal ranges of all the cephalometric measurements. This set of instructions was written in a scientific computer language known as FORTRAN IV.

FORTRAN, which is a shorthand form of formula translation, translates the problem-solving procedures into simple instructions the computer can understand and obey. This translation can be carried out by a human being, or the computer may assist in the process by the use of a compiler. A compiler is a large set of computer instructions which can accept a problem-solving procedure, written in a form resembling the language of the procedure, and produce from it the proper elementary machine instructions that will solve the problem. A compiler that is designed primarily for scientific and engineering problem-solving is generally spoken of as an algebraic compiler. The user of an algebraic compiler is not forced to learn the detailed operations of the computer. He is therefore able to concentrate from the onset on the problems to be solved rather than on how the computer works.

Thus, it is seen that FORTRAN is a language in which instructions, or a program, can be written, as well as a compiler program. The compiler program, usually written by the manufacturer of the machine, takes a FORTRAN program as input (source program) and translates it into an object program. This translation is the compiling. The object program, or machine language program is a sequence of numbers, letters, or special characters, called operation codes, which activates the circuitry of the computer to cause the machine to carry out the operation codes.

Running a problem on the computer using FORTRAN involves two phases. In the first phase, the computer (IBM 1401) is controlled by the compiler. In the second phase, the computer is controlled by the object program.

A diagram of the 1401 computer system used for this study is illustrated in Figure 9.

The first step in formulating the FORTRAN program was to arrange a worksheet or flowchart. This chart contained all the required operations, in sequence, to outline the computer program. The flowchart with explanations is illustrated in Figure 10.

After the flowchart had been prepared, the program was written in FORTRAN IV. It is beyond the scope of this discussion to explain FORTRAN programming. In general, however, it is a series of statements or instructions using capital alphabetic characters, numerals, and special characters. Each statement is printed onto a coding sheet that contains eighty columns. One alphanumeric or special character is printed into each column of one line. If the statement contains more than eighty characters, it is continued onto the next line or lines of the coding sheet until the statement is completed. Each line of the coding sheet represents one IBM punch card; therefore, each statement, depending upon its length will be contained in one or more cards (Figure 11).

The punched cards were then placed into the 1402 card reader. Here the cards were read, and the information

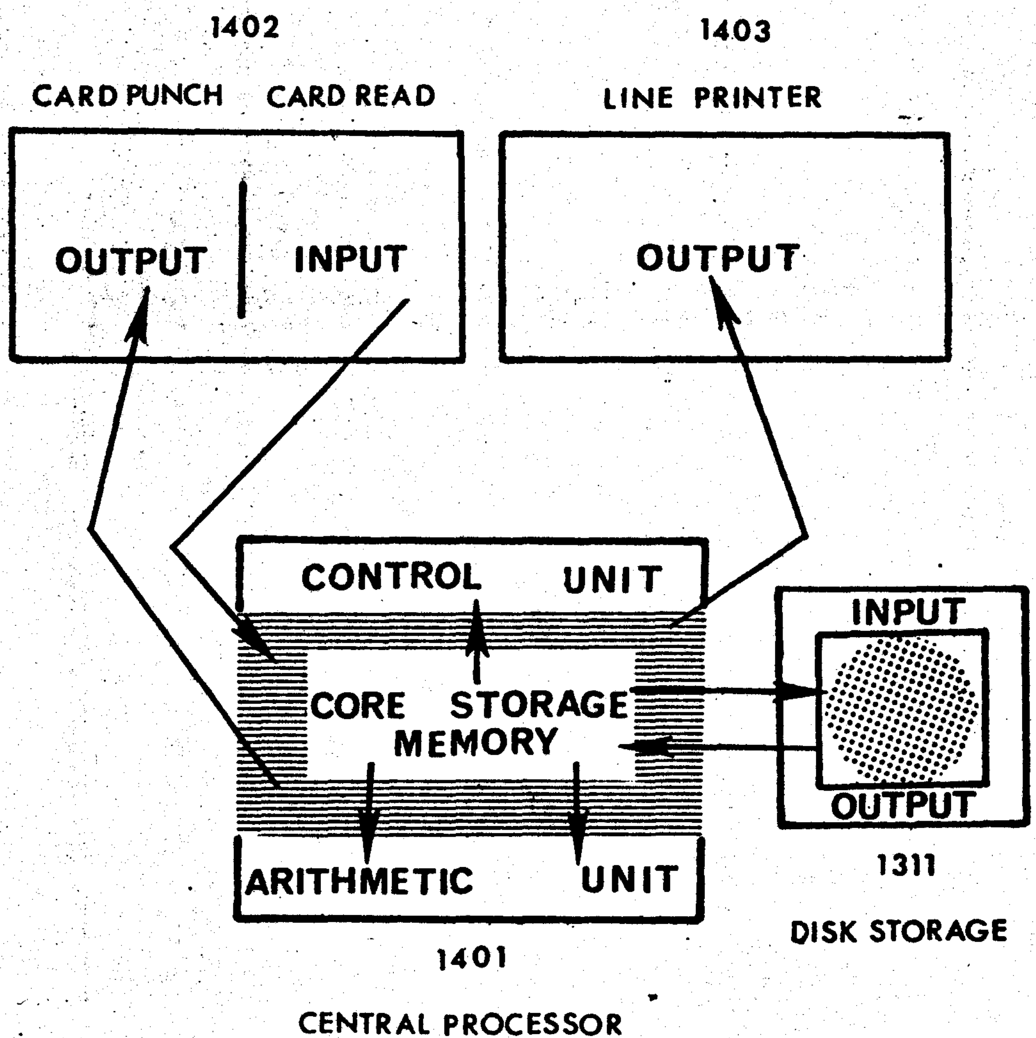
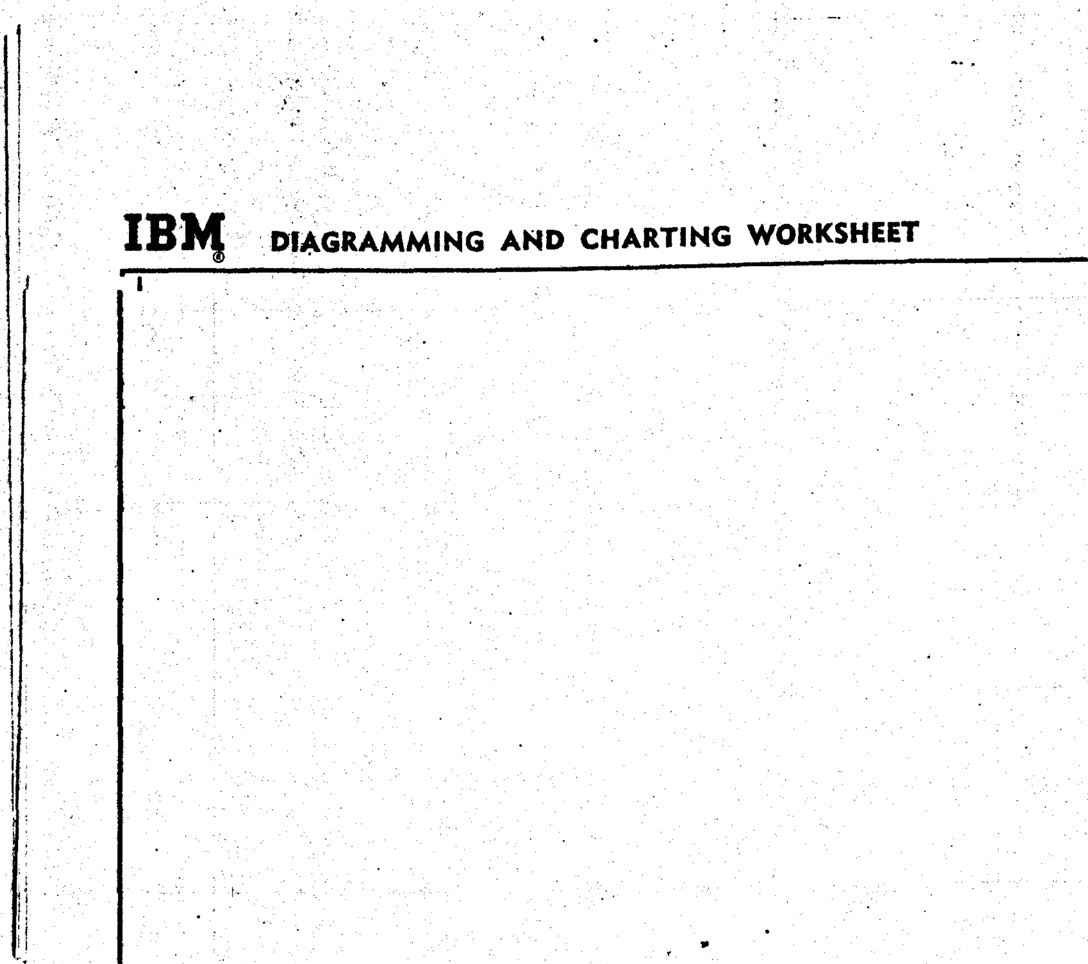


FIGURE 9

DIAGRAM OF THE IBM 1401 SYSTEM



IBM DIAGRAMMING AND CHARTING WORKSHEET

FIGURE 10

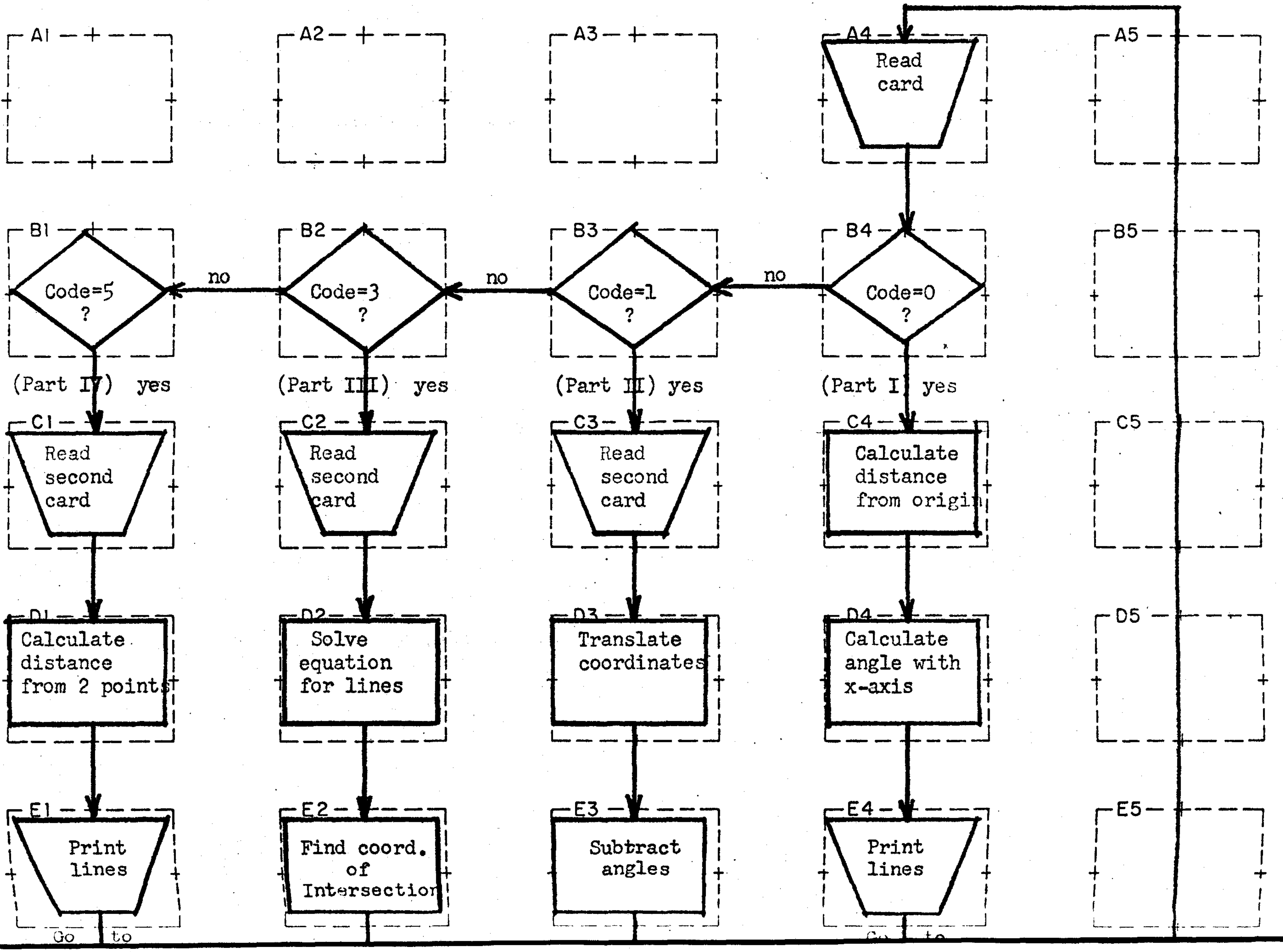
IBM FLOWCHARTING WORKSHEET

IBM **Flowcharting Worksheet**

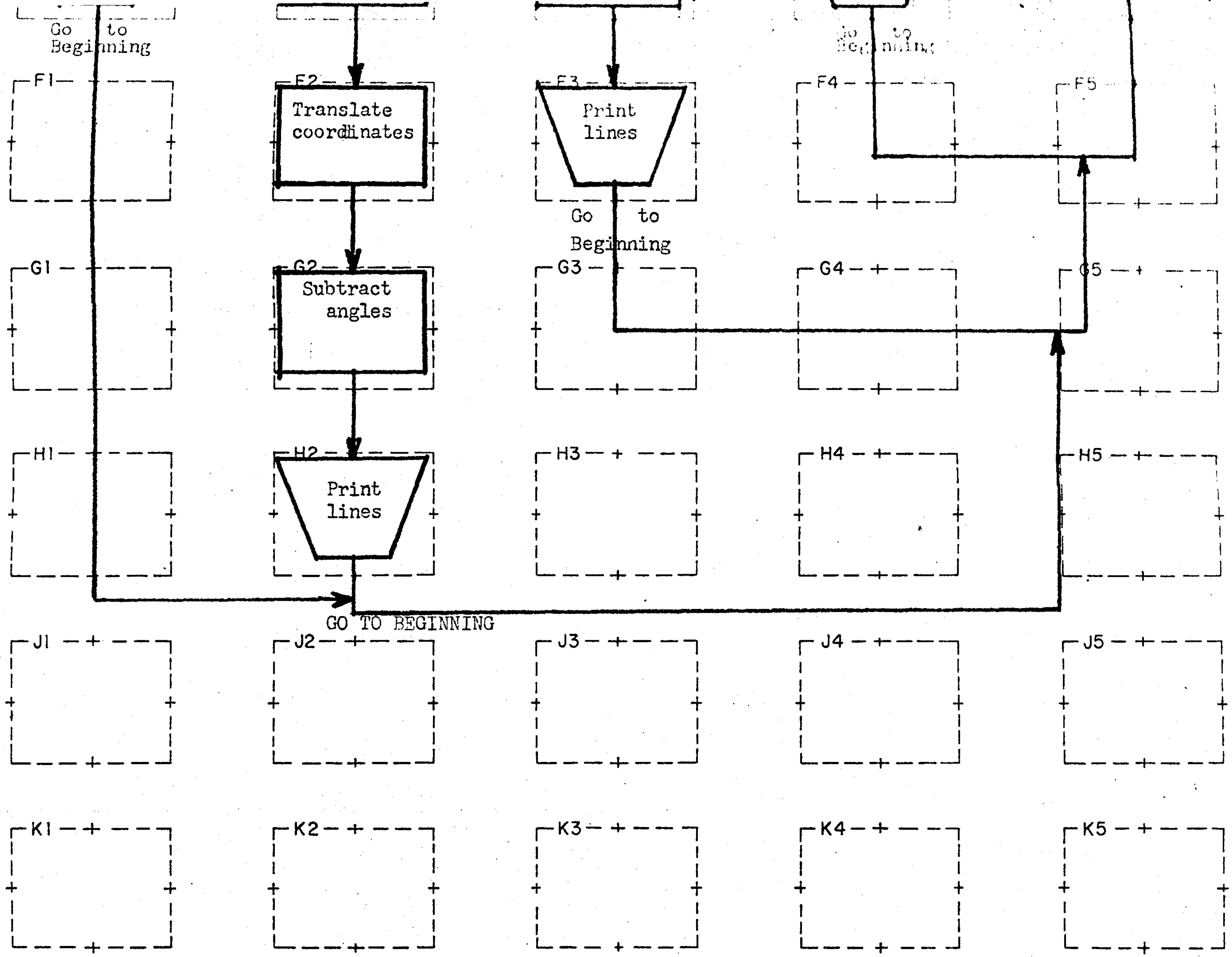
PRINTED IN U.S.A.
X20-8021-2

Programmer: Ashley Program No.: 1 Date: Page: 1

Chart ID: Chart Name: Loyola--Orthodontics Program Name: Cephalometric Analysis



Fold under at dotted line.



Fold under at dotted line.

FIGURE 11

IBM FORTRAN CODING FORM

IBM

FORTRAN CODING FORM

	Punching Instructions		Page of
Program	Graphic	Card Form # *	Identification
Programmer / Date	Punch		73–80

C FOR COMMENT

STATEMENT NUMBER (1–5)	Cont. (6)	FORTRAN STATEMENT (7–72)

* A standard card form, IBM electro 888157, is available for punching source statements from this form.

contained in them passed onto the 1401 computer. Within a few minutes another machine, the 1403 line printer, reproduced the program on paper.

Once the FORTRAN program had been corrected and perfected or "debugged", the cards containing the means and ranges of the points signifying the cephalometric measurements were placed into the card reader. This information was transferred to the computer where the previously stored FORTRAN program calculated the ranges and means of the linear distances and angles under study. The results were then produced on paper by the line printer.

J. Electronic Computer Program for Diagnosis of the Lateral Cephalogram:

The previously described FORTRAN program demonstrated that the electronic computer could be utilized successfully to calculate angles and distances from Cartesian coordinates. It was then necessary to develop a program that would assess or diagnose any lateral headfilm.

In the description of the cephalometric measurements each appeared in one of five categories depending upon to which group it contributed. This arrangement was deliberate with the cephalometric diagnosis program in mind.

The overall outline of the cephalometric assessment applicable to an electronic computer follows on the next page.

Skeletal Assessment

Posterior Cranial Assessment

Retrognathic	Normal	Prognathic

Anterior Cranial Assessment

Retrognathic	Normal	Prognathic

Facial and Growth Axis Assessment

Retrognathic	Normal	Prognathic

Dentoalveolar Assessment

Maxillary Assessment

Retrognathic	Normal	Prognathic

Mandibular Assessment

Retrognathic	Normal	Prognathic

Run data obtained from dental casts.

The collected data were obtained from a sample whose occlusions were within normal parameters. The range (ninety-five percent confidence limits) established the limits within which a measurement had to fall to be considered normal. Skeletal or dentoalveolar morphology would assumed to be other than normal if any of the cephalometric measurements fell outside of these restrictions. In addition, requirements assuring correct maxillary to mandibular tooth relationships were imposed. They were:

1. The x coordinate of the point identifying the tip of the crown of the maxillary central incisor must have a value equal to or greater than the x coordinate of the corresponding point on the mandibular central incisor.
2. The x coordinate of the point identifying the tip of the crown of the mandibular first molar must be greater than the x coordinate of the corresponding point on the maxillary first molar.
3. The y coordinate of the point identifying the crown of the maxillary central incisor must be equal to or greater than the y coordinate of the corresponding point on the mandibular central incisor.

A FORTRAN IV program to assess lateral cephalograms was then developed. It was similar to the original program differing only in the addition of the above limitations and the elimination of range values. The program was compiled and stored in the 1401 computer.

Headfilms not previously assessed were then selected to test the validity of the computer method of evaluation. Five young adult Caucasian males were chosen as subjects. All possessed a full complement of teeth except third molars. One candidate had excellent occlusion, another was clinically diagnosed as a Class I arch length discrepancy malocclusion. Of the three remaining subjects, one possessed a Class II, division 1 malocclusion, another a Class II, division 2, and the third had a Class III malocclusion. These headfilms were then spotted by the described technique and measured using the coordinate method. The values for their x and y coordinates were punched into IBM cards, and the headfilm data were evaluated by the FORTRAN program.

CHAPTER IV

FINDINGS

Data cards containing x and y coordinate values locating cephalometric landmarks had been prepared prior to the development of the FORTRAN program. The data cards were fed into the computer and information was received on the means and normal ranges of the 106 cephalometric measurements under investigation.

The observed ranges, means, standard deviations, normal limits, and coefficients of variation of the coordinate values of each landmark are listed in Table I. The mean values and ninety-five percent confidence limits of each cephalometric measurement are found in Tables II through VI. These tables correspond to the five divisions of the cephalometric assessment program previously described. Each angular or linear measurement is listed in one of the five tables according to the area of assessment to which it contributes.

The computer program was also tested for ability to distinguish between normal occlusion and malocclusions. Headfilms of subjects with normal and abnormal teeth and jaw relationships were measured by the described method of rectangular coordinates. These values were subjected to the computer program and the results are listed in Table VII. Cephalometric measurements of the test runs that do not conform to the normal limits are also indicated in the table.

In the preparation of the principle data, subjects were selected for this study because their functional and morphological arrangement of teeth, jaws, and cranial skeletons were considered to be normal. To be more specific in determining normal ranges in biologic studies, ninety-five percent confidence limits are employed. The ninety-five percent confidence level means that ninety-five percent of the population which satisfied these requirements for normal occlusion should conform to the normal ranges established herein for each landmark and measurement.

The standard deviation, an indication of the sample distribution about the mean, is used to calculate the ninety-five percent confidence levels. In this study, a sample of fifty, the standard deviation of each coordinate or cephalometric measurement is multiplied by 1.96. This factor is obtained from statistical tables describing distribution frequencies for samples of various sizes (T-tables). Each value is then added to its mean to establish the upper limits of the normal ranges and subtracted from its mean to determine the least value of the ninety-five percent confidence limits.

The coefficient of variation was also determined for each x and y coordinate. The coefficient of variation relates the variability of a distribution to the average magnitude of the variables being measured. It is a pure number, independent of original units of measurement, and one coefficient of variation can be compared to any other. It is signified a V, and is calculated by dividing the mean into the standard deviation multiplied by 100,

$$V = \frac{s \times 100}{\bar{X}} .$$

The coefficients of variation of the x and y coordinates range from a low to a relatively high value. Since this measurement is employed to relate variability or precision, it can be postulated that coordinates with large V values are not measured as precisely as those with smaller readings of variation, or that those measurements with greater V values actually have greater variation. Each structure was placed into one of three groups depending upon its coefficient of variation value. Group I consists of landmarks with x and y coordinates with small coefficients of variation. The structures in Group II have either or both an x or y coordinate with a large coefficient of variation (fifteen or more). These landmarks can be easily located, therefore they show a wide range of natural variation. Group III lists the landmarks that have a large V value because they are difficult to locate precisely. These findings are listed in Table I.

Many of the cephalometric measurements have been described in the literature and are used widely. After these measurements were taken, their means, standard deviations and normal ranges were computed. These measurements, taken on young adult Caucasian males, 20 years, 11 months to 36 years, 3 months old, are reported as to their significance and compared with the results published by previous investigators. These measurements are listed in Tables VIII through XI.

Many of the remaining measurements were described previously in the literature but are not widely employed in cephalometric analysis. Other measurements were introduced by this study. These measurements were tested to the rectangular coordinate system to facilitate data reduction for computer calculations. These are the measurements from sella turcica to each landmark, and results were determined both angularly and linearly. The significance and findings of each of these measurements follows: The mean linear distance from sella turcica and the angular measurement from the abscissa follows each measurement in parentheses.

1. Sella to First Cervical Vertebra (56.7 mm, 108.5°)---This measurement relates the first cervical vertebra to the cranial bases. It also describes vertical development of the craniofacial complex in relation to the vertebral axis.

2. Sella to Second Cervical Vertebra (94.8 mm, 107.0°)---This determines the position of the second cervical vertebra in relation to the cranial bases, and it can also relate vertical craniofacial development to the vertebral column. Gonion was observed to lie, at an average, twelve millimeters anterior and opposite the anteroinferior border of this vertebra. This measurement could be employed as a diagnostic criterion for the position of the gonial angle. This method of assessing the position of the gonial angle to structures in the vertebral column has not been previously reported.
3. Sella to Third Cervical Vertebra (116.1 mm, 104.8°)---This measurement relates the third cervical vertebra to the cranial bases. The hyoid bone has been reported to lie opposite CV_3 in dolichocephalic faces and lower in brachycephalic faces (opposite CV_4).
4. Sella to Condyle (34.0 mm, 112.0°)---This measurement relates the condyle to sella turcica anteroposteriorly and vertically. Mandibular posture is directly related to condylar location.
5. Sella to Gonion (91.2 mm, 98.8°)---The relationship of gonion to sella relates the mandibular angle to the cranial bases. This measurement is an indication of

vertical development of the ramus and its direction of growth.

6. Sella to the Anterior Border of the Pharynx (112.0 mm, 97.9°)---This measurement evaluates the width of the pharynx at the level of the third cervical vertebra. This measurement can be used to evaluate pharyngeal size and perhaps the etiology of pharyngeal disorders.

7. Sella to the Posterior Border of the Pharynx (52.3 mm, 103.5°)---This measurement, taken at the level of the first cervical vertebra, is an indication of pharyngeal development at the level of the palate.

8. Sella to Porion (36.5 mm, 146.1°)---This measurement locates porion in relation to sella turcica. Its position will generally vary, vertically and anteroposteriorly, with cranial morphology. The linear distance from sella to porion and the measurement from sella to condyle are very nearly in a 1 to 1 ratio.

9. Sella to Anterior Nasal Spine (106.1 mm, 37.2°)---This measurement is an indication of the forward and downward development of the nasal portion of the maxilla in relation to the cranial bases.

10. Sella to A Point (92.1 mm, 41.5°)---This measurement locates the maxillary basal bone to cranial anatomy. It

indicates the anteroposterior and vertical position of the maxillary denture base.

11. Sella to B Point (121.0 mm, 61.1°)---The mandibular basal bone is located both anteroposteriorly and superioinferiorly to the cranial bases by this measurement.

12. Sella to Glabella (85.7 mm, 8.4°)---This distance measures the anteroposterior depth of the skull from sella turcica to the most prominent point between the supraorbital ridges. The angular measurement locates glabella vertically to the anterior cranial base. The distance measures not only the length of the anterior cranial base, but also the depth of the frontal sinus. Its value will, therefore, be dependent upon frontal sinus development as well as anterior cranial base length.

13. Sella to Gnathion (140.0 mm, 68.0°)---This measurement evaluates chin position. It indicates the forward and downward development of the mandible in relation to the cranial bases. Essentially the angular measurement is identical to the Y-Axis.

14. Sella to Hyoid Bone (126.4 mm, 86.1°)---This measurement relates the hyoid bone to cranial anatomy. The position of the hyoid bone can be an indication of facial type, tongue size and posture, and nasopharyngeal patency.

15. Sella to Infradentale (115.2 mm, 56.1°)---This measurement locates the highest projection of the mandibular aveolar process between the central incisors. It relates anterior alveolar height of the mandible to the cranial bases.

16. Sella to Key Ridge (68.1 mm, 49.5°)---This locates the key ridge in relation to sella turcica.

17. Sella to Orbitale (63.1 mm, 26.5°)---This locates the lowest point on the orbital rim in relation to the cranial bases. It is an indication of development, anteroposteriorly and vertically, of the superior one-third of the face from the anterior cranial base to the maxillary antrum.

18. Sella to Pogonion (137.1 mm, 64.9°)---This measurement relates the most anterior point on the chin to the cranial bases. It evaluates the downward and forward direction of facial growth.

19. Sella to the Posterior Cortical Plate of the Symphysis (123.1 mm, 68.1°)---The linear and angular relationship of the most prominent point on the posterior contour of the mandibular symphysis to the cranial bases is indicated by this measurement. This measurement, with the measurement of sella to pogonion, could relate the width

of the symphysis.

20. Sella to Posterior Nasal Spine (54.2 mm, 70.5°)---This measurement relates the position of the posterior nasal spine. Its location can aid in evaluating the length and the cant of the palate and indicate the degree of development of the posterior portion of the maxilla.

21. Sella to Prosthion (104.5 mm, 46.5°)---This measurement locates the crest of the maxillary alveolar process between the central incisors and relates this landmark to cranial anatomy. It can be employed to evaluate the degree of alveolar growth in the anterior region of the maxilla.

22. Sella to Pterygomaxillary Fissure (48.2 mm, 68.3°)---This measurement is useful in defining the posterior border of the maxilla.

23. Sella to Sigmoid Notch (41.1 mm, 86.3°)---This angle and distance relates the depth of the sigmoid notch to sella turcica. Ricketts, on the basis of morphological differences, places all mandibles in three classes. With other criteria, the sigmoid notch measurement can aid in describing the types of mandibles.

24. Sella to Crista Galli (50.4 mm, 19.6°)---This landmark located on the superior surface of the ethmoid bone could

be useful in describing the length of the anterior cranial base from sella to that point. It would, therefore, assess the posterior three-quarters of the anterior cranial base as to its length and direction of growth.

25. Sella to the Intertable of the Frontal Bone (70.0 mm, 10.1°)---Growth of the anterior cranial base, after approximately seven years of age, increases by virtue of the development of the frontal sinuses. This measurement could aid in assessing the height and depth of the frontal sinus and its contribution to facial growth and development.

26. Sella to Tip of Crown of 1 (114.0 mm, 51.4°)---This measurement locates the tip of the crown of the maxillary central incisor in relation to sella.

27. Sella to Tip of Root of 1 (89.5 mm, 43.5°)---This measurement locates the tip of the root of the maxillary central incisor in relation to sella.

28. Sella to Tip of Crown of 6 (90.0 mm, 64.5°)---This measurement locates the tip of the mesiobuccal cusp of the maxillary first molar in relation to sella.

29. Sella to Tip of Root of 6 (74.3 mm, 54.8°)---This measurement locates the tip of the mesiobuccal root of the maxillary first molar in relation to sella.

30. Sella to the Distal Contour of the Crown of $\underline{6}$ (84.5 mm, 65.5°)---This measurement locates the most prominent point on the distal contour of the crown of the maxillary first molar in relation to sella.

31. Sella to the Distal Contour of the Crown of $\underline{7}$ (74.2 mm, 72.5°)---This measurement locates the most prominent point on the distal contour of the crown of the maxillary second molar in relation to sella.

32. Gnathion to Infradentale (35.4 mm)---This linear distance measures the height of the mandible at the symphysis. It is a measure of the vertical development of the body and its alveolar process at the central incisor region. It could be useful in differentiating alveolar from skeletal dysplasias.

33. Condyle to the Tip of the Crown of $\overline{1}$ (109.4 mm, 89.9°)---Jarabak has proposed that for maximum stability of the mandibular incisors, the long axes of these teeth should describe an angle of ninety degrees with the line drawn from the hinge axis to the tip of their crown. This study has shown this hypothesis to be well founded and sound.

34. Sella to Tip of Crown of $\overline{1}$ (111.0 mm, 51.4°)---This measurement locates the tip of the crown of the mandibular

central incisor in relation to sella.

35. Sella to Tip of Root of $\overline{1}$ (120.2 mm, 62.5°)---This measurement locates the tip of the root of the mandibular central incisor in relation to sella.

36. Sella to Tip of Crown of $\overline{6}$ (91.2 mm, 62.8°)---This measurement locates the tip of the mesiobuccal cusp of the mandibular first molar in relation to sella.

37. Sella to Tip of Root of $\overline{6}$ (106.0 mm, 72.2°)---This measurement locates the tip of the mesial root of the mandibular first molar in relation to sella.

38. Sella to the Distal Contour of the Crown of $\overline{6}$ (87.0 mm, 69.1°)---This measurement locates the most prominent point on the distal contour of the crown of the mandibular first molar in relation to sella.

39. Sella to the Distal Contour of the Crown of $\overline{7}$ (79.5 mm, 74.5°)---This measurement locates the most prominent point on the distal contour of the crown of the mandibular second molar in relation to sella.

TABLE I

COORDINATE VALUES OF CEPHALOMETRIC LANDMARKS
(IN MILLIMETERS)

LANDMARK NUMBER, NAME AND VARIATION GROUP	OBSERVED RANGE		MEAN		STANDARD DEVIATION		95% CONFIDENCE LIMITS				COEFFICIENT OF VARIATION	
							x		y			
	x	y	x	y	x	y	Low	High	Low	High	x	y
1. ANS (I)	+64.3 to +90.1	-51.4 to -69.3	+77.5	-57.3	5.7	3.2	+66.2	+88.8	-50.9	-63.7	7.3	5.6
2. A Pt. (I)	+54.7 to +83.1	-51.4 to -71.3	+69.2	-61.2	5.4	4.3	+58.5	+79.9	-52.7	-69.7	7.8	7.3
3. Ar (II)	-12.8 to -28.3	-27.2 to -42.2	-21.4	-32.9	3.9	3.3	-13.7	-29.1	-26.4	-39.4	18.2	10.3
4. B Pt. (II)	+47.3 to +75.1	-90.4 to -123.1	+59.6	-105.6	9.9	6.5	+40.1	+79.1	-92.7	-118.5	15.1	6.2
5. 1 CV (III)	-6.5 to -30.0	-44.3 to -76.2	-18.5	-53.5	5.2	5.7	-8.1	-28.8	-42.1	-64.8	27.5	16.5
6. 2 CV (III)	-13.7 to -48.0	-78.8 to -106.3	-28.6	-90.6	7.3	6.3	-14.1	-43.1	-78.1	-103.0	25.5	8.1
7. 3 CV (III)	-19.7 to -54.0	-97.3 to -128.1	-34.0	-111.2	8.9	7.4	-16.4	-51.5	-96.7	-125.8	26.2	6.7

TABLE I (CONT'D)

LANDMARK NUMBER, NAME AND VARIATION GROUP	OBSERVED RANGE		MEAN		STANDARD DEVIATION		95% CONFIDENCE LIMITS				COEFFICIENT OF VARIATION	
							x		y			
	x	y	x	y	x	y	Low	High	Low	High	x	y
8. Co (II)	-7.6 to -26.1	-24.7 to -48.0	-15.1	-30.6	3.6	4.7	-8.0	-22.2	-21.3	-39.9	23.8	13.6
9. Gl (III)	+74.3 to +100.6	+ 7.5 to +19.1	+85.1	+12.6	5.4	2.7	+74.4	+95.8	+ 7.3	+17.9	6.2	21.4
10. Gn (II)	+34.7 to +70.2	-110.7 to -143.4	+53.9	-128.7	8.8	7.0	+36.6	+71.2	-114.9	-142.6	16.3	5.4
11. Go (II)	-0.5 to -32.0	-74.6 to -116.1	-16.6	-89.2	5.2	6.5	-6.2	-26.9	-76.5	-102.0	31.3	7.2
12. HB (III)	-13.3 to +21.2	-112.6 to -145.1	+8.2	-125.9	5.8	7.8	-3.2	+19.6	-110.5	-141.3	70.7	6.2
13. In (I)	+49.7 to +78.0	-81.2 to -108.0	+66.6	-95.4	6.3	5.6	+54.0	+79.1	-84.4	-106.5	9.3	5.8
14. KR (I)	+30.7 to +53.1	-43.1 to -68.2	+44.5	-51.8	5.1	5.2	+34.5	+54.5	-41.5	-62.2	11.2	10.4
15. N (I)	+68.7 to +89.1	0.0 to 0.0	+78.0	0.0	4.7	0.0	+69.3	+87.3	0.0	0.0	0.0	0.0

TABLE I (CONT'D)

LANDMARK NUMBER, NAME AND VARIATION GROUP	OBSERVED RANGE		MEAN		STANDARD DEVIATION		95% CONFIDENCE LIMITS				COEFFICIENT OF VARIATION	
							x		y			
	x	y	x	y	x	y	Low	High	Low	High	x	y
16. Or (I)	+44.9 to 70.6	-20.9 to -35.4	+57.3	-29.3	4.5	2.8	+48.4	+66.3	-23.7	-34.9	7.1	9.6
17. Ant. Phar. (III)	0.0 to -36.1	-83.9 to -128.4	-16.1	-111.1	8.5	8.1	-0.6	-32.8	-95.2	-127.1	52.7	7.3
18. Post. Phar. (III)	+2.0 to -24.1	-44.6 to -59.3	-11.2	-50.5	5.6	3.5	+0.7	-22.3	-43.6	-57.5	50.0	6.9
19. Po (I)	+43.2 to +76.2	-103.7 to -136.1	+61.6	-122.4	7.7	7.1	+46.4	+76.9	-108.4	-136.4	12.5	5.9
20. Por (III)	-19.8 to -39.6	-12.6 to -32.2	-29.1	-20.0	3.9	4.6	-21.4	-36.8	-11.0	-29.0	13.3	23.0
21. PCP Syn. (III)	+28.9 to +60.0	-91.9 to -131.2	+45.9	-114.2	7.3	7.2	+31.4	+60.3	-100.0	-128.3	15.9	5.4
22. PNS (III)	+7.4 to +27.6	-44.6 to -59.3	+17.9	-50.5	4.1	3.4	+9.7	+26.0	-43.8	-57.3	22.9	6.7
23. Pr (I)	+56.8 to +84.1	-63.6 to -85.2	+72.6	-75.5	5.6	4.6	+61.5	+83.7	-66.5	-84.6	7.7	6.1

TABLE I (CONTINUED)

LANDMARK NUMBER, NAME AND VARIATION GROUP	OBSERVED RANGE		MEAN		STANDARD DEVIATION		95% CONFIDENCE LIMITS				COEFFICIENT OF VARIATION	
							x		y			
	x	y	x	y	x	y	Low	High	Low	High	x	y
24. PTM (III)	+6.9 to +26.7	-38.6 to -54.0	+17.7	-45.5	3.9	3.5	+10.0	+25.4	-38.5	-52.5	22.0	7.7
25. S (I)	0.0 to 0.0	0.0 to 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26. Sig. Not. (III)	-8.1 to +13.0	-31.6 to -49.1	+3.6	-40.9	3.4	4.2	-3.2	+10.4	-32.7	-49.2	94.4	10.2
27. TC-1 (I)	+54.1 to +86.0	-77.6 to -100.1	+72.3	-89.0	6.1	4.6	+60.2	+84.3	-79.9	-98.0	8.4	5.2
28. TR-1 (I)	+49.0 to +76.3	-52.9 to -72.1	+64.5	-62.5	5.5	4.3	+53.6	+75.4	-54.0	-71.0	8.5	6.8
29. TC-6 (I)	+30.0 to +50.1	-70.0 to -91.2	+40.1	-80.0	5.7	5.5	+28.7	+51.4	-69.1	-90.9	13.2	6.3
30. TR-6 (I)	+33.7 to +56.0	-53.7 to -67.1	+42.6	-60.5	5.0	5.3	+32.8	+52.5	-50.0	-71.0	11.8	8.8
31. TC-$\overline{1}$ (I)	+53.8 to +83.2	-72.4 to -99.4	+69.5	-85.7	6.0	5.4	+57.7	+81.3	-75.1	-96.3	8.6	6.3

TABLE I (CONTINUED)

LANDMARK NUMBER, NAME AND VARIATION GROUP	OBSERVED RANGE		MEAN		STANDARD DEVIATION		95% CONFIDENCE LIMITS				COEFFICIENT OF VARIATION	
							x		y			
	x	y	x	y	x	y	Low	High	Low	High	x	y
32. TR-$\overline{I}$ (I)	+37.9 to +68.0	-92.9 to -118.8	+55.8	-106.6	6.4	5.1	+43.1	+68.4	-96.5	-116.7	11.5	4.8
33. TC-$\overline{6}$ (I)	+37.9 to +68.0	-92.9 to -118.8	+55.8	-106.6	6.4	5.1	+43.1	+68.4	-96.5	-116.7	12.3	5.5
34. TR-$\overline{6}$ (III)	+14.9 to +46.7	-61.9 to -113.1	+33.7	-100.7	6.8	7.6	+20.2	+47.2	-85.7	-115.7	20.2	7.5
35. FB (III)	+60.0 to +82.1	+7.0 to +19.1	+69.0	+ 12.6	5.1	2.7	+58.9	+79.0	+ 7.3	+ 17.9	7.4	21.4
36. CG (III)	+23.0 to +63.1	+11.1 to +22.4	+48.3	+ 16.1	7.5	2.8	+33.4	+63.2	+10.5	+ 21.7	15.3	17.4
37. DC-6 (III)	+24.7 to +46.3	-66.7 to -84.0	+32.8	- 74.4	4.9	4.2	+23.1	+42.5	-66.2	- 82.7	14.9	5.6
38. DC-7 (III)	+13.7 to +33.9	-60.4 to -80.4	+22.8	- 70.3	5.0	4.8	+12.8	+32.8	-60.7	- 79.9	21.9	6.8
39. DC-$\overline{6}$ (III)	+23.5 to +45.6	-71.0 to -90.4	+32.3	- 80.5	5.0	4.4	+22.3	+42.2	-71.9	- 89.1	15.4	5.5
40. DC-$\overline{7}$	+12.3 to +34.4	-63.7 to -86.8	+21.6	- 76.5	5.2	5.0	+11.3	+31.9	-66.6	- 86.4	24.1	6.5

TABLE II
POSTERIOR CRANIAL ASSESSMENT
VALUES OF SELECTED CEPHALOMETRIC MEASUREMENTS
(In Millimeters or Degrees)

MEASUREMENT	OBSERVED RANGE	MEAN	STANDARD DEVIATION	95% CONFIDENCE LIMITS Low	High
1. Saddle Angle	110.1 - 134.1	123.3	5.1	113.2	133.4
2. Articulare Angle	130.3 - 161.2	144.2	6.9	130.8	157.7
3. Gonial Angle	111.7 - 135.6	122.4	5.3	112.0	132.6
4. Sum	367.9 - 399.9	389.5	5.2	379.4	399.6
5. PCB Length	35.6 - 50.0	40.1	3.3	33.7	46.5
6. Ramus Height	45.3 - 64.1	55.5	4.2	47.3	63.7
7. Body Length	70.2 - 90.3	81.5	4.4	73.2	89.9
8. Sella-1st C.V.					
Distance	40.6 - 72.3	56.7	6.9	42.6	70.9
Angle	98.6 - 119.4	108.5	4.2	81.2	113.7
9. S-2 C.V.					
Distance	81.2 - 113.4	94.8	7.8	79.5	111.1
Angle	100.1 - 116.7	107.0	3.5	102.5	113.5
10. S-3 C.V.					
Distance	98.9 - 132.3	116.1	8.7	98.5	133.7
Angle	91.6 - 118.8	104.8	3.3	99.5	114.1
11. S-Co Distance	22.9 - 53.1	34.0	6.2	30.2	49.1
Angle	101.0 - 131.4	112.0	4.2	104.4	120.4
12. S-Go Distance	78.4 - 102.1	91.2	7.2	77.2	105.5
Angle	87.7 - 111.6	98.8	5.0	92.1	104.5
13. S-Ant. Phar.					
Distance	83.9 - 128.4	112.0	8.6	95.5	129.6
Angle	90.0 - 107.9	97.9	3.6	90.8	105.0
14. S-Post. Phar.					
Distance	44.6 - 64.5	52.3	3.8	44.8	59.8
Angle	88.1 - 113.0	103.5	3.7	96.0	110.0
15. S-Por Distance	22.4 - 51.6	36.5	6.2	24.2	48.5
Angle	133.0 - 148.3	146.1	3.1	137.2	145.3

TABLE III

ANTERIOR CRANIAL ASSESSMENT
VALUES OF SELECTED CEPHALOMETRIC MEASUREMENTS
(In Millimeters or Degrees)

MEASUREMENT		OBSERVED RANGE	MEAN	STANDARD DEVIATION	95% CONFIDENCE LIMITS Low	High
1. ACB Length		71.0 - 89.6	78.0	5.6	67.5	89.1
2. SNA		75.6 - 90.0	81.8	3.3	75.4	88.2
3. SNB		75.7 - 89.1	80.7	3.1	74.7	86.6
4. ANB		- 4.0 - + 8.1	1.1	2.6	- 3.8	+ 6.0
5. N-ANS		50.4 - 63.6	57.1	3.0	51.2	63.0
6. S-ANS	Distance	96.6 - 123.2	106.1	3.8	99.2	113.5
	Angle	35.3 - 38.2	37.2	1.6	34.2	40.2
7. S-Point	Distance	78.1 - 106.0	92.1	2.1	84.1	100.2
	Angle	40.0 - 45.3	41.5	1.1	39.4	43.6
8. S-B Pt.	Distance	100.2 - 142.3	121.0	7.6	106.1	136.0
	Angle	56.9 - 67.1	61.1	3.7	54.0	68.2
9. S-Gl	Distance	74.5 - 97.2	85.7	4.6	76.6	94.8
	Angle	5.5 - 11.1	8.4	1.9	4.8	12.2
10. S-Gn	Distance	121.1 - 156.2	140.0	7.4	126.6	154.1
	Angle	64.1 - 73.1	68.0	2.4	63.5	72.5
11. S-HB	Distance	110.1 - 148.1	126.4	6.8	113.5	139.3
	Angle	83.0 - 92.2	86.1	2.1	82.1	90.1
12. S-In	Distance	100.1 - 132.1	115.2	6.4	103.3	127.1
	Angle	53.7 - 57.0	56.1	1.5	53.3	58.9
13. S-KR	Distance	68.1 - 82.6	68.1	3.4	61.6	74.6
	Angle	48.3 - 54.5	49.5	1.1	47.5	51.5
14. S-Or	Distance	54.5 - 71.2	63.1	2.8	57.1	69.1
	Angle	23.0 - 29.2	26.5	1.2	24.4	28.6
15. S-Po	Distance	127.3 - 154.0	137.1	4.4	128.6	145.6
	Angle	60.0 - 70.3	64.9	1.7	61.6	68.2

TABLE III (CONTINUED)

MEASUREMENT		OBSERVED RANGE	MEAN	STANDARD DEVIATION	95% CONFIDENCE LIMITS Low	High
16. S-PCP	Distance	115.0 - 140.8	123.1	4.6	113.6	132.6
	Angle	65.0 - 74.1	68.1	1.9	64.5	72.7
17. S-PNS	Distance	44.7 - 62.7	54.2	4.9	44.7	63.7
	Angle	66.0 - 78.1	70.5	3.1	64.5	76.5
18. S-Pr	Distance	90.8 - 116.4	104.5	4.4	96.0	113.0
	Angle	42.5 - 49.6	46.5	1.3	44.0	49.0
19. S-PTM	Distance	39.5 - 58.4	48.2	2.7	43.0	53.4
	Angle	64.1 - 75.4	68.3	2.1	66.3	70.3
20. S-Sig. Not.						
	Distance	33.6 - 50.6	41.1	3.9	33.6	48.6
	Angle	78.5 - 96.2	86.3	4.0	78.5	94.1
21. S-CG	Distance	38.0 - 66.2	50.4	5.2	40.4	60.4
	Angle	16.6 - 28.2	19.6	2.5	14.8	24.4
22. S-FB	Distance	59.5 - 81.2	70.0	2.1	66.0	74.0
	Angle	7.1 - 12.9	10.1	1.3	8.0	12.2

TABLE IV

FACIAL AND GROWTH AXIS ASSESSMENT
VALUES OF SELECTED CEPHALOMETRIC MEASUREMENTS
(In Degrees)

MEASUREMENT	OBSERVED RANGE	MEAN	STANDARD DEVIATION	95% CONFIDENCE LIMITS	
				Low	High
1. Go-Gn-Sn	21.2 - 39.2	29.8	4.2	21.7	37.9
2. FMA	13.1 - 36.2	23.2	4.9	13.6	31.8
3. Y-Axis	53.4 - 66.2	59.1	3.0	53.2	65.0
4. Facial Depth Angle	35.6 - 49.7	42.5	3.2	36.4	48.6
5. Angle of Facial Convexity	- 8.7 - 10.1	1.8	4.1	- 6.2	9.8

TABLE V

MAXILLARY DENTOALVEOLAR ASSESSMENT
VALUES OF SELECTED CEPHALOMETRIC MEASUREMENTS
(In Millimeters or Degrees)

MEASUREMENT	OBSERVED RANGE	MEAN	STANDARD DEVIATION	95% CONFIDENCE LIMITS Low	High
1. 1 - SN	93.7 - 122.1	105.6	5.6	95.7	115.9
2. 1 - FN	102.1 - 127.4	113.4	5.4	103.2	123.6
3. 1 - $\bar{1}$	114.0 - 149.1	130.3	7.9	115.2	145.4
4. 1 - NA	10.2 - 36.3	24.4	4.0	16.6	32.2
5. 1 - NA (mm)	2.7 - 10.1	6.4	2.1	2.4	10.4
6. ANS - Pr	11.8 - 22.8	18.0	3.0	12.1	23.9
7. Sella - TC 1					
Distance	100.1 - 128.9	114.0	6.6	102.9	127.1
Angle	47.7 - 56.2	51.4	2.0	47.5	55.3
8. S - TR 1					
Distance	76.0 - 104.1	89.5	6.7	76.9	98.4
Angle	41.1 - 46.7	43.5	1.4	40.8	46.2
9. S - TC 6					
Distance	78.8 - 102.3	90.0	5.5	78.8	100.2
Angle	60.1 - 67.7	64.5	2.1	60.5	68.5
10. S - TR 6					
Distance	59.5 - 87.0	74.3	4.6	65.3	83.3
Angle	51.4 - 57.5	54.8	2.0	50.9	58.7
11. S - DC 6					
Distance	72.0 - 103.4	84.5	4.9	75.1	93.9
Angle	62.9 - 72.1	65.5	2.4	61.3	69.7
12. S - DC 7					
Distance	62.5 - 86.1	74.2	4.0	66.4	82.0
Angle	69.0 - 78.1	72.5	2.0	68.6	76.4

TABLE VI

MANDIBULAR DENTOALVEOLAR ASSESSMENT
VALUES OF SELECTED MEASUREMENTS
(In Millimeters or Degrees)

MEASUREMENT	OBSERVED RANGE	MEAN	STANDARD DEVIATION	95% CONFIDENCE LIMITS Low	95% CONFIDENCE LIMITS High
1. $\overline{1}$ - NB	13.6 - 33.5	24.6	4.9	15.1	34.1
2. $\overline{1}$ - NB (mm)	0.0 - 9.7	4.8	2.3	0.4	9.2
3. Po - NB	1.0 - 8.1	3.7	1.6	0.6	6.8
4. $\overline{1}$ - Po Ratio	9:1 - 1:7	1.3:1	2.1	5.3:1	1:5.3
5. IMPA	83.6 - 102.5	93.4	4.8	84.4	102.4
6. Chin Angle	57.7 - 76.2	66.8	4.6	58.0	75.6
7. Gn-In	30.7 - 39.3	35.4	2.2	31.4	39.4
8. Co-TC $\overline{1}$	76.0 - 102.1	89.9	5.9	78.3	101.5
9. Co-TC $\overline{1}$ (mm)	99.2 - 124.0	109.4	6.2	101.4	117.4
10. S-TC $\overline{1}$ Distance	95.1 - 121.2	111.0	4.3	102.9	119.1
Angle	48.5 - 54.7	51.4	1.2	49.3	53.5
11. S-TR $\overline{1}$ Distance	105.4 - 132.3	120.2	6.2	108.2	132.2
Angle	59.8 - 67.1	62.5	1.1	60.5	64.5
12. S-TC $\overline{6}$ Distance	79.0 - 103.5	91.2	3.8	83.6	98.8
Angle	57.5 - 67.5	62.8	2.2	58.8	66.8
13. S-TR $\overline{6}$ Distance	88.1 - 115.2	106.0	6.1	94.0	118.0
Angle	68.5 - 77.1	72.2	2.0	76.1	88.3
14. S-DC $\overline{6}$ Distance	79.1 - 98.1	87.0	2.1	83.0	91.0
Angle	65.0 - 73.7	69.1	1.7	65.4	72.8
15. S-DC $\overline{7}$ Distance	68.6 - 82.6	79.5	3.2	73.4	85.6
Angle	70.0 - 80.8	74.5	2.2	70.4	78.6

TABLE VII

CEPHALOMETRIC VALUES FOR TEST CASES
(* Indicates measurement beyond normal limits

MEASUREMENT		NORMAL RANGE	NORMAL TEST	CLASS I ARCH LENGTH DISCREP.	CLASS II,** DIVISION 1	CLASS II,** DIVISION 2	CLASS III**
1. Saddle Angle		113.2 - 113.4	115.1	122.1	132.6	129.2	125.2
2. Articulare Angle		130.8 - 157.7	155.7	146.8	139.0	140.7	134.6
3. Gonial Angle		112.0 - 132.6	120.3	130.2	124.1	125.0	127.5
4. Sum		379.4 - 399.6	391.1	399.1	395.7	393.8	387.3
5. PCB Length		33.7 - 46.5	41.7	37.2	38.2	39.4	39.9
6. Ramus Height		47.3 - 63.7	57.1	53.0	48.1	54.7	60.2
7. Body Length		73.2 - 89.9	82.0	77.1	74.6	79.0	85.7
8. S-1st CV	Distance	42.6 - 70.9	58.2	64.1	51.0	56.0	48.2
9.	Angle	81.2 - 113.7	100.2	103.2	120.1*	113.7	108.4
10. S-2d CV	Distance	79.5 - 111.1	95.0	95.7	86.4	92.1	85.5
11.	Angle	102.5 - 113.5	104.3	105.2	115.9*	110.4	108.5
12. S-3d CV	Distance	98.5 - 133.7	115.2	115.3	107.3	111.7	115.5
13.	Angle	99.5 - 114.1	100.1	106.2	104.7	108.0	101.2
14. S-Co	Distance	30.2 - 49.1	35.0	37.6	38.7	39.4	32.3
15.	Angle	104.4 - 120.4	107.1	104.8	132.0*	129.6*	118.0
16. S-Go	Distance	77.2 - 105.5	96.1	86.2	79.4	86.1	92.7
17.	Angle	92.1 - 104.5	95.5	100.3	108.0*	102.0	97.5

TABLE VII (CONTINUED)

MEASUREMENT		NORMAL RANGE	NORMAL TEST	CLASS I ARCH LENGTH DISCREP.	CLASS II,** DIVISION 1	CLASS II,** DIVISION 2	CLASS III**
18. S. Ant. Phar.	Distance	95.5 - 129.6	110.0	113.7	115.2	109.4	103.2
19.	Angle	90.8 - 105.0	92.2	102.1	102.9	101.7	93.8
20. S-Post. Phar.	Distance	44.8 - 59.8	56.3	58.2	50.1	55.0	47.5
21.	Angle	96.0 - 110.0	97.3	103.7	108.9	107.8	100.1
22. S-Por	Distance	24.2 - 48.5	33.7	31.6	32.8	40.0	31.2
23.	Angle	137.2 - 145.3	143.4	145.2	141.6	143.2	135.5*
24. ACB Length		67.5 - 89.1	82.1	76.3	82.5	77.2	78.0
25. SNA		75.4 - 88.2	83.0	80.0	70.5*	82.0	80.9
26. SNB		74.7 - 86.6	84.5	78.0	69.2*	79.0	86.8*
27. ANB		- 3.8 - 6.0	- 1.5	2.0	1.3	3.0	- 6.1*
28. N-ANS		51.2 - 63.0	59.0	56.3	61.0	59.2	62.8
29. S-ANS	Distance	99.2 - 113.5	112.5	90.2*	90.1*	94.0*	107.5
30.	Angle	34.2 - 40.2	35.0	39.4	38.7	39.7	39.8
31. S-A Point	Distance	84.1 - 100.2	98.2	89.6	84.4	92.7	92.0
32.	Angle	39.4 - 43.6	42.3	43.2	43.1	42.2	43.2
33. S-B Point	Distance	106.1 - 136.0	130.7	120.2	106.8	115.1	138.2
34.	Angle	54.0 - 68.2	56.9	63.4	65.0	60.1	58.0
35. S-Gl	Distance	76.6 - 94.8	88.4	94.3	90.2	84.0	85.0
36.	Angle	4.8 12.2	6.1	8.0	6.0	6.1	8.7

TABLE VII (CONTINUED)

MEASUREMENT		NORMAL RANGE	NORMAL TEST	CLASS I ARCH LENGTH DISCREP.	CLASS II,** DIVISION 1	CLASS II,** DIVISION 2	CLASS III**
37. S-Gn	Distance	126.6 - 154.1	150.2	140.2	123.0*	132.6	146.0
38.	Angle	63.5 - 72.5	69.0	71.6	73.6*	67.0	64.5
39. S-HB	Distance	113.5 - 139.3	136.7	125.2	111.2*	126.4	116.5
40.	Angle	82.1 - 90.1	82.3	90.0	96.0*	89.7	80.4*
41. S-In	Distance	103.3 - 127.1	124.0	115.0	111.9	108.0	123.2
42.	Angle	53.3 - 58.9	55.9	58.6	61.0*	55.9	51.4*
43. S-KR	Distance	61.6 - 74.6	71.2	66.4	63.1	62.1	70.2
44.	Angle	47.5 - 51.5	49.9	49.2	51.2	48.2	50.5
45. S-Or	Distance	57.1 - 69.1	66.7	63.5	58.0	59.3	62.5
46.	Angle	24.4 - 28.6	27.0	27.9	29.0*	28.2	27.8
47. S-Po	Distance	128.6 - 145.6	142.1	138.0	122.2*	129.3	145.8*
48.	Angle	61.6 - 68.2	61.9	68.2	69.6*	62.9	61.5*
49. S-PCP	Distance	113.6 - 132.6	130.0	122.0	107.3*	114.4	127.5
50.	Angle	64.5 - 72.7	65.7	72.0	73.4*	63.7*	63.6*
51. S-PNS	Distance	44.7 - 63.7	58.2	59.2	53.6	50.1	57.1
52.	Angle	64.5 - 76.5	68.9	71.3	71.5	72.0	71.5
53. S-Pr	Distance	96.0 - 113.0	110.0	101.1	95.0*	103.7	112.0
54.	Angle	44.0 - 49.0	46.3	47.7	50.1*	48.9	46.6
55. S-PTM	Distance	43.0 - 53.4	50.6	51.4	50.5	47.0	50.0
56.	Angle	66.3 - 70.3	67.5	72.3*	69.5	72.0*	72.5*

TABLE VII (CONTINUED)

MEASUREMENT		NORMAL RANGE	NORMAL TEST	CLASS I ARCH LENGTH DISCREP.	CLASS II,** DIVISION 1	CLASS II,** DIVISION 2	CLASS III**
57. S-Sig. Not.	Distance	33.6 - 48.6	45.9	45.3	39.2	42.4	42.7
58.	Angle	78.5 - 94.1	80.2	87.4	79.4	93.1	83.2
59. S-CG	Distance	40.4 - 60.4	43.1	51.8	60.4	55.5	44.5
60.	Angle	14.8 - 24.4	22.7	22.8	17.1	17.0	18.2
61. S-FB	Distance	66.0 - 74.0	68.7	72.6	73.1	70.2	72.2
62.	Angle	8.0 - 12.2	10.1	11.0	10.7	9.1	10.5
63. Go-Gn-Sn		21.7 - 37.9	30.0	37.4	35.9	28.0	26.5
64. FMA		13.6 - 31.8	24.9	30.1	24.3	24.1	19.0
65. Y-Axis		53.2 - 65.0	57.2	63.0	59.6	61.2	60.2
66. Facial Depth Angle		36.4 - 48.6	46.1	43.2	36.1*	42.0	44.6
67. Angle Facial Convex		-6.2 - 9.8	-3.0	2.0	4.0	2.0	-11.1*
68. $\underline{1}$ - SN		95.7 - 115.9	112.0	111.9	98.4	91.8*	109.8
69. $\underline{1}$ - FH		103.2 - 123.6	118.2	119.2	109.2	95.3*	112.5
70. $\underline{1}$ - $\overline{1}$		115.2 - 145.4	133.3	120.1	129.0	153.0*	134.9
71. $\underline{1}$ - NA Angle		16.6 - 32.2	30.1	31.6	28.1	8.0*	29.5
72. $\underline{1}$ - NA (mm)		2.4 - 10.4	6.1	6.1	8.0	0.0*	10.6*
73. ANS - Pr		12.1 - 23.9	20.6	18.0	19.2	18.2	13.7

TABLE VII (CONTINUED)

MEASUREMENT		NORMAL RANGE	NORMAL TEST	CLASS I ARCH LENGTH DISCREP.	CLASS II,** DIVISION 1	CLASS II,** DIVISION 2	CLASS III**
74. S - TC 1	Distance	102.9 - 127.1	120.1	108.3	115.3	109.2	116.0
75.	Angle	47.5 - 55.3	50.0	52.6	56.4*	54.7	50.5
76. S - TR 1	Distance	76.9 - 98.4	95.2	87.2	81.6	88.0	90.1
77.	Angle	40.8 - 46.2	45.0	46.2	47.1*	44.1	45.1
78. S - TC 6	Distance	78.8 - 100.2	91.7	88.6	84.9	86.1	87.5
79.	Angle	60.5 - 68.5	62.0	65.7	67.2	66.9	63.0
80. S - TR 6	Distance	65.3 - 83.3	76.2	73.7	70.7	72.0	72.5
81.	Angle	50.9 - 58.7	56.3	57.1	57.3	56.2	55.7
82. S - DC 6	Distance	75.1 - 93.9	80.0	81.0	75.4	77.6	80.0
83.	Angle	61.3 - 69.7	65.3	67.2	69.5	67.8	67.0
84. S - DC 7	Distance	66.4 - 82.0	81.2	74.6	67.0	67.9	74.5
85.	Angle	68.6 - 76.4	70.1	74.0	74.1	73.2	72.4
86. T - NB Angle		15.1 - 34.1	19.2	27.2	21.2	25.0	22.0
87. T - NB (mm)		0.4 - 9.2	2.2	3.0	4.0	1.0	7.0
88. Po - NB		0.6 - 6.8	6.0	1.0	5.0	4.0	1.0
89. $\overline{T}$ - Po Ratio		5.3:1 - 1:5.3	1:3	3:1	4:5	4:1	7:1*
90. IMPA		84.4 - 102.4	86.2	89.2	96.0	87.2	87.8
91. Chin Angle		58.0 - 75.6	61.4	67.0	67.0	69.0	76.0*
92. Gn-In		31.4 - 39.4	38.7	38.1	33.7	35.0	38.0

TABLE VII (CONTINUED)

MEASUREMENT	NORMAL RANGE	NORMAL TEST	CLASS I ARCH LENGTH DISCREP.	CLASS II,** DIVISION 1	CLASS II,** DIVISION 2	CLASS III**
93. Co - TC $\bar{1}$ Angle	78.3 - 101.5	97.1	89.0	83.9	83.1	95.1
94. Co - TC $\bar{1}$ (mm)	101.4 - 117.4	104.7	98.4*	93.1*	96.8*	110.0
95. S - TC $\bar{1}$ Distance	102.9 - 119.1	116.2	108.3	97.3*	101.0*	115.2
96. Angle	49.3 - 53.5	50.0	53.0	55.4*	52.6	47.0*
97. S - TR $\bar{1}$ Distance	108.2 - 132.2	130.4	117.0	105.5*	115.7	128.7
98. Angle	60.5 - 64.5	62.1	64.2	69.0*	64.9*	58.4*
99. S - TC $\bar{6}$ Distance	83.6 - 98.8	94.9	89.4	81.6*	83.1*	88.0
100. Angle	58.8 - 66.8	62.0	63.7	68.6*	59.6	57.4*
101. S - TR $\bar{6}$ Distance	94.0 - 118.0	108.3	114.6	93.0*	99.1	108.2
102. Angle	76.1 - 88.3	77.7	76.7	78.4	75.4*	72.0*
103. S - DC $\bar{1}$ Distance	83.0 - 91.0	89.4	86.4	78.1*	79.9*	87.8
104. Angle	65.4 - 72.8	67.2	69.2	71.4	73.8*	67.1
105. S - DC $\bar{7}$ Distance	73.4 - 85.6	82.0	74.1	67.2*	68.4*	78.5
106. Angle	70.4 - 78.6	72.0	74.0	77.0	73.2	73.0
				**Failed limitation 2 describing maxillary and mandibular molar relationship.	**Failed limitation 2 describing maxillary and mandibular molar relationship.	**Failed limitation 1 describing maxillary and mandibular incisor relationship.

TABLE VIII

MEASUREMENTS FROM BJORK ANALYSIS
(Bjork's data is obtained from 21-22 year-old Swedish males)

		MEAN	STANDARD DEVIATION	NORMAL RANGE
1. Saddle Angle The measurement of the angle at sella turcica provides a means of measuring the shape of the cranial base. Its architecture has a direct influence on mandibular position.	Bjork	123.6°	5.33°	107.1° - 139.0°
	This Study	123.3°	5.10°	113.2° - 133.4°
2. Articulare Angle This angle measures the forward or backward diversion of the mandibule.	Bjork	143.3°	6.91°	122.5° - 164.0°
	This Study	144.2°	6.90°	130.8° - 157.7°
3. Gonial Angle This measurement at gonion describes the angular relationship of the ramus of the mandible to the mandibular body.	Bjork	130.9°	7.31°	108.9° - 152.8°
	This Study	122.4°	5.30°	112.0° - 132.6°
4. Sum of the Three Angles The sum is an indicator of the direction of cranial growth and its influence on facial morphology.	Bjork	397.0°	5.90°	381.4° - 403.0°
	This Study	389.5°	5.20°	379.4° - 399.6°
5. Anterior Cranial Base Length This linear measurement will partially determine the degree of facial prognathism.	Bjork	73.2 mm	3.26 mm	63.4 mm - 83.0 mm
	This Study	78.0 mm	5.60 mm	67.5 mm - 89.1 mm

TABLE VIII (CONTINUED)

		MEAN	STANDARD DEVIATION	NORMAL RANGE
6. Posterior Cranial Base Length The length of the posterior cranial base, in part, determines the backward or forward divergence of the mandible.	Bjork	37.0 mm	3.3 mm	27.1 mm - 47.0 mm
	This Study	40.1 mm	3.3 mm	33.7 mm - 46.5 mm
7. Ramus Height The length of the ramus of the mandible partially determines the height of the face.	Bjork	53.2 mm	5.16 mm	37.8 mm - 68.7 mm
	This Study	55.5 mm	4.2 mm	47.3 mm - 63.7 mm
8. Mandibular Body Length The length of the body of the mandible will effect facial height and prognathism of the profile.	Bjork	80.7 mm	5.16 mm	65.2 mm - 96.1 mm
	This Study	81.5 mm	4.4 mm	73.2 mm - 89.9 mm
9. Chin Angle This angular measurement indicates the degree of mandibular alveolar procumbency.	Bjork	64.2°	6.43°	45.0° - 83.5°
	This Study	66.8°	4.60°	58.0° - 75.6°
10. Nasion to Anterior Nasal Spine This linear measurement evaluates nasal height.	Bjork	55.41 mm	3.25 mm	51.2 mm - 63.0 mm
	This Study	57.1 mm	3.0 mm	50.4 mm - 63.6 mm

TABLE IX

MEASUREMENTS FROM DOWNS ANALYSIS
(Downs' data was obtained from 12 to 17 year-olds, male and female)

		MEAN	STANDARD DEVIATION	NORMAL RANGE
1. Angle of Facial Convexity (NA-Po) This angle measures the degree of protrusion of the maxillary portion of the face to the total profile.	Downs	0° (or 180°)	4.3°	10° - 8.5°
	This Study	1.8°	4.1°	9.8° - 6.2°
2. Y-Axis This angle measured at its intersection with the Frankfort horizontal plane evaluates the direction and degree of forward and downward development of the face in relation to the cranium.	Downs	59.4°	3.7°	53.0° - 66.0°
	This Study	59.1°	3.0°	53.2° - 65.0°
3. Frankfort Mandibular Plane Angle (FMA) This angle measures the skeletal degree of existing facial divergence.	Downs	21.9°	4.6°	17.0° - 28.0°
	This Study	23.2°	4.9°	13.6° - 31.8°
4. Incisor Mandibular Plane Angle (IMPA) This angular measurement relates the mandibular central incisors to mandibular apical base.	Downs	91.4°	4.4°	82.5° - 97.0°
	This Study	93.4°	4.8°	84.4° - 102.4°
5. $\underline{1}$ to $\overline{1}$ This angle measures the degree of procumbency of the maxillary and mandibular incisor teeth.	Downs	135.4°	5.7°	130.0° - 150.5°
	This Study	130.3°	7.9°	115.2° - 145.4°

TABLE X

MEASUREMENTS FROM STEINER ANALYSIS
(Data obtained from Reidel of Individuals over 18 years of age)

			MEAN	STANDARD DEVIATION	NORMAL RANGE
1.	SNA The angle SNA locates the maxillary apical base to the cranial plane S-N.	Steiner	82.0°	3.89°	
		This Study	81.8°	3.3°	75.4° - 88.2°
2.	SNB This angle relates the mandibular apical base to the cranium.	Steiner	79.97°	3.6°	
		This Study	80.7°	3.1°	74.7° - 86.6°
3.	ANB Difference This measurement is Steiner's method to indicate the anteroposterior relationship of the maxillary and mandibular basal arches.	Steiner	2.04°	1.81°	
		This Study	1.1°	3.1°	3.8° - 6.0°
4.	Go-Gn-SN This angle indicates the vertical development of the mandible and the direction of facial growth.	Steiner	32.0°	4.1°	23.7° - 38.6°
		This Study	29.8°	4.2°	21.7° - 37.9°
5.	$\underline{1}$ to NA This measurement relates the maxillary central incisors anteroposteriorly to the maxillary denture base. It is a method of relating these teeth to a landmark in the face rather than the cranium.	Steiner	22.0° 4.0 mm		
		This Study	24.4° 6.4 mm	4.0° 2.1 mm	16.6° - 32.2° 2.4 mm - 10.4 mm

		MEAN	STANDARD DEVIATION	NORMAL RANGE
6. $\bar{1}$ to NB The mandibular central incisor is related to the mandibular denture base both linearly and angularly by these measurements.	Steiner	25.0° 4.0 mm		
	This Study	24.6° 4.8 mm	4.9° 2.3 mm	15.1° - 34.1° 0.4 mm - 9.2 mm

TABLE XI

MEASUREMENTS OF OTHER INVESTIGATORS

		MEAN	STANDARD DEVIATION	RANGE VARIATION
1. Po to NB This measurements relates the chin to the NB Plane.	Holdaway	4.0 mm		
	This Study	3.7 mm	1.6 mm	0.6 mm - 6.8 mm
2. $\underline{1}$ to Po (Holdaway Ratio) This measurement relates the mandibular incisor to the chin.	Holdaway	1:1		
	This Study	1.3:1	2.1 mm	5.3:1 - 1:5.3
3. Facial Depth Angle (S-N-Go) This describes the antero-posterior depth of the face and indicates the morphology and direction of growth of the mandible.	Jarabak	42.0°		
	This Study	42.5°	3.2°	36.4° - 48.6°
4. $\overline{1}$ to SN (Jarabak and Schaffer) This angular measurement evaluates the relationship of the maxillary central incisor to the cranial base plane sella - nasion.	Reidel	103.97°	5.8°	95.7° - 114.8°
	This Study	105.6°	5.6°	97.5° - 115.9°
5. $\overline{1}$ to FH This measurement relates the maxillary central incisor to the cranial base plane F-H.	Reidel	111.2°	5.9°	101.7° - 121.6°
	This Study	113.4°	5.4°	103.2° - 123.6°

CHAPTER V

DISCUSSION

Programming orthodontic treatment is one of the most critical tasks confronting an orthodontist. Growth, morphologic patterns of the craniofacial complex, sizes and shapes of teeth, dental size ratios between the teeth in the two arches, and facial asymmetries are but a few of the major considerations which enter into the development of a treatment plan. It is the purpose of this research to prepare the groundwork for treatment programming using an electronic computer. In order to accomplish this, it was necessary to arrange the data derived from the cephalogram into various categories amenable to the computer process.

These data were arranged as follows:

1. Conversion of all measurements into rectangular coordinates.
2. Arranging these data to establish:
    a. The morphology of the posterior cranial base.
    b. The morphology of the anterior base.
    c. The morphology of the mandible.
    d. The relationship of the cranial bases to each other.
    e. The relationship of the teeth to each other.
    f. The relationship of the teeth to their respective apical bases.

In order to give meaning to the data, it was necessary to establish some standards. This was done by selecting a sample comprised of young adult males who had completed their growth and who had nearly ideal occlusions. By using a sample of non-growing subjects, the influence of growth was excluded from this investigation. Eliminating this complex factor until such a time when the computer program is perfected removed many problems. Growth assessment answers will come from future studies after a basic program is designed.

Successful programming demands isolating data into specific yet meaningful components which can be understood, electronically, by the computer. This was done as outlined by converting all data into rectangular coordinates and then arranging these data to ascertain what each of the various areas of the craniofacial complex contributed to total facial morphology.

Rectangular coordinates are discrete packets of information readily accepted by the computer, that is, these data are in a form suitable for computer computations. So that the machine could receive this information, the coordinates of the selected landmarks were recorded on punch cards, in various sequences, that constructed specific cephalometric measurements. The exact layout of the cards and the methods to accomplish this are explained and illustrated in Chapter III. This information is now permanently recorded in an easily retrievable form, thus the task of regathering these primary data is eliminated.

Once the data is contained within the machine, instructions supplied by the computer program dictate the calculations that are to be carried out. This program was written in a problem-oriented language known as FORTRAN which is a general mathematical or formula-translating computer language. This is the language of choice for solving scientific problems; therefore, it was used in this research. These data were manipulated as instructed by the program and the results--distances, angles, and points of intersection--resulted. These then were the measurements that were used to assess the lateral cephalograms.

Examining the data now becomes necessary if it is to have meaningfulness in designing a diagnosis and treatment planning program oriented to the computer. Since these were adult subjects, it might be well to compare data derived from these individuals with those from other investigators and show how these data were arranged for computer programming.

Considering the numerical breakdown of the posterior cranial base first, it is interesting to note that this area, morphologically speaking, compares favorably with the observations made by Bjork. The saddle and articulare angles in the two populations were nearly identical. Bjork found a value of 123.06 degrees for the saddle angle, the same angle in this study was 123.3 degrees. Articulare angle values are 143.3 degrees from Bjork's study and 144.2 degrees as established here. The values of these two angles indicate Bjork's population (Swedish males, 21 to 22 years old, disregarding occlusion) was about the same as the American population of a comparable age.

The gonial angle of the American population was significantly smaller than the Swedish conscripts. This means that the relationship between ascending ramus and body was more acute. From this we may gather that mandibular growth was more horizontal in the American than the Swedish males. Bjork reported a value of 130.9 degrees, this study 122.4 degrees.

The sum of these three angles is an indicator of the direction of growth of the posterior cranial base. As the mandible is directly connected to this portion of cranial anatomy, the morphology of the posterior cranial base influences mandibular position. The sum of the three angles was significantly less for this investigation, and this reduction can be attributed to the decreased gonial angle.

The chin angle was another angular measurement employed by Bjork for which this research reported findings. This measurement was included in the mandibular dentoalveolar assessment section. The American population showed somewhat more mandibular alveolar procumbency, as indicated by the increase in this angle, than the Bjork sample. The difference between the two studies was 2.6 degrees and is not considered to be significantly great.

Five linear measurements proposed and evaluated by Bjork were also used in this assessment program. These were the anterior and posterior cranial base lengths, ramus height, mandibular body length, and the distance from nasion to anterior nasal spine. The measurements for the anterior and posterior cranial bases in the two investigations showed significant differences. Both cranial bases were larger in this population, and the increase in growth was nearly proportional. Bjork found a mean value of 73.2 millimeters and 37.0 millimeters, respectively, for the anterior and posterior cranial bases. This research reports values of 78.0 and 40.1 millimeters, respectively. The length of the anterior base partially determines the degree of facial prognathism, while the posterior cranial base length, in part, establishes the forward or backward divergence of the mandible and influences facial height.

Ramus height and mandibular body length were also studied. Both of these measurements are included in the posterior cranial assessment division of the analysis. Ramus height influences facial height, and body length facial prognathism. No significant differences were found between the American and Swedish subjects. The other measurement investigated in this and the Bjork study was the linear distance from nasion to anterior nasal spine which assesses nasal height or height of the upper face. Both studies again report essentially similar findings, Bjork reporting a length of 55.41 millimeters while this study gave a mean of 57.1 millimeters. This measurement is placed in the anterior cranial assessment for purposes of programming.

A cephalometric method of recording the skeletal and facial pattern by which facial form can be measured was introduced by Downs (1948). His research was conducted on a group of twenty individuals, 12 to 17 years old, with excellent occlusion. Five angular measurements of the Downs analysis were included in this assessment program. Comparison between the results of this study and Downs' original work follows.

Three measurements are essentially similar in both investigations. The Y-axis assess the direction and degree of downward and forward development of the face in relation to the cranium. Downs reported a mean of 59.4 degrees, this study 59.1 degrees. This is a significant observation because it points out the fact that beyond a certain age, 14 years according to Downs, there is very little change in the vertical height of the face, a distance assessed in part by the Y-axis. This measurement and the Frankfort mandibular plane angle were part of the growth axis division of the assessment program. The FMA, a measure of existing facial anterior teeth was seen in this sample by its reduced value. Here the angle was found to be 130.3 degrees, while Downs reported the mean as 135.4 degrees.

Steiners clinical cephalometric analysis is comprised of thirteen measurements of which eight were used in this computer assessment program. The angles SNA and SNB relate the maxillary and mandibular apical bases to cranial anatomy. Reidel has studied these values for various age groups, and our data will be compared with findings derived by Reidel for subjects over 18 years of age. He reported the SNA measurement to be 82.0 degrees. This study, relocating A point as advocated by Jarabak, found a mean of 81.8 degrees. As A point (Jarabak) is located posterior to the point generally employed, and since the two studies report basically similar values, this population has more maxillary procumbency than the Reidel sample. The SNB values are nearly identical (Reidel--79.97 degrees, this study--80.7 degrees). The ANB difference, found by Reidel as 2.04 degrees, was reduced to 1.1 degrees for our population. The difference is explained by the locations selected for A point in the two investigations and therefore are presumed to be nearly identical.

Reidel also reported values for the angle Go-Gn-SN for a population 18 years or older. Reidel found a mean value of 32.0 degrees; it was 29.8 degrees in this study. As this angle is an indicator of the vertical development of the mandible and the divergence of facial growth, the population of this study shows a pattern of facial development more forward and less downward. This is also in agreement with the information derived from Bjork's findings. The Go-Gn-SN measurement was included in the growth axis assessment of this analysis.

The four remaining measurements of the Steiner analysis evaluate the maxillary and mandibular central incisors, anteroposteriorly, to their denture bases. The measurement $\underline{1}$ to NA is assigned a value of 22.0 degrees and 4.0 millimeters by Steiner. The findings of this research are 24.4 degrees and 6.4 millimeters. An increase for these measurements was expected as A point was located more posteriorly in this study. Relocating A point in this way increases both the angular and linear measurements, and this was found. Therefore, the results of both investigations are considered to be essentially similar. The angular measurement of $\overline{1}$ to the NB plane is given a value of 25.0 degrees by Steiner, and the linear distance is placed at 4.0 millimeters. The findings derived from this population are almost identical, the means being 24.6 degrees and 4.8 millimeters.

Holdaway has proposed a ratio that relates the position of the mandibular incisors to the chin. The linear values of $\underline{1}$ - NB and Po to NB were measured and compared. Ideally both measurements should be 4.0 millimeters, and a 1 to 1 ratio should result. This study found results favorable to those advocated by Holdaway, as the mean ratio was calculated to be 1.3 to 1 with a standard deviation of 2.1. This measurement is found in the mandibular dentoalveolar section of the assessment program.

Jarabak has proposed, that for maximum stability of the mandibular incisors, the long axes of these teeth should describe an angle of ninety degrees with the line drawn from the hinge axis radius to the incisal edges of the mandibular central incisor crowns. This research has proved this suggestion quite valid as the mean was found to be 89.9 degrees.

The facial depth angle (S-N-Go), measured at nasion, evaluates the morphology and growth direction of the mandible as well as describing the anteroposterior depth of the face. Jarabak has suggested this angular measurement, and a value of 42.0 degrees is generally accepted as the norm. This study reported a mean of 42.5 degrees. It is included in the growth axis assessment section.

The angular measurements of $\underline{1}$ to the SN plane (Jarabak and Schaeffer) and $\underline{1}$ - FH relate the maxillary incisor teeth to cranial planes. Reidel, investigating patients 18 years old or older, reported a mean of 103.97 degrees for the $\underline{1}$ - SN measurement. A mean of 105.6 degrees was arrived at in this study.

Reidel, using the same sample, gives a value of 111.2 for the angle 1 to FH, while our finding was a mean of 113.4 degrees. These two measurements, by their increase, denote a greater degree of maxillary incisor procumbency for this population.

All the measurements calculated by the machine were also measured manually. Both methods produced comparable results, and the feasibility of using the computer and the rectangular coordinate system for assessment of lateral cephalograms was established. This approach makes it possible to develop programming methods which can furnish vast quantities of fundamental diagnostic data. This, in turn, can lead ultimately to a complete orthodontic assessment and diagnosis by the electronic computer.

Angles and distances suggested by other researchers were discussed previously. New measurements, computed from the rectangular coordinates, were introduced by this investigation. These measurements provide for a more sensitive and useful assessment of the various parts of the craniofacial complex and thereby aid in arriving at a more accurate diagnosis. The significance of these various lines and angles was discussed in Chapter IV.

To test the validity of the computer program to detect differences in the points, angles, and distances established for normal occlusion and those of malocclusions, five cephalograms were selected and processed in the computer. These headfilms are described in Chapter III.

The cephalogram of normal occlusion successfully met all the requirements established by this investigation for normal occlusion, that is, no angles, lines, or points were rejected by the machine.

In testing a Class I arch length discrepancy malocclusion against the control sample, three measurements were not accepted by the computer. One of these was the linear value from sella turcica to the anterior nasal spine. This measurement was nine millimeters shorter than the standard established by the control sample. Next was the measurement from sella to the most inferior tip of the shadow representing the pterygomaxillary fissure. This was an angular value, and the difference was two degrees less than the established normal limits. The combined value of these two measurements pointed out the fact that the overall anteroposterior depth of the upper face and length of the maxilla were less than that shown in the sample of adult normals.

The third measurement to fall outside of the normal limits was the distance from the condyle to the tip of the crown of the mandibular central incisor. This distance was three millimeters below the lower limit of the normal range. A decrease in the measurement, without a concomitant change in the gonial angle measurement, signifies a reduction in mandibular body length.

This can explain the mandibular arch length discrepancy, just as the diminished anteroposterior depth of the maxilla can account for the arch length discrepancy in that jaw.

The Class II, Division 1 malocclusion failed to place thirty-two measurements within the parameters of normal. Both the SNA (70.5°) and SNB (69.2°) measurements were decreased indicating both jaws were posterior to cranial anatomy. Although many of the other commonly employed diagnostic measurements gave an indication of the malocclusion, only these two fell beyond the normal limits. However, familiar cephalometric criteria detected evidence of abnormality and located the specific areas of dysplasia. Several of the measurements to various points on the mandible were diagnostically consistent and implicitly illustrated the morphology and relationship of the lower jaw to the remainder of the craniofacial complex.

Some of these measurements will now be discussed. The angular measurements from sella to condyle, gonion, gnathion, pogonion, the posterior border of the symphysis, and infradentale were all increased above the limits for the normal in the range of one to two degrees. These increased angles indicated a mandible more backward divergent than normal. Linear measurements, less than average, from sella to gnathion, the posterior border of the symphysis, and pogonion suggested that the mandible was smaller than that observed in the normal sample. They also suggested that the mandible was in a more downward and forward position. The facial depth angle (S-N-Go) was also less than normal which indicated that gonion did not occupy a position in space normal to cranial anatomy. This, combined with the increased angular measurement from sella to the condyle, was indicative of a mandible in a more superior position in the cranium.

The posterior position of the maxilla in relationship to cranial anatomy was again indicated by the diminished linear measurements from sella turcica to the anterior nasal spine and prosthion. The angles from the horizontal reference plane to prosthion and orbitale were greater than in the normal occlusion group. Together these distances and angles suggested a pattern of maxillary development that was more downward and less forward than those in the control. The linear measurement from the condyle to the mandibular central incisor was less than in the normal group indicating that the mandible was shorter. The linear measurements from sella to the crown and root of this tooth were also decreased and substantiated the preceding observation. The angular measurements to the crown and root of the mandibular incisor were above the normal limits and indicated that this tooth was more downward and less forward in relation to cranial anatomy than found in normal occlusion. Linear measurements to the first and second mandibular molar crowns were decreased and below those of the normal group. This suggested that the vertical height of the posterior portion of the face was less than that observed in the control. All angular measurements from sella to these landmarks were above normal values, indicating the mandible was posterior to the upper face.

The Class II, division 2 molocclusion had seventeen measurements that were not in agreement with values of the normal population. The distance from sella turcica to the anterior nasal spine was less while the angle to the pterygomaxillary fissure was greater. Together these indicated that the maxilla was related more posteriorly to cranial anatomy than found in the normal group. The angular measurement from sella to the condyle was above the normal range of values which indicated that the condyle was more superiorly placed to the structures in the posterior cranial base. The angle from sella to the posterior border of the symphysis was also increased signifying the mandible was more backward divergent than the normal occlusion group, and this agreed with the preceding observation. The distances from sella and the condyle to the crown of the mandibular central incisor were shorter than the normal limits which suggested that either the mandible was shorter or it was oriented more posteriorly to the cranial anatomy than seen in the control sample. As would be expected in a Class II, division 2 malocclusion, the angular values of 1 to SN and 1 to FH were smaller as were the linear and angular measurements of 1 to NA. These measurements all indicated that the maxillary central incisor was much less procumbent than it was in the normal occlusions. This decreased procumbency of the maxillary central incisor was responsible for the large interincisal angle. Distances from sella to the crowns of the mandibular first and second molars were less than normal signifying there was a deficiency in the vertical height of the posterior part of the face.

The Class III malocclusion had eighteen measurements which were rejected by the computer. The SNB angle was much greater than normal and the ANB difference was minus 6.1 millimeters. The hyoid bone was positioned more anteriorly as evidenced by the decreased angular measurement from it to sella. Porion was located anteriorly which indicated a small saddle angle. Measurements to various points on the mandible pointed out the presence of mandibular dysplasia. The angular measurements from sella to infradentale, posterior border of the symphysis, and pogonion were below normal limits while the linear measurement to the latter landmark was increased. These all indicated that the mandible was longer than found in the normal occlusion group. The angle of facial convexity was far beyond the normal range (-11.1 mm). The Holdaway ratio and chin angle were larger indicating dental and alveolar mandibular procumbency in addition to the mandibular skeletal disharmony. Greater than normal growth of the mandible was also seen by the decreased angular measurements from sella turcica to the crowns and roots of the mandibular central incisor and first molar. The angle from sella to the pterygomaxillary fissure was greater than in the normal sample and suggested that the maxilla was forward to cranial structures. The distance 1 to NA was 10.6 millimeters and might be considered a functional adaptation of the maxillary incisors to the anteriorly positioned mandibular incisors.

A single test case of each of the classes of malocclusion does not imply that this program was capable of differential diagnosis without further refinements. This was not the purpose of this research, rather it was to demonstrate that a computer program could be developed to distinguish normal occlusion from malocclusions. This goal was achieved in part.

This study was also an investigation of normal occlusion. Therefore, a large number of measurements were necessary to develop a thorough research. These increased the sensitivity of the computer program considerably. Many of the measurements appear to be duplicates, and in the further refinement of assessment programs it might be best to discard angles or distances that are repetitious or of little diagnostic value. Because electronic computers can readily store and evaluate great quantities of data, it is not inferred that a diagnosis program should be reduced to just a few measurements. This is not necessary when employing the computer.

It is not the aim of this investigation to evaluate malocclusion data. Those values that are other than normal and distinguish one malocclusion from another are peculiar to each group. Future studies of all classes of malocclusion will be necessary whereby means and ranges of the various measurements can be established for each of the groups. Comparison between normal occlusion and the classes of malocclusion can then be performed by the electronic computer.

Although the validity of this computer program was demonstrated, it is not proposed that it is the ultimate model of an orthodontic assessment program. Further work will provide new ideas, additional data will be made available, new machines developed, and the capabilities of electronic systems expanded. The possible applications of electronic computers in orthodontics should be thoroughly investigated. Their use should be initiated as another tool in the advancement of refining orthodontic diagnostic criteria. Human error in judgement can thus be reduced, and a more scientific and reliable approach to orthodontic endeavors can be realized.

CHAPTER VI

SUMMARY AND CONCLUSIONS

This thesis was designed to accomplish two objectives. The first was to investigate normal occlusion in young adult Caucasian males through cephalometric measurements. The second was to develop an initial program of orthodontic assessment applicable to an electronic computer.

Nearly five hundred individuals were examined before a final sample of fifty was selected. Those chosen fulfilled not only the dental requirements set forth by this investigation, but also satisfied a number of other requirements as to function, skeletal, and facial morphology. The imposed limitations contributed to the homogeniety of the sample.

Cephalometric information was obtained in a form acceptable to the electronic computer. Data collection and reduction was accomplished through the use of Cartesian coordinates. By knowing the coordinates of the landmarks in the dentofacial structure, a considerable quantity of information concerning their location, position, and interrelationships was obtained. An accurate analysis of the craniofacial complex can be designed by the employment of the Cartesian coordinates. The collected data is readily adaptable to the electronic computer.

The cephalometric study was divided into five areas of assessment. Each measurement was placed into one of these five groups according to the area to which it contributed. Many of the angles and linear distances were established measurements of proven merit in orthodontic diagnosis. Other measurements were developed for and introduced by this investigation. A sizeable number of angles and distances were employed so that every area of assessment could be thoroughly investigated.

A series of explicit instructions, the computer program, was developed to interpret the coordinate readings so that specific angles and linear distances could be calculated by the machine. This step was accomplished by using a problem-oriented computer language known as FORTRAN. Results of the cephalometric measurements were obtained, and standards for the angles and distances were established.

The capabilities of the computer assessment program were also tested. Coordinate data obtained from previously unassessed cephalograms were compared to information stored in the computer. These measurements were collected from a headfilm of an individual with normal occlusion and from headfilms of subjects with malocclusions. The automata calculated the required measurements and it was found to be capable of recognizing differences between the data collected from normal occlusions and malocclusions.

The following may be concluded from this study:

1. An accurate and reliable analysis of the craniofacial complex can be designed by the use of rectangular co-ordinates.
2. Analytical problems are readily adapted to the electronic computer through the use of rectangular coordinates.
3. The computer is a time-saving device which can eliminate or minimize human error. Primary data can be retrieved from the computer, thus eliminating the repetitious collection of this information.
4. A research problem must be concise and explicit, then stated in an organized language acceptable to the computer to effect a workable program.
5. A computer program was developed that can differentiate between data collected from cephalograms of normal occlusions and malocclusions.
6. Through future efforts and investigations, a complete, unbiased program of orthodontic assessment by the electronic computer is feasible.
7. The computer is now available as an orthodontic research tool. Its application to orthodontics should be initiated without hesitation.
8. Many craniofacial landmarks are located with less precision on the lateral cephalogram, and the natural varia-

tion in location for some structures is greater than it is for others.

9. Cephalometric measurements of young adult males with normal occlusion show a wide range of variation.

10. Cephalometric measurements have been standardized from a large sample with normal occlusion for a specific age, sex, and racial group.

11. New measurements for cephalometric assessment are introduced. Their possible significance, means, and normal ranges are reported.

12. Cephalometric measurements suggested by other investigators were also studied. The results of this research generally concur with values reported previously; however, several findings differ significantly:

    a. The gonial angle is more acute in this population than in the Swedish males investigated by Bjork.

    b. Both the anterior and posterior cranial bases are larger in the American sample than in the Swedish population.

    c. A greater degree of maxillary procumbency is observed in this sample than found in populations previously described. This is evidenced by the increased values for the NA-Po, $\underline{1}$ - FH, and $\underline{1}$ - SN angles. A decrease was also observed in the interincisal angle value.

13. The Y-axis value found in this study is essentially identical to that reported by Downs for a younger sample. Therefore it can be concluded that facial height does not change appreciably from teenage to adulthood.

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APPROVAL SHEET

The thesis submitted by Dr. Gerald L. Ashley has been read and approved by members of the Departments of Anatomy and 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 24-1966
DATE

Joseph R. Jarabak
Signature of Advisor