The Value of Cephalometrics and Computerized Technology

ROBERT M. RICKETTS, D.D.S., M.S.

Another explanation of the use of roentgenographic cephalometrics would seem redundant. However, a momentous time in history is being witnessed as investigators, together with clinicians, are precipitating knowledge, programming it on the computer and supplying this information to the clinical orthodontist.[1,2,3] As in all new developments, widespread opposition and fear are encountered. The nature of the controversy has ranged from emotional outbursts to outrageous misinterpretation. The purpose of this writing, therefore, is to attempt an explanation of the logic and benefits of this development. It is hoped that, through understanding and dialogue, better progress can be made in the science, art and philosophy of orthodontics together with the profession of dentistry at large.

Naturally, all of the observations and facts leading to the computer program which the author founded cannot be covered in a one-hour presentation. It does seem fitting, however, to examine the hypotheses, theories, facts and principles on which the program was based. It would be helpful to bring out into the open basic scientific controversies before discussing the method or the specific values employed for the computer programming.

Several fundamental premises on which clinical cephalometric roentgenography and its computerization are thought to be based are also considered to be applicable to the controversy:

(1) Bone tissue constitutes a calcified system of stress.[4]

(2) Bones, as organs, working with other bones to function as supporting structures, serve for the registration stress systems through the analysis of their architectural patterns.[5]

(3) With the use of the cephalometer the bony stress systems of the head and neck; teeth and soft tissues are recorded in the x-ray film and may be reliably measured by the use of detailed tracing of anatomical parts.

(4) A competent mathematical description of dental and skeletal relationships may serve as an aid to the understanding of the integration of the stress systems involved in orthodontics.

(5) Because some base line of reference is needed, an atlas of the normal, or some basic reference of the central tendency, must be made available for the comparison and communication of problems in patients possessing dysplasias or abnormalities.

(6) A valid interpretation of the stress systems by the orthodontist made possible by accurate and complete, in-depth analysis will aid him in choosing a most appropriate treatment plan and aid in making a prognosis.

(7) However, before any atlas of the normal can be applied with reliability, biologic corrections must be made for the individual for his age, sex, ethnic type and constitutional type (size). Otherwise the child might be evaluated by adult standards.

(8) In order to ascertain the *prognosis,* the *possibilities of growth* and the *effects* rendered by mechanics both must be related to the individual stress system as a basis for independent biologic *treatment planning.*

(9) A body of information may be

Given at the meeting of the western components of the Angle Society, November 1971.

programmed and stored in the computer regarding known changes induced clinically together with the accepted objectives discovered from large clinical samples of successfully treated cases.

(10) By the application of certain principles and considering growth and treatment alterations of the stress systems, a forecast of desirable changes during the treatment term is feasible together with the long-range forecasting of possible results; to date both treatment objectives and growth projections to maturity are developed more than adequately for the practical planning of treatment in the clinical situation.

(11) A computer program, correctly administered, provides data for later retrieval, is helpful in communications regarding patient transfers, and provides a standardized clearinghouse for information.[6]

It would seem that the arguments regarding the truth or validity of the move to computerize cephalometrics and to employ it as a prescribed aid to treatment planning would hinge around the foregoing premises. Therefore, let us examine the basis for each of these premises in order to discover the strength and weaknesses inherent in the program under consideration.

Bone tissue as a stress system

Several facts lead the biologist to the conclusion that bone functions to receive and transmit stress or otherwise to support and protect organs. The most immediate part which comes to the mind of the orthodontist is the alveolar bone. This bone comes into existence only as the teeth form, develop, erupt and function, and it disappears when the teeth are lost. Furthermore, alveolar bone will display particular designs for the different teeth. While cancellous bone is striated and will reveal bracing or connecting patterns, the majority of stress is carried in the denser plates on the outside portion of tubular bones or the inner and outer tables of flat bones.

Biologically, when stress of a particular character in duration and amount occurs, even the tendon and the muscle have been shown to calcify as a means of economization of energy and tissue.

Bone as an organ of stress systems

While details of the morphologic relationship and effect of stress upon bone is open to question, and genetics and environment are controversial, it has been suggested by Lorenz that even physiologic behavioral patterns are carried in the genes.[7] Regardless of the argument, it usually is conceded that the strength in bones is reasonably related to their bulk. In osteoporosis associated with senility hip fracture is common, as the load of such a simple movement as a step downward will break the femur.

More directly related to the field of orthodontics is the hyoid bone which is free-floating, apparently designed for receiving stresses and for bracing the attachments of the suprahyoid and infrahyoid muscles at their junctions at the base of the tongue. It is well known that tongue postures and function can be appraised and measured by the study of hyoid bone position (Fig. 1).

The fact is that bone form represents the combination of shear, torsion, compression and tension and acts as a lever to the attachments and their counterparts. The organization of trabeculae in the bone tends to run parallel to the predominant stress vector.

Accordingly, bone as an organ displays a central order stress system responding to the aggregate of forces encountered. Extensions or processes from the bodies of bones supply mechanical advantage by lever principles. The joints serve as breaks in the stress system in order that limbs be enabled to

Fig. 1 Nine-year-old boy with characteristics of mandibular prognathism. Imagine the hyoid bone at a central point of stress for bracing of pharyngeal and tongue muscles. Note the hyoid level above the chin but at expected level between the third and fourth vertebral bodies. Note further the crypts of the lower third molars directly on the plane of the buccal occlusion.

produce motion and work. Bone structure can be used as a medium to evaluate stress systems when a study is approached from an analysis of external form and internal architecture. Wolff's law of functional adaptation is accepted as a biologic tenet when modified by including stress duration and amount, as explained by Steindler.[8]

Roentgenographic cephalometric films

Techniques such as Log-E-tronic processing can bring even the soft tissues up to a level of good visibility in the x-ray film (Fig. 1). Positioning the patient in the natural upright posture for x-ray exposure will help record the natural relations of parts and functions. The natural bite, natural lip seal, barium swallowing, physiologic rest, wide-open jaw position, speech phonation and other functional positions can be recorded on the film.

For the frontal orientation the lateral canthus of the eye measures about fifteen mm above the floor of the orbit. Leveling the corner of the eye to such a mark above the ear rod will serve to standardize the headfilm on Frankfort plane with greater consistency than the usual orbitale selection externally (Fig. 2). In this manner conventional lateral and frontal cephalometric films taken with care will reveal the structural elements in relative dependability.

Routinely, good anatomical tracings constructed by trained technicians can do much to help visualize anatomy in the cranium, joint, and soft tissue which frequently may be overlooked or disregarded by cursory observation of the head plate alone.

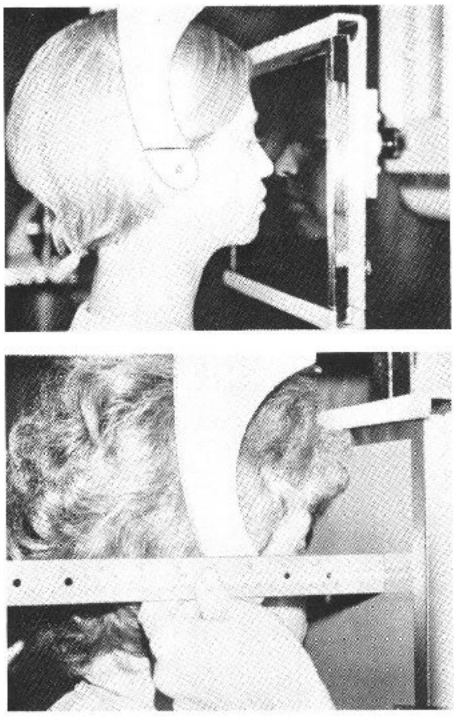

Fig. 2 Above: for frontal orientation the patient is seated upright facing the cassette, positioned on the ear rods and lowered until the top of the external canal fits snugly against the rods. Note the line scribed on the ear rod assembly 15 mm above the top of the rod. Below: for controlled Frankfort plane orientation the outer canthus of the eye is leveled to the line for the exposure. This technique eliminates frequent errors caused by the difficulty of locating orbitale.

Descriptive analysis

Essentially, three main divisions of interest are necessary for consideration in description in orthodontics. These pertain to the head and neck *skeleton,* the *denture* and the *soft tissue.*

From the beginning, arguments have centered on methods of reference. It is important to understand the *advantages* and *disadvantages* of each point or plane of reference. It is better not to draw conclusions by employing only one base line reference method for interpretation of the structural entirety.

Two levels of consideration are also involved in the computerization of the problem, gross characteristics and comprehensive detail.

First are the gross characteristics (Fig. 3). By working with peripheral facial aspects, the formulation of the scheme purports to explain the nature of maxillomandibular relation of the horizontal and vertical conditions. In the denture, likewise, it becomes a matter of relating the denture to the skeletal apparatus.

However, in a more comprehensive consideration of the face and denture, an analysis should include enough detail to permit a re-creation of the facial and dental morphologic relationship for complete description. The skull base, the facial skeleton, the denture, and the soft tissue can with certain knowledge be reconstructed from only thirty points and forty-three parameters in the lateral perspective. It is a matter of selecting those factors which are most representative of the true morphologic considerations of interest to the clinical orthodontist.

While orthodontists may note a variation by gross inspection of the head film, they often cannot associate the morphologic causes for the variation. One of the benefits of a detailed, comprehensive analysis is that dysplastic parts may be identified, and the clinician's attention drawn to them. Without an understanding of the complete morphologic factors with which he is dealing, the clinician could initiate

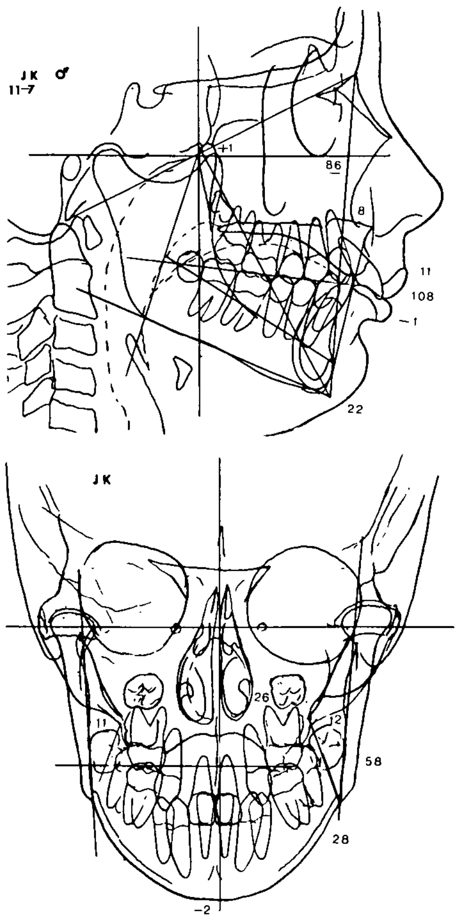

Fig. 3 Lateral and frontal tracings on a male (J.K., age 11 years 7 months. The facial axis of +1 shows favorable chin direction. The facial angle of 86 shows the chin depth to be average. The mandibular plane of 22 suggests normal ramal height. The 8 mm convexity with the normal chin suggests the maxilla to be protrusive. The lower incisor is lingual to the APo line and the upper is 11 mm protrusive. The nasal cavity is normal in width, the intercanine width is normal but the arch at the molars is wider than average and a slight midline deviation is present. The comprehensive descriptive analysis suggests the mandible to be wide and that the upper molars can be expanded in this patient to the wide lower arch.

an erroneous treatment plan for his patient.

The twenty measurements employed in the frontal, in the analysis under question, will not permit a complete reconstruction of the face in the frontal film. But the transverse features of the dental arch and facial skeleton are added to the lateral; collation of parts in the three-dimensional consideration thereby is possible.

An effort was made to select the fewest and most reliable parameters needed to fulfill the objective of adequate description of existing conditions. A focus was made on those factors known to be related to growth and treatment analysis in the clinical experience.

Atlas of the normal

From the inception of cephalometrics Broadbent sought an atlas of the normal growing child. In any other system of cephalometrics (and for that matter, in any clinical classification) the norm concept is employed for communication as a reference of central tendency. The "norm" is used as a basis for understanding dysplasia. However, analyses as published often have not been corrected for biologic factors. The clinician cannot draw from memory all of the details of values for each ethnic type, age, sex, etc. A computer, on the other hand, can supply an atlas of peak of the curve of normal morphology of skeletal and dental relation as a basis for comparison (Figs. 4-8) and further, the computer data may contain the *natural statistical distribution* to be expected. Through the vehicle of clinical deviation, the program contains the characteristics of variation within a given population. In this manner the program is designed to reveal at which level dysplasia reaches clinical concern (i.e., when asterisks or stars appear with the printout value). "Clinical deviation" is a value derived from the study of normal and treated cases and is employed similarly to statistical standard deviation. Values are corrected to meet the clinical needs of the practicing orthodontist. "Clinical deviation" was discovered to be needed as a consensus or aggregate of the clinical literature because there was great lack of agreement in samples reported

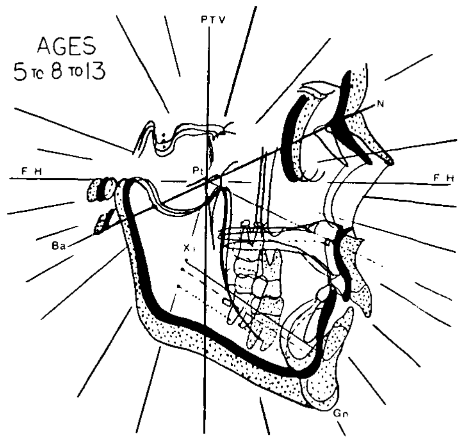

Fig. 4 Atlas of normal morphology by age levels as shown by orientation for descriptive analysis. Coordinates employed are the Frankfort horizontal at pterygoid vertical and basicranial axis (BaN) at vertical to foramen rotundum (Pt). Note "explosion" growth phenomenon at this orientation.

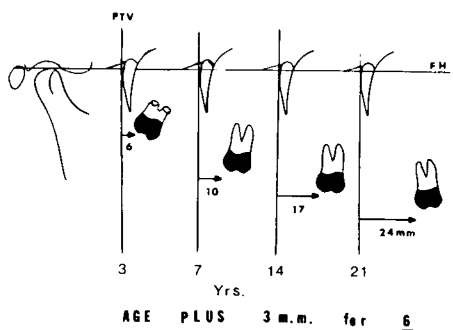

Fig. 5 Note position of upper molars at various age levels as programmed by the computer. This is an evaluation of upper molar positioning from Frankfort horizontal at pterygoid root vertical and displays the molars in relationship to the vertical at the various age levels. The mean has been found to be the age + 3 mm.

to be "normal." This feature was designed for the practicing orthodontist needing to make clinical decisions. It was based on some 2000 successfully treated cases followed, after treatment, for several years.

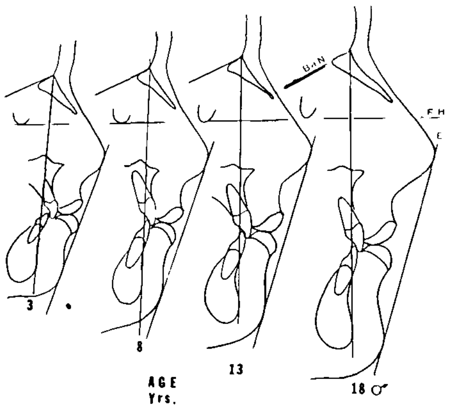

Fig. 6 Bony and soft tissue profiles as programmed for a normal atlas modified for sex and ethnic types and constitutional types as well as age. Note natural straightening of the profile, growth of the nose and retraction of lips to nose and chin by normal development.

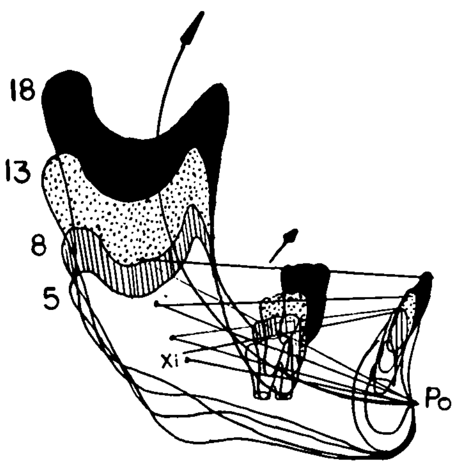

Fig. 7 Growth of the mandible and the changes in occlusal plane as programmed in the computer, and as demonstrated using the principle of arcial growth of the mandible, superimposed at pogonion and the anterior border of the ramus. Note the upward and forward growth of the ramus along the arc and resorption of the lower border of the mandible.

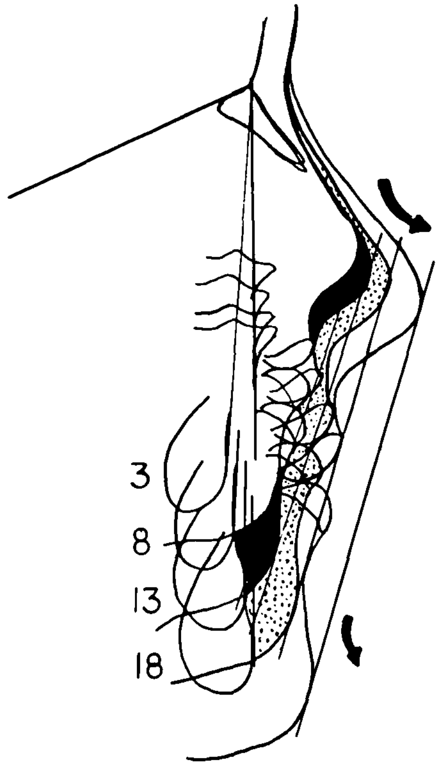

Fig. 8 Illustrating the change in the bony profile and soft tissue profile from the anterior cranial base (basion-nasion superimposed at nasion). Observe the arrow illustrating the downward and forward tip of the nose and the lower arrow, indicating the downward and forward growth of the chin with the resultant straightening of the profile and the relative retraction of the lips at ages 3, 8, 13 and 18 years.

Interpretation of dysplasia

Thus, by computerization of a most desirable morphologic image for a type, to include the variation within that type, a broader base for comparison was made available, one which most orthodontists could not obtain from the use of simple analyses. In addition, this ideal image can be related more appropriately to treatment conditions.

In the comprehensive analysis or print out, divisions of interest are established so that better understanding can be reached regarding dysplasias or disorders. Six general families of morphologic interest are programmed. The first four areas (occlusal relation, maxillomandibular relation, denture to skeleton, and lip relation) contain factors which, within limits, are under the clinician's control. The last two fields of interest (craniofacial relation and internal structural problems) contain skeletal relations which generally lie outside of his ability to change clinically. Therefore, treatable conditions are located in the first four divisions. Those factors working against the clinician (or in his favor) on a skeletal morphologic basis are located in the last two groups of measurements.[9]

Treatment planning

Many orthodontists are dominated in their treatment plans by a consideration of arch length or crowding of the lower teeth. To that arch length, the upper to lower arch relation is added for the determination of anchorage needs and planned moves. Plans too frequently terminate on this "static" basis of arch length, and arch relation is determined from the dental cast alone.

On the other hand many orthodontists make prognostications on the basis of original facial patterns. The thought is that different anchorage values are required for different facial-morphologic and growth types. This prediction concept by Downs was the first and probably still is the most common attempt to apply growth or change dynamics. Consequently, with the use of "pattern" extension method (to be discussed later) we hear of treatment plans for "high mandibular plane cases." The presumption is that the high plane will open more during treatment. The lower mandibular border canting is unreliable as a growth predictor alone, but is a factor to be considered. This practice of prediction of growth by reading mandibular angles demonstrates the point that predictions currently are made almost routinely by many orthodontists—like it or not. Other factors need consideration and, in addition, growth must be applied in a direct and specific manner if it is to be equated to anchorage considerations. These "other" factors for analysis require more discussion. The extension technique may be grossly misleading, particularly when a wrong plane of reference is selected at the start.

Biologic corrections

Certain angular measurements so characterize the population that the mean and variation from the central tendency is the same for all ages and types (Fig. 9). Other measurements or parameters must be corrected at each age level for sex and ethnic types. In addition, disharmony and disproportion may be represented best by certain linear measurements which express size. These values for size measurements, in order to be meaningful, must also be corrected for the particular individual so that they may express disproportion of sorts (not merely a measured relation to a population sample).

Accordingly, in our computer system a program was written for such biologic considerations. First, age was considered since values at age levels on a chronologic basis are a basic concern. If wrist plates are available, the chronologic age is corrected to the physiologic age.

Second in consideration was the sex of the individual. Postpubertal differences between the sexes are well known. Some prepubertal differences seem to be expressed prior to the stage of development of the mixed dentition. Also, the teeth are slightly larger in the male which suggests differences very early in life.

The third consideration is the ethnic type. This was most important for den-

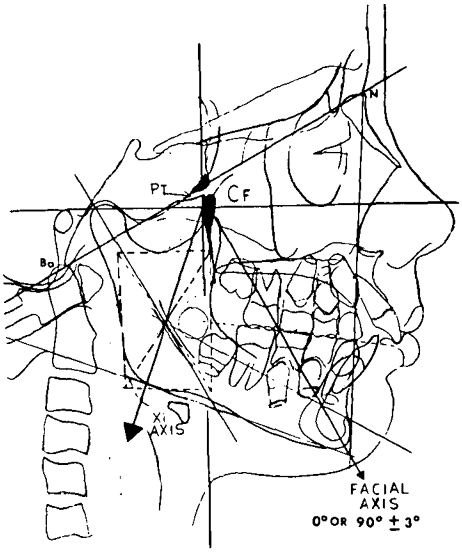

Fig. 9 The facial axis and Xi axis are shown. The facial axis is formed from the point of the lower border of the foramen rotundum through gnathion. When the facial axis is measured from basion-nasion, it crosses from a right angle (90° or 0°, ±3°). This is essentially true for the population as a whole and for all ages. The pterygoid vertical crosses Frankfort plane at the base of the pterygoid plates and from this intersection a line is drawn through Xi point (the Xi axis). This particular orientation is vital to long-range forecasting. the variation also is quite descriptive of malocclusions and morphologic types.

ture balance and certain aspects of facial maxillomandibular relation. We attempted to set up a program which would reveal dysplasia and standardize within the given ethnic type, and not necessarily relate one type to another.

Finally, the correction for size differences was made by the use of a method which we called the cube root index (CRI). For this the computer was instructed to calculate the volume of the face. Because the measurements are three-dimensional, the cube root of the volume was used as a reference for other linear measurements. The assessment of harmony, balance and proportion could be made in this manner. The resulting figure was used as an index or a ratio to which seven linear measurements were corrected.

Consequently, when a printout is rendered, the information now has been treated statistically several times and corrected to yield a more reliable measurement for the consideration and interpretation by the clinical orthodontist.

It should be remembered that the analysis still is only descriptive but that description helps the clinician to understand the location and extent of the skeletal, dental and soft tissue problems. In other words, it tells him where he is. Other factors are needed to tell him where he is going or should be going or to suggest the possibilities and alternate goals at his disposal in treatment.

Prediction Method I:

Growth investigation was the original objective of the cephalometric procedure. From the beginning the nature of facial growth as revealed by cephalometric orientation appeared to be much more orderly than had been supposed by orthodontists prior to its use. The "constancy" of the pattern explained by the early investigators led orthodontists to prediction by simple pattern enlargement. A method of growth prediction in almost universal practice was the assumption of extension of the pattern. However, many patients did not follow their original patterns in growth.

Prediction Method II:

Later, a second type of prediction was made. By the comparison of two serial head film tracings, a "trend" was observed. Through yearly or biannual trend comparison, the clinician made forecasts of behavior in the future based on a behavior of the year before. However, slight mandibular rotation may be experienced as the pattern may "bounce" as eruption and functional factors intercede in the growth expression. Even two-year trends do not always show the true long-range trend and several comparisons are necessary, over several years, in order to draw highly reliable conclusions.

In following trends an oversimplified explanation of facial growth was offered. The downward and forward growth of the chin was alleged to be caused by upward and backward growth of the mandibular condyle. Space for lower molars was thought to be created by resorption of the anterior border of the ramus. The midface was explained to move downward and forward by the adjustment at the maxillary sutures.

Through the last forty years much information on growth has been accumulated and the knowledge has become refined. One benefit of computerization of cephalometrics is that various methods for growth orientation could be re-examined in extensive detail. As a study, most of the proposed analyses were "put in one bag and shaken out" to find the most valid descriptive parameters and meaningful measures for longitudinal work.

As mentioned previously, one problem of studying growth behavior was that of basic longitudinal references. This deserves some discussion in connection with the controversies outlined in this presentation. This is so because the reference planes are controversial and are not "just a bunch of lines," but each point and plane has biologic significance and well-thought-out purpose.

The anterior cranial base depicted by the floor of the cranium has been employed as a stable reference base for facial growth. It is representative of the olfactory bulbs and the frontal lobe of the cerebrum. Often it has been selected because the contours compare favorably with tracings of the same site made at a later date, particularly the inside contours of the anterior cranial base.

Because brain growth is completed early, the anterior base, including the cribriform plate and sella turcica, has been employed as the reference point from which facial growth has been measured. True, at the midline these anatomical landmarks represent primitive systems. However, the *colossal error of judgment is the assumption that all else in the skull is growing away from these parts.*

If only the sella turcica area is considered, it includes counterparts of the first three brain divisions and nuclei of the first four cranial nerves, which generally are concerned with olfaction and sight.[10] However, it will be recalled that, phylogenetically and embryologically, the brain is formed in five basic divisions: the telencephalon, diencephalon, mesencephalon, metencephalon and myelencephalon.

The infundibulum, the hypophysis and optic chiasma sit on this anterior floor and are elements of the diencephalon, or second part. However, the frontal lobe of the cerebrum dominates the anterior cranial base and is derived from the telencephalon, or first portion. Further, the parietal, occipital and particularly the temporal lobes all dominate the middle cranial base. The cerebellum, of the metencephalon origin, occupies the posterior fossa.

The medulla lies on the clivus and contains centers for the remainder of the cranial nerves. The nuclei for the fifth and sixth nerves are located in the medulla although a sensory root is located in the mesencephalon. The nuclei of the fifth, sixth, seventh and eighth nerves lie in close consort with the petrous bone of the temporal. The petrous portion in turn displays close association with the glenoid fossa which is located immediately to its lateral aspect (Fig. 10).

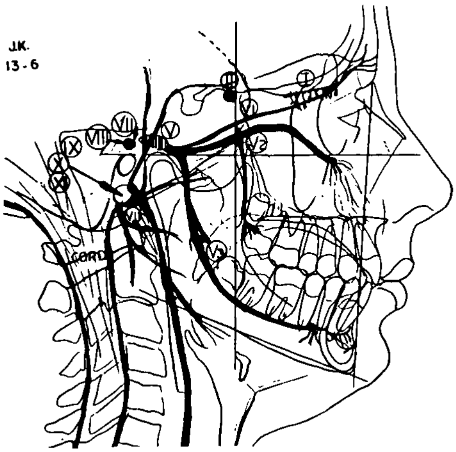

Fig. 10 This patient (J.K.), at the end of treatment can be used to demonstrate the alignment of the cranial nerves as viewed from the foramina in the x-ray; Vi, Vii, and Viii will be noted as the branches of the trigeminal nerve. It is felt these nerves are quite important to the organization of facial morphology. The olfactory nerve is at I and the optic nerve at II is at the dark area noting the optic chiasma. The ganglion of the fifth nerve is seen to lie on the petrous portion of the temporal bone immediately above the glenoid fossa. The Vii and Viii nerves enter the acoustic meatus as shown in another dark area, while the IX, X, and XI nerves take their exit at the jugular foramen which is circled.

Phylogenetically, embryologically and morphologically, therefore, there is little to support the fact that the face develops from the anterior base alone. Anterior reference alone as a basis for most cephalometric systems appears to be more for convenience than for biologic realism (Figs. 11 and 12).

It follows that, because the anterior base may be misleading, a question arises as to the most significant reference for describing facial growth behavior.

The facial skeleton is made up of the two orbital cavities, the nasal cavity, the oral cavity, and pharyngeal cavities. Originally the whole face (in lower vertebrates) developed to support the mouth and protect vital sense

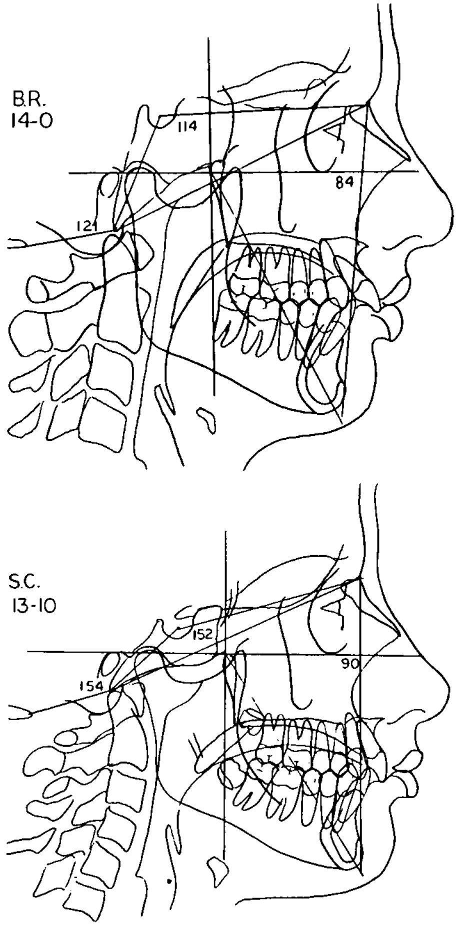

Fig. 11 Above: patient B.R., with a classic Class II, Division 1 malocclusion. The facial angle of 84° suggests that he is slightly retrognathic for a boy age 14 years; the profile is straight.

Below: S.C., another classic Class II, Division 1 malocclusion. S.C. has a facial angle of 90° and a convexity of 6 mm. However, it will be noted that patient B.R. has a cranial base angle of 114° as compared with 152° of patient S.C.

organs. For functional integration it seems quite clear that a strong relation came to exist between orbital and midface development in conjunction with the anterior cranial scaffolding for olfaction. Thus, in the human, the basic pattern with parts united shows relative stable gnomic figures of development for the cavities of the skull, as studied

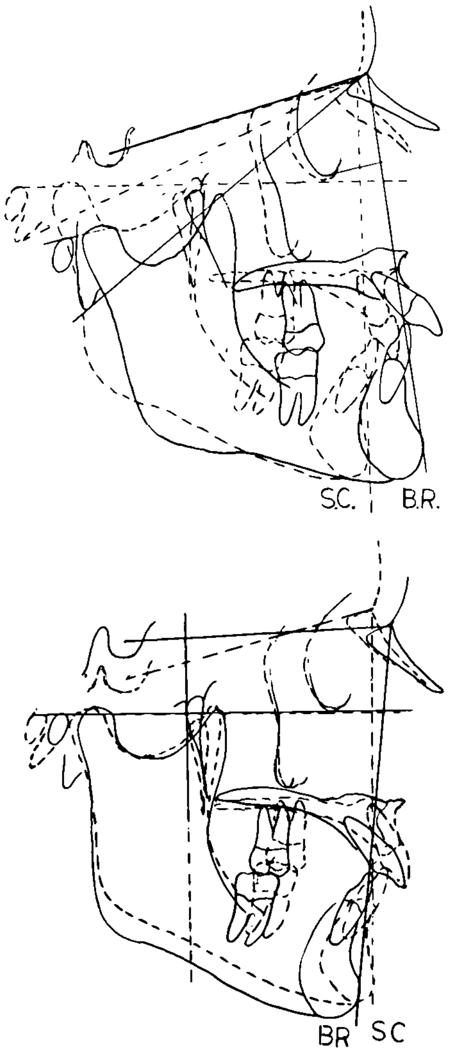

Fig. 12 Above: the same two cases are oriented on SN and registered at S. With this superpositioning it will be noted that the patient with the weak chin (B.R.) actually is more than 1 cm more protrusive than S.C. The explanation lies in the excessive variation in the anterior cranial base.

Below: the comparison of the two cases on the Frankfort plane at the pterygoid vertical. It will be noted that excellent order is established by the use of Frankfort plane and the pterygoid vertical intersection for the analysis of the jaw relations and the malocclusion. Cases of this type are one reason why Frankfort plane was selected over anterior cranial base morphology for the total computer program.

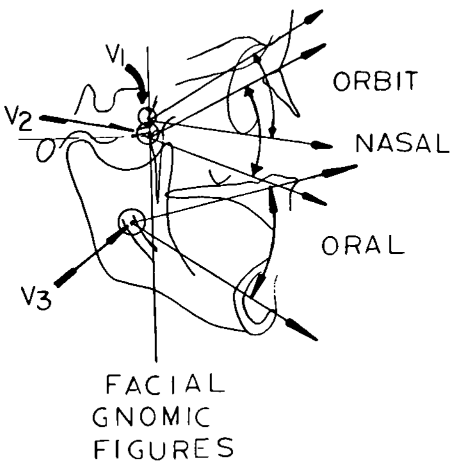

Fig. 13 Shows a composite of children at age 5 years with the orientation of the VI at the lower border of the superior orbital fissure. VII is located at foramen rotundum, and VIII at mandibular foramen. When lines are extended from the superior orbital fissure base to the superorbitale and orbitale points, the organ of the orbit can be appraised by the analysis of this angle. As Pt point at foramen rotundum is employed in a similar manner, the nasal capsule can be described as the angle from nasion to Pt to point A. In the oral capsule the line from the anterior nasal spine to Xi point is evaluated from the corpus axis. The Po-Xi-ANS angle serves to describe the oral cavity, lower face, or denture height.

under the theories of D'Arcy Thompson[11] (Figs. 13 and 14). There is relative dependence in the behavior of the maxilla and upper face with the anterior cranial base regardless of the general plane employed.

The "catch" occurs, however, in trying to correlate lower face development or mandibular growth behavior with only the anterior base as a reference. Practically all statistical studies have shown no correlation, consequently people have rejected prediction methods based on studies using the anterior base—and rightfully so. There seems to be relative independence between the anterior, middle and posterior bases of the skull[12] (Fig. 15). This basic phenomenon has made conclu-

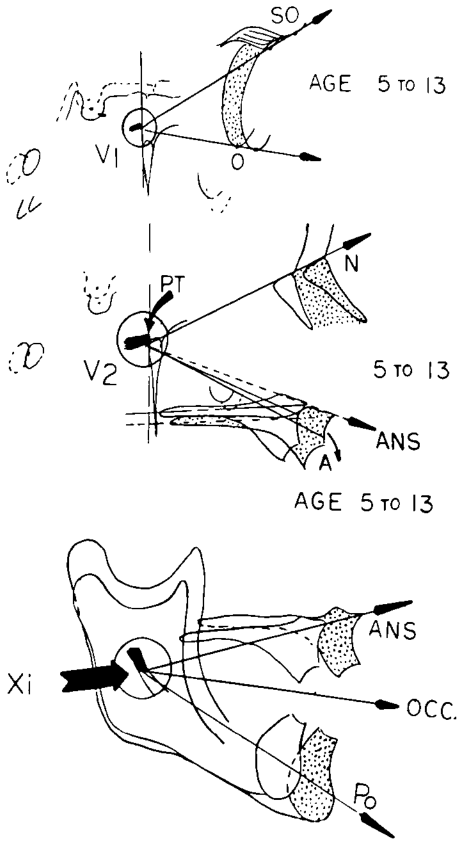

Fig. 14 Top: growth from age 5 to 13 years in a series of 40 patients as analyzed with the vertex of the orbital angle shown. Middle, a similar superpositioning, but notice that point A drops downward as does the anterior nasal spine slightly as the nasal capsule or nasal angle reflects the behavior of the oral capsule. Bottom, the development of the oral cavity with the vertex of the angle at Xi point, which is located over the mandibular foramen, or the oral angle. This superpositioning yields a high degree of order to the forecasting of the oral cavity.

sions from growth studies most confusing. For this reason pattern enlargement became a doubtful theory as a method of prediction.

Because early cephalometers blotted out the temporal bone, attention became directed only to the anterior basal portion which was related to the maxilla and midface. The real problem in analyzing both structural morphology and growth as well as facial orthopedics in clinical orthodontics relates to the clinician's concern with the chin in the face. Ricketts' work seemed to indicate that vertical facial patterns were caused mostly by "horizontal" condylar growth, while forward-moving chins were most often identified with vertical growth of the condyle and ramus.

Prediction method III

With the problems described in the foregoing discussion in mind, we hypothesized a third method of prediction which may be called the projection technique.[13] This theory was based on the independent consideration of individual parts such as (a) forecast of the anterior and posterior cranial bases by the basal triangle extensions, (b) the projection of the mandible from the posterior and middle base, and (c) the maxilla or midface from the anterior base. The principle inaccuracy of that early forecasting method was the inability to predict cranial base behavior (except in strict average quantities). The maxilla and mandible independently were predictable within quite acceptable clinical accuracy. The problem lay in their connection at the skull base. The projection technique proved to be useful and reliable when used together with treatment objectives in a setup for treatment planning in the short range.

The theories of Ricketts remained highly controversial and were questioned until Björk in 1963 reported the findings from implant studies.[14] These not only tended to confirm Ricketts' earlier theories but also showed that growth variations could be even more extreme than he had hypothesized from short-term laminagraphic investigations. A series of new experiments and hypotheses resulted. The details of these are reported elsewhere.

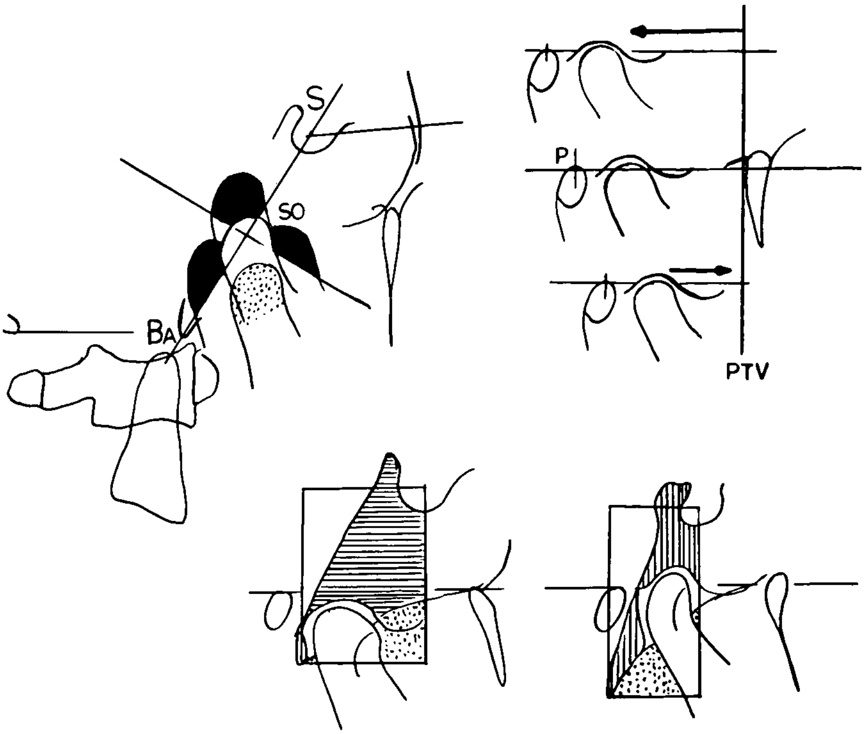

Fig. 15 This depicts the results of various studies of the glenoid fossa and temporomandibular morphology. The upper left view shows the variations seen in a study of 200 cases. Superimposition on the sella-basion line and the glenoid fossa shows the mandibular condyle as displayed relative to midsagittal base landmarks. This observation suggests again that porion, together with the Frankfort plane, is most productive in orientation procedures in descriptive morphology. The upper right view displays the variations in a study of 40 longitudinal cases showing the dimensions observed between porion and the pterygoid vertical, with the intent being to evaluate the anteroposterior position of the glenoid fossa as a whole. The mean, at age 9 years, was 39 mm ± 3 mm. On the lower left it shows the dimension between basion and sella to be very wide when oriented to the Frankfort plane. The right shows the condyle upward and forward toward sella. The conditions shown on the right are somewhat typical of Class III malocclusions; the morphology observed on the left is quite typical of Class II, Division 2 malocclusions in which the condyle is located downward and backward relative to the midsagittal landmarks.

To further improve the information on changing morphology, techniques were assayed in the computer and reliable composites resulted. A variety of comparisons including statistical data became available. The conclusion was reached that the separation of the face anteroposteriorly seemed to be located at the anterior surface of the base of the pterygoid plates on a vertical line running parallel to the general direction of the pterygopalatine fossa. A vertical through Frankfort plane at this point is found to be in agreement with the functional plane of the coronal suture complex (Figs. 4 and 16).

The face as a whole seemed to be represented as a cone, as suggested by Brader,[15] with the basion-nasion plane as the base, the chin as its apex, and the foramen rotundum as a point on the base near its central axis.

In the endeavor for improved knowledge concerning growth, further studies led to a gradual emergence of a new explanation for the mechanism of mandibular growth. Clues regarding the "master" control or the integration of the various functional parts also were coming to light.

It is sufficient to state that research has culminated in a new principle of mandibular growth. This principle states that the mandible does not grow by straight line projection, but rather on an arc. With this arc it is suggested that "normal" mandibular growth in the human takes place with little or no resorption at the anterior border of the ramus, but with profound resorption on its lower border (Fig. 7).

Effects of treatment (possibilities, not limitations)

Prior to 1952 the scientific cephalometric evidence was overwhelmingly against the ability to clinically affect the growth of the face.[16] The conviction grew, on the basis of studies of treatment before that time, that only alveolar alteration probably was affected.

This was confirmed repeatedly as intermaxillary elastics were shown to tip the occlusal plane and physiologic rotation seemed to take place in the mandible only to partially or fully recover with later growth. Certain cases such as Class III tended to stay open as an explanation for correction of prognathism. Opening tendencies were attributed to vertical growth types. Ricketts began to make prognostications for clinical patients on the basis of the findings from those numerous investigations. The patient's type was considered and mean values were derived for sex and age as a basis for estimations.

In the early 1950s the use of extraoral traction became widespread. By 1955 Ricketts showed evidence of changes in the maxilla far beyond those previously predicted or observed. The hypothesis at that time was that changes following treatment with extraoral traction extended beyond the maxillary alveolus. Working with Dr. Phil Klein in 1956, the authors demonstrated that the palatal plane and Point A probably were affected by extraoral traction.[17]

In order to further evaluate the theory Ricketts began a study of a larger series of patients using one hundred growing nontreated individuals as a control. Two groups of fifty treated cases were compared; all had been treated with some type of extraoral traction. The findings were conclusive. We could no longer believe that orthodontics was limited strictly to changes of alveolar bone. We could no longer measure tooth change solely from the palatal plane. The findings were eleven times greater than that needed for statistical significance.[18]

Consequently, with growth being better understood and especially with certain possibilities shown, we began to emerge from the doctrine of limitations which had gripped the profession for the previous two decades.

Short-range growth and treatment forecasting

It followed that utilization of lighter and more continuous forces together with recognition of the ability to intrude teeth began to make an impact on general orthodontics. It was recognized that the effects of treatment dominate the forces of growth during the treatment experience. A large part of treatment prediction or forecasting therefore consisted of understanding the probable effects of the appliance or mechanism to be employed. The procedure included the drawing up of a plan of action in a visualized form for consideration and then making the desired changes occur by execution of an appropriate plan. Accordingly, Holdaway termed it a "Visualized Treatment

Objective" (VTO).[19] Therefore, it is a prediction only to the end that average values of growth expression serve as a base of reference for determining objectives.

Consequently, with agreement as to the principle of the procedure as practiced by Ricketts, the ability to first objectivize or to predict clinical treatment was contingent upon understanding and applying known growth and anchorage behavior in various kinds of faces. The orthopedic effects, physiologic and skeletal, were superimposed over the projection of the natural internal pattern in the visualization of the plan.

It is of interest now to note that these same objectives have withstood the test of time, are becoming widely accepted, and have been programmed into the computer. Therefore, in the short-range forecast for the Preliminary Treatment Objective (PTO) offered by the computer program, the factors of standard objectives have been weighted and are considered. This constitutes a trial cephalometric setup for considering the practical objectives more than it qualifies as a prediction. It is a "prediction" in the sense that the clinician is prophesying that he can bring about the changes with his treatment.

For the procedure the natural growth for two units or modules is plotted and the mandibular rotational effects and the midfacial orthopedic effects are added.[20] The denture is set to the peak of the curve of idealism. This display now can be used by the orthodontist as a frame for consideration in prescribing treatment (Fig. 17). It is preliminary but, if it is feasible in his mind, makes sense and is practical, he then can apply the forecast to plan his anchorage and moves with direct decision and confidence (Fig. 18).

While following the computer

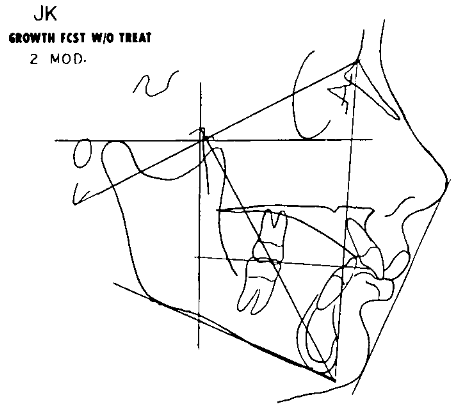

Fig. 16 This workup done by the computer service organization demonstrates the growth forecast without treatment for patient J.K. This patient was 11 years of age with a severe Class II malocclusion (as originally seen in Fig. 3). With two years, or two modules of growth, it is observed that the condition of the patient does not improve.

method and standards of perfection offered as a guide, more conservative biologic principles can be evoked. More communication is needed regarding the "progressive technique" (light square), but it may be stated that the principles set forth in that approach are useful in fulfilling objectives and achieving goals. The progressive technique is mentioned in connection with cephalometrics because its development has been the result of feedback from the clinical behavior of cases and the effort to achieve desirable objectives.[21,22]

Long-range forecasting as a biologic principle

Until 1970 it was never implied by us that sensible forecasts could be derived for periods longer than two to three years. Never was the goal to be absolute in amount of growth predicted, but the typical incremental expectancy for a one-year cycle was selected as a single module or unit in order to build in a usual growth expectancy in the planning of anchorage. In the application of short-range growth

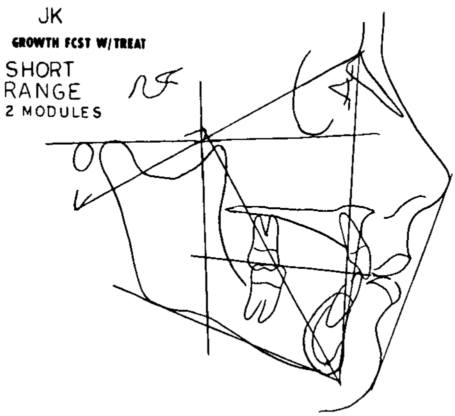

Fig. 17 This workup as done by the computer service demonstrates the growth forecast with treatment. This essentially is not only a prediction of growth but also a statement of treatment objectives and constitutes the desirable treatment changes built into the two-year growth experience.

clinically, therefore, the idea was that the desired tooth arrangement and change should be achieved to a certain state when a specified amount of growth had occurred. This related growth to the treatment experience and, when added to the changes caused by treatment, a feedback was produced to evaluate results before they occurred. This technique revealed the target for conditions at treatment's end and, if accepted, provided a means to establish needed anchorage. Therefore it was akin to the plaster setup with the addition of the dynamics of growth, treatment objectives (skeletally) and esthetics, and with cephalometrics employed as the tool rather than the model and an articulator (Figs. 17 and 18).

Now with the advent of recent breakthroughs and as a result of computer studies, a long-range forecast of eight to ten years or longer is feasible and useful.[23] Discussed earlier was the discovery of the arc of the mandible. This in itself is a major addition to our fund of biologic knowledge. Equally important, however, are the biologic conditions affecting the position of the mandible in the face (Fig. 19).

It long has been an axiom in clinical pathology that muscle dominates or directs bone when the two are in conflict. Therefore the systematic changes observed were not, in this research, considered as bone-directed changes but rather as occurrences resulting from the organization of functional systems. Now it has been shown that even basic to the muscle as its directive is the organization of the nervous system and particularly the entire neurotrophic bed. It is recognized that bone is subordinate to the entire sensory input with the neural field as an integrated feed-back mechanism.

It was suggested by Ricketts (in his first method of projecting growth) that the presence of a particular form already is indicative of certain mechanisms and forces in a system which has made it that way. Thus by the projection of these biologic courses of events and their relations, he sought to predict future behavior at the practical short-term level. Stated again, the problem in the early methods which made it difficult to prognosticate over long range was in determining the connection between the anterior cranial base and the mandible. Independently, the palate and middle face could be forecast with great consistency from the anterior cranial elements. Most recent investigations have corroborated Brodie's theories on the constancy of that pattern, particularly in the middle face or the gnomic growth of the nasal cavity. In a like manner and independently, the mandible now can be forecast with great reliability. The problem still lay in finding the nature of the central connection of the upper to the lower jaw, which ultimately must include the temporal bone together with the glenoid fossa and the suspensory apparatus of the mandible.

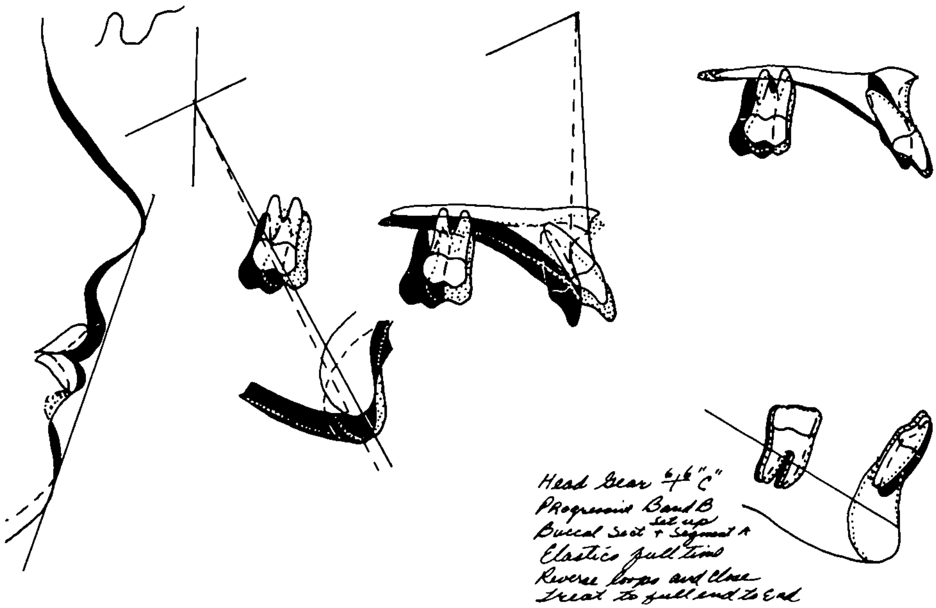

Fig. 18 This shows the differences between the initial case as viewed in Figure 3 and the growth without treatment as in Figure 16, and growth with treatment in Figure 17. On the left will be observed the expected profile changes showing that the lower lip will be enhanced sublabially and the upper lip will be retracted. The figure in the center shows the chin and mandible as viewed from the facial axis, the upper molar will be seen in the solid outline to move downward and forward without treatment, as illustrated in the dotted area. With treatment the upper is moved downward and backward to the location of the solid black molar. With treatment it will be noted that the facial axis will be opened up slightly. In the maxilla the dotted area shows the downward and forward movement of the incisors and molars, as viewed from point N without treatment; with the expected changes resulting from treatment, the darkened area shows the distal movement of the upper molar and the retraction of the maxilla and the consequent changes of the upper incisor. In the upper right, as viewed from the palatal plane, it will be noted that the upper incisors will need to be intruded and brought back, the upper molar can be moved downward and backward from the palate. Finally, as seen in the lower right, the lower molar must be stabilized and the lower incisors will need to be intruded and brought forward in the treatment of this particular case.

Through use of reliable composites, the nature of growth and the vertex of triangles or the base of quadrangles could be located as certain gnomons were observed in growth. Once a center was located, it was discovered that the growth of the face tended to behave under a principle mathematically as the volume of a sphere. Therefore, a polar center for the face was located at the base of the pterygoid plates. This showed a principle of growth at work, indicating that the growth tended to be accumulative, and the farther from the polar center, the greater the increase with growth. (See Fig. 4).

It is of interest to note that, with these facts revealed, we were led back to the Frankfort plane as the most useful, reliable and revealing plane of orientation for prediction or forecasting as well as morphologic description.[24] This was despite the fact that porion sometimes was difficult to ascertain. Further, the growth connection of the mandible with the face could not be determined with any degree of confidence until finally the an-

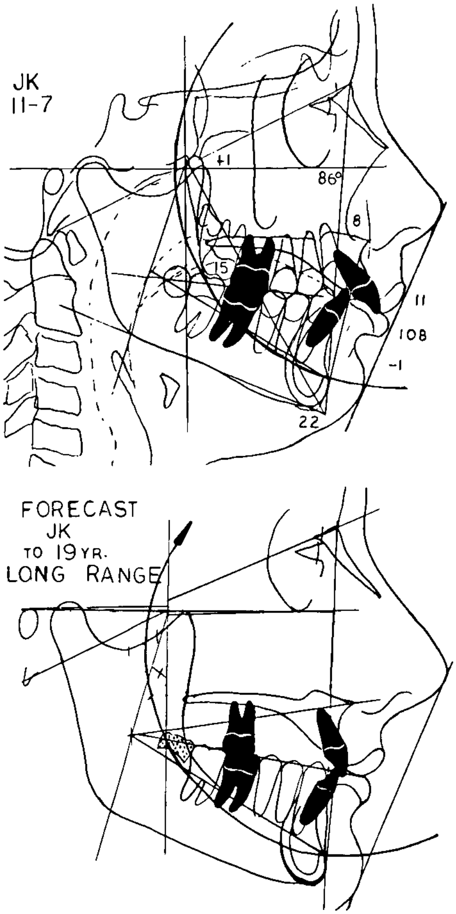

Fig. 19 This figure (above) shows the original case with the arc drawn through the mandible and the conditions that exist. The original facial pattern and morphology will be observed. From this lateral film the arc through the mandible is generated, which is used in the long-range forecast. Below: the convexity change and the influence of long-term growth of the mandible is observed together with the projected growth of the nose in this patient to the age of 19 years. Note also that there is only a 10 per cent chance of eruption of the lower third molar in this patient who was treated nonextraction.

terior cranial base was abandoned as a landmark. Lateral structures represented by the orientation of the sense organs and the organization of the cranial nerves came to be employed.

This latter orientation showed that the vertical through the pterygopalatine area began to line up significantly with the pattern of the branching of the trigeminal nerve. This nerve, through its sensory branches, is the great sensory receptor for the face. Through its motor branches it controls the muscles of the jaw. Simple reflex arcs are present and the nuclei of this nerve lie in close proximity to other cranial nerves from the fourth through the eighth nerve. In addition, the vascular bed connections are in immediate juxtaposition at the entrance sites of the nerves into their appropriate capsules.

The geometric relation and orientation of rotundum and mandibular foramen probably are established early. This, therefore, became the key to the long-sought organizational relation. Most investigators (including the author) had sought the organization or orientation in the wrong places. This only proves that all of the mathematics, all of the biology, and all of the powerful statistical tools do not help if the wrong thing is being measured in the first place.

With the orientation in a vertical manner around the relationships of foramen rotundum (Pt point) and mandibular foramen (Xi point), better order was established for long-range projection of facial growth.

Now not only was short-range projection feasible because treatment dominated the scene but, finally, with long-range forecast, the picture of posttreatment growth together with posttreatment physiologic rebound could be visualized (Fig. 20).

We can say with reasonable assurance that forecasting of growth and behavior is possible both in the short range and long range.

The short range is modified by treatment. Anyone who believes that mechanical procedures make no difference in the physiologic behavior of the man-

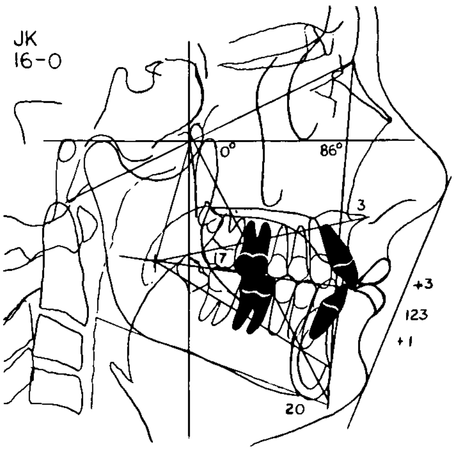

Fig. 20 In Figure 17 the short-range projection for this patient at 13 years of age is illustrated. Figure 20 shows the actual case 3 years after treatment, or at age 16 years, to show the balance of the denture. The expected maturation and long-range forecast is observed in Figure 19-below.

dible and the effects on the maxilla simply has not availed himself of the pertinent data. It is necessary, therefore, that each clinician fully understand his own technique. In this regard, by working with the computer program, he can accumulate his own data bank as a method for improvement and routine analysis of his own treatment procedures.

However, years later, treatment effects can be discounted for the most part unless pathologic problems ensue. Therefore, long-range forecasting can be made for the mandible in the same manner with or without treatment considerations.

The long-range forecast is more than adequate within useful clinical limits. It has proven to be beneficial even though its opponents may point out instances of inaccuracy, as it has served as a frame of reference for determining abnormal growth behavior (in fact, it quite often is more accurate than the ability to select anatomical landmarks on the head film).

Those patients who have encountered biologic insults or disturbances great enough to override the natural or normal growth propensities will show up in the comparison of normal projections to the actual. These insults are speculated to include such problems as bruxism, postural abnormalities of the head, or even extremes in growth ectomorphism in the head and neck regions which pull the mandible downward in growth behavior. These conditions typify a ptosis of the mandible. Also, true mandibular prognathism is atypical of natural growth but is subject to computer programming with alternate changes. As more extensive series are studied, certain clues now are available for the prediction of ultimate surgical candidates in these particular conditions.

Through the storage of data made possible by computerization, a service organization offers the orthodontist an opportunity to compare his case or group of cases to an atlas of normal growth. This facet is ever-improving. The opportunity of retrieval offers almost instantaneous advanced clinical research for the clinician who desires it. It becomes a powerful tool for research.

Through centralization, the orthodontist's patient records are stored so that, in the event of transfer of a patient, records can be forwarded, treatment continued by the new operator, and consistency of orthodontic management preserved.

A service organization provides a clearinghouse of information made available to the profession as the data on thousands of patients are recorded. Standardization of a complete method makes possible the evaluation of almost any treatment method ever proposed, and this becomes a marvelous tool of education. Further, flexibility is maintained for the continuous update of standards or broadening of standards, as the profession dictates.

Finally, these records may serve to educate the patient, to aid in communication with the parent and referring dentist, which will, without question, elevate the image of the orthodontic profession.

Discussion

It is evident that more extensive research on morphology and growth and its application to the science of dentistry and orthodontics has been accomplished through the use of the computer. This research has made possible a whole series of genuine advancements. New findings, new theories and newly-proposed principles already have affected the thinking of scholars and have influenced the mechanical approach by many clinicians. A greater impact probably will be witnessed as the facts become better known. Moreover, the accumulation of patients (now numbering several thousand) is a source of continual research material and the effort is being made to mold the new concepts into a more concise form.

With utilization of the computer and the innovation of service organizations, this new information and other knowledge is extended to those in the orthodontic profession not blessed with time for critical cephalometric analysis, interest in cephalometric research, research skill and ability, or opportunity. The use of the computer program has proven to be highly reliable. In most previous methods clinical decisions were drawn only from a superficial cephalometric analysis or the static dental cast analysis.

Gross characteristics for diagnosis are shown on the tracings. The computer measurement and more complete method has the potential to make the records of each patient a complete research case if so desired by the operator, as (for example) conditions of dysplasia are presented in a logical sequence in a comprehensive descriptive analysis covering six fields of concern clinically.

The clinician, following complete orientation, can benefit immensely from a program written for known possibilities of change in the contemporary treatment experience. It is recognized that treatment changes in the teeth and the orthopedic effects on the jaws often dominate the scene during the short range of a two-year treatment experience. The orthodontist can judge the feasibility of trying to achieve results to the peak of the curve of idealism. He must weigh the factors needed to bring about an ideal result and make compromises from idealism when practical, economical, health or social factors dominate the case.

When the final decision is made, he can refer to the analysis of the forecast to determine his anchorage needs and plan a progression of movements.

In this manner the computer program, when understood and applied with some experience, is a great aid to planning and management for the orthodontist.

The treatment possibilities and ideal objectives are exhibited in a manner wherein they can be visualized by the orthodontist and by the patient. Moreover, a longer range forecast brings into focus the long-range propensities of the individual from a biologic standpoint, and is not merely a mechanical tool.

Judgment is no longer contingent upon immediate results; instead, the effects of probable individual maturation and development now can be taken into account. Therefore, the orthodontist may thoroughly study the case in a routine manner in order to arrive at the best, most sensible, practical, functional and esthetic equilibrium under the given set of circumstances and possibilities, and can convey his findings and plans to the dentist and patient.

Computerized cephalometrics, used with intelligence and not as a blind dictum, is a profound service to the profession. It can help in bringing perfection and sophistication as well as efficiency into the clinical regime. Cephalometrics, when computerized, becomes the most powerful tool of information yet devised for the practicing orthodontist. Above all, it elevates biologic dynamics in the hands of the clinician so that he is not limited by the dictates of one or another appliance or type of mechanics, but can treat his patient with more finesse, in the achievement of his ultimate goal, to full maturity.

984 Monument St.
Pacific Palisades
California 90272

References

1. Solow, Beni: The pattern of craniofacial associations, *Acta Odontologica Scandinavica*, Vol. 24, Supplementum 46, 1966.
2. Walker, G. F.: A new approach to the analysis of craniofacial morphology and growth, *Amer. J. Ortho.* 61: 3, 221-230, 1972.
3. Ricketts, R. M.: Introducing computerized cephalometrics, Rocky Mt. Data Systems, Inc., March 1969.
4. DuBrul, E. L. and Sicher, Harry: *The Adaptive Chin*, Chas. C Thomas, Springfield, Ill. 1954.
5. Moss, M. L.: Functional analysis of human mandibular growth, *J. Pros. Dent.* 10:1149-1159.
6. Ricketts, R. M.: The evolution of diagnosis to computerized cephalometrics, *Amer. J. Ortho.* 55:6, 795-803, 1969.
7. Lorenz, K. Z.: The evolution of behaviour, *Scientific American*, Dec. 1958.
8. Steindler, Arthur: *Kinesiology of the Human Body*, Chas. C. Thomas, Springfield, Ill. 1955.
9. Ricketts, R. M., Bench, R. W., Hilgers, J. J. and Schulhof, Robert: An overview of computerized cephalometrics, *Amer. J. Ortho.* 61:1, 1-28, 1972.
10. Patten, B. M.: *Human Embryology*, McGraw Hill Book Co. Inc., New York Second ed. 1953.
11. Thompson, Sir D'Arcy: *On Growth and Form*, Cambridge Univ. Press, London, 1966.
12. Krogman, W. M.: Anthropology—faces of the past, present and future, Presentation to the Loyola-Jarabak Orthodontic Foundation meeting, Feb. 1963, Chicago, Ill.
13. Ricketts, R. M.: Planning treatment on the basis of the facial pattern and an estimate of its growth, *Angle Ortho.* 27:14-37, 1957.
14. Björk, A.: Variations in the growth pattern of the human mandible, longitudinal radiographic study by the implant method. *J. Dent. Res.* 42:400-411, 1963.
15. Brader, A. C.: Presentation before the American Association of Orthodontists, May 1971, New Orleans, La.
16. Brodie, A. G., Downs, W. B., Goldstein, A. and Myer, E.: Cephalometric appraisal of orthodontic results, *Angle Ortho.* 8:261-351, 1938.
17. Klein, P. L.: An evaluation of cervical traction on the maxilla and the upper first permanent molar, *Angle Ortho.* 27: 61-68, 1957.
18. Ricketts, R. M.: The influence of orthodontic treatment on facial growth and development, *Angle Ortho.* 30: 103-133, 1960.
19. Holdaway, Reed: The 1971 Denver summer meeting for the Advancement of Orthodontic Practice and Research, Denver, Colorado.
20. Ricketts, R. M. and Bench, R. W.: *Syllabus for Advanced Orthodontics Seminar*, 1968, Ricketts & Bench Seminars, Inc. Pacific Palisades, Calif.
21. Gugino, Carl: *An Orthodontic Philosophy*, Edco Associates, Fifth ed., 1971, Denver, Colorado.
22. Ricketts, R. M., Bench, R. W. and Hilgers, J. J.: Newsletter, Foundation for Orthodontic Research, Vol. 3, issues 1-4.
23. Ricketts, R. M.: Proceedings for Foundation for Orthodontic Research, 1971.
24. Ricketts, R. M., Bench, R. W., Hilgers, J. J.: "Developing Confidence in Cephalometrics," Scientific Exhibit presented to American Association of Orthodontists, May 2-6, 1971, New Orleans, La.