A Principle of Arcial Growth of the Mandible

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Possibly no other bone can rival the mandible as a target for scientific study. Being vital to both the basic vegetative systems of mastication and respiration, it has been a subject of investigation by the natural scientist, the biological scientist and clinical scientist. Recent research has reached a point whereby it is reasonable to propose a principle of arcial development as a basis for explanation of mandibular growth in the human.

Principles in biology are extremely difficult to come by. This is true because principles must be universally acceptable and must prove effectual in repeated application to the related science. For this reason it is noteworthy that a new explanation be proposed for the growth of a complicated anatomical part such as the human mandible. The byproducts of this finding could change the viewpoint of the field of dentistry, together with allied disciplines in medicine.

The purpose of this paper is to explain a method for finding the arcial growth of the mandible, to enumerate some of the uses of the principle, and to explore changes in present clinical concepts which will be rendered necessary by the application of this biologic principle.

The essence of the principle is as follows: A normal human mandible grows by superior-anterior (vertical) apposition at the ramus on a curve or arc which is a segment formed from a circle. The radius of this circle is determined by using the d'stance from mental protuberance (Pm) to a point at the forking of the stress lines at the terminus of the oblique ridge on the medial side of the ramus (point Eva).

Historical Review

Just 200 years ago in 1771, Hunter[1] compared a series of dried mandibles and concluded that, in order to attain space for the development of permanent molar teeth, the mand.ble must grow by posterior apposition of the ramus accompanied by anterior ramal resorption. Later, Humphry[2] in 1866 tied wires around the mandibles of pigs and showed that the wire became imbedded in the posterior margin and free in the anterior area of the ramus which seemed to verify the Hunter hypothesis.

Brash[3] in 1924, following the work of Humphry, fed pigs the madder plant root which contains the red stain alizarin and which labeled appositional bone growth. The conclusions were the same: Apposition occurred posteriorly and superiorly on the ramus of the growing pig mandible.

The duplication of these studies by later scientists on the rat[4] and the monkey[5] also tended to confirm this phenomenon in other mammals. More recently, several studies have been conducted with the use of tetracycline stain by Moffett and h's co-workers.[6] Bone remodeling has been studied under numerous experimental conditions by Storey[7] and his students. Extensive studies of bone growth using staining have been conducted by many other investigators.

Experimental surgery and basic research studies have been conducted. Sarnat, for his studies, removed the condyles from growing monkeys.[8] Also, amalgam and other metal implants have been placed in the growing facial bones of experimental animals.

Growth in size and position of the mandible has been studied extensively with the method of roentgenographic cephalometrics.[9,10,11] This method led to the idea that the bud or crypt of a tooth will invaginate or invade the bone during tooth development. The plane of the lower border of the mandible tended to be more or less stable when related to cranial references. A plethora of work in cephalometric procedures and other x-ray techniques formed the background for work in body-section x-ray. These works culminated in the development of the tool of cephalometric laminagraphy.[12,13,14] Longitudinal work with the laminagraph (sometimes called tomograph) suggested variation in growth of the mandibular condyle and the ramus as a key to behavior of different facial types. The question was, whether the mandibular form and type caused the face to grow or growth resulted from deeper functional phenomena.[15,16]

The principle of implants was applied to the human mandible by Björk.[17] The aid of implants made it possible to locate the probable sites of growth when subjected to serial cephalometric methods. The study of size of the mandible as well as the sites of apposition and resorption were revealed. Björk showed extensive variation in mandibular bending and also showed *resorption of the lower angular border* to be the typical phenomenon in the normal patient. His findings suggested the crypt of the lower third molar to be a stable longitudinal reference.

Growth of the mandible was studied by Enlow by using the histologic evidence of surface characteristics.[18] By identifying areas of depository and resorptive areas, and by describing reversal areas of stability, a typical pattern of three-dimensional growth was described. This work stressed the remodeling effect and the drifting effect on morphogenesis of the mandible.

But neither histologic sections nor implants are practical solutions to clinical problems. They help to develop principles and to show facts on which the clinician can interpret results or build theories.

Moss became interested in the more profound biologic determinants of morphogenesis.[19] His study of the "organ" supported by bone led him to accept the concept of the functional matrix as a prime morphogenetic factor. Brodie, by expressing a division between the respiratory and digestive systems in the palate, has stressed the biologic rationale of this kind of thinking.[20]

Further, an analysis of the relationship of the neurovascular or neurotrophic bundle led Moss to other conclusions. With the cephalometer and the concept of gnomic growth described by D'Arcy Thompson,[21] Moss speculated that the phenomenon of *growth of the mandible was predictable.* He reasoned that the foramen ovale, the mandibular foramen and the mental foramen behaved in an orientation to a logarithmic spiral during the growth process. He further discounted some of the importance of the condyle to the growth of the ramus as claimed by a host of basic and clinical investigators.

Clinical Investigation and Prediction of Mandibular Growth

Body-section roentgenography (laminagraphy) reveals the details of the condyle and the ramus to a critical extent. Through the studies of laminagraphy it was recognized that, under proper exposure and with the use of headholding devices, the condyloid and coronoid processes could be reasonably identified in the routine lateral cephalometric head film.[22]

The early laminagraphic studies of Ricketts suggested that tendencies toward squareness, heaviness and strength of the mandibular ramus tended to be associated with forward development of the chin and deep faces. Obtusity, fragility and weakness of the mandible seemed to contribute to more downward or backward development of the symphysis in the face. The interest in determining growth factors stemmed from the need for applying basic knowledge to the correction of malocclusion and facial deformities, particularly as growth and morphology relate in a clinical context to open and closed bite.

Therefore, on the basis of these early studies, a primary method of "prediction" of development was devised. By plotting a line through the long axis of the condyle and neck and extending it to the lower border of the mandible, the bending of the mandibular form during growth had been studied. Consequently, findings from this method suggested that the technique could serve as a working hypothesis for growth projection for the clinical problem of prognosis of growth.[23]

It will be noted that a bending of the mandible from infancy to maturity has been described in some of the earliest anatomical textbooks. It became a problem to relate the characteristics of such bending to each growing mandible because patients seemed to vary extensively and the causes for bending needed exploration.

Although the method originally described was useful for practical short-range predictions, a method was sought whereby mandibular growth patterns could be identified with greater certainty. As mentioned before, the findings of Björk's implant studies had revealed that the lower border of the mandible was resorbing and that the *mandibular plane was not acceptable as a reference base for growth analysis.*

The next move toward improving the method was to identify a "central core" cephalometrically. As noted previously, many authors had employed

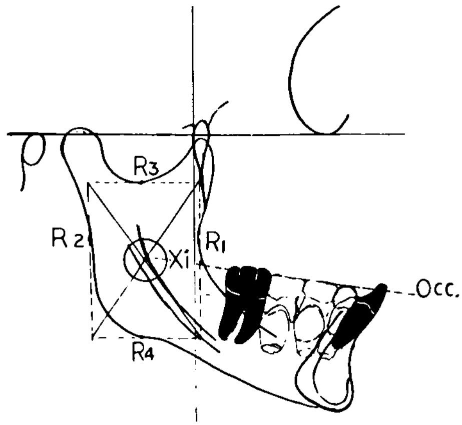

Fig. 1 Shows the method for the determination of Xi point. The deepest point on the subcoronoid incisure or R1 is selected, and a second point R2 is selected directly opposite that point on the posterior border of the ramus. R3 is picked at the depth of the sigmoid notch, and R4 is a point directly inferior on the lower border of the ramus. By using these four points the centroid of the ramus (Xi) is selected by forming a rectangle and connecting the corners. The occlusal plane holds a strong tendency to pass through Xi point . Xi also represents the entrance of the neurotrophic bundle into the mandible.

the external mandibular form for references (mandibular plane, ramus plane, and condyle—symphysis dimension). Enlow also concluded that the mandibular ramal surface is subject to remarkable remodeling and therefore not reliable for reference. The attempt to overcome surface variation and to determine central or internal structural phenomenon resulted in the promulgation of new reference points as follows.

First, a point (Xi) in the center of the ramus was located. The determination of a point of reference at the ramal centroid was difficult (Fig. 1). It is recognized that lateral roentgenographic cephalometry does not reveal the mandibular canal with certainty. Neither does the selection of the mental foramen appear certain, although frequently *both* the mandibular canal and the mental foramen may be visible.

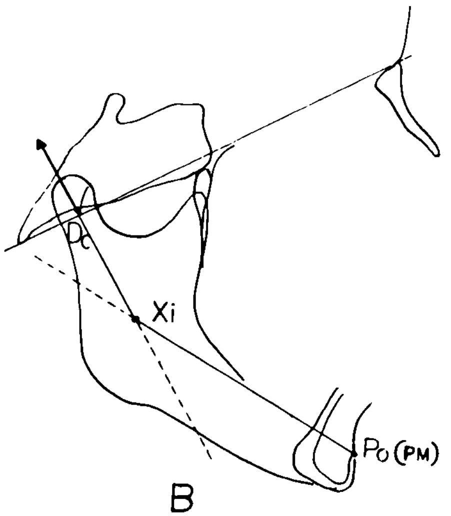

Fig. 2 With Xi point a new condyle axis is erected bisecting the condyle neck (DC). Xi, when connected with suprapogonion (PM), is used to describe the corpus axis of the mandible. This central "core" through the ramus and body circumvented the variation of peripheral mandibular structure.

Second, a point at the superior aspect of the symphysis was selected as *suprapogonion.* It was labeled Pm (for protuberance menti). This is substantiated as a reference because it is located at approximately a stress center (Ricketts); it is the site of a reversal line (Enlow); and also it is consistent with the findings from implant studies (Björk) which indicated stable unchanging bone in this area of the chin. Therefore, a bone crest, located at the superior aspect of the compact bone on the anterior contour of the symphysis, was accepted as the most stable and useful reference for anterior-most basal bone in the mandible[24] (Fig. 2). Recognizing this problem, the center of the mandible was located geographically by measurement. By bisecting the height and width of the ramus at its narrowest dimension, a geometric center was determined and labeled "Xi" point. Investigation of normal mandibles from twenty-five dried skulls showed in every instance that this point fell in contact with the mandibular canal.

Third, a point was used which previously had been described by us from earlier work with laminagraphs. This was a point at the bisection of the condyle neck as high as visible in the cephalometric film below the fossa. This point was labeled "Dc".

Accordingly, by connecting Dc point with Xi point, a repeatable "condyle axis" was established. Further, by connecting Xi to Pm, a "corpus axis" was erected. Consequently, by studying linear growth on these planes and the form change as a change in angulation between the two, an interpretation could be gained regarding the characteristics of mandibular growth in a given patient as well as for groups with sex and age differences (Fig. 2).

Once values were determined for these dimensions and corrected for biologic considerations, the changes in magnitude and angular relations served as a second method for predicting mandibular growth with a projection technique. A great deal of biological emphasis still was placed on condylar growth with this forecasting technique by employing internal lines. This method proved to be more accurate than the previous method of relying on surface lines. It not only was more successful as a method of forecasting, but also served as a catalyst for more extensive research in mandibular growth.

The objective of research was still toward finding a method to critically predict future form and size of the mandible over the long range or to maturity as a basis for treating deformities in the child, and for the best esthetic and functional equilibrium by adulthood.

A Computer Study

A five-year growth study of the man-

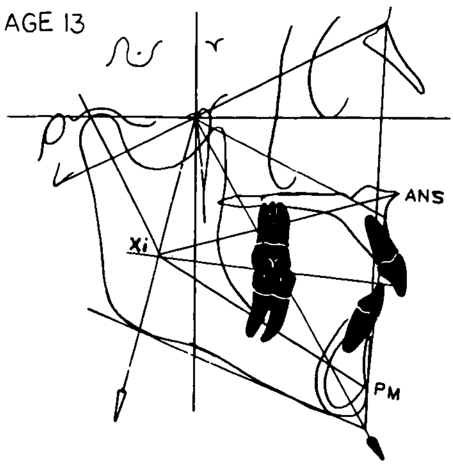

Fig. 3 Shows a composite of forty patients studied at age 13 years. The facial axis is shown (dark arrow) from pterygoid point which on average almost coincides with the polar center. The open arrow shows the Xi axis. ANS-Xi-PM represents the denture height angle and was found to be highly stable.

dible and lower dental arch was conducted as a part of a large computer study of craniofacial morphogenesis. The principle of triangulation in cephalometric points was followed in order to eliminate or correct possible errors in measurement.

In the lateral and frontal head films, 362 measurements were employed for the complete study. Standard deviations were studied and every measurement was correlated with every other by the coefficient correlation in both Time 1 (beginning) and Time 2 (end). Standard deviation of change and growth correlations also were rendered by the computer as a comparison analysis.

The material for this primary computer study consisted of lateral and frontal cephalometric films on forty patients. The beginning films were made at the average age of 8 years; the second group averaged 13 years of age. The range was ± 2 years of the 8-year level. However, this sample was selected to cover the transition from the mixed dentition to development of the permanent dentition and not to an exact chronologic time. None had been treated orthodontically. Half of the sample were males and half were females; twenty were Class I and normal occlusions while the other twenty possessed Class II malocclusions. One objective of the study was to test for any differences in growth of patients with malocclusions as compared with individuals with normal occlusions.

Findings

The findings are summarized for this report, so that major characteristics of the mandible can be shown more clearly. Due to the large number of measurements, only the results are shown. The changes are displayed by comparison of composites made from computer printouts (Fig. 3).

Comparisons of the Time 1 and Time 2 renderings also are exhibited as superimposed at Xi point and the mandibular body (corpus axis) (Fig. 4).

The Secondary Study

After producing accurate composites a more detailed mechanism was sought to *explain* the phenomenon of mandibular development.

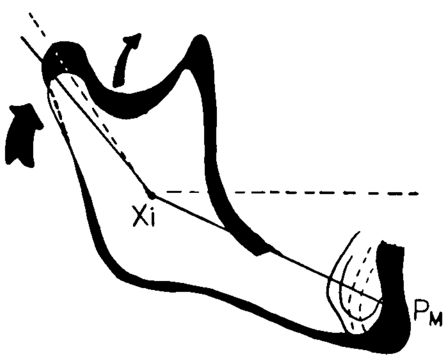

Fig. 4 The samples are superimposed on the corpus axis and registered at Xi point as the mandible was found to bend about one half degree each year.

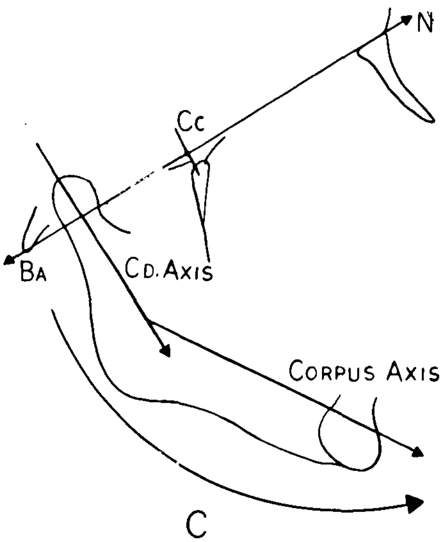

Fig. 5 Shows the technique of study of the change in the mandible which is also the method used in forecasting procedures. For forecasting with the computer on short range, a center (CC) is picked on basion-nasion plane perpendicular to the lower border of foramen-rotundum (Pt). The condyle axis is forecast to move with basion in the downward and forward direction. The condyle axis is lengthened and the corpus axis is added to produce the positioning of the chin. This is the method used to connect the mandible with the skull base in forecasting.

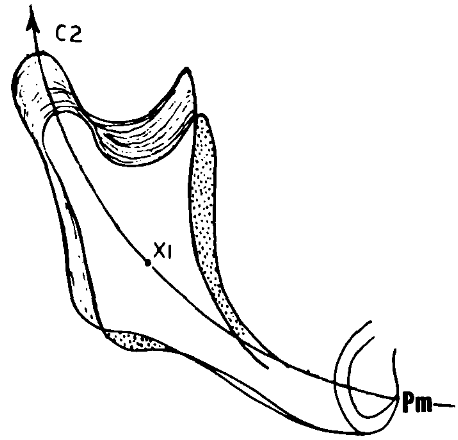

Fig. 6 This shows the methods used to determine the true arc of growth of the mandible. Pogonion (Po), Xi and the center of the condyle head (C2) were connected in a circle and increments added. The mandible became more obtuse than was the actual behavior of the sample.

It was recognized that a bending was occurring in an orderly manner and therefore the greater the magnitude of growth, the greater the bending. It was apparent that a growth arc was operative. It was of interest to see if this arc could be reduced to a segment of a circle, an ellipse or a spiral curve.

After using the Pm, Xi and Dc points as a method of depicting the cortical "core" of the mandible (Fig. 2 and Fig. 5), experiments were undertaken to determine a method by which the form and size of the mandible, after a five-year growth interval, could be predicted with use of only the first x-ray as a reference. The size increases and form alterations were available from the computer study as a working medium of information and as a basis for later work.

The first move was the construction of an arc in the Time 1 composite through the three points: Pm, Xi, Dc. By extending this arc the size increase was produced but not enough bending in form resulted (Fig. 6). We were satisfied that Pm was a reliable reference and retained it for further study.

A second arc was explored by using the tip of the coronoid process, the anterior border of the ramus at its deepest curve (R1) and the same Pm point. The extension of this curve exhibited the segment of a circle too small in radius and resulted in excessive bending of the mandible when the same gradient of growth was employed for a projection (Fig. 7).

It was obvious that the characteristics of typical growth had been bracketed by the two arcs produced: one straightening the mandible too much and the other resulting in too much bending. A true arc of growth

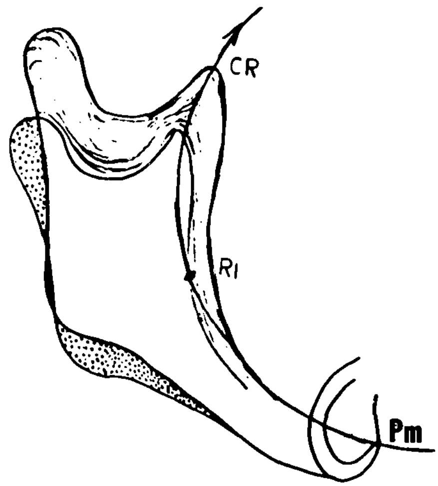

Fig. 7 The anterior border of the ramus (R1) and coronoid process (CR) were connected in an arc to pogonion. This showed that the mandible bent too much. These findings suggested that the true arc of growth of the mandible lay somewhere between the Xi point and the anterior border of the ramus and between the condylar and coronoid processes.

therefore must lie somewhere in the mandible between the condyloid and the coronoid processes and between the ramal center and its anterior border. It was decided to construct an experimental arc bisecting the two previous arcs. By establishing a halfway point between Xi and R1 points (the center and anterior border of the ramus) and using the distance from this point to Pm as a radius of a circle, an arc could be produced. The use of this arc still bent the mandible a fraction too much. In addition, a radius selected from this point would increase with size of the mandible and a progressive increase or a changing arc or ultimate spiral shape would result. Growth therefore could not be represented as a simple segment of a circle, if these dimensions were employed.

It was thought that perhaps the stress lines of the mandible would reveal its hidden secrets. The study of mandibular slices through the center of the ramus failed to show definite architectural designs because the inner and outer plates are very heavy and carry the load. Attention therefore was directed to a mandible, alleged to be 850 years old, which had been given to the author by the late William B. Downs. This mandible had been weathered to a state of disintegration of the interprismatic substance of the external cortical bone, and therefore clearly showed stress lines in the outer and inner plates (Figs. 8, 9 and 10). The lines thus exhibited the design of the mandible for bracing externally. It was hoped that these functional stress lines would also yield some clues regarding the possible development of the mandible, for we know that stresses tend to run parallel to bone trabeculae.[25] The load being carried in the superstructure of a bone thus can be analyzed. By the analysis of compression, extension, shear and torsion, these lines begin to fit a pattern.

Close examination confirmed the convergence of stress lines at the protuberance menti (Fig. 8). The stress lines seemed to swing downward and then upward and backward and outward through the external oblique ridge (Fig. 9). From this ridge on the external table, the stress pattern was divided at the base of the coronoid process. An irregular gnarled area was located at this area on the lateral surface as the stress seemed to divide forward or backward in respect to coronoid and condyloid demands.

However, great attention was directed toward the medial side. On the internal aspect (Fig. 10) even greater forking was noted than was seen on the lateral side. The stresses here followed the mylohyoid ridge upward into a thick mass to terminate at a Y-shaped bony prominence (Fig. 10-YM). This was almost the center of the upward and forward quadrant of the ramus on the lingual

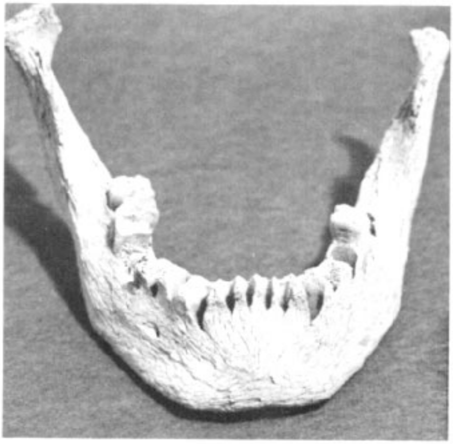

Fig. 8 An 850-year-old mandible with stress lines quite evident converging at the mental protuberance. Even the stresses for the support of the canine teeth emanate upward and outward, seemingly to hold the canines apart. The lines of stress go downward and outward into the mental tubercles and from there out to the trihedral eminences.

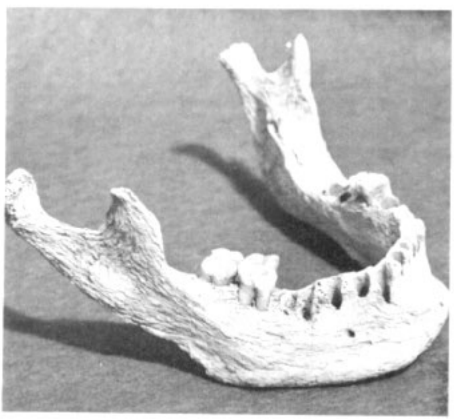

Fig. 9 View of the right side. An arc is very clear in the stress lines running from the mental tubercle, swinging upward through the external oblique ridge and then dividing into the coronoid and condylar processes. Notice that a gnarled area of bone is present at the base of the coronoid at its junction with the condylar process.

aspect and, in fact, might be the base of the tuberosity of mandibular growth. Accordingly, both the inner and outer tables showed confluence at this area of the mandible.

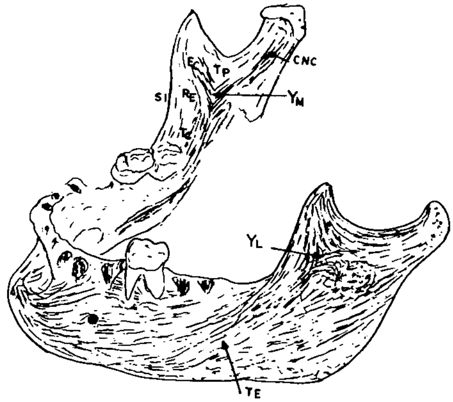

Fig. 10 Tracings of the left side show a stress pattern at TE, or trihedral eminences; YL - forking of the stress lines at the base of the coronoid process; YM - forking on the medial border of the ramus; CNC - endocondyloid crest; EC - the endocoronoid crest; RE - the area of the mandibular recess; SI - the subcoronoid incisure; TC - temporal crest. Notice also that an arc is present on the lingual aspect of the mandible, almost to correspond with the stress directions of the external oblique ridge.

Further study of several dozen mandibles led to the observation of small, apparently nutritive foramina immediately superior to this area on the medial side of the ramus at the triangular plane (Fig. 10-TP). It was hypothesized that these might be trophic to what now was looming as possibly an important mandibular growth area.

Experimentally, two new points (Eva and TR) were located geometrically (Fig. 11). Point Eva is also a biologic point as it is located over the point of forking of the stress lines in the ramus. When the size increase of the mandible as determined in the computer study was incrementally added to the arc at the sigmoid notch, it was found that the predicted mandible was almost absolutely correct in size and form when compared with the final composite (Fig. 12). The method as devised for k factors (constants) proved extremely accurate in fifty treated cases which were predicted

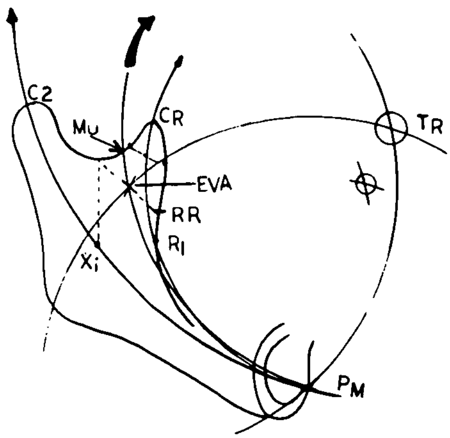

Fig. 11 Should be compared with the experimental studies shown in Figures 6 and 7, representing the search for the true arc of growth of the mandible. A line from Xi point to the sigmoid notch is bisected and a parallel point (RR) is selected on the anterior border of the ramus. (This point is used in growth forecasting as seen below). RR point is connected to point R3 at the lower border of the sigmoid notch. This line is crossed by a second line selected from a point midway of the base of the coronoid process to the Xi point. The cross ng of these two lines (called point Eva) approximates the center of the upward and forward quadrant of the ramus. Eva almost exactly coincides with the forking of the stress lines on the internal and outer table of the ramus (Fig. 10). A third point is selected, of equal distance from Eva and PM, which is TR (true radius), the true arc for growth of the mandible. This point is used for the center of the circle which is drawn from pogonion through Eva. The heavy arrow shows the direction of growth of the mandible. At the point of intersection of the arc with the border of the sigmoid notch, a point was selected wh ch was called point Mu.

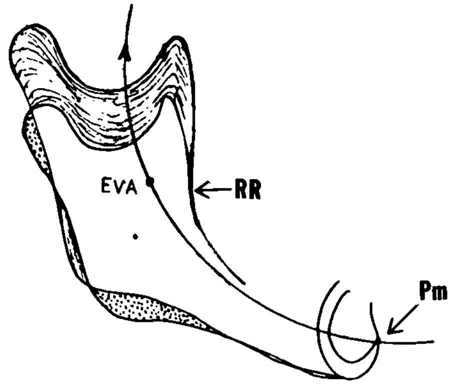

Fig. 12 As the 8-year composite was extended on the arc, with the increments added, the mandible was duplicated almost absolutely, confirming the true arc of growth.

and compared for periods of as long as fourteen years later.

For a more definitive explanation and demonstration, the head films of a male patient, age 9 years, were chosen. This patient was observed until almost 19 years of age and no orthodontic treatment of any kind was rendered. The original lateral tracing of this patient is seen in Figure 17. The technique is shown in Figures 13, 14, 15 and 16. The completed forecast is displayed in Figure 18 and the final tracing is presented in Figure 19. In Figure 20 the predicted mandible is compared with the actual.

Having become satisfied with the arc as a tool for prediction, the next problem lay in the amount of growth to forecast on the arc. The yearly increase from the combined studies was discovered to be almost precisely 2.5 mm. Averaged over the years of time, it was an excellent population constant. Cutoffs for growth were determined to be 14.5 years for females and age 19 for males.

It now became important to study the development of the superior part of the ramus because this loomed as highly significant in the accurate projection of a case and later construction of the face in the long range forecasting.

Next, twenty longitudinal cases with a range of duration from five to twelve years were measured. That study revealed that the increases in the condylar and coronoid processes were different when measured from a point at the crossing of the arc with the sigmoid notch. The point of crossing was labeled point Mu (Figs 11, 13 and 14).

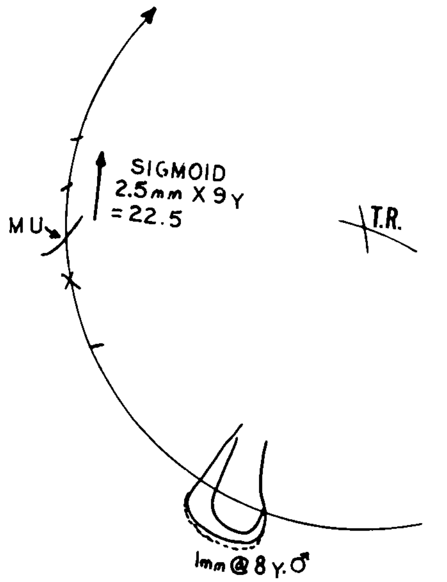

Fig. 13 Shows the initial steps in long-range growth forecasting (which is a different method from the short range). Apposition of the lower border of the symphysis for males occurs at about 1 mm each 8 years. From point Mu the mandible is grown on the arc at the sigmoid notch about 2.5 mm each year.

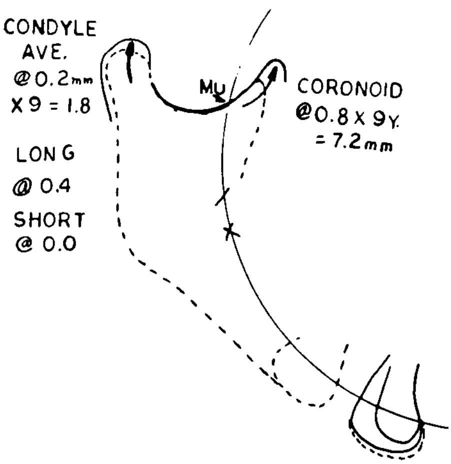

Fig. 14 Shows the second series of steps. The coronoid is extended upward and outward at a rate of 0.8 mm per year. The condyle in this average individual is extended upward and backward 0.2 mm per year. Long condyles grow 0.4 mm per year. Short and weak condyles are given no further growth in the forecasting technique.

The coronoid and condylar processes grow upward and outward in a direction essentially as a function of the curve of the original arc (Fig. 14). This means that sigmoid notches with arcs of a small radius tended to stay small, while widely divergent condyles and coronoid processes or notches with wide radii tend to stay extended. As these values were determined and used experimentally on more than 100 patients, a k factor for the coronoid process growth came to be 0.8 mm per year.

The condylar k factor was discovered to be variable. Some condyles did not grow at all from the original point Mu, while others grew significantly. The short and small condyles were found not to grow and the weak condyles were given 0.0 mm for forecasting. Good, well-formed condylar heads with long necks accordingly were given a k factor of 0.4 mm per year. Average condyles were to be given 0.2 mm per year or 1 mm of extra growth (from the ramus) every five years.

It should be mentioned that damaged condyles did not behave normally, nor did true prognathic types. Neither fit the principle of normal growth. These conditions are rare and need to be identified because, as cases of this kind are observed, the forecast becomes diagnostic of *abnormal growth*. In fact, some patients were discovered who possessed actual degeneration of the condylar head when it should have grown. (The reader can imagine the bite opening and mandibular rotation effected by this condition).

Further studies were consistent with the behavior of gonion in the computer study. The combined studies showed that the gonial angle drifted posteriorly on the arc almost exactly one half the total increase in mandibular growth on the arc (Fig. 15).

One final consideration is needed to

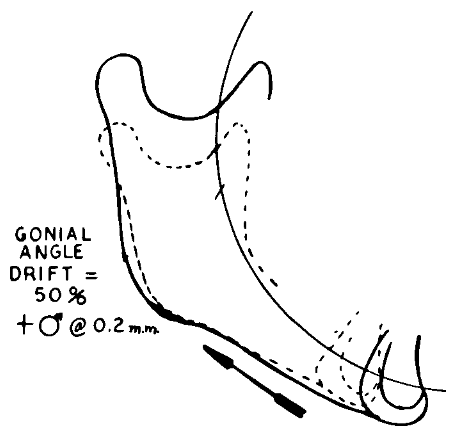

Fig. 15 Shows the method to determine the drift of the gonial angle on the arc. In females no further additions are given on the border of the mandible from the arc; however, in males additions of 0.2 mm per year are given. The drift of the mandible occurs almost precisely at a pace of 50 per cent of the total mandibular growth.

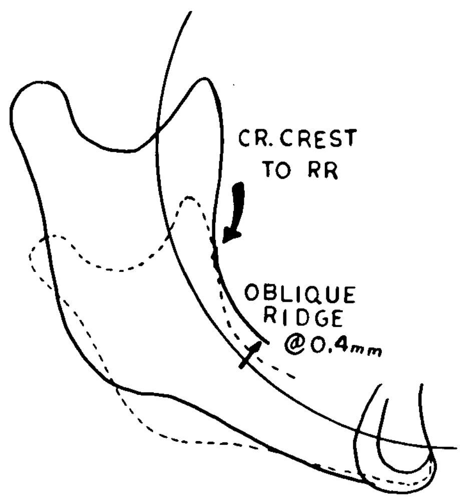

Fig. 16 Represents the last in the series of steps in forecasting the growth of the mandible. Art work for normal contours is employed as connections are made from the coronoid process to point RR on the coronoid crest. The oblique ridge of the mandible shows appos tion by this method of about 0.4 mm each year. (See Figure 15 for comparison to the actual.)

complete forecasting of the mandibular form. This is a critical point because it helps to determine the space available for the developing mandibular third molar at the anterior border of the ramus or the external oblique ridge. For this determination the RR point was re-employed (Fig. 16). As the Time 1 tracing is compared with the forecast being constructed, it is assumed that stable bone is located here. Thus with normal anatomical contouring the coronoid process is connected to RR point, which tends to determine ramal width. Slightly below this point, the external oblique ridge will show apposition of almost 0.4 mm per year.

By constructing the growth arc, growing the mandible on the arc, extending the processes and drifting the angular process according to the k factors of the studies, a new forecasting technique now could be tested. It was extremely valuable to have available, from the computer, data in all of these anatomical details. This information alone significantly increased the confidence levels.

Studies on the occlusal plane and eruption of mandibular teeth

The author made extensive investigations in 1955 on the treatment behavior of the occlusal plane. (Figs. 3 and 21-A). The occlusal plane was again studied relative to more than three dozen points and other planes as well in a nontreated sample.

Five relations will be discussed which seem pertinent to new clinical implications.

First: The *angle* of the occlusal plane to the corpus axis tended to be regular and orderly (Fig. 21-B).

Second: There seemed to be some functional or biologic relation to the development of the posterior end of the *occlusal plane to Xi point* (which,

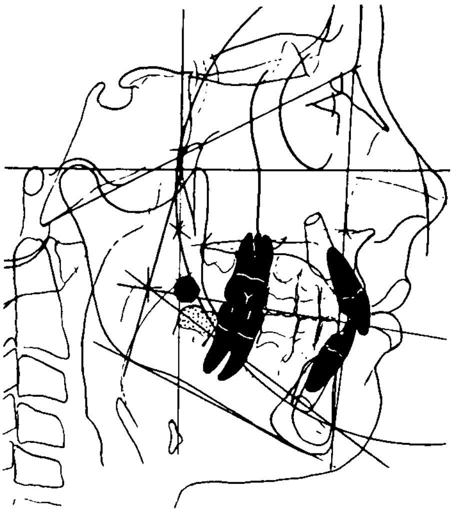

Fig. 17. Tracing of a male, age 9 years 7 months, which will be forecast in the subsequent illustrations. The patient had a mild Class I malocclusion, almost end-to-end in the molars, and was never treated. Note that the darkened crypt for the developing third molar is almost precisely on the occlusal plane and located immediately above the second molar.

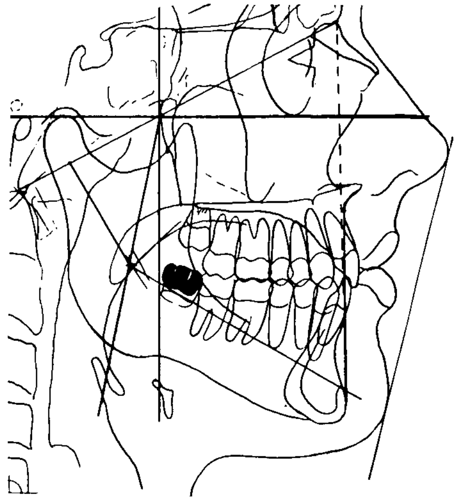

Fig. 19 Patient MW, tracing at age 18.5 years. It will be noted that the third molar has about a 40 per cent chance of eruption, while it was given about a 50 per cent chance in the prediction. The height of the lower molar (shown in Fig. 20) was missed about 1.5 mm. Notice the remarkable likeness of the profile and the form of the mandible as Fig. 18 is compared wi.h Fig. 19. The interincisal angle was forecast to the ideal, so this miss does not constitute an error.

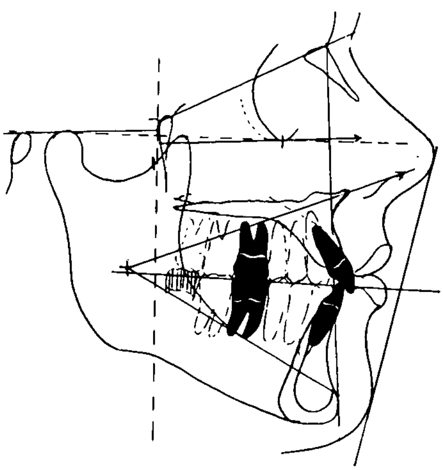

Fig. 18 The final projected mand:ble is used as a frame of reference from which the rest of the face also is forecast. The other steps in facial growth forecasting are not discussed in this article, but are shown here for orientation. The prognosis for position of the third molars also is included. An end-to-end position of the canines was projected and the lips and chin tissues were included. Compare this "prediction" with F.g. 19 and see the overlay comparison in Fig. 20. It will be observed that at no point in the entire face was there more than 2 mm of error in forecasting of this patient over the nine years.

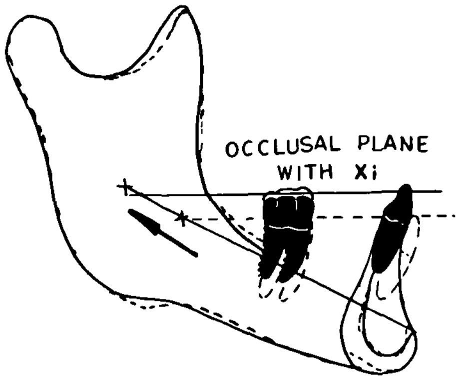

Fig. 20 Shows forecast of the mandible compared with the actual (Fig. 19). The solid line is the prediction; the dotted line is the actual. A slight difference will be noted at the coronoid process (which could be a tracing error either in the beginning or the ending). The slight apposition on the lower border of the ramus is insignificant remodeling. Therefore, prediction in this case was almost absolute. The hashed lines show the original position of the lower incisor, lower molar and the occlusal plane. The solid teeth show the final position of the lower incisor and the lower molar. The solid line shows the position of the predicted lower molar (note about 1.5 mm vertical error). The predicted position of the lower incisor was almost absolute. The arrow indicates the upward and backward movement of Xi point. Note further the angle between the occlusal plane and the corpus axis did not change. The occlusal plane was predictable by the prediction of the movement of Xi point.

it will be remembered, represents the mandibular foramen). While the distal end of the plane from the true buccal occlusion dropped downward slightly with growth, a plane, if drawn through the second molar, would move it back up to its original position. This is a biologic clue to the development of the curve of spee.

Third: The occlusal plane tended to hold its relation to the embrasure of the lips at the forward end. (Note: without treatment)

Therefore, it seemed that the vertical development of the lower dental arch and the occlusal plane took place naturally as a *function of mandibular growth.* As the arc was growing, the symphysis or chin was pushed under the denture as the teeth erupted upward and forward. This explained

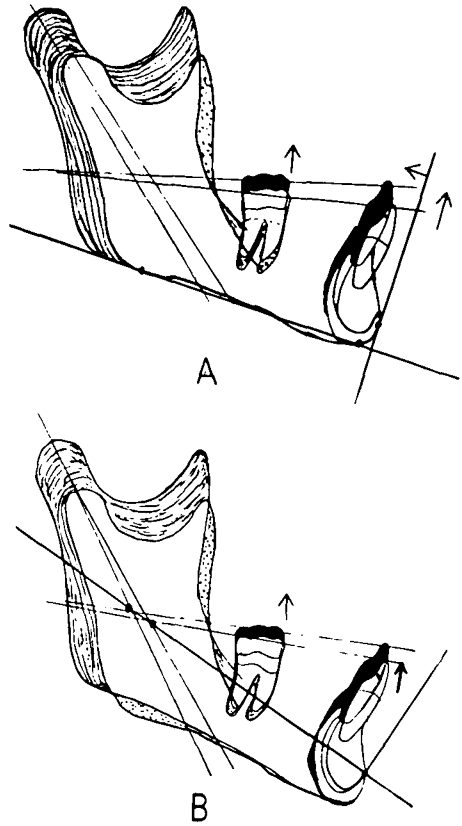

Fig. 21 A. By the old method of superimposing on the symphysis and lower border of the mandible, it will be noted that the condyle is extending upward and backward, resorption is shown on the anterior border, the lower molar moves straight upward and the lower incisor moves upward and backward. The occlusal plane also is increasing to the mandibular plane.

B. Bending is seen in the mandible as corpus axis is superimposed at pogonion. Compare with Fig. 4 in which the same composites are shown registered at Xi. Notice that the occlusal plane tends to be more constant to the corpus axis and that the lower incisor tends to erupt in a straighter upward direction when oriented in this manner. This is an excellent method for the evaluation of the behavior of the lower dentition.

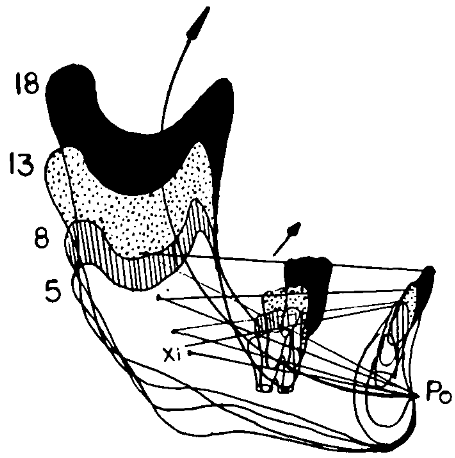

Fig. 22 Shows the author's concept of growth of the mandible. These drawings were made from composites from the computer in a sample of patients aged 5, 8 and 13 years. Another sample was used for a study of patients in males alone, 18 years of age. For this method of superpositioning, pogonion and the anterior border of the ramus at the coronoid crest are employed. These points represent the true nonresorbing cortical bone which can be located reasonably well with cephalometrics. The vertical apposition at the superior border of the ramus is displayed. It will further be noted that the occlusal plane is moving with Xi point which moves progressively upward. It also will be noted that the lower incisor moves upward and forward as resorption and remodeling and thinning of the alveolar process occurs. The lower molar is seen to move in an upward and forward direction, which accounts for the creation of space for the second and third molars.

"chin button" development (Fig. 22).

Fourth: The horizontal or anteroposterior movement of the lower incisor seems to be biologically related to the APo plane. The mean values for lower incisors to the APo plane tend to match for malocclusions and normals and successfully-treated cases. This means that the lower incisor relates to the convexity or facial type in all age groups. The prediction of the anterior position of the lower incisor is, therefore, related to the prediction of change in convexity by whatever factor is causing the change (Figs. 18 and 19).

Fifth: The lower molar tends to erupt upward and forward with the occlusal plane from the mental protuberance. Given the adjustment which may occur with leeway space in the transition stage, the molar can be predicted as a function also of mandibular growth (Fig. 22). This shows clearly that space for the erupting third molar is made by upward and forward eruption of the dental arch in front of it (Fig. 18). If the lower arch is held backward, space loss for third molar teeth can be expected. If space is created by forward movement, a better prognosis should follow.

Because so little is available in the literature, especially with regard to the arcial concept of growth, more study was needed. If the consideration of the third molar could be added to diagnostic procedures, another facet could be added to knowledge and treatment planning. Prognosis of the third molar may no longer need to be so guarded or speculative if, by this method, accurate estimates are made of space available.

Impaction of third molars and arcial growth prognosis

All these studies pointed the way to still another study of meaningful interest to clinical orthodontics. This is the lower third molar problem.

Twenty-five adult skulls exhibiting normal occlusions were studied, many with the aid of a lateral head film. From this group of skulls an hypothesis was determined that the lower third molar must lie fifty per cent ahead of the external ridge for a fifty per cent favorable prognosis for its eruption. Theoretically (as far as space is concerned), the prognosis could be one hundred per cent favorable if the molar (in cephalometric lateral view) is located completely mesial to the ridge. Conversely, the farther distal (or the more it is covered by the ridge), the poorer the prognosis for eruption.

CHART I

CHART OF THIRD MOLAR STUDY AND PROGNOSIS

SAMPLE		
Number 31	Bicuspids Extracted 13 (42%) Impacted Third Molars 10 (33%) Space for those Impacted 20% Range 0-60%	Nonextraction 18 (58%) Erupted Third Molars 21 (66%) Space for Erupted Molars 65% Range 0-120%
Extraction Number 13	Impacted Third Molars 2 (15%) Space for Third Molars 30% Range 0-60%	Erupted Third Molars 11 (85%) Space for Erupted Thirds 74% Range 10-120%
Nonextraction Number 18	Impacted Third Molars 8 (45%) Space Available 19% Range 0-40%	Erupted Third Molars 10 (55%) Space Available 49% Range 0-80%
Erupted Cases 21	More than 50% Space 13 (66%)	Less than 50% Space 33%

To check this hypothesis, thirty-one treated cases including a variety of malocclusions were studied. The head films were taken at an average age of twenty-one years. This sample should, however, in no way be construed to represent the average of a practice because the cases were in a group which had been selected for other purposes. The findings must, at best, be considered preliminary and a sample of 200 cases is being accumulated. Chart I will show the analysis of the sample. Remember, the position of the third molar relative to the ridge was value-judged because of the nature of the external ridge being oblique in character.

The preliminary conclusion from the twenty-five skulls and thirty-one head films seems to verify the hypothesis of the 50 per cent favorable prognosis mentioned earlier. The nonextracted cases, with third molars erupted, averaged 49 per cent space in the lateral headplate. Those cases extracted averaged 74 per cent space. This would seem to suggest that a 25 per cent increase in space available for the third molar occurs in the average of cases treated with bicuspid extraction. Taken further in this logic, without extraction, 55 per cent of the cases may erupt third molars, while in this small sample 80 to 85 per cent did so with extraction, or about a 25 to 30 per cent improved prognosis. This pertains to space available and not ectopic eruption. It should be added that the sample is small, and that we feel intuitively that our extraction cases are experiencing eruption of the third molars in 65 per cent of the cases.

This would seem to verify, also, another hypothesis: that the third molar can be prognosed early and should be removed if nonextraction is to be a part of the planned treatment, because 45 per cent of the nonextracted cases required third molar extractions. It should be remembered, too, that 15 to 20 per cent of the cases required third molar extractions even with bicuspid extractions. Accordingly, over one half of our patients are candidates for lower third molar extraction. Let me again say that these are preliminary conclusions only, and further verification is needed. It is, however, a start to bringing some order out of this bewildering third molar issue.

Discussion

There is little doubt that the mandible grows in an arc of some form. The theory herein promulgated is that human mandibular growth can be reduced to a simple segment of a circle in a lateral cephalometric image. If this arc represents the true character of mandibular growth, the traditional viewpoint that "normal" lower molar teeth acquire space for eruption by ramal resorption must be modified. Rather, it is suggested from recent studies that eruption and alveolar growth in the upward and forward direction is the process by which the space is made available.

The modus operandi of mandibular growth described herein as a technique probably closely approximates the true nature of growth and is not merely a technique. It is recognized that the cephalometric image is two-plane rather than three and, further, that the condyle and ramus grow laterally in the third dimension. However, the arc explanation seems to answer many clinical questions which could not be answered by accepting the previous theories of growth and ramal border resorption. When applied, this technique seems to yield new views as to possibilities of clinical treatment.

Let us enumerate some of these possibilities:

(1) It appears (through superpositioning of outlines) that the symphysis rotates essentially during growth from a horizontal to a more vertical inclination, and the suggestion is presented that the genial tubercles and the lingual plate drop downward in the process. This explains the major part of the form characteristic of the symphysis in the cephalometric film (chin button development). Implant studies have shown that greatest apposition takes place at the inferior margin of the symphysis (and perhaps the posterior side) in the preschool years. The growth by apposition may appear lateral to the midline on the symphysis as bulk is needed for bracing.

(2) This phenomenon explains why reversal lines are observed at the area of pogonion and suprapogonion.

(3) It explains why the mandibular plane changes extensively in some individuals and not in others.

(4) It shows why ankylosed teeth are observed to affect occlusal plane development.

(5) It explains how the early ankylosis of a lower molar tooth terminates with the tooth located at the lower border of the mandible; the mandibular arc simply continues and this tooth becomes trapped within cortical bone and the lower border resorbs up to it.

(6) It suggests a reason why mandibular anchorage is risky in retrognathic faces, because less space is available for molar eruption due to a more vertical eruption in that type than prognathic types.

(7) It explains why the lower arches of brachyfacial or square faces (tight arc cases) can be expanded and brought forward, and will remain stable.

(8) It explains why good dentures may become progressively more crowded in long, tapered faces and sometimes even in normal faces.

(9) It explains how third molar impaction can occur by bone growth around the molar rather than its submergence into the ramus (however, it appears likely that this still does occur, and both processes are involved).

(10) It offers a possibility that impaction of third molars can be prevented by simple enucleation (at age

6 to 8 years) of the bud which lies on the surface, not within the bone.

(11) It suggests that abnormal growth or warping of the mandible can be understood as a function of relative contribution of the coronoid and condyloid processes.

(12) It shows why positioning of the roots of the lower first molar to the buccal, or locking them under cortical bone, will prevent upward and, therefore, forward eruption of the whole lower dental arch thereby enhancing anchorage of the lower arch.

Summary and Conclusions

Several individual investigations are summarized as they apply to the central theme: the discovery of an arc of a circle which, when extended and properly located, will permit the clinical projecting or forecasting of the natural growth of the normal mandible well within desirable clinical limits of accuracy. The regularity and accuracy with which this arcial method is now applied suggests that a principle may be operable for the phenomenon of mandibular development (even though it may appear as two-dimensional for use with the lateral cephalometric x-ray).

This resulting concept of growth behavior:

(a) demonstrates that the mandible must grow on an arc because it was shown to bend in form;

(b) is in harmony with phylogenetic principles as an explanation of man's shorter snout and upright posture;

(c) converges with the theory of the capsular matrices and the concept of the logarithmic spiral of mandibular development;

(d) supports implant studies which have shown that the lower border resorbs in normal growth;

(e) is in general agreement with the patterns of reversal lines shown by histologic bone analysis;

(f) is in harmony with recent tetracycline staining investigations showing an upward and forward condylar growth tendency;

(g) generally is confirmed by isolated cases of ankylosed teeth which act as implants;

(h) suggests a probable growth tuberosity on the superior medial wall of the ramus generally directed or facing upward and inward;

(i) offers a clear picture and explanation of clinical problems and phenomena which have not been understood or explainable in the past, particularly the behavior of the third molar;

(j) probably reveals, if not the principle of mandibular growth, patterns which approximate the absolute growth mechanism; and

(k) permits the possibility of prognosis of impacted third molars as early as the bud stage.

As in all biologic phenomena, variation is the rule in nature and more details of growth characteristics and explanations for rare extremes are needed. However, the consistency with which this procedure permits accurate forecasts suggests that it might be applied as a principle for prediction.

Following the testing on 200 cases, it was observed that the principle would hold unless some input into the oromandibular pharyngeal complex or an environmental disturbance was experienced which was of sufficient magnitude to upset its *total neurologic equilibrium.*

Further, the incremental principle does not seem to be directly applicable to patients with true mandibular prognathism, but must be modified for that specific situation. Pathologic growth should not be confused with normal growth. In this sense a normal projection employed as a comparison might be used as a diagnostic tool to determine aberration of growth.

It must be understood that the growth expressed on the arc and the resulting mandibular effect on the face are different processes. Upward and forward ramal mandibular growth on the arc as described would lead to an upward and forward shift of the chin in the face. As the arc develops, there must be a downward rotation of the mandible in the face in order to maintain the central axis of the face, or facial axis as a constant on the average. This phenomenon tends to be keyed to the neurologic bed of the face, namely, the orientation around the branches of the trigeminal nerve. The postural kinetic chain or neurophysical input to the muscles which position the mandible in the face constitute other factors.

Preliminary studies as a part of this work have suggested that in the typical orthodontic practice, with proper attention, there is a likelihood of as much as fifty per cent incidence of the eruption of functional third molars.

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