A Cephalometric Investigation of Craniofacial Growth Based on an Occlusal Reference System

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INTRODUCTION

Since the introduction of cephalometrics, the cranial base has been the most popular reference source. Longitudinal investigation of the growing face when analyzed from the lateral roentgenographic cephalogram necessitates the use of a reference system to evaluate comparative growth changes. The problem is this: the long existence of a cephalometric reference system does not in itself demonstrate that the system is necessarily the most correct, the most useful, or beyond improvement.

The purpose of this investigation is to develop and test a new cephalometric reference system that would yield information to support our present biologic knowledge of craniofacial growth and to provide a system that would be clinically useful to the orthodontist. Any reference system is selected because of its relative invariance, and therefore its use aids the demonstration of growth changes of the other related parts in the facial skeleton.

If we permit our thinking about reference systems to imply relative stability with allowable interpretation for error, then significant meaning can be attached to the facial growth processes acknowledging, of course, that all skeletal landmarks are moving at different rates and in different directions. Therefore, a reference system is a vantage point from which all growth changes may be evaluated and compared.

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REVIEW OF THE LITERATURE

Roentgenographic Cephalometrics

Broadbent[4] introduced a technique to standardize roentgenographic cephalometrics by designing a cephalostat. He concluded the cranial base to be the most stable reference source to measure the growth changes in the teeth, jaws, and face.[5]

Brodie[6] evaluated Broadbent's reference triangle comparing it with the line S-Na with S registered. He concluded both to be essentially equal, but the latter could be more reliably traced.

Tirk[29] applied a planimetric method to serial cephalometric data. Tirk's findings were: (1) consistent proportion throughout the growth period and early definement of pattern for all facial regions, (2) differential pattern of craniofacial growth when compared with facial growth and (3) growth occurring in a smooth, diminishing rate.

Coben[12,13] investigated individual facial skeletal variants relative to their role in modifying facial form. He agrees totally with Scott's[27,28] theory of craniofacial growth and considers basion as its best exemplary.

Lande,[22] using serial cephalograms from three to eighteen years, evaluated growth changes based on the reference source S-Na, registered at S, and found: (1) convexity of the face nearly always decreased, (2) no correlation existed between original facial type at seven years and the growth of Gn from seven to seventeen years, and (3) prognathism increased after seven years of age.

Nanda[25] studied facial growth from

serial cephalograms from four to twenty years. Instead of using the traditional reference methods, rates of growth were studied. He concluded that all dimensions do not grow at the same relative rate and, therefore, the form of the face changes during growth.

Björk[9] focused his investigations on the individual between twelve and twenty years finding facial structures changing in pattern during adolescence. He related this to a similar growth change taking place in the occlusion of the bite. In a later study[10] of cranial base development he compared the cephalometric records of individuals at twelve and twenty years. He reported: (1) shape of the cranial base remains stable on the average and varies with the individual, (2) cranial base growth directly affects the growth direction of the mandibular condyle by altering the glenoid fossa, and (3) the S-Na line represents constancy to the anterior cranial fossa and therefore is a good reference line. To improve the stability of reference points in serial cephalometric evaluations, Björk[11] introduced the metallic implant method for reference orientation. This procedure revealed information in vertical facial development and the mode of eruption of the teeth. His conclusions emphasized individual growth variability.

Merrow[23] appraised facial growth from longitudinal cephalograms at the ages of eight and fifteen years. Using a coordinate system orienting Frankfort plane as the X axis and a constructed perpendicular through Broadbent's R point as the Y axis, his findings were: (1) A point and the maxillary central incisor have proportional growth, (2) the upper face is stable horizontally, but grows more vertically, and (3) the lower face grows horizontally and is stable vertically.

Bergersen[2] introduced a new reference source for evaluating growth in the lateral cephalogram. The orientation was on successive calvarial outlines and registered by maintaining Na and ANS in absolute straight lines at successive age superimpositions. The basis for selecting this reference scheme was related to Brodie's findings that the face tended to grow in straight lines. Comparing his method with Broadbent's R point and Brodie's S-Na, he concluded that his method was superior. In applying his method[3] to serial cephalometric records from one to thirty years he concluded: (1) the inclination of the mandibular lower border was not correlated with growth direction at early ages, but was at later ages, (2) no correlation existed between mandibular growth and overbite changes at any age, (3) anterior facial landmarks, excluding the mandible, migrated in straight lines, (4) the mandible became more horizontal in position, and (5) Na, ANS, and Rh had the least variability, while Pog and B point were the most variable.

Collateral Research

Moore,[24] Baer[1] and Craven[14] all used vital staining as a method of investigating craniofacial growth on experimental animals. This technique locates and grossly measures the gradients of bone deposition. Moore concluded the sutures to be the most active site of bone deposition in the face. Baer's findings agreed with Moore, but further added the concept of proportional facial growth as a resultant of differential sutural growth. Craven's findings agreed with Moore and Baer.

Ford,[18] using dried human skulls, measured the growth of the cranial bone from basion to nasion. He concluded: (1) S-Na grew continuously through adult life, while S-foramen caecum ceased between six and seven years, and (2) S-Ba grew continuously through adult life.

Enlow[15] studied in great detail the

remodeling changes of well-preserved human mandibles ranging in age from four to twelve years. Using undecalcified transverse sections prepared for microscopic examination, endosteal and periosteal bone deposits were studied by a mapping technique to enable a detailed analysis of growth directions. This investigation revealed and explained how the growing mandible maintains proportionality in form while overall growth changes its size, shape and axis. As a sequel,[16] Enlow described the young growing maxilla in similar fashion revealing that the actual posterior growth of the maxilla and the mandible have a resultant forward and downward repositioning.

Enlow[17] analyzed facial growth patterns by correlating serial cephalometric tracings with his previous findings of growth in the mandible and maxilla. The method used to superimpose serial growth data was not based on fixed reference points. Rather, the method provided an account of changes in the facial skeleton during growth, but did not permit quantitation of facial growth.

Sample Selection

The total sample consisted of twenty individuals, all of whom had longitudinal cephalometric records ranging in age from four to twelve years of age (4, 6, 8, 10, and 12 years). The main criteria used in the cephalogram selection were: (1) clarity, (2) constancy in occlusal position throughout the age period studied, and (3) no individual had received orthodontic treatment.

The cephalometric series for each individual in the sample was of *normal skeletal type*. The sample was selected by a screening method using a cephalometric template developed by Harris et al.[19]

Investigative Methods

The final method in this investigation was selected after a series of preliminary investigations seeking: (1) a reference system with relative and related equal growth stability when compared with the growth rates of the remaining craniofacial skeleton, (2) a reference system of biologic stability rather than mere location, and (3) cephalometric reference landmarks reproducible with minimum error.

Preliminary Investigative Methods

The common denominator that was chosen as representative of the above listed criteria was the *functional relationship of the occlusion of the teeth* (FOP).This plane, located by inspection, approximates the occlusal surfaces, in functioning relation, of the maxillary and mandibular first and second deciduous molars and first permanent molars or the first and second premolars and first permanent molars. The selection was based on the following: (1) in the development of occlusion, teeth actively erupt until they meet their antagonists creating an occlusal system with relative stability; (2) the teeth, when positioned in functional occlusion, represent a homeostatic system of relative invariance when compared with the relatively variant facial skeleton during growth.

When applying this reference system to serial growth data, interpretations then would be based on the following hypotheses:

1. The occlusion of the teeth when positioned in functional relationship represent a reference system of relative stability from which measurable growth changes in the craniofacial region can be analyzed by cephalometric landmarks.

2. The functional occlusal plane of necessity represents a zone of neutral growth activity, because it will be the reference area to which all growth is compared.

In order to give equal directional weighting in interpreting cephalometric landmarks, *horizontal* and *vertical* planes were included in the reference source. The functional occlusal plane (FOP) was chosen as the best probable representative of a horizontal reference plane. This left the consideration of a vertical reference plane which must also be representative of the functional occlusion of the teeth. The following preliminary methods of vertical reference plane orientation were considered (Fig. 1):

1. $\underline{e}$ and $\bar{e}$ points were located on the cephalogram and repositioned by perpendicular lines to the FOP. The centroid point between these two points was then located on and bisected as a vertical plane perpendicular to the FOP.

2. $\underline{e}$, $\bar{e}$ and Sp were located on the cephalogram and repositioned by perpendicular lines to the FOP. The centroid point between these three points was located on and bisected as a vertical plane perpendicular to the FOP.
3. $\underline{e}$, $\bar{e}$, A and B points were located on the cephalograms and repositioned by perpendicular lines to the FOP. The centroid point between these four points was located on and bisected as a vertical plane perpendicular to the FOP.
4. A and B points were located on the cephalogram and repositioned by perpendicular lines to the FOP. The centroid point between these two points was located on and bisected as a vertical plane perpendicular to the FOP.

Each preliminary method above was applied to three individuals having longitudinal cephalometric records chosen from the sample. Cephalometric tracings for each individual were then superimposed at progressive age intervals. The results obtained by each of the four methods were then compared and evaluated by visual inspection. The following conclusions were made:

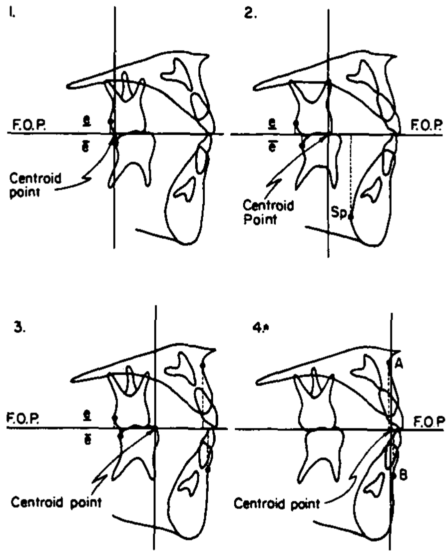

Fig. 1 Preliminary reference methods considered in this investigation. *Final reference method selected for this investigation.

(1) very similar growth patterns were observed when each method was compared, (2) methods 1, 2, and 3 artificially held $\underline{e}$ and $\bar{e}$ points in constant relationship through the stage of occlusal development. However, minor observable anteroposterior changes of $\underline{e}$ and $\bar{e}$ were visible in the lateral cephalograms when comparing one individual at progressive age intervals. This also artificially held the full expression of skeletal growth. Consequently methods 1, 2, and 3 were discarded. (3) Since method 4 permitted $\underline{e}$ and $\bar{e}$ points to move naturally through the stage of occlusal development and still reflected growth changes that were equally comparable with the other three methods, it was elected as the final reference method to be used in this investigation.

Final Investigative Method

The scheme of analysis that was applied to the Functional Occlusal Reference System was X-Y coordinate axes. The X axis would be represented by the FOP and the Y axis by a perpen-

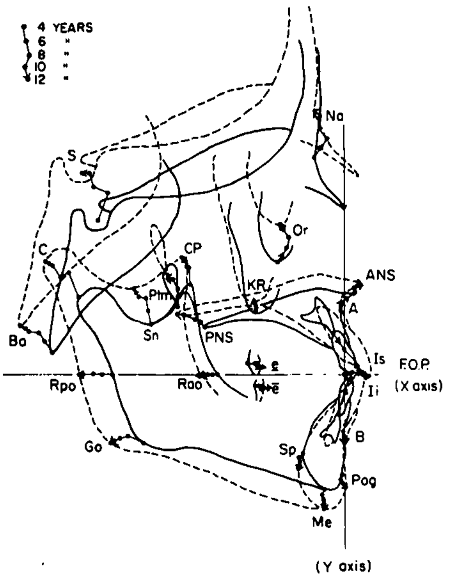

Fig.2 A cephalometric tracing of landmarks used in this investigation based on the Functional Occlusal Reference System.

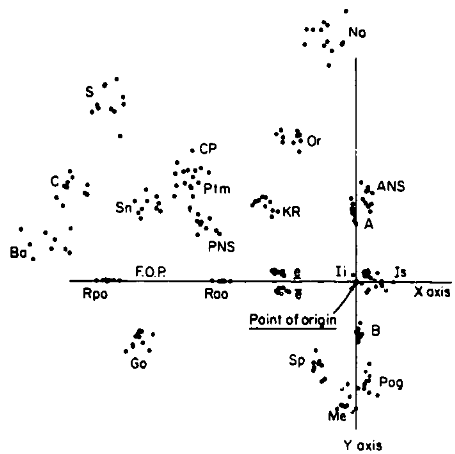

Fig. 3 A scattergram tracing of cephalometric landmarks determined by the Functional Occlusal Reference System.

dicular plane to the X axis that was derived from the centroid point of A and B points bisected on the FOP. This scheme of analysis was chosen to enable the precise location of each cephalometric landmark used.

Each cephalogram was traced and included the location of the following cephalometric landmarks: Na (nasion), S (sella), Ba (basion), C (condylion), Sn (sigmoid notch), CP (coronoid process), Go (gonion), Rpo (ramus posterior occlusal), Rao (ramus anterior occlusal), Ii (incisor mandibular), B (Down's B point), Pog (pogonion), Me (menton), Sp (symphysis posterior), Ptm (pterygomaxillary), Or (orbitale), KR (key ridge), PNS (posterior nasal spine), ANS (anterior nasal spine), A (Down's A point), Is (incisor maxillary), $\underline{e}$ (maxillary molar), and $\bar{e}$ (mandibular molar).

The tracings at the five age-intervals of each cephalometric series were then superimposed on their respective X and Y axes to complete a single composite tracing as a graphic representation of each individual's growth pattern (Fig. 2). Accordingly, each of the twenty-three cephalometric landmarks were included and represented an individual scattergram (a collection of superimposed points represented for each cephalometric landmark). Hence, graphically the typical variation or spread was noted (Fig. 3). Each cephalometric landmark was now represented by individual scattergrams that were analyzed by inspection to provide a point of central tendency (derived midpoints from individual scattergrams). These points of central tendency were then superimposed on the X-Y axes at each progressive age interval to provide one final composite tracing (Fig. 4). From this final graphic record, findings and conclusions were formulated by visual inspection and interpretation.

For comparative purposes the Cranial Base Reference System was also used in the same scheme of analysis as described above for the Functional Occlusal Reference System (Figs. 5 and 6). The reference system chosen in the cranial base was constructed as follows: the S-Na line formed the horizontal

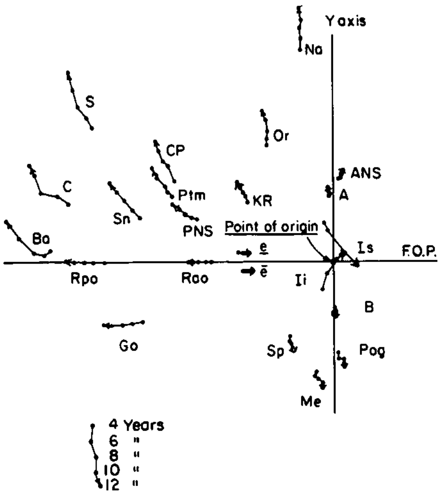

Fig. 4 A composite tracing of cephalometric landmarks and derived points of central tendency determined by the Functional Occlusal Reference System.

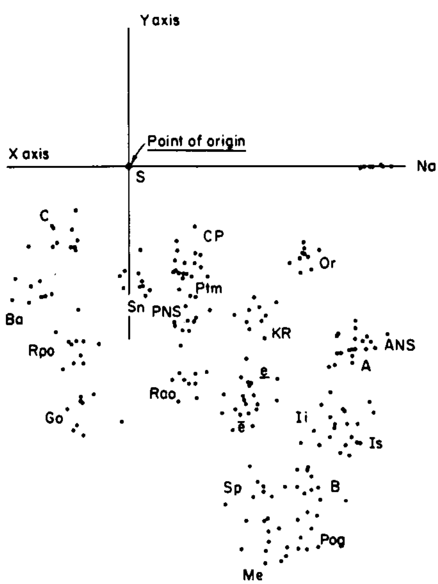

Fig. 5 A scattergram tracing of cephalometric landmarks determined by the Cranial Base Reference System.

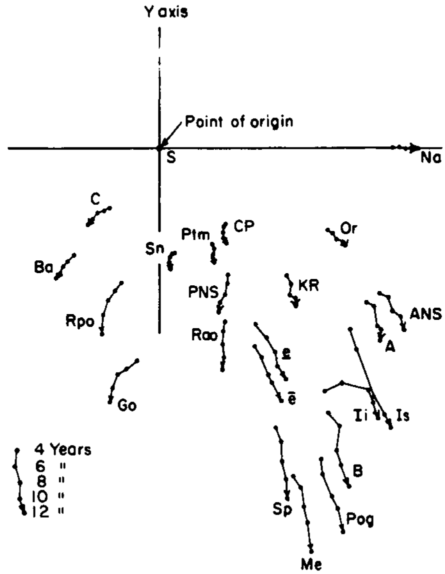

Fig. 6 A composite tracing of cephalometric landmarks and derived points of central tendency determined by the Cranial Base Reference System.

(X axis), and a constructed perpendicular bisected through S provided the vertical (Y axis). The same cephalometric longitudinal records were used and included the twenty-three cephalometric landmarks.

All findings and conclusions were based upon visual inspection and interpretation of the data collected. No measurements were made and therefore no quantitative interpretations by statistical analysis were utilized.

Findings

Functional Occlusal Reference Systems

As representative of the scattergram composite tracings which were utilized at the five age intervals of the sample, Figure 3 is illustrative of the pattern of total variability for each of the twenty-three cephalometric landmarks. The following observations were made from the scattergrams:

1. Generally, the trend of total spread of variability for each cephalometric

landmark was directly related to the distance from the point of origin (intersection point of X and Y axes). That is, the greater the distance from the point of origin, the larger the total scatter size of variability. This observation was exhibited at all age intervals.

2. When comparing the pattern of total variability of each cephalometric landmark by progressive ages, a trend toward maintenance of constancy of total pattern size was evident. In Figure 4 the composite tracing representing all cephalometric landmarks as points of central tendency at the five age intervals is illustrated. The following general trends were observed from the points of central tendency:

a) The total magnitude of change, from four years to twelve years, for all cephalometric landmarks, with the exception of Is and Ii, was directly related to the distance from the point of origin. That is, as this distance increased, the total magnitude of change proportionately increased;

b) The rate of incremental change (which is a measure by age-interval within the total magnitude of change) for each cephalometric landmark tended to exhibit a constant even pattern, with the exception Is and Ii;

c) The total incremental pattern, noted for the majority of all cephalometric landmarks when inspected individually, demonstrates direction and uniformity;

d) The vector patterns for all cephalometric landmarks when viewed in total perspective was *not* a spectrum of lines radiating evenly from the point of origin of the X-Y coordinate axes.

Cranial Base Reference System

Representing the composite tracings of scattergrams and points of central tendency, Figures 5 and 6 are illustrated in the same manner as Figures 3 and 4 were for the Functional Occlusal Reference System. However, one general difference was observed from the composite tracing of points of central tendency. This difference was related to the vector pattern of cephalometric landmarks. In this system the vector pattern when viewed in total perspective was more directly related as a spectrum of lines radiating evenly from the point of origin of the X-Y coordinate axes.

Comparison of Reference Systems

The following general observations were noted:

1. Scattergram comparisons revealed a general trend toward greater total variation of pattern size for most cephalometric landmarks in the Cranial Base Reference System than in the Functional Occlusal Reference System (Figs. 3 and 5).

2. When excluding the cranial base landmarks Ba, S, and Na, the total magnitude of change and incremental rate of change for all remaining cephalometric landmarks was generally much greater in the Cranial Base Reference System (Figs. 4 and 6).

Discussion

Cephalometrics offers an unparalleled method to study craniofacial growth providing a suitable reference system based on skeletal landmarks may be found. When one attempts to evaluate growth change from a reference system, a basic problem is always present. The problem is to identify and interpret the change in position of a cephalometric landmark in relation to the reference system. To understand the problem requires the use of two concepts. These concepts are: (1) the magnitude of change measured from any fixed reference system to a given cephalometric landmark represents *all* of the *intervening* growth variables by cumulative addition, and (2) all skeletal landmarks of the growing face are interrelated and constantly moving at different rates and directions. Therefore, the relative stability of a reference system must also be considered, as it indirectly obscures the measured growth change of a given cephalometric landmark. Now to apply these concepts, the following example is given. To interpret the growth change of the landmark pogonion, measured from the Cranial Base Reference System, involves all the intervening growth variables in the mandible, nasomaxillary complex and cranial base by cumulative addition. Conversely, the growth change of pogonion measured from the Functional Occlusal Reference System involves only the intervening growth variables in the mandible.

When comparing the relative merits of these two reference systems, the statement, "This one is better than that one," really has no meaning unless one qualifies the statement. That is, the preferred reference system is the one which can most efficiently test and demonstrate clarity in growth, and thereby facilitate its interpretation. Therefore, when evaluating the growth changes observed from the Functional Occlusal Reference System, the growth of the mandible and maxilla are relatively clearly demonstrated because the reference system is located at their interface. However, interpretation of growth of these same structures when evaluated from the Cranial Base Reference System is somewhat obscure, because the reference system is farther away. Similarly, the growth changes of cephalometric landmarks more closely related to the Cranial Base Reference System are more clearly demonstrated than from the Functional Occlusal Reference System. Therefore, mere location of the reference system must be given careful consideration in the demands of growth studies of the face.

Furthermore, growth changes measured from a reference system must have the capability of being interpreted from a foundation of biologic knowledge of the face. The direction and rate of growth is always expressed from the reference system, but the actual growth changes in the face are not easily given biological interpretation. This is due to the "masking effect" inherent in any reference system. Therefore, to meaningfully interpret growth findings from a cephalometric reference system requires the application of biologic knowledge.

To evaluate specifically and interpret the findings of this investigation, the following discussion will include the results obtained from both cephalometric reference systems studied, namely, the Functional Occlusal Reference System (FORS) and the Cranial Base Reference System (CBRS). The discussion will include: (1) evaluation of method and location of reference systems, (2) interpretation of growth changes from serial data, and (3) its clinical application in orthodontics.

Evaluation of Reference Systems

As reported in the Findings and illustrated in Figure 1, the FORS was oriented on the basis of the functional relationship of upper and lower jaws. Similarity of findings, revealed from testing four occlusally orientated methods, definitely suggests the reliability and stability in this area. Cranial base orientation also suggests these attributes, as evidenced by similar findings reported here and in the literature.

When examining the growth changes illustrated in Figure 4 by cephalometric landmarks, the FORS is seen to be located at the resultant growth interface of upper and lower jaws. Note the growth changes represented by the cephalometric landmarks relative to the X and Y axes. This reference system tends to minimize the effect of cumulative addition of the intervening growth sites within the maxilla and mandible.

In Figure 6 the location of the CBRS is outside the jaws and dental region and therefore the growth variables represented by the cephalometric landmarks in these areas are magnified by the effect of cumulative addition. One may compare the magnitude of change indicated at $\underline{e}$, $\bar{e}$, Sp, Me, Pog, B, Ii and Is in Figures 4 and 6.

Location of a reference system is then of primary importance to understand growth changes. Stability, on the other hand, is of secondary importance here, since both are of relative equal stability.

Interpretation of Growth Changes

The basis of interpreting growth changes rests on our present knowledge of the face. The growth changes observed in the upper and lower jaws of the face can be more easily interpreted from the FORS. Note the landmarks representing the growth changes in the mandible and maxilla in Figure 4. Total growth changes of rate, direction, and magnitude of change can be observed. In the mandible (1) the points representing the symphyseal area (B, Pog, Me, and Sp) are changing proportionately with respect to one another, (2) the ramus area (Rao and Rop) demonstrates anterior resorption and posterior deposition with the latter having a greater magnitude of change, (3) the condyle (C) has the greatest magnitude of change in an upward and backward direction, while the sigmoid notch (Sn) and coronoid process (CP) show related proportional changes. The dentition is recorded by $\underline{e}$, $\bar{e}$, Is and Ii. Note the mesial shift of the molar teeth and the recorded eruption of the incisors. In the maxilla (1) PNS demonstrates the greatest magnitude of change while Ptm is related proportionately, (2) ANS and A show related proportional change.

The above recorded changes are not in perfect agreement with experimental facial biology but their interpretation is easier and more consistent than observed from the CBRS.

Now, compare the growth changes in the dentition, maxilla and mandible recorded by the CBRS. The growth changes observed here are difficult to interpret from our present knowledge. The reason for not easily understanding these growth changes should now be quite clear. That is, the cumulative addition effect, as described earlier, is magnified by the location of the CBRS and therefore obscures its interpretation.

Clinical Application

The orthodontist needs to understand the growth of the face relative to the occlusion. The clinical examination of the patient, as well as plaster models, is focused at the occlusal area. And yet, the majority of diagnostic and treatment analyses using cephalometrics are derived from the cranial base. Therefore, because of its location, and not its stability, the growth of the teeth and jaws is difficult to interpret from CBRS.

However, the FORS should provide a more useful method of interpreting growth changes as well as treatment diagnosis and evaluation of the teeth and jaws.

Summary and Conclusions

The purpose of this investigation was to develop and test a new cephalometric reference system related to the occlusion of the teeth and to apply it on serial facial-growth data. For better understanding and historical reasons, a cranial base reference system was also used for comparison.

A sample of twenty individuals having serial cephalometric records of normal skeletal type was selected. The findings of this investigation were evaluated by visual inspection and interpretation.

The following conclusions were observable:

1. The described Functional Occlusal Reference System offered significant clarity in interpreting growth changes in the developing dentition, maxilla and mandible.

2. The Functional Occlusal Reference System demonstrated the growth of the individual bones of the craniofacial complex in relation to the developing dentition.

3. The Functional Occlusal Reference System may be a useful and meaningful method to analyze longitudinal growth changes of the maxillomandibular complex.

4. A better understanding of facial growth was possible when *both* the Functional Occlusal Reference System and the Cranial Base Reference System were utilized.

5. The value of each reference system was directly related to its location within the growing craniofacial complex. The measure of its value was based on the degree of clarity revealed in facilitating the interpretation of growth changes of several cephalometric landmarks.

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