A Comparative Study Of Cephalometric Superimposition

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INTRODUCTION

Little research is evident in the field of cephalometric superimposition. Perhaps the reason for this is due to the difficulty involved in objectively interpreting and comparing the various methods of orientation. Attempts to appraise one method to another have resulted in subjective conclusions[1,2,3] as no cranial area or landmark, necessary as a reference point, appears to remain constant in size and position during growth. Since most presently - used methods of orientation are of untested reliability, it seems that any results of studies dependent upon these methods are of questionable significance.

Broadbent[4,5] was probably the first to recognize the problems of interpreting cephalometric radiographs on a longitudinal basis. He noticed that the cranial base showed a relatively small amount of size increase with growth and, therefore, used this as a basis for orientation on registration point.

McDowell,[1] in evaluating different methods of orientation, thought that the most desirable method was that of using successive calvarial outlines as a means of reference. He employed lambda, bregma, and Bolton points to control the rotation of these outlines. McDowell felt that this method was superior to other methods because several reference points were used to orient the outlines. Since approximately 90% of calvarial growth is completed by six years of age, this method afforded a large minimal growing area as a reference base.

Brodie[6,7] made use of the sella to nasion line registered on sella as a method of orientation because it served as a division between the cranial vault and face, and provided a stable reference base against which sutural facial growth could take place. The use of sella turcica and nasion as reliable fixed reference points, however, has been criticized in recent studies. Baume[8] said that sella could not be considered a reliable reference point since its position is dependent on the active growth of the cranial base (spheno-occipital synchondrosis) and the investing pituitary gland. By using dried skull material, Scott[9] found that there was a superior migration of the landmark, nasion. The anterosuperior direction of the suture, as viewed from a sagittal section, tends to support this finding. Moore,[10] by using the vital staining technique on macaque monkeys, found the presence of stain on the nasal surface of the nasofrontal suture and interpreted it as growth in this particular area.

Another reference line, the cribriform plane, was introduced as a superior method of superimposition by De Coster.[11] This line is made up of the jugum sphenoidale, the cribriform plate, and the internal plate of the frontal bone and is credited to be of constant shape after seven years of age. Ford[12] substantiated this constancy on dried skull material.

The fact, however, that a particular area is unaltered in shape during growth does not totally substantiate its usefulness in superimpositioning. Any

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alteration in position of an area, whether stability of shape is a characteristic or not, will reduce its accuracy in orientation. A strong possibility exists that a displacement of De Coster's cribriform plane may be the result of normal growth of the spheno-occipital synchondrosis.

Therefore, it is the purpose of this investigation to develop a method of superimposition which may be more accurately adapted to longitudinal cephalometric research. It will then be compared statistically to other presently-used methods to ascertain its relative accuracy.

Material

The lateral cephalometric radiographs used in this study were obtained from the records of the Bolton Study of the Development of the Face of the Growing Child, Department of Anatomy, School of Medicine, Western Reserve University, Cleveland, Ohio, through the courtesy of its director, Dr. B. Holly Broadbent. Tracings of longitudinal radiographs were made from forty subjects, twenty white females and twenty white males. The age distribution of this sample appears in Fig. 1.

The cases were selected on the basis of the following criteria:

1. Non-orthodontically treated.
2. No serious diseases which could affect growth.
3. No operations on the facial area with the exception of tonsil and adenoidectomies.
4. No fractures of the skull or other areas of the head.
5. All anterior permanent teeth present.
6. Natural posterior occlusion present.
7. No clefts of the lips or palate (soft or hard).
8. Clarity of radiographs.

Details concerning the sampling of the individuals of the Bolton Study are discussed by Simmons and Todd.[13] In general, they stated that the sample was primarily of North European ancestry, while willingness on the part of the parents to allow their children to take part in the study was the greatest criterion of selection.

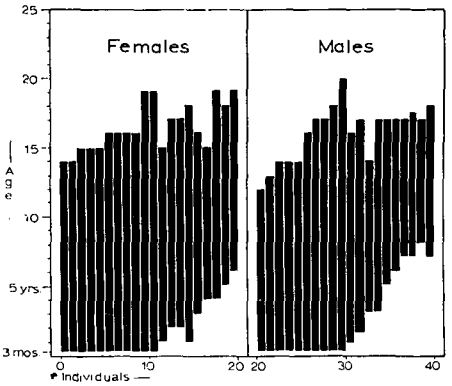

Fig. 1 Age distribution of sample.

Method

Lateral cephalometric radiographs were traced to include the structures indicated in Fig. 5. Each of the forty series of tracings was oriented according to the following technique. Each calvarial outline was centered so that an equivalent amount of growth enlargement could be seen anteriorly, superiorly, and posteriorly between each preceding tracing. The bony landmarks, nasion and anterior nasal spine, were maintained on absolute straight lines throughout each longitudinal series as each calvarial outline was centered concentrically around the previous tracing. The above orientation has been termed the intersection point method of superimposition (Fig. 7).

The two angles, nasion-intersection point-anterior nasal spine and intersection point-nasion-anterior nasal spine (Fig. 7) were measured for each orientation and repeated to obtain three trials for each of the forty series. Aver-

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ages for each pair of angles for every individual of the entire sample were then used to permanently superimpose each series.

All angular measurements were read to the closest 0.5 degree, while the linear measurements were read to the closest 0.5 millimeter. Correctional scales for enlargement compensation, based on the midsagittal plane to film distance, were applied to all linear measurements to the accuracy of 0.25 millimeter.

In order to ascertain whether proportionality of growth movement of maxillary landmarks existed, the statistical analysis of variance[14,15] was applied to linear measurements of nasion and anterior nasal spine.

The reliability of the yearly measurements over that of an inclusive measurement for the whole age range of each individual in this study was established by statistical means. The coefficient of reliability between the individual annual measurements and one inclusive measurement was significant at the 1% level of confidence ($r=0.983$)*.

It was observed that during growth there was a tendency for the posterior extensions of incremental growth lines of maxillary landmarks to intersect at a common point. This tendency provided a basis of comparing other orientation methods with the method used in this study. The point of intersection of posterior extensions of the incremental growth lines of nasion and anterior nasal spine was located for the intersection point method of superimposition. It was also located similarly for the sella-nasion registered on sella method and the registration point method. For the latter two methods of superimposition, the earliest (not under two years of age) and latest tracings of each series were used to locate the necessary landmarks**. The age of each of these tracings varied between individuals, but not between the three techniques.

Since the location of the intersection of nasion and anterior nasal spine incremental lines is part of the intersection point method of orientation, it was not necessary to relocate it. The three intersection points were designated as I for the intersection point method, I (SN) for the sella-nasion registered on sella method, and I (R) for the registration point method.

The analysis of variance was used to determine differences between the three superimposition techniques. This analysis was calculated from the measurements of the proximity of extensions of incremental landmark lines to this intersection point. Three additional upper facial landmarks (rhinion, pronasale soft tissue, and point A) were located for each individual from the earliest and latest tracings, as before. Straight lines connecting the two points of each landmark were extended posteriorly (Fig. 2). The closest distance that each line came to the intersection point for each method of superimposition was measured. The results of the analysis of variance and tests of designed comparisons[14,15] appear in Table I.

Most landmarks, reference points, and lines used in this study are midline structures and are defined in terms of norma lateralis in the cephalometric radiographic film. Anterior nasal spine, ANS, posterior nasal spine, PNS, nasion, N, sella, S, Bolton point, Bo, and palatal line, ANS-PNS are familiar points and lines.

*The confidence level of "P" (probability) is less than 1%.

**Following two years of age, most of the subjects of the Bolton Study were fixed in the cephalostat in the routine manner. Prior to two years of age, however, the individuals were usually fixed in a reclining position. Therefore, this potential variation was eliminated.

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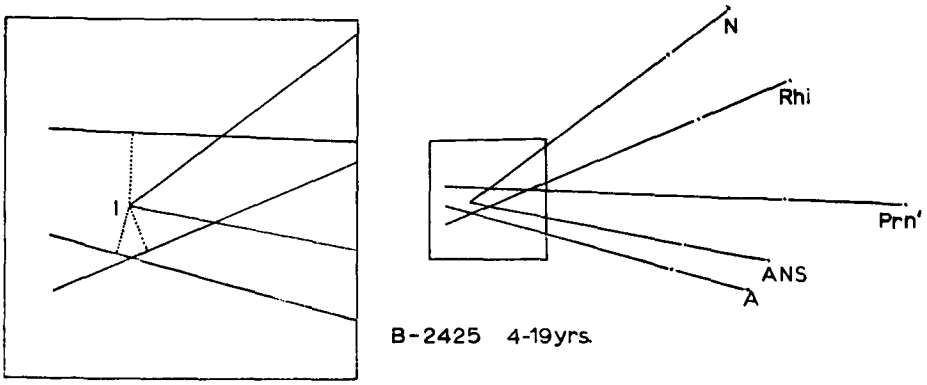

Fig. 2 Technique of obtaining measurements representing the proximity of extensions of incremental landmark lines to the intersection point, I. Left, Enlargement of measured distances from pronasale soft tissue (Prn'), rhinion (Rhi), and point A (A) to intersection point (I). Right, Straight lines connecting earliest and latest landmarks with posterior extensions. The intersection of extensions of nasion (N) and anterior nasal spine (ANS) demarcates the intersection point (I).

Other points and lines are:

Intersection point, I. The intersection of the posterior extensions of the incremental growth paths of landmarks nasion and anterior nasal spine when they are maintained on straight lines, as the calvarial outlines are concentrically centered upon one another.

Intersection point by sella-nasion method, I(S-N). The intersection of the posterior extensions of the lines joining the earliest (not under two years of age) and latest landmarks of nasion and anterior nasal spine in a series superimposed on sella-nasion registered on sella method.

Intersection point by registration method, I(R). The intersection of the posterior extensions of the same lines in a series superimposed on registration point method.

Rhinion, Rhi. The most inferior point on the internasal suture.

Pronasale soft tissue, Prn'. The most anterior tip of the nose as defined by a tangent, which is perpendicular to the palatal line (ANS-PNS).

Point A. The most posterior point on the inner curvature of the maxillary alveolar process. When a tangent is drawn perpendicular to the palatal line (ANS-PNS) to contact the most posterior point on the inner curvature of the maxillary alveolar process, this point delineates Point A.

Calvarial outline. The midline outline of the external surface of the frontal, parietal, and occipital bones.

Incremental growth line. A straight line joining a longitudinal series of points representing the same landmark as it progresses during growth.

Discussion and Findings

The Problems Involved in Superimposition.

There are two general purposes of superimposing tracings of lateral radiographic cephalograms. One is for analyzing local changes within a very limited area. The other is for analyzing more generalized regions or relations between different areas. Both purposes have one common problem in that it is difficult to locate any particular point or area that is without modification in shape due to growth and development.

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In the generalized type of orientation, where large areas are of concern, another problem is evident. This is one of shifting relations between different regions. For ideal generalized superimpositioning, it is necessary to locate a reference point void of changes not only in shape, but also in position, during all stages of growth and development. For example, the crowns of teeth are essentially void of changes in shape, but not of position, during the growth process. It would, therefore, be inaccurate to orient cephalometric tracings on the successive outlines of one central incisor and proceed to describe the progress of growth of other areas on this basis.

The fact that different areas grow at different rates, which are not proportional, indicates that a perfectly accurate method of orientation will never be found which satisfies all areas at all stages of growth. Many investigators have found that the cranial vault is more rapid in growth than the face at early ages. Incremental growth graphs and statistical findings show that the rates vary and that they are not proportional.[16] Preceding two years of age, the cranial vault increases in size at a more rapid rate than the facial structures, while, at a later stage, the situation is reversed. The shifting rates of growth between the two areas would produce error in one, if the other were used as a basis of orientation. Therefore, when the cranial vault is of primary interest, an orientation technique within this area is indicated. However, if the primary concern is within the facial area, an orientation, which utilizes the cranial vault, introduces error into any findings resulting from this method.

The problem in superimposition is to find a center or axis of movement from which all growing areas are radiating or moving. If certain areas, such as the cranial base, remain unaltered in shape during growth, they are not necessarily well adapted to orientation. The possibility exists that entire areas may be shifting due to the growth of another region. Since no perfect technique of superimposition can satisfy all areas, the best method would be one which would most ideally orient certain cranial regions of primary interest.

The accuracy of orientation, according to the sella-nasion method (with sella registered), seems questionable in that sella is part of a rapidly growing region. For sella to remain in a stable position while the growth at the sphenoccipital synchondrosis is dissipated in a downward and backward direction is unlikely. The possibility of nasion moving along a straight line arbitrarily drawn from sella to nasion is also unlikely.

Tracings of calvarial and facial outlines in a longitudinal series can be superimposed without having these outlines intersect. Therefore, it is suspected that errors exist when such intersections occur in some of the common methods of superimposition (Figs. 4, 5, and 6). A method of orientation is needed which eliminates intersections of calvarial and facial outlines of progressive tracings. It should also minimize error by satisfying the superimposition requirements of different areas or of any particular area.

The Hypothesis of Straight Line Landmark Movement During Growth.

Brodie[6] observed that individual landmarks tended to progress on relatively straight lines in serial cephalometry. The implication of this statement is that growth or movement of different landmarks occurs proportionally, but not necessarily at the same rate or in the same direction. In order to have two or more landmarks progress on straight lines, the growth rates must be proportional so that fluctua-

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tions in one will produce proportional fluctuations in the other landmarks. It is evident that similar factors must be operating to produce this proportionality, otherwise, curved lines of landmark progression would result.

The intersection point method of orientation is partially dependent on the principle that certain landmarks progress on straight lines during growth. To statistically analyze the validity of this principle, the analysis of variance was used. This analysis was applied to show the interaction between the landmarks and the incremental movement during specific intervals of time. This interaction between the landmarks nasion and anterior nasal spine and the millimetric increments measuring the movement of landmarks during a definite time interval, when insignificant ("F" ratio less than 1.0), would support the hypothesis that different landmarks grow proportionally.

The results indicated that landmarks do not grow proportionally when measured at yearly intervals. This evidence would indicate that straight line progression of facial landmarks is doubtful. However, when two-year increments were used, the landmarks nasion and anterior nasal spine showed proportional movement, evidenced by insignificant "F" ratios (0.841, 0.173, and 0.466) of interactions between the landmarks and increments in three age groups (2-10 years in 17 cases; 6-16 years in 19 cases; and 10-16 years in 11 cases).* The differences in the results between annual and two year increments could be due to a one year growth lag of one landmark over another, to slight rotations of the series during orientation, or to the inherent error below the limits of measuring accuracy.

Statistical Comparisons of the Three Methods of Superimposition.

The tendency for incremental paths of maxillary landmarks to radiate from a common center indicates that a center of growth movement might exist for the maxillary area. When such a center of growth movement is used as a means of orientation (e.g. intersection point method) certain desirable results seem to be produced. In this technique a greater tendency for facial landmarks to progress on symmetrically radiating lines over that of other techniques was noted. There also seemed to be fewer areas of cranial outline intersections,

*Additional statistical data is available at the Northwestern University Dental School Library, Chicago, Illinois.

TABLE I

SUMMARY OF ANALYSIS OF VARIANCE OF THREE METHODS OF SUPERIMPOSITION

SOURCE	DEGREE OF FREEDOM	MEAN SQUARE	"F" RATIO	DIVISOR
Methods†	2	67.1543	20.470**	M/SM††
Sella-nasion x registration pt.	1	0.2638	0.080	S-NxR/SM
Intersection pt. x sella-nasion & registration pt.	1	134.0449	40.858**	IxS-N&R/SM

†Sella-nasion x registration pt. x intersection pt.

††Divisor (SM) represents Subjects x Methods.

**The confidence level of "P" (probability) is less than ½%.

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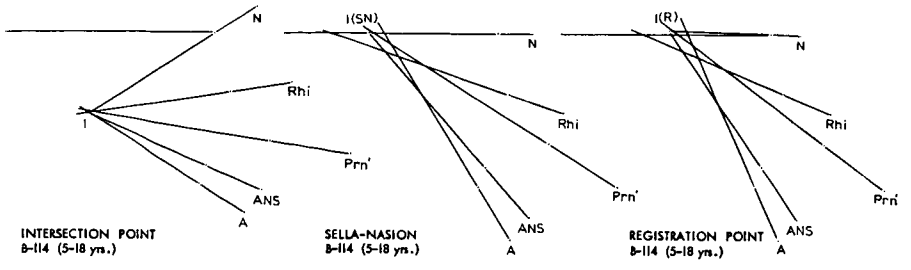
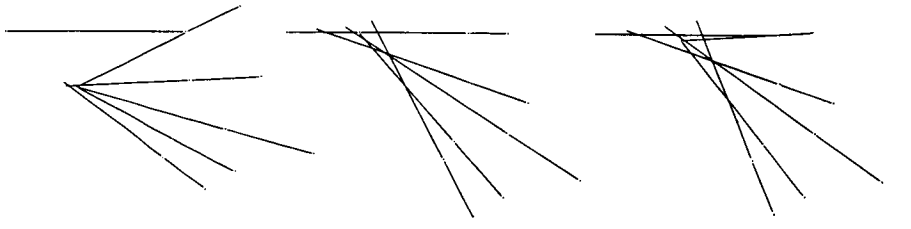
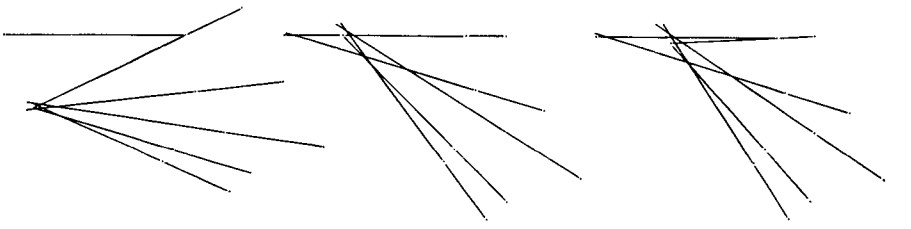


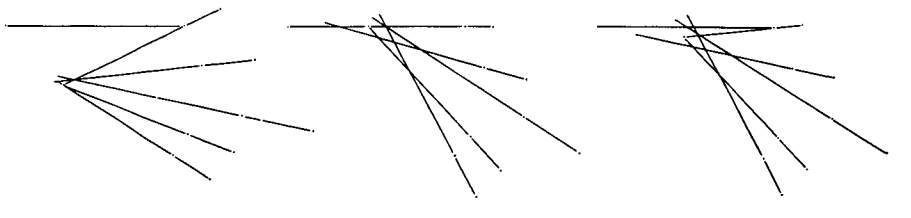
INTERSECTION POINT B-114 (5-18 yrs.) | SELLA-NASION B-114 (5-18 yrs.) | REGISTRATION POINT B-114 (5-18 yrs.)



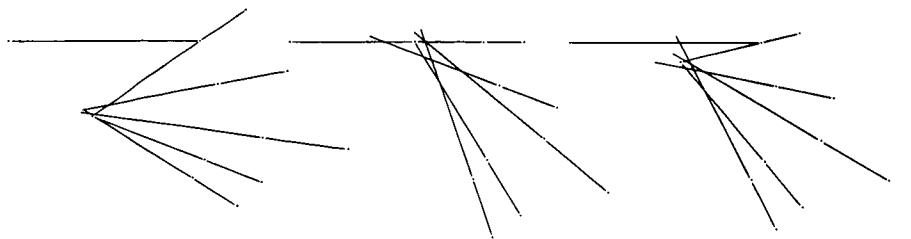
INTERSECTION POINT B-1921 (2-16 yrs.) | SELLA-NASION B-1921 (2-16 yrs.) | REGISTRATION POINT B-1921 (2-16 yrs.)



INTERSECTION POINT B-1908 (2-17 yrs.) | SELLA-NASION B-1908 (2-17 yrs.) | REGISTRATION POINT B-1908 (2-17 yrs.)



INTERSECTION POINT B-1156 (5-18 yrs.) | SELLA-NASION B-1156 (5-18 yrs) | REGISTRATION POINT B-1156 (5-18 yrs.)



INTERSECTION POINT B-3047 (3-19 yrs.) | SELLA-NASION B-3047 (3-19 yrs.) | REGISTRATION POINT B-3047 (3-19 yrs.)

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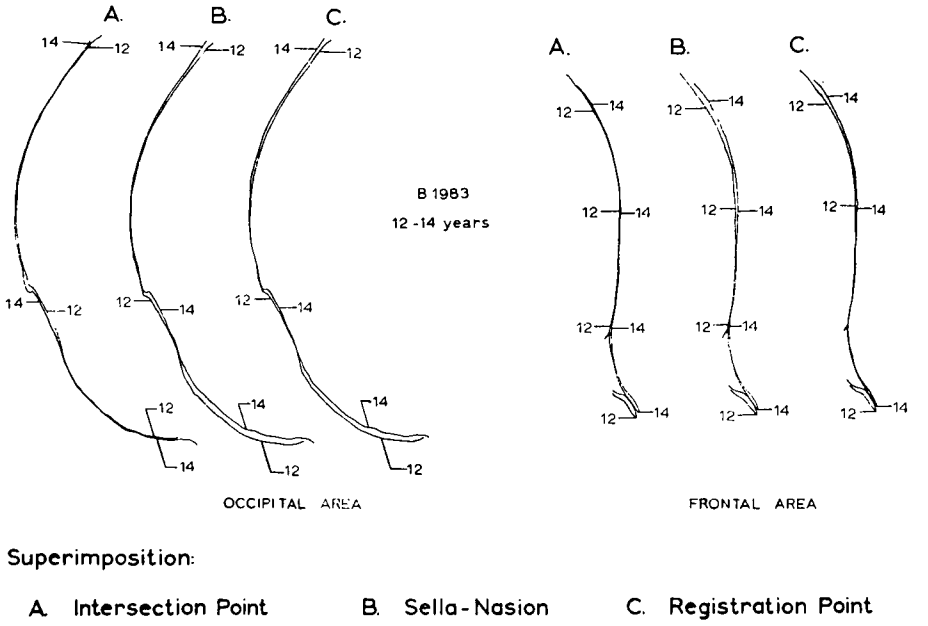

Fig. 4 Illustration of typical calvarial outline intersections. A, represents superimposition by the intersection point method showing lack of intersections. B, represents superimposition by the sella-nasion registered on sella method showing occipital intersections. C, represents superimposition by the registration point method showing occipital intersections.

particularly in the nasal and occipital areas.

The ability of facial landmarks to move symmetrically from one another during growth enabled a statistical comparison to be made between different methods of orientation. The posterior extensions of incremental lines representing the landmarks, rhinion, pronasale soft tissue, and point A facilitated the measuring of skewness about a common intersection point created by nasion and anterior nasal spine.

There is a significant difference (Table I) at the 0.5% level of confidence between all three methods of superimposition ("F" ratio=20.470**). When the sella-nasion and registration point methods were statistically compared (Table I), an insignificant difference resulted ("F" ratio=0.080). However, when the intersection point method was compared to the other two methods (sella-nasion and registration point) combined, a significant difference at the 0.5% level of confidence ("F" ratio = 40.858**) resulted. Statistical evidence, therefore, indicates that the intersection point method of orientation enables landmarks of the maxillary area to move apart from one

**The confidence level of "P" (probability) is less than ½%.

Fig. 3 Illustration of differences in proximity of posterior extensions of landmarks rhinion (Rhi), pronasale soft tissue (Prn'), and point A (A) to intersection point (I), formed by extensions of nasion (N) and anterior nasal spine (ANS) landmarks. Left, represents intersection point method of superimposition. Center, represents sella-nasion registered on sella method of superimposition. Right, represents registration point method of superimposition.

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another more proportionately than in the other methods tested. Also, the posterior extensions of the upper facial area landmarks in the intersection point method of superimposition intersect more readily at a common point or center of movement (Fig. 3).

Generally, in any orientation method, fewer intersections of outlines occur as the growth between calvarial tracings increases. It is, therefore, relatively easy to obtain techniques of superimposition that do not produce intersecting outlines during early ages. The intersection point method of orientation, however, becomes more accurate as the rate of growth of the cranial vault decreases, which minimizes the space between successive tracings of calvarial outlines. Since the whole series can be rotated to the extent of these spaces, the correct position of orientation would be present within this leeway space.

Intersections of any calvarial or facial outlines were rarely seen when the intersection point method of orientation was used. Figure 4 illustrates the tendency for the sella-nasion and registration point methods of superimposition to have intersections of cranial outlines in the occipital area. This is particularly apparent at ages when the cranial vault is close to completion of its growth. These intersections are probably due to a clockwise rotation of the serial orientations. There is a possibility that the natural growth directions of nasion and sella are being restrained by the sella-nasion and registration point methods of orientation, which would create this rotation. This rotation also produces intersections of the external nasal and lip outlines (Figs. 5 and 6). The intersection point method of orientation (Fig. 7) illustrates the anterosuperior growth of nasion, which allows the nose to move predominantly forward. The questionable intersections in the nasal, lip, and occipital areas are thereby eliminated.

Growth Findings Characteristic of the Intersection Point Method.

Without exception, nasion migrated in an anterosuperior direction from the original sella-nasion line. Nasion also had greater linear movement than sella in all forty individuals of the sample. In only one case did sella move posterosuperiorly from the original sella-nasion line, while, in the remaining cases, the movement was anterosuperior in direction. In general (37 of the 40 cases), the direction of movement of sella was more vertical than that of nasion. Of the remaining three cases, one had the same vertical angulation for both landmarks and, in the other two cases, sella had less vertical angulation than nasion. Due to the greater linear movement of nasion, the angular comparison of the earliest to latest sella-nasion lines exhibited an opening of the angle in the anterior direction. The above findings which concern the behavior of sella and nasion, although dependent on the method of orientation, are in agreement with the findings of Baume,[8] Scott,[9] and Moore.[10]

In 90% of the sample (36 of 40 individuals), the palatal line, during growth, descended at the posterior nasal spine more rapidly than at the anterior nasal spine. Only 2.5% of the individuals exhibited a parallel descent of the palate (palatal line). These findings are in contrast to those of Brodie's,[7] which were based on a sample of 19 individuals using the sella-nasion method of orientation. In his study, 52.6% of the sample showed a parallel descent of the palate; 42.1% descended at a greater rate in the anterior region of the palatal line, while 5.3% descended at a greater rate in the region of the posterior nasal spine.

The present study (40 individuals)

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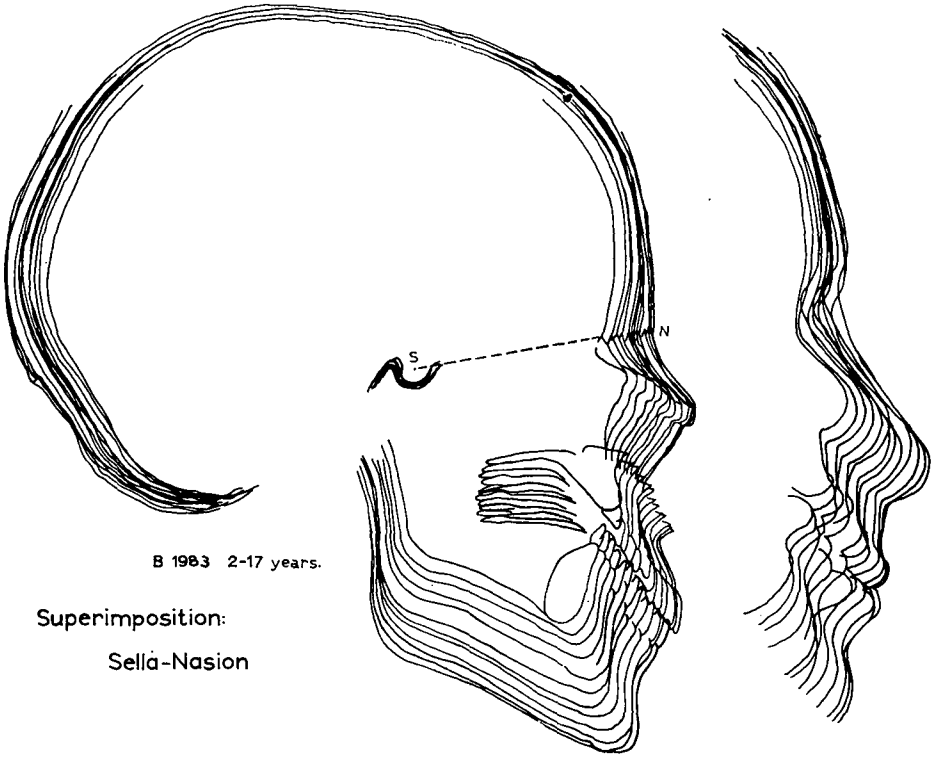

Fig. 5 Serial orientation of an individual by the sella-nasion registered on sella method of superimposition. Note the external nasal and lip outline intersections.

was oriented on the sella-nasion line as a means of comparison to Brodie's study. The following differences resulted. Ten per cent of the cases in the author's sample descended in a parallel manner; 50% had more descent in the anterior region, and 40% had a greater descent in the posterior region of the palatal line. Therefore, the present study indicates that, regardless of the method of superimposition, the palate descends, during growth, at a greater rate in the area of the posterior nasal spine than has been previously believed. This finding is particularly evident (90% of individuals) when cases are oriented according to the intersection point method.

In the intersection point method of superimposition, sella, irrespective of the position of the intersection point (I), moved anterosuperiorly in a somewhat parallel fashion to the long axis of the posterior cranial base. This finding is consistent with presently accepted theories concerning the direction of growth of the spheno-occipital synchondrosis and its influence on the anterosuperior migration of the basisphenoid, including the structure of sella turcica.

The comparative movements of facial landmarks between the three methods of superimposition are illustrated in Figure 8. All facial landmarks, when oriented by the sella-nasion and registration point methods, were rotated in an inferior (clockwise) direction from the same landmarks when oriented by the intersection point method. In comparing the landmark behavior of the

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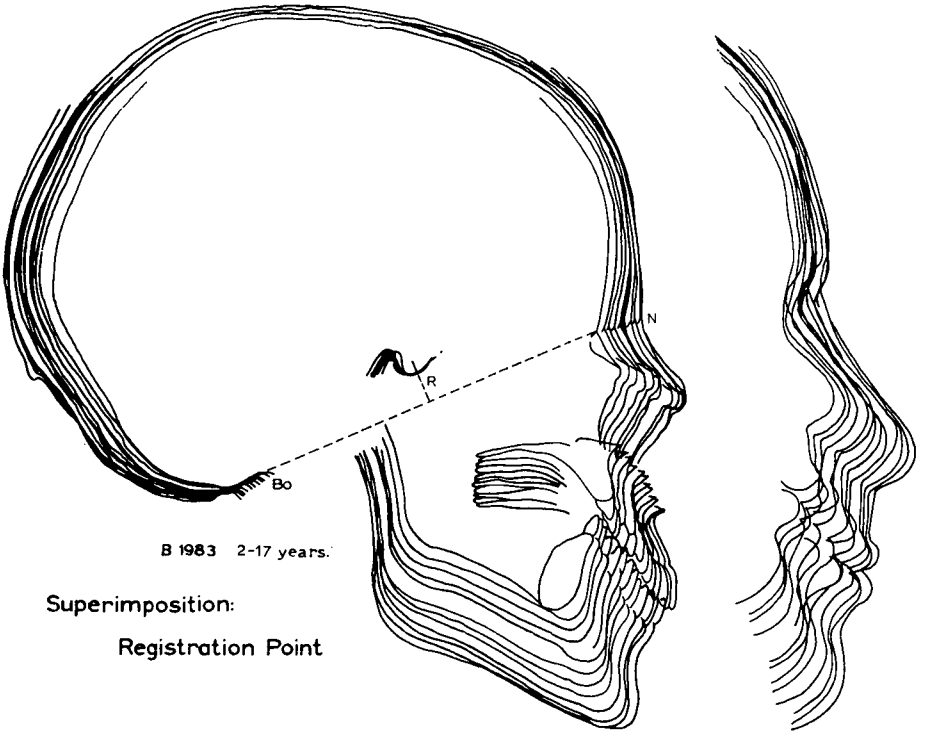

Fig. 6 Serial orientation of an individual by the registration point method of superimposition. Note the external nasal and lip outline intersections.

TABLE II

THE DIRECTIONAL BEHAVIOR OF LANDMARKS NASION (N) AND ANTERIOR NASAL SPINE (ANS) ORIENTED ON SELLA-NASION COMPARED TO THE SAME LANDMARKS OF THE REGISTRATION POINT METHOD

	Inferior to N (of reg. pt.)	Superior to N (of reg. pt.)	Same as N (of reg. pt.)	Size of Sample
N (of sella-nasion)	29 (72.5%)	7 (17.5%)	4 (10 %)	40
	Inferior to ANS (of reg. pt.)	Superior to ANS (of reg. pt.)	Same as ANS (of reg. pt.)	Size of Sample
ANS (of sella-nasion)	14 (35 %)	21 (52.5%)	5 (12.5%)	40
	Inf. to N & ANS (of reg. pt.)	Sup. to N & ANS (of reg. pt.)	Inf. to N Sup. to ANS (of reg. pt.)	Inf. to N Same as ANS (of reg. pt.)	Same as N Sup. to ANS (of reg. pt.)
N & ANS (of sella-nasion	14 (35 %)	7 (17.5%)	10 (25 %)	5 (12.5%)	4 (10 %)

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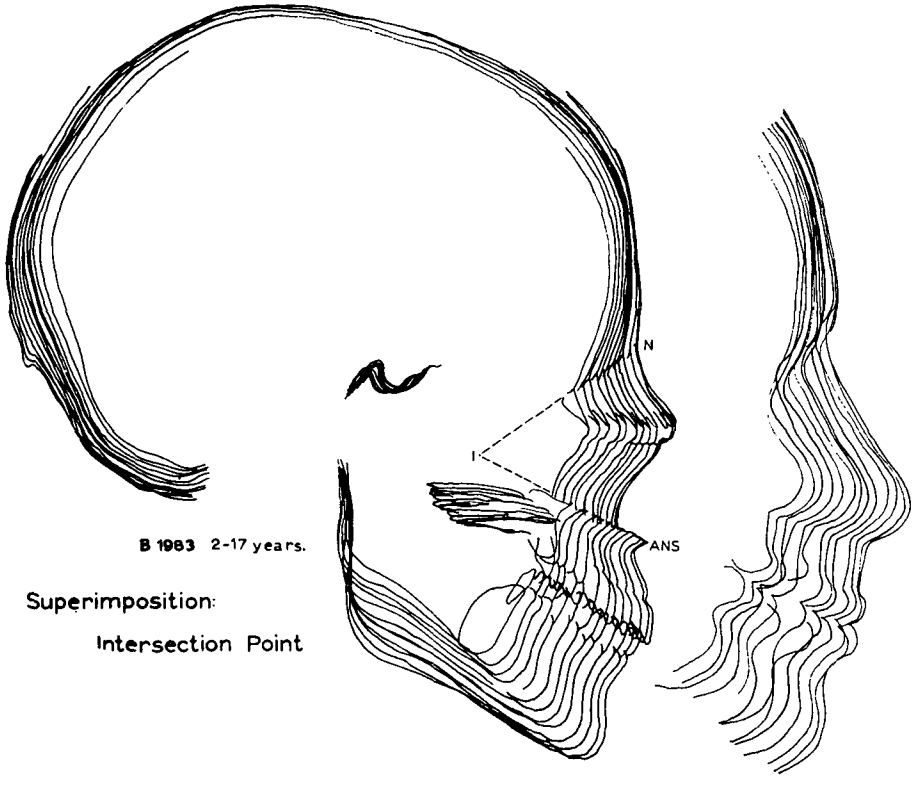

Fig. 7 Serial orientation of an individual by the intersection point method of superimposition. Note the lack of external nasal and lip outline intersections.

sella-nasion to the registration point methods (Table II), the landmarks of the sella-nasion technique were rotated clockwise in 35% of the cases and counterclockwise in 17.5% from those of the registration point technique. Of the remaining 47.5% of the sample, the displacement of landmarks in varying directions complicated the determination of rotations. From these findings, it is evident that, in the sella-nasion and registration point methods, there is no consistent relation of one orientation method to the other. The statistically insignificant differences between the two methods, previously discussed, substantiates this finding.

Summary and Conclusions

Few investigations have been devoted to cephalometric superimposition and these have generally been subjective in nature. Since a large portion of the results of research in growth and development has been based on particular methods of orientation, it is important that the reliability of these methods be established. The validity of some of the present methods of superimposition has been questioned by many investigators. It has been the purpose of this study to develop a method of orientation which might be more accurately adapted to longitudinal cephalometric research and to compare it statistically to other presently-used methods.

The headplates of forty individuals, whose ages ranged from three months to twenty years, were studied longitudinally. These records were obtained

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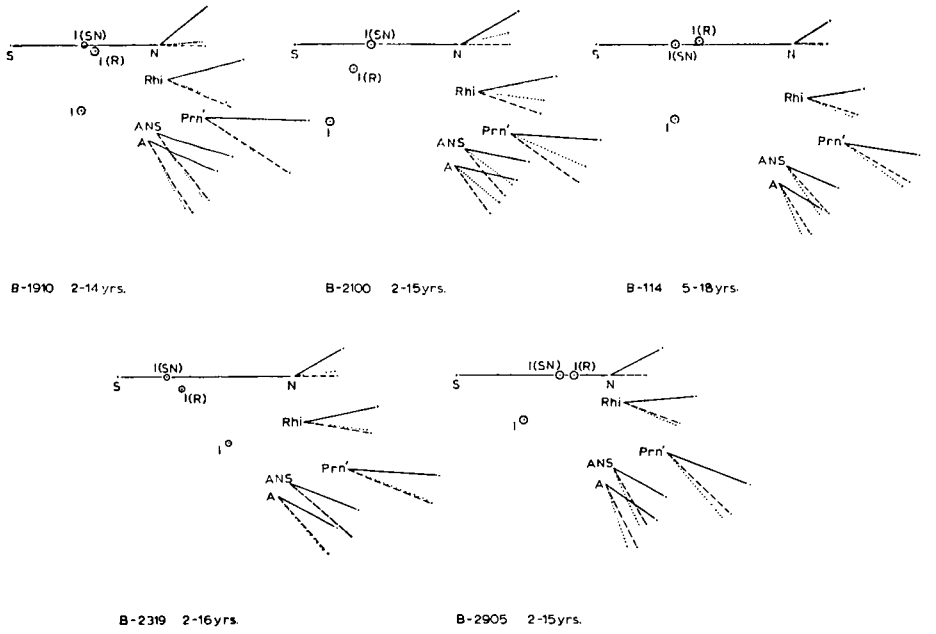

Fig. 8 Illustration comparing the difference in growth directions of facial landmarks by three methods of superimposition: Solid line, intersection point method; dash line, sella-nasion method; dotted line, registration point method.

from the Bolton Study through the courtesy of Dr. B. Holly Broadbent. The cephalometric tracings were serially oriented by maintaining the landmarks nasion and anterior nasal spine on straight lines while centering all calvarial outlines concentrically. This intersection point method of orientation was then compared statistically to the sella-nasion (registered on sella) and registration point methods of superimposition.

As a result of this investigation, the following conclusions can be made:

1. There is a significant difference (at the 0.5% level of confidence) between the intersection point, sella-nasion, and registration point methods of superimposition. There is, however, no significant difference between the sella-nasion and registration point methods, while there is a significant difference (at the 0.5% level of confidence) between the intersection point method and the latter two methods collectively.

2. Statistical evidence indicated that, during growth, facial landmarks emanate more accurately from a common center of movement and migrate apart from each other more proportionately in the intersection point method than in the other two methods.

3. There were very few cranial and facial intersections in the intersection point method of orientation. The other two techniques had many intersections, primarily in the occipital, nasal, and lip outline regions.

4. Nasion, in all forty individuals, oriented by the intersection point method possessed greater linear movement in an anterosuperior direction than did sella. Sella had a greater vertical angulation to the original sella-nasion line than did nasion in 92.5% of the individuals during growth. Sella also moved anterosuperiorly from the original sella-nasion line in all individuals except

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one, which moved posterosuperiorly.

5. Only 2.5% of the sample illustrated a parallel descent of the palatal line during growth, while 90% descended more at the posterior than at the anterior nasal spine. A greater anterior than posterior descent of the palatal line occurred in 7.5% of the cases.

6. In the sella-nasion and registration point methods of orientation, the directions of movement of all facial landmarks studied were more inferior to the directions present in the intersection point method of orientation.

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