New Perspectives on Orientation and Their Benefits to Clinical Orthodontics - Part I

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The Frankfort horizontal plane has been both accepted and condemned since 1897,[1] but it is like a friendly dog, it keeps coming back after a scolding to lick your hand.

To study changes in skull size early scholars in growth measured points in the face from the top of the external auditory meatus. Furthermore, the left side was selected for horizontal orientation, and the vertical for coordinates, if used, was erected through porion[2] (Fig. 1). To facilitate measurements from the Frankfort plane (FH) and overcome the irregularities of rounded surfaces of the skull for direct calculation, a craniostat was devised by Todd. Broadbent, working under his guidance, visualized the adaptation of the craniostat to the head X-ray so that serial or longitudinal series could be made available in the living, growing child (Fig. 2). Thus was born roentgenographic cephalometry.

Simon[3] had earlier utilized a perpendicular from orbitale in gnathostatic orientation and employed the erected orbital plane as a diagnostic guide. As the upper canine lay forward or backward of this line, a malocclusion characteristic was assessed. This vertical line was included in Broadbent's early work as well as a vertical through the pterygomaxillary fissure.[4]

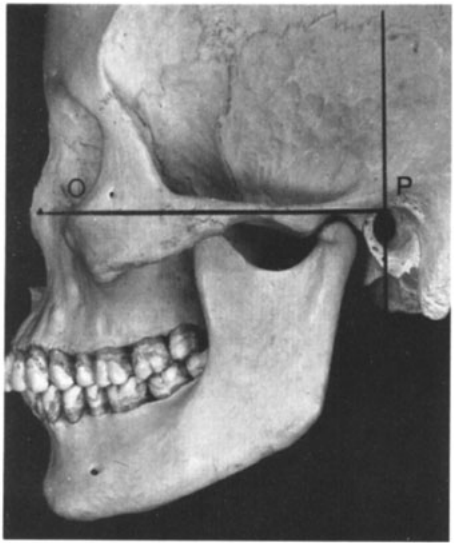

Fig. 1 The left side of the skull with a line from porion to orbitale bisecting the zygomatic arch. Note the bony outline of the external auditory canal and the anatomy in that area with the slight groove behind the tympanic plate marking its separation from the mastoid process. Also note the start of the styloid process immediately anterior to the tympanic plate. Early investigators dropped a perpendicular through porion for measurements and references. Note the outline of the condyle and the glenoid fossa which shows that the top of the condyle is very near the Frankfort plane. In skulls the left side is placed next to the film for measurement which means that the profile is to the right.

Other explorations had been made, however, in the comparison of dried skulls. Midsagittal landmarks had been established to orient the jaws and cranium. One such guide was the basicranial axis of Huxley. This line was extended from basion, at the anterior border of foramen magnum, to areas in the anterior cranial base (Fig. 2). With the visualization of skulls in the headplate in a sagittal orientation it was natural to attempt to reduce orientation to central anatomy. Thus, sella turcica came to be employed. Broadbent found difficulty in perceiving basion, due to the design of the headholding apparatus, as well as confusion with the superpositioning of basion over the tympanic ring in very young skulls. He therefore employed the Bolton point at the recess behind the

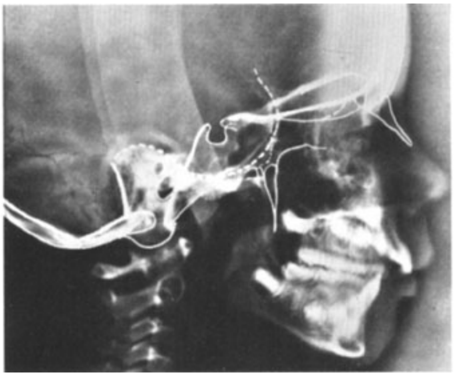

Fig. 2 Tracing of a 7-year old female with a Class II open bite malocclusion. The three cranial fossae will be noted. The anterior cranial fossa is seen to lie between the two orbits, and the heavy crest is usually the medial crest of the orbital cavity. The thinner line at the midline is the position of the cribriform plates and the crista galli is seen to lie directly behind the radiolucent area which is the foramen secum. Notice the dotted outline of the middle cranial fossa extending from the great wings of the sphenoid back to the petrous portion of the temporal bone. The middle cranial fossa narrows down to the outline of the pituitary fossa. The posterior cranial fossa is seen from the clivus down to basion with the heavier portion for the occipital condyles and back thence to the occipital plate. The outline of the external and internal acoustic meatus is usually identified with the posterior cranial fossa since the internal acoustic meatus is inside of the great ridge or petrous portion of the temporal bone. The crest of the great wing of the sphenoid usually lies directly over the pterygopalatine fossa and serves to divide the anterior from the middle cranial fossa.

occipital condyles. A basicranial triangle was established for growth reference with a registration point located at the center of the triangle; this was the original cephalometric growth reference.

Brodie's work tended to establish parallelism of growth as orientation to the line SN and registration at sella (Fig. 3).[5] Björk[6] likewise found usefulness with this orientation, later adapted by Steiner.[7] Even more important, the *upper face* or nasal cavity tended to remain consistent in growth related to the anterior cranial base as the palatal plane tended to remain parallel to it. Also, the angle SNA stayed relatively constant as a guide for natural growth analysis. Later, Hitchcock[8] found a smaller deviation from SN than the Frankfort, but the ear rod had been used for his study and not the true external meatus. While Brodie used SN for serial work, other investigators tried to use it for description or classification of mandibular prognathism which Brodie never intended.

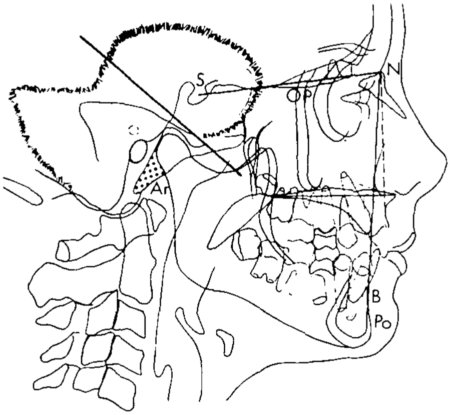

Fig. 3 The line SN is often used for facial typing and for growth analysis; point B is often used instead of pogonion for the position of the chin. The use of SN is further complicated, with the reference articulare employed to register condyle positions. The oblique line was drawn to separate sella from the joint area to depict the difference between the temporal bone and middle fossa from the anatomy of the anterior cranial base. One of the confusing problems in cephalometrics, particularly with prediction but also as description, has been the lack of connection and correlation of elements in the middle and posterior cranial fossae with the anterior cranial base, hence, the search for more useful planes.

Exception was taken to the use of nasion by researchers for three reasons. First, as a cranial point, due to its external location and its irregularity of change from internal cranial configuration, the frontonasal suture was con-

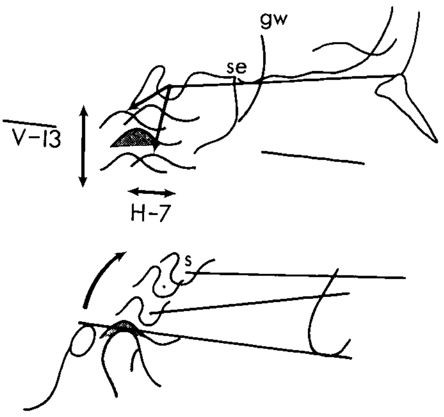

Fig. 4 Should be considered together with Figure 3. A comprehensive consideration is made with regard to the relative position of the glenoid fossa to sella. It will be noted that the variation in 40 subjects showed a total vertical variation of 13.0 mm while a variation of 7.0 mm was present in the horizontal relation. In the lower figure notice the extreme in variation of SN to the Frankfort plane.

sidered to be unstable in behavior. Because the neural cavity is completed in growth earlier than the face, the internal structure of the anterior cranial vault was therefore selected to replace nasion. But here a problem of interpretation was frequently encountered regarding the anatomy of the internal anterior base by those objecting to nasion. Many employed the outline of the internal crest of the orbital cavity as a midsagittal structure while erroneously referring to said structure as the ethmoidal cribriform plate.[9] The bottom of the olfactory bulbs and the cribriform plates are actually below the outline of the medial border of the orbit (Figs. 2, 3). Another suggestion was made for the junction of the small wings of the sphenoid with the ethmoid to be used for reference, but lack of identification of the sphenoethmoidal suture led to the use of the contour of the vertical portion of the great wing of the sphenoid (Fig. 4). In fact, superpositionings in the anterior base are frequently the anatomy of the orbital cavity at its medial border.

The second objection was perhaps of greater significance. This was the assumption that implicit with the use of SN (or any other anterior area alone) the temporal bone with the glenoid fossa was located backward and downward or grew that direction from the anterior base rather than the anterior base positioned away from the temporal complex (Figs. 2, 3, 4).

The third factor underlying the whole controversy is the lack of direct relation of the glenoid fossa to the SN line together with an absence of statistical correlation with the mandible. The clinical orthodontist and the student of morphology soon learn it is the chin on the mandible that dominates concern. Attempts to relate any part of the mandible to the anterior cranial base alone soon lead to bewildering confusion, particularly when correlations and predictions are attempted.[10] It has been shown statistically that any reference to the anterior cranial base alone is a weak method for facial typing or classification of prognathism of the chin, and this has, in turn, led to pessimism regarding prediction.

In essence, the steadfast acceptance of SN alone by clinicians and workers in facial growth is remarkable. Studies from SN are further complicated by the additional use of point articulare as a condylar reference.[11]

It is apparent that progress in communication or even credibility of the use of cephalometrics itself will not take place until the sufficient factors of facial morphology and growth can be better understood. The purpose of this presentation is, therefore, to describe recent scientific studies to help clarify cranial references as they apply to clinical usage and to show other emerging points of positioning adopted for computer methods.

USES AND REQUISITES OF PLANES OF ORIENTATION

There are two primary uses of the basic references. First is as methods for *description* and interpretation of craniofacial morphology. This leads to classification. Second is their application for superimposing to show *longitudinal* changes. A further distinction should be made regarding longitudinal change because the clinician has an interest both in short range change during treatment, and longer range methods from birth to maturity. While one superimposing method will suffice for one function, it may not serve well for another.

Three major important factors are involved in description and interpretation. The first factor involved is the establishment of basic coordinates so that data can be obtained and information easily compiled and used. Secondly, standard values or tables for biologic considerations such as age, sex, and ethnic type must be available. Thirdly, methods must be capable of correction by individualization so that analysis will apply to a personalized standard of size rather than to the total population.

Some major factors are involved in the objectives of longitudinal application of cephalometrics, particularly as it is employed for clinical use. The change should be a true change in the part studied rather than a change in the reference point itself. Any method should contain a central reference so that over-all facial growth behavior can be analyzed in addition to various local sites for analysis of parts. The method should be critical enough to differentiate treatment changes of the teeth from functional or growth changes. A superimposing method should be at such a location that three-dimensional changes can be evaluated from a single loci. Finally, longitudinal references should be made from biologically determined and functionally significant points of concern.

A COMPUTERIZED STUDY FOR TESTING OF METHODS OF ORIENTATION

Efforts to reach agreement on orientation among the scholars at a workshop in cephalometrics on a world scale proved to be unfruitful.[12] On that fact an extensive research was warranted. The hypothesis was made that if the older, established methods could be compared by a large computer study, conclusions might be drawn with regard to the most appropriate systematic analysis. Measurements were made on the frontal and lateral headplate tracings of 40 nontreated individuals at an average age of eight years and again at age thirteen years. Whenever feasible, a triangulation technique was employed to locate points by more than one measurement to improve reliability. Each of 362 measurements was analyzed for means, ranges, and standard deviations at the beginning and end for each subject during the study period. The change was calculated and reduced to yearly cyclic increments. The standard deviation of change or variation of behavior was derived. In addition, the coefficient of correlation was determined for each measurement compared with each other measurement, and the coefficient for the measured change compared each with the other. Finally, the triangulation on points permitted trustworthy composites to be made of each sample so that visualized changes could be analyzed together with the study of the statistical analyses.

The first section of that detailed study concerned the cranial base. Twenty different points were recorded. Measurements of the points and planes pertaining to the cranial base anatomy were analyzed. Facial structures were

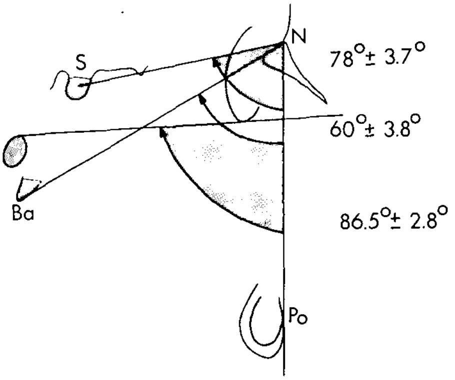

Fig. 5 At age 8 the mean angle SNPo is 78 degrees with a S.D. of 3.7. The mean from basion is 60 degrees ± 3.8. There is no significant difference, therefore, in the descriptive position of the chin from sella or basion. However, note that the angle from the Frankfort plane showed 86.5 with a deviation of 2.8. A significant difference in the spread around the Frankfort shows a higher degree of order and interpretation of the facial plane from Frankfort than in the SN or BaN planes.

studied in relation to morphologic location and change from different references throughout the cranial base.

FINDINGS

The statistical comparison of a few of the planes to conventional planes, commonly used clinically, showed that variation around the true FH made a tighter order of fit than did anterior cranial landmarks. The findings in part of that master study at age 8 are shown in Figure 5. The order of behavior in a later study of 50 cases followed from 6 to 15.5 years is shown together with the standard deviation of *change* for the Frankfort, SN and BaN planes in Table I.

In addition to the statistical data, a polar center phenomenon was located near the intersection of the FH-BaN planes and at the base of the pterygoid plates off the body of the sphenoid as Time 1 (age 8) and Time 2 (age 13) were studied. By taking the composites and superimposing them on a polar grid, the best order and best fit were discovered to be at the Frankfort plane centered at a vertical off the anterior border of the base of the pterygoid plates and the basion-nasion planes (Fig. 6). It will be noted in Figure 6 that the chin as well as other mandibular points stayed on a constant gradient and the teeth portrayed similar behavior.

DISCUSSION

The findings were utilized for determination of the most sensible and practical approach for clinical orthodontics, immediate and long range, both

TABLE I

LONGITUDINAL CHANGES FROM CRANIAL PLANES

Point	*Mean* x (Horiz.)	*Mean* y (Vertical)	*S.D.* x (Horiz.)	*S.D.* y (Vertical)
		FRANKFORT PLANE		
Po	1.59	—1.92	0.35	0.40
A	0.88	—0.95	0.20	0.22
Xi	—0.14	—1.34	0.26	0.26
		SN PLANE		
Po	—0.59	—2.48	0.55	0.47
A	0.60	—1.43	0.34	0.30
Xi	—0.47	—1.43	0.35	0.32
		BaN PLANE		
Po	0.05	—2.32	0.48	0.36
A	0.09	—1.25	0.25	0.24
Xi	—0.90	—0.80	0.27	0.24

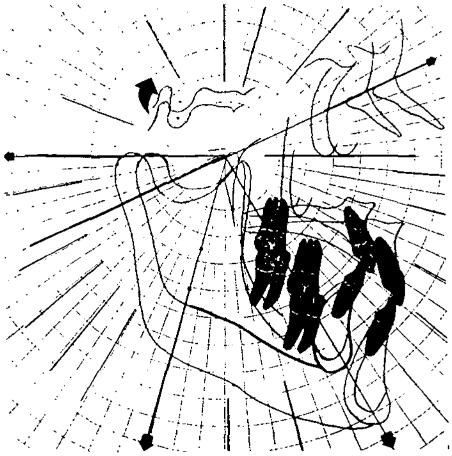

Fig. 6 A representation of growth on the polar grid. Note the farther outward the points are located from the center of the pole, the greater is dispersion as the elements in the face tend to hold their proportion.

for description and longitudinal comparison.

The whole issue is a square-off between SN and FH, with BaN on the sidelines. The Frankfort horizontal plane seemed to fit the total needs for description in a most satisfactory manner for a number of reasons. The use of Frankfort for a large part of cephalometric morphologic description can be argued strongly and the use of BaN for longitudinal use is of equal importance.

The orbit and ear tragus can be visualized clinically, and a horizontal from this plane is useful for visual orientation and clinical communication.

Both the external auditory canals and both orbits are visible in the lateral headplate (Figs. 7, 8).

The reference points for FH and BaN orientation are more distant from each other than SN which provides a wider margin in selection without significantly altering the interpretation (See also discussion on longitudinal rationale).

If the lateral is to be related to the

Fig. 7 Close examination at the area of the joint will show the distance that the ear rod was located from the true external auditory canal. Notice also the slightly darkened area above the external canal which is the internal acoustic meatus. Note further the area of the pterygomaxillary fissure and the pterygopalatine fossa. A small crest will be seen at the upward margin of the pterygopalatine fossa which is the outline of the maxillary nerve channel. Note the position of the coronoid process which is visible in these prints.

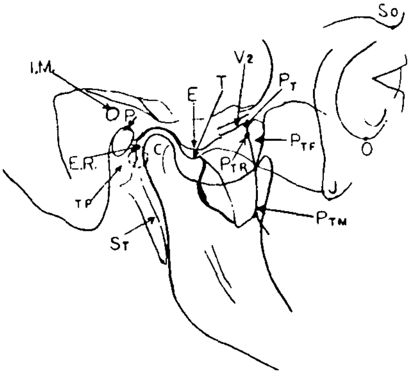

Fig. 8 Tracing of the structures shown in Figure 7. IM, the internal acoustic meatus; P, porion or the top of the ear hole; ER, dotted ear rod; TP, area for the tympanic plate; ST, styloid process; C, condyle; E, the eminence; T, articular tubercle; PTR, position of pterygoid root vertical; V2, aforementioned channel for the maxillary nerve; PT, apex of crest of bone below the border of foramen rotundum; PTF, pterygopalatine fossa; PTM, pterygomaxillary fissure; point J, the jugal point or the bottom of the key ridge; O, orbitale; and SO, supraorbitale.

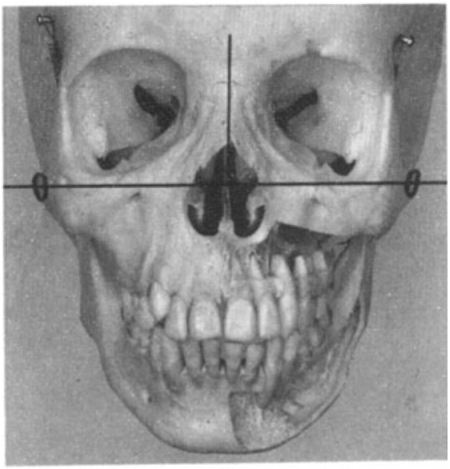

Fig. 9 Skull with the zygomatic arches traced showing a frontal Frankfort plane through the bisection of the two zygomatic arches. A vertical through the nasal septum shows the orientation in the frontal headfilm as a central sagittal plane. Compare with Figure 1 for the lateral.

frontal, the zygomatic arches are seen to be bisected directly with the Frankfort plane (Fig. 9). These provide a method, therefore, to relate frontal and lateral dimensions in the headplates for description as orientation on Frankfort in the frontal also provides an X-Y coordinate from a midline zero point. Any anterior cranial base reference such as SN, DeCoster's line, or the great wing of the sphenoid cannot accomplish this because they cannot be visualized sufficiently in the P-A film.

By dropping a perpendicular through the Frankfort plane at the posterior margin of the pterygopalatine fossa (or the anterior border of the pterygoid plates) a representation was established as a zero bench mark in an XYZ coordinate system. Of equal importance this vertical line serves as a reasonable hafting zone for the forward and backward dimensions of the facial complex. This line virtually parallels the coronal suture complex and forms an excellent clinical division for forward and posterior facial parts. This is quite an important concept to consider. Several other workers have employed a line somewhat similar including Broadbent,[3] Bimler,[13] and Enlow et al.[14]

Porion can serve as a gross reference for location of glenoid fossa (via a "center" of the temporal bone) to serve as a condylar and mandibular reference (Fig. 8). True porion can also be located from a study of the temporal bone anatomy. Further, a Dome (Ricketts) template may be employed, if necessary, to help locate the external canal for the location of porion from the glenoid fossa, eminence, or zygomatic arch. The pterygopalatine fossa border can be easily identified and the sides bisected for improved accuracy.

All three of these basic points, porion, orbitale, and pterygoid root, have distinct biologic significance. They are related to basic sense organs or neural functions as keys to the vital centers. The orbital rim may grow slightly downward but still represents effective completion of size at an early date. Porion, representing a point in the temporal bone, is in juxtaposition with the semicircular canals. The temporal bone contains the organ of hearing and provides protection to the vital vegetative centers such as the carotid canal, the seventh and eighth nerves, as well as the jugular foramen. Finally, the point on the base of the pterygoids is almost exactly the site of the exit of the maxillary division of the fifth nerve from the base of the skull (see Fig. 8). These points of reference are highly individualistic and serve as references for basic arrangement of the particular morphology.

By employing FH orientation, a second orientation plane can be employed for a secondary check. The crossing of basion-nasion with FH is near and sometimes exactly on the pterygoid vertical axis (see Fig. 6). By using these central landmarks and dual plane orientations, variation of parts of the face take a high degree of order for comparison in assessment of dysplasia.

The FH and PTV serve as a reference for the coronoid process which averages about 5 mm forward and 3 mm downward from the PTV crossing. The mean orientation of nasal capsule is at right angles to FH.

The lower face tends to orient by adulthood to a right angle (the facial angle develops to around 90 degrees).

Early growth of sphenoid and temporal bones follows FH orientation, the great wings swing up in orderly manner, and internal and external auditory canals maintain their relations to FH.

The FH plane in vertical perspective tends to display polarization for the two temporal bones in growth behavior.

The decision to use Frankfort plane as a method for description of facial morphology, therefore, seems to possess great merit. It includes a reference near the temporomandibular joint and a reference within the middle face complex at the orbital matrix. Thus, the characteristics of the two jaws to each other can be studied by its use. When the added significance of polar centering is considered, further implications are dramatic.

This orientation yields the smallest deviation as related to conventional points on jaw structures and is statistically proven to be of great comparative value (Table I and Fig. 5). The S.D. from FH is 2.8 degrees and from SN is 3.7. It was also found statistically that true Frankfort revealed a mean of almost 0 degrees and a very low S.D. with the optic plane of Sassouni.[15] It is the most useful orientation for mechanical procedures in long range growth forecasting.[16] Aside from the difficulty of anatomic porion and orbital location, Frankfort plane orientation is not hard to explain or accept by clinicians. It has served orthodontics for fifty years. This is because of the long history of the mandibular plane angle and Tweed's approach to cephalometrics with the incisor to FH measurement.

CONTROVERSY OVER PORION, ACCURACY STUDIES AND ANATOMICAL CONSIDERATIONS

It should be realized that the machine ear rod was not employed in these studies nor is it used in present day clinical analysis. To repeat, the ear rod is untrustworthy and can vary as much as a full cm from true porion and its use may lead to gross error. Therefore, the *true porion* or ear canal outline must be sought and employed if the Frankfort plane is to be used and trusted (Figs. 7, 8).

Probably the greatest objection to Frankfort plane use is the lack of visibility and selection of porion. Four technicians were instructed to test this problem. Seven headplates were taken at random from different samples. Each film was marked for reference on the corners so that comparisons could be made by two fixed points. The accuracy or agreement in the selection of S, N, P, O, and Ba was compared together with FH, SN and BaN planes. The tracings of one technician were used as a base line for comparison of all others. The S.D. of difference between the technicians was calculated as a measure of the validity of one plane over the other as far as selection alone is concerned. The results showed the deviations were SN 0.66 degrees, FH 0.70, and BaN .72. Thus no significant differences were seen in the difficulty of selection of any of the three planes.

Several facts and theories should be brought to light regarding dependence on FH. The biologic significance of the temporal bone has already been mentioned. Also, it is evident that attempts at references to the mandible are employed through the use of articulare or even basion although basion at the midline is distant from the temporal bone and the mandible (See Fig. 3 and compare with Fig. 7). Variation in joint location has been measured from sella as though sella were more reliable than the temporal bone for understanding three dimensional craniofacial morphology. In light of today's knowledge this is questionable as outlined in this paper.

The anatomy seen in the X-ray needed clarification. The radiolucent area observed above the external canal was thought in the past to be the tympanic antrum due to observations from earlier laminagraphic studies. By drilling a hole straight through the internal canal it was discovered that this radiolucent area is probably the internal acoustic meatus. Several cases of longitudinal growth over a span of 14 years or more were studied. It was discovered that the relationship of the external and internal canals changed so little that one could accurately be estimated later if the other were located. This, however, needs further checking for the range of variation and temporal bone have not been studied extensively.

Thus, a quadruple check is possible for porion. Porion may be located by a bisection of the two external auditory canals in the X-ray. The outline of the glenoid cavity and eminence may be used because porion is usually located one half distance from the depth of the fossa. Porion can be corrected to the roof of the petrous temporal bone or the internal acoustic meatus as just described. Finally, the external canal will be continuous with the anterior border of the mastoid process as it meets the tympanic plate. If some of these factors are considered in the selection of porion, perhaps even greater agreement is possible.

LONGITUDINAL RATIONALE

If the end points used for a descriptive baseline reference are distant from each other, a minor error in selection probably will not alter a measurement enough to influence the interpretation significantly. The same selection error between tracings in a series, however, is of great consequence. Because of the delicate nature of a change cephalometrically, a millimeter error in points close together may result in a higher degree of difference in interpretation. Variations in the form and size of structure are much greater than usual growth directional change. Any serial study, therefore, cannot be approached on a casual basis. Any technician must make certain that the points selected are the same for each tracing so that superimposing errors can be minimized and the change recorded will be, in fact, a true change.

Difficulty may be experienced when porion-orbitale (or FH) is used for longitudinal comparison because of the growth changes, also because the patient may be positioned slightly differently in the headholder at each visit. It is therefore necessary for good serial use of Frankfort plane that porions and orbitales be bisected on each tracing to reduce points to a common midline representation. The pterygoid points and pterygopalatine fossae also should be bisected. In a series it is best that each original headplate and tracing be available for aid in the anatomical selections.

A CONTEMPORARY BASICRANIAL AXIS

To increase the confidence in cephalometrics more than one basic reference plane is desirable. While the anterior cranial base is useful for short range and maxillary development, the complete cranial base has been found more useful to assess the direction of facial growth.

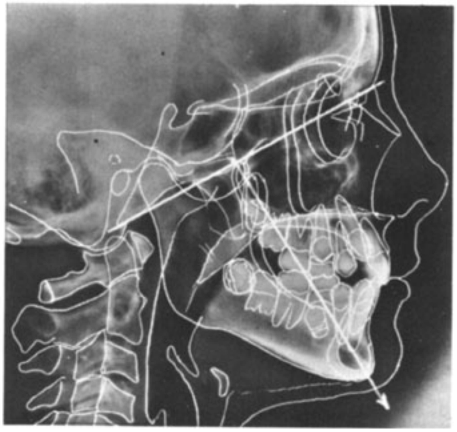

Fig. 10 A lateral headplate showing the general location of the basion-nasion plane. The PT point and the facial axis are displayed with the arrow pointing downward and forward which is the usual direction of growth of the chin. In this 12-year old female the internal acoustic meatus is dotted, the external canal, the glenoid fossa, and condyle head are traced.

The basion-nasion plane represents a line of separation of the face from its supporting superstructure. It crosses the base of the pterygoid plates and the horizontal alae of the great wings of the sphenoid at the floor of the middle cranial fossa (Fig. 10).

Studies have shown that the chin (or gnathion) tends to be located almost at right angles to the basion-nasion plane at the base of the skull for all ages as the facial axis (Pt-Gn) is 90 degrees ± 3 degrees. The basicranial axis, therefore, serves as an excellent reference for description, for growth analysis, and as an aid for a quick prediction of the chin. Averaged out, the central axis of the face (facial axis) tends to stay constant for a given population sample, although it may move in either direction for the individual (SD ± 1.5 with five year sample, N = 40, SD ± 2.3 in a ten year sample, N = 50).

In addition to the fact that the chin grows off the BaN plane the terminus in the profile tends to hold its proportion to the maxilla and nasal capsule slightly better than the use of SNA. As a basic plane for study of growth behavior of both the chin and the maxilla, the BaN plane offers distinct advantages over SN and has come to be adopted as the primary plane for analysis of treatment results by many clinicians.

Both the Frankfort horizontal and the basion-nasion (basicranial) planes are now employed together because neither serves the complete clinical need. The author would propose that BaN be considered the contemporary basicranial axis for reference work and reported studies.

SUMMARY

The historical development of cranial reference lines, basic to cephalometric orientation, was discussed. The evolution to, away from, and back again to the Frankfort horizontal plane for descriptive and communicative purposes as benefits to the clinical orthodontist was explained.

Objectives were set forth as a basis for selecting the most appropriate method in orienting the headplate for measurement and assessment. The major functions of cephalometrics were pointed out to be its use for description or classification of the face together with the malocclusion and for superimpositioning for longitudinal comparison. Each of these purposes calls for particular requirements pointing to the need for combinations of planes and multisuperimposing.

The statistical findings via a computer pointed to the use of the Frankfort plane as the most desirable basic reference for descriptive reasons. Composites also suggested good order from Frankfort horizontal when serial tracings were compared. It was emphasized that true porion was used, not the ear rod of the cephalometer. For growth

analysis the basion-nasion plane was shown to be longitudinally of superior value for chin behavior.

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