THE SKELETAL NASAL AIRWAY, CRANIOFACIAL ASYMMETRY, AND MALOCCLUSION

by

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Abstract

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There is much discussion of the part the airway plays in orthodontics. However, almost all "airway" literature concerns the nasopharyngeal and oropharyngeal regions. Another area of increasing concern to the orthodontist is bilateral symmetry. Again, not a great deal of study had previously been undertaken in this area.

The question of whether the structure of the nasal airway area is related to types of occlusion gave rise to the present study. By not considering the soft tissues, we were looking at the framework of the nasal airway, much as one might look at the iron framework of a building under construction, before a facade is built. The notion of symmetry considerations began with observing the asymmetry of the airway, and it was decided to include other craniofacial lateral dimensions as well.

Records of eighty-four individuals were selected and broken down into five groups. The first was a control group of Class I occlusions for whom orthodontic treatment was not indicated. The

remaining four groups had malocclusions which were treated, however records for this study were obtained before treatment began.

Records consisted of lateral and P-A cephalograms. Measurements were made directly from the cephalograms and some computed variables were included. All variables were statistically analyzed by analysis of variance, Scheffe's multiple range test and Tukey's HSD test, or Pearson correlation. Some variables were included in all tests. After evaluation of the data, the following conclusions were drawn:

1. In evaluating the skeletal nasal airway as related to control and malocclusion groups, no significant differences were found for either the computed variables, skeletal nasal airway index and skeletal nasal airway volume index; or the measured variables, skeletal nasal airway length, skeletal nasal airway height, and skeletal nasal airway width. The differences were not of sufficient magnitude to define separate populations. Rather, the differences were within the limits of variation which might be expected within a population.

2. There existed a high correlation of skeletal nasal airway index with the midcranial base angle. This may or may not be a direct cause and effect relationship. More logically, it is a mutual response to a multifactorial influence which could include such factors as development of the midbrain and cerebral hemisphere.

3. Craniofacial asymmetry is widespread and extremely variable. The only significant relation to the control or malocclusion groups of this study was that Class III malocclusions had larger dimensions to the left.

4. Unilaterally, right measurements are highly correlated, as are left measurements. Correlations of right measurements to left are not highly correlated except for the orbits and mandible. It is this low correlation which relates to asymmetry. The orbits are close to the cranial base and are associated with cranial nerves. This might explain the high correlation of right and left for the orbits. The rationale for mandibular symmetry is more conjectural but might be related to function. The mandible may function better with a higher degree of symmetry.

5. A high direct correlation exists between the angles of the anterior nasal margin, posterior nasal margin and midcranial base. The high correlation of the anterior and posterior nasal margins might be expected as they are associated with the nasomaxillary complex. The high correlation of the midcranial base angle is probably the result of a common, multifactorial influence to all elements of the angles.

6. The present study is an initial one and its general nature places some limitations on the interpretation of its results:
   a. In selecting the sample, differentiation of various types of Class II malocclusions (after Enlow et al., 1971), might have proved productive. Likewise, the open bite group could be broken down by Angle classification.

   b. The possibility exists that cephalometric landmarks of greater biologic significance could be selected. There may be different radiographic points which would more meaningfully assess the airway.

   c. No attempt was made to test the positional relationships of the skeletal nasal airway to the cranial base or dentition.

   d. A breakdown of the sample by sex could provide additional discriminatory data, because it is known that dimensional differences exist in the nasal region that relate to sexual dimorphism.

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INTRODUCTION

The use of cephalometric radiographs is almost universal among orthodontists. Although much discussion continues over which are the most valuable landmarks and analyses, few would deny the overall impact and value of cephalometrics in both clinical practice and research. The commonly used lateral cephalogram is ideal for demonstrating the anteroposterior relationships so important in orthodontics.

More recently, the significance of lateral dimensions and relationships has been better understood. An increasing amount of orthodontic literature deals with the airway. The dimension of width must be an integral part of any airway evaluation. Facial asymmetry, another growing field for the orthodontist, requires assessment of lateral dimensions. These needs are fulfilled by the posteroanterior (P-A) cephalogram. Long relegated to the research laboratory, the P-A cephalogram is finding a place in the diagnostic armamentarium of the clinician.

For these reasons, both the lateral and P-A cephalograms were utilized for this investigation.

It is proposed to evaluate basic structural relationships as they relate to the airway, lateral asymmetry and malocclusion. It is not suggested that soft tissues play no part in airway problems, nor that structural asymmetry is the cause of all malocclusions.

Rather, it is the purpose of this study to determine if there are certain basic skeletal structural configurations in the skeletal nasal airway and in facial bilateral symmetry which consistently occur in various malocclusion types. Two separate studies will be considered:

1. An investigation of possible differences in dimensions of the skeletal nasal airway among certain types of malocclusion and correlation with certain elements of craniofacial morphology.
2. An investigation of the extent of bilateral asymmetry of selected craniofacial structures and their relationships to each other and to certain types of malocclusion.

REVIEW OF THE LITERATURE

Nasal Airway

The airway and its role in dentofacial development are increasingly popular topics for discussion among orthodontists. The largest volume of literature on the airway concerns itself with the nasopharyngeal and oropharyngeal region. It is this area which is presumably most affected by tonsillar and adenoid hypertrophy. Certainly, partial or complete obstruction of these parts of the airway is associated soft palate function, tongue posture and certain orthodontic problems.

Subtelny (1954) used a combination of cephalometric radiography and cephalometric laminagraphy to study adenoid tissue in 15 patients with no history of adenoid removal and also in 20 patients who underwent ademoidectomy. Using the unoperated subjects he noted a growth cycle of adenoid tissue beginning with its appearance at about six months postnatal age. There was an increase in size to about age 10 or 11, followed by atrophy beginning in the mid-teens which was complete by adulthood. In those individuals with an excessive amount of adenoid tissue, members of the group who had adnoidectomies, certain preoperative conditions were noted:

1. A downward and forward positioning of the tongue. Normally the posterior dorsum of the tongue, at rest, would be in contact with the soft palate. He suggested that

repositioning of the tongue was required to open an airway to permit mouth breathing.

2. The lips, in repose were parted.
3. Usually an accompanying depression in the position of the mandible.
4. A progressive procumbency of the maxillary anteriors due to a lack of the restraining influence of the lip musculature.
5. A narrowing of the maxillary arch due to a lack of influence of the tongue musculature to counteract the lingual pressure of the buccal musculature.

A high palatal vault sometimes referred to in describing "adenoid faces" was attributed by Subtelny to an illusion resulting from the constricted maxillary arch. He stressed that the above findings were limited to those subjects with nasopharyngeal obstruction due to abnormally large adenoids.

Ricketts (1958) also cited the possibility of a narrowed maxillary arch due to a lowered tongue position. He also pointed out that the head and neck were often extended in an apparent effort to improve the oropharyngeal airway in mouth breathers. Thus, he suggested changes in body posture due to a compromise of the nasopharyngeal airway.

Ricketts (1968) made additional observations on the skeletal nasal airway. He suggested several other factors which could affect the airway:

1. Nasal atresia or natural impatency due to diminutive choanae or the piriform aperture.
2. Vertical maxillary asymmetries caused by abnormal mandibular growth.
3. Cranial base dysplasia involving growth failure in the sphenoethmoidal or spheno-occipital syndhondroses. This would result in a high and forward displacement of the cervical vertebrae due to lack of descent of the occipital condyles.
4. Excessively acute cranial base angle resulting in a retropositioned maxilla or a vertically inclined clivus. Either would reduce the anteroposterior dimension of the nasopharynx.

Others have published investigations which support the preceding findings. Richardson and Brodie (1964) stressed the influence of the muscular environment on the course of eruption and axial inclination of the teeth. They suggested that a lower, more forward tongue position represents a change in that environment which is capable of affecting tooth alignment and occlusion.

Harvold (1973) induced mouth breathing in monkeys by nasal obstruction. He noted an increase in total face height due to an opening of the bite, and also a decrease in maxillary intercanine distance, maxillary arch length and mandibular intercanine distance. Nasal airway obstruction, he concluded, can qualify as an etiologic factor by setting up a response chain leading to malocclusion.

Steele and Fairchild (1968) cautioned that airway obstruction and adenoid faces are not solely the result of adenoid or tonsillar hypertrophy. They suggested nasal injury, nasal deformity, allergic reactions in the nasal soft tissues, foreign bodies, neoplasms, and polyps as other possible causes.

The role of allergy in causing nasal obstruction is well documented. This problem was addressed by Balyeat and Bowen (1934) and Todd, Cohen and Broadbent (1939). Rubin (1979) cited cow's milk as a major cause of allergy in the newborn. These allergies can cause nasal airway obstruction, he stated, interfering with normal facial development. If allergic episodes can be prevented in the first year of life, he claimed, the child may avoid more severe allergic manifestations later on. He suggested breast feeding as a primary deterrant to airway obstruction due to allergy.

Linder-Aronson (1979) studied 81 mouth breathing patients, with enlarged adenoids, who underwent adnoidectomy. His findings of a narrowed maxillary arch, incisor crowding, open bite tendency, normal palatal vault height, increased facial height, lower tongue posture and decreased sagittal depth of the nasopharynx agreed with the previous studies noted above. Contrary to earlier reports, however, he found the incisors to be retroclined as opposed to proclined, and noted a normal anteroposterior jaw relationship, not a Class II relationship.

After adenoidectomy a normalization of several of these characteristics occurred, namely:

1. Incisor inclination
2. Maxillary arch width
3. Sagittal depth of the nasopharynx.

He attributed this normalization to a change from the low tongue posture of the mouth breather to the normal higher, more distal tongue posture. This was permitted by creating a patency of the nasopharyngeal airway through removal of the excess adenoid tissue. Concomitantly, the lips in repose were now in contact normalizing the influence of the lip musculature.

Anthropologists have also investigated the nasal airway. Davies (1932) mentions a nasal index, which is a ratio of the width of the fleshy nose to its height. This soft tissue index is not to be confused with the skeletal nasal index discussed later in this paper.

Wolpoff (1968) suggested that climate, i.e., temperature and moisture content of the air, affects nasal airway width. Cooler, drier air is associated with a decrease in width. He also cited non-climatic influences such as form of the cranium and masticatory function. A hard diet, requiring more vigorous mastication was reported to be associated with a wider palate and nasal airway.

Other studies by Steegman (1970, 1972) and Koertvelyessy (1972) also suggest association of climatic conditions to craniofacial development.

Dahlberg and Graber (1975), however, take issue with the notion of climatic influence on craniofacial form in a study of

Eskimo populations. They put far greater influence on the functional aspect, citing large biting forces and a heavy masticatory apparatus. These are associated with the Eskimo's tough diet and his common habit of using his teeth as a third hand. Craniofacial characteristics of that population are related to the size and attachment locations of the muscles of mastication and the need for morphologic features which are capable of dissipating heavy masticatory forces.

This brings us to the subject of the nasal airway as opposed to the more commonly studied nasopharynx. Very little investigation concerning the nasal airway, in particular, has been done.

Perhaps the most significant evaluation of the nasal airway volume was done by Montgomery (1979). He used the technique of computed tomography. Through the use of a rotary scanner, frontal section films were obtained from four adult cadavers. The number of views utilized in the airway volume computations varied from 14-17. Lateral and posteroanterior (P-A) cephalograms were also obtained for subjective comparison to the tomographs. Volumes were computed mathmatically from the tomographic sections.

These computations were checked by making impressions of the nasal airway, using silicone impression materials. The airway was first sectioned from the head and silicone casts were prepared. The volumes of these casts were then compared to the computed volumes. Differences occurred in both directions. Some computed volumes were greater, some less than the cast volumes. The reported error was 1%. This error computation will be addressed in the Discussion.

The largest error was in tracing. Even with the high resolution of the tomograms, precise airway delineation was difficult. It was proposed that a computer system might be programmed to more accurately trace the airway.

At any rate, this was the first study to attempt to specifically quantify nasal airway volume. The development of an effective method for computed tomography in vivo would be of value. However, the problem of increased radiation exposure precludes use of this technique for all but the most serious problems such as tumor assessment, severe craniofacial deformity, or trauma. Also, radiation notwithstanding, the high cost (U.S. average of $226.00, 1979) of the procedure could certainly limit its use in orthodontics.

The need for an effective, reliable and relatively easy method for quantifying nasal airway volume from readily available records, i.e., lateral and PA cephalograms, is apparent.

An investigation to clarify the value of lateral and posteroanterior radiographs as a means of evaluating nasal respiratory function was done by Holmberg and Linder-Aronson (1979). Actually, he used the lateral cephalogram to assess the nasopharyngeal airway with particular regard to size of the adenoids. The degree of obstruction of the nasal airway, both bony and soft tissue, was estimated from the posteroanterior cephalogram.

These radiographic evaluations were then checked against other estimations. The adenoids were evaluated clinically by an

ear, nose and throat specialist utilizing posterior rhinoscopy. Nasal airway was correlated with measurement of nasal airflow in liters per minute.

Adenoids had been graded in four or five sizes ranging from "no adenoid" to "very large". Nasal airway obstruction was of three degrees, "none", "partial" or "total".

After statistical analysis, Linder-Aronson concluded:

1. Radiographic and clinical assessments of adenoids are significantly related.
2. Radiographic assessment of nasal airway capacity and nasal airflow are significantly related.
3. Lateral and posteroanterior cephalograms are satisfactory for evaluating the dimensions of the nasopharynx and the airway capacity.

Vig and Hall (1980), in a critique of the Holmberg/Linder-Aronson investigation referred to above, generally take issue with the imprecision of Holmberg's and Linder-Aronson's airflow measurements and interpretation of their statistical data. Vig and Hall suggest a larger experimental error might well exist in a reproduction of the airflow experiment with a more refined procedure. While they agree that some of the evidence is statistically significant, they question the clinical significance. Indeed, they claimed there were not any subjects with a truly critical amount of nasal resistance. Vig and Hall conclude that cephalograms are inadequate for assessing airway impairment. While

they do not recommend cephalograms for the diagnosis and selection of patients for surgical treatment of nasal obstruction, they stop short of claiming they are of no value whatever.

Craniofacial Asymmetry

Various reports have been published about craniofacial form, development and asymmetry. Woo (1931) studied a series of 800 Egyptian skulls. He found almost all of them to be definitely and markedly asymmetrical. He also noted that, on the whole, the right cranial bones were larger than the left, particularly the frontal and parietal bones. This right dominance was attributed to the right cerebral hemisphere being larger than the left. Only the malar bone showed predominance for the left but he points out that this bone has less relation to brain development than those of the cranial vault.

Greene (1931) and Boder (1953) examined craniofacial asymmetry in newborn infants. For his study, Greene rejected the cause of asymmetry as due to molding during labor, which he regarded as temporary and self-correcting within a few days to several weeks. He associated a great deal of cranial asymmetry with the postural position of the infant in the crib. While he admitted that an asymmetric condition can sometimes be associated with rickets, non-rachitic conditions such as bony osteoporosis were more often linked to the children he studied.

Treatment of Greene's patients consisted of periodically changing the infant's position in the crib so that pressure fell to the opposite, non-flattened, side of the head. This technique met with success with obvious improvement occurring within a few weeks. He suggests that failure to take these measures would likely permit the asymmetry to persist into later childhood and perhaps become permanent.

Boder's work placed considerably greater emphasis on incidence of congenital craniotabes and congenital cranial osteoporosis, defined in his paper as congenital softness of the skull and deficient calcification of the cranium, respectively. Afflicted children showed a frequency of facial asymmetry five times greater than that of infants with normal bone development, i.e., firm, well-ossified skulls.

Asymmetry of the "soft skull" infants was attributed to intrauterine pressure and postural position. For instance, a shoulder might press against one side of the head or the chin may be pressed against the sternum. Also, first children, because they are subject to greater intrauterine pressure, demonstrated a higher incidence of asymmetry than did subsequent children.

The children with deficiencies of bony ossification were shown to be more sensitive to pressure habits such as thumb sucking. These habits can lead to asymmetry and widespread malocclusion. This thesis was then extended to include children who developed diseases of deficient bony ossification at a later age. They were

found to be predisposed to malocclusions due to pressure effects of such habits as thumb or finger sucking.

Boder agrees with Greene in stating that the resultant asymmetry or malocclusions may be permanent.

Sigel (1939) found low calcium and phosphorus levels in children with all forms of malocclusion. He concluded that bony density resulting from faulty mineral metabolism is a major factor in malocclusion.

Scott (1958) attempted to analyze facial growth in general as a synthesis of related growth areas rather than picking specific points, making measurements and creating "norms". He suggested certain main determinants of facial growth such as the cartilage of the nasal septum, condylar cartilage, and the cranial suture system. He also cited the alveolar bone as a major site of compensation and holds that this compensation serves as an adjustment between the upper facial skeleton as directed by the cartilage of the nasal septum, and the mandible as determined by the growth of the condylar cartilage. He claimed that the pattern of dental occlusion was directed by the growth of the intervening alveolar processes.

Moss (1960, 1962) suggested the functional matrix theory to describe what paces the growth of the craniofacial region. He suggests various "capsules" or elements which direct skeletal growth. Even spaces such as the oral cavity or nasal airway are considered by Moss as functional components which influence growth. He does not address asymmetry specifically but points to the

inter-relation among certain parts and the independence of others. One stimulus will not necessarily trigger a response in every other element. In comparing the effects of heredity to environment, he suggests that, for bony structures, genetics plays an initiative role. Environment serves to maintain and adapt. It is difficult, if not impossible, to say which has a greater effect. However, environment seems to have greater effect on anteroposterior dimensions than on height.

Chierici, Harvold and Dawson (1970) created facial asymmetry by producing unilateral surgical clefts in the premaxilla and palate. Asymmetry was obvious in the maxilla, dentition, soft tissues of the face, nasal septum and nasal cavity. Asymmetry did not, however, extend to the zygoma. This would indicate that the zygoma is not part of a response system acting through the dentition of the rhesus monkey.

Mulick (1965) studied asymmetry in identical and fraternal twins. He concluded:

1. Heredity was not the factor controlling craniofacial asymmetry.
2. Asymmetry present was not intensified with dimensional changes associated with an increase in age. The degree of asymmetry was constant.
3. Ranges or limits of asymmetry were established.

Lundstrom (1961) described asymmetry as qualitative, of the all-or-none type such as missing or supernumerary teeth; and quanti-

tative, with varying degrees of asymmetrical form such as tooth size. He further stated that asymmetry can be of genetic or non-genetic origin and points to the liklihood of a combination of genetic and non-genetic influences.

Smith and Bailit (1979) also evaluated genetic influence. They concluded that asymmetry can be the result of several factors:

1. Imperfect genetic control, i.e., different genotypic influence for right and left.
2. Precise genotype which allows for adaptive modifications between right and left intrinsic environments which are different.
3. A combination of less than precise genetic information which is, in addition, influenced by different local environments.

A precise quantification of genetic vs. enviornmental influence was deemed impossible from their data. They mentioned, however, that dental occlusion as a whole demonstrated a high magnitude of asymmetry and that evidence over the last several thousand years shows that human dentition may be becoming more variable.

Lavelle (1979) also agreed that environment and genetics has a varying influence on different skull shapes. In his study of brachycephalic and dolichocephalic subjects, he correlated teeth, dental arch and craniofacial dimensions to cranial form. The dolichocephalics demonstrated more integration, or higher correlations to each other than the brachycephalics.

Perhaps one of the greatest problems in studying asymmetry is the establishment of reference planes that are meaningful and accurate. For evaluation of lateral asymmetry from the posteroanterior cephalogram, the mid-sagittal plane is most critical.

Harvold (1954), in his cleft lip and palate study, presented an X-line method. He drew a line connecting the lateral parts of the zygomatico-frontal sutures. A perpendicular was then constructed through the root of crista galli. Ninety percent of the time, the anterior nasal spine was within 1.5 mm of the X-line. The index of symmetry thus obtained closely corresponded to anthropometric findings.

Cheney (1961) found that a vertical plane through crista galli and anterior nasal spine closely approximated the mid-sagittal plane. It also approximated Harvold's mid-sagittal plane.

Marmary, et al (1979) cited various reasons for investigation to derive yet another midline plane of the skull. They utilized the foramina of the cranial base because of their presumed stability, reliability and consistency. Selecting foramina spinosum, a line was drawn connecting them. A perpendicular bisector of this line was designated as the midsagittal plane. This technique requires the use of an additional cephalogram, the basilar view.

Midline considerations are not the only pitfalls inherent in asymmetry studies. Mulick (1965) made the first determination of

ranges of asymmetry of the upper facial skeleton. He devised a method for expressing anatomic landmarks in three planes. By locating these landmarks on both the lateral and posteroanterior cephalograms, each landmark could be assigned coordinates which described their locations in each dimension. He also developed an "index of asymmetry" as follows:

$$\text{Asymmetry} = \frac{\text{Right measurement - Left measurement}}{\text{Right measurement + Left measurement}} \times 1000$$

or more simply,

$$A = \frac{R - L}{R + L} \times 1000$$

This was said to provide a conversion of absolute differences to relative differences.

METHODS AND MATERIALS

Source

The cephalograms utilized in this investigation were provided by the Orthodontic Department, Case Western Reserve University, and by the Bolton-Brush Foundation of CWRU.

General

Records were selected randomly without regard to age or sex. All records were prior to any orthodontic treatment, in those cases that were treated orthodontically.

Selection of Angle classifications was based on position of first molars only. Borderline cases, sub-division cases, and cases which were not clearly of certain classification were rejected.

Sample

A sample of 20 control subjects was selected from the Bolton records. They met the following criteria:

1. Each had a Class I molar relationship.
2. Dental crowding was almost always zero but never more than 1 mm in an arch.
3. Overbite was less than 50%.
4. These patients (control group) had been deemed not in need of orthodontic treatment.

A second group of subjects consisted of patients who were about to receive orthodontic treatment in the Graduate Orthodontic Clinic at CWRU. The total sample consisted of 64 individuals classified in the following manner:

1. 20 Class I malocclusions--these patients exhibited a Class I molar relationship with varying degrees of crowding, overjet, overbite and other problems. The only selection criteria, however, were a good Class I molar relationship and orthodontic problems for which orthodontic treatment was appropriate.
2. 20 Class II malocclusions--the selection criteria were a Class II molar relationship and appropriateness for orthodontic therapy.
3. 12 Class III malocclusions--Class III molar relationship and appropriateness for orthodontic treatment to help correct the malocclusion. This sample group did include some patients who were treated surgically at a later date.
4. 12 Open Bite malocclusions--these cases were selected without regard to molar classification. The only requirement was an anterior overbite which was less than 0%.

Technical Details

The lateral and P-A cephalograms for all patients had been obtained using a Bolton-Broadbent type cephalostat. Tracings were made on .003" acetate and a Pentel Ultra-Thin (0.05 mm) medium soft lead pencil.

Measurements

All tracings were done by one observer. The required points were digitized and measured utilizing the Department of Orthodontics computer (DOC).

A summary of all cephalometric points used is shown in Figures 1 and 2. A total of 41 points were recorded on each set of one lateral and one P-A cephalogram for each subject. Not every point was utilized for the final evaluations later carried out.

The important elements of the computer system used for digitizing and measuring included:

1. Alpha Micro central processing unit
2. Soroc video display console terminal
3. Texas Instruments 810 dot matrix printing terminal
4. Dual floppy disk drive
5. Summa Graphics digitizer

The central processing unit controls the operation of the entire system. The console terminal is used to communicate with the operating system and program. This is done through a keyboard similar to a standard typewriter.

The dual floppy disk drive is the primary data storage device. These disks provide quick access to stored data. Hard copy is provided by the 810 printer.

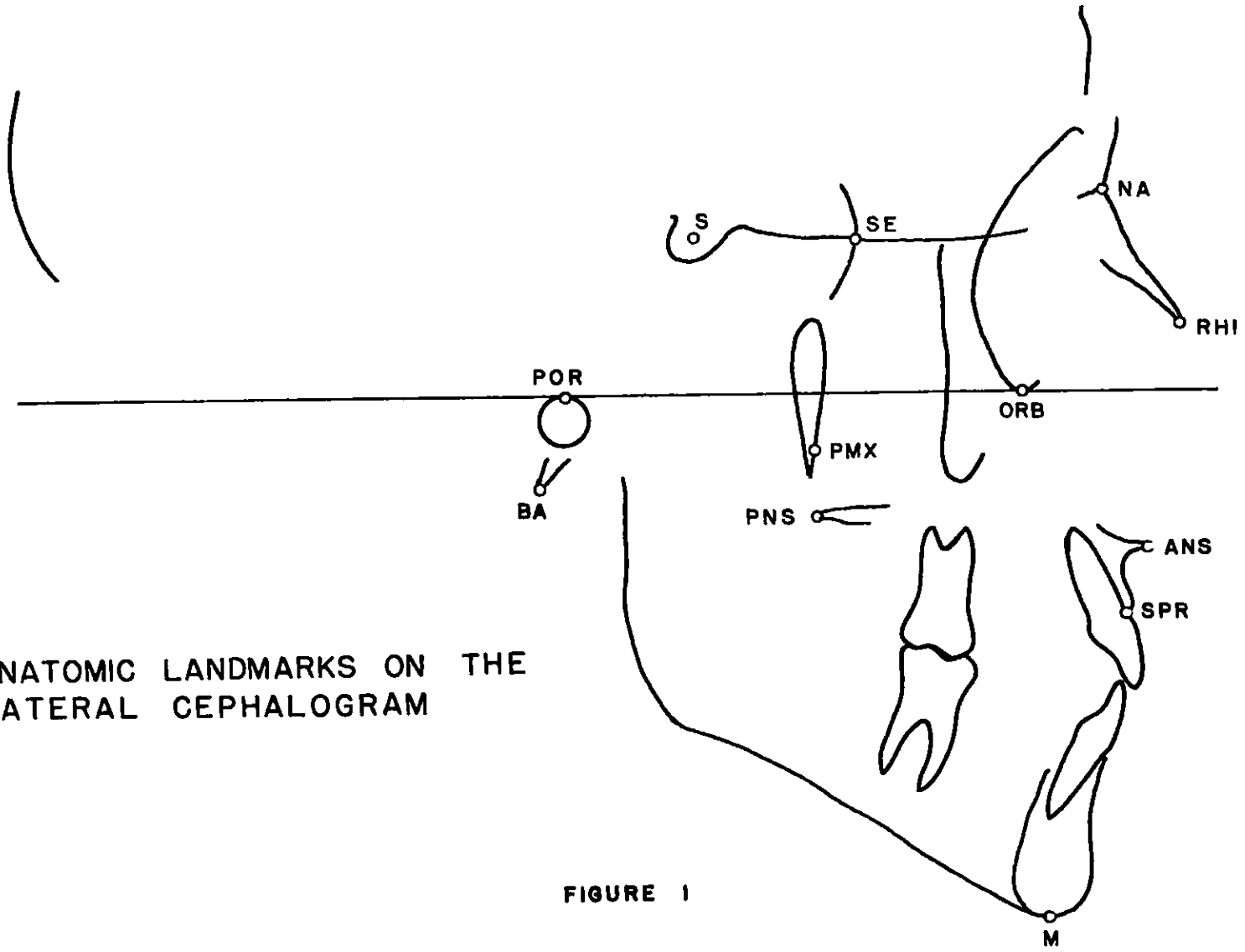
The digitizing board has a single point transmission mode with a resolution capability of 200 points per inch. Selection of

TABLE I

DEFINITION OF ANATOMIC LANDMARKS ON THE LATERAL CEPHALOGRAM

Landmarks	Definition
ANS	Anterior Nasal Spine--the anterior most projection of the anterior nasal spine of the maxillae.
N	Nasion--the most anterior point on the naso-frontal suture.
S	Sella--the center of the sella turcica.
PNS	Posterior Nasal Spine--the most posterior projection of the posterior nasal spine of the palatine bones.
SPr	Superior Prosthion--the most anteroinferior point of the maxilla at its labial contact with the maxillary central incisor.
M	Menton--the most inferior point on the mandibular symphysis.
Por	Porion--mechanical porion--the most superior point on the ear rod shadow.
Or	Orbitale, averaged--the most inferior point on the averaged tracing of the orbits.
Ba	Basion--the median point of the anterior margin of the foramen magnum.
Rhi	Rhinion--most anterior point of shadow of nasal bone.
Ptm	Pterygomaxillary fissure.
SE	Sphenoethmoidal junction--intersection of the averaged shadows (left and right) of the greater wings of the sphenoid with the floor of the anterior cranial fossa.
PMX	Posterior Maxilla--the curved line which is the posterior outline of the maxillary tuberosity.

Figure 1. The landmarks referred to in Table I are shown graphically on the lateral cephalogram.



ANATOMIC LANDMARKS ON THE LATERAL CEPHALOGRAM

FIGURE 1

TABLE II

DEFINITION OF ANATOMIC LANDMARKS ON THE POSTEROANTERIOR CEPHALOGRAM

Points	Definition
CG	Crista Galli--most superior point of crista galli of ethmoid bone.
SPr	Superior prosthion--the most anterior anteroinferior point on the maxilla at its labial contact with the maxillary central incisor.
Orb	Orbitale--the most inferior point on the rim of the orbit.
MPt	Molar point--the most inferior point on the mesio-buccal cusp of the upper first permanent molar.
Go	Gonion--the most lateral point of the mandible in the gonial region; in practice, sometimes estimated.

Figure 2. The landmarks referred to in Table II are shown graphically on the postero-anterior cephalogram. The letter "R" designates the right side, "L" the left.

ANATOMIC LANDMARKS ON THE POSTEROANTERIOR CEPHALOGRAM

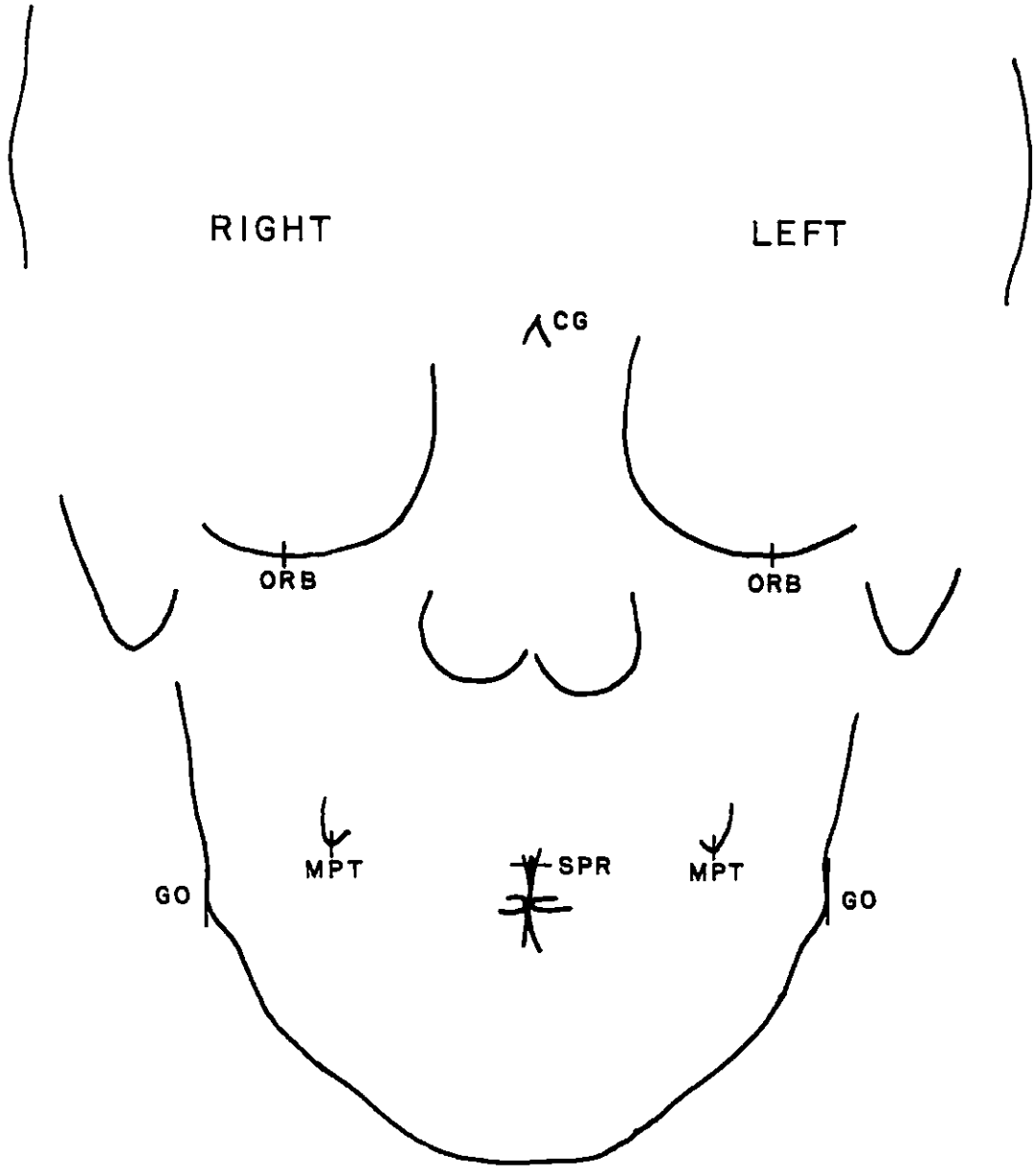


FIGURE 2

points was performed with a pen-type stylus. Points recorded are transferred into coordinate values and transmitted to a memory buffer in the processor. Description and graphic representations of the measurements are to be found in the appropriate Tables and Figures. The rationale for the anatomic basis for the measurements used is described below.

The superior boundary of the skeletal nasal airway is delineated by the ethmoid, frontal and nasal bones. The inferior boundary is made up of the maxillae and palatine bones, and was judged to coincide with the palatal plane.

The height of the nasal airway was measured between the roof and the floor (palatal plane) on a perpendicular to the Frankfort horizontal plane. This perpendicular was positioned anteroposteriorly so as to approximate the posterior border of the key ridge. When this landmark was curved or slanted, the perpendicular was constructed so as to be centered between the anterior and posterior extents of the ridge. It was felt that using this landmark would provide some anatomical basis for standardizing the measurement of nasal height.

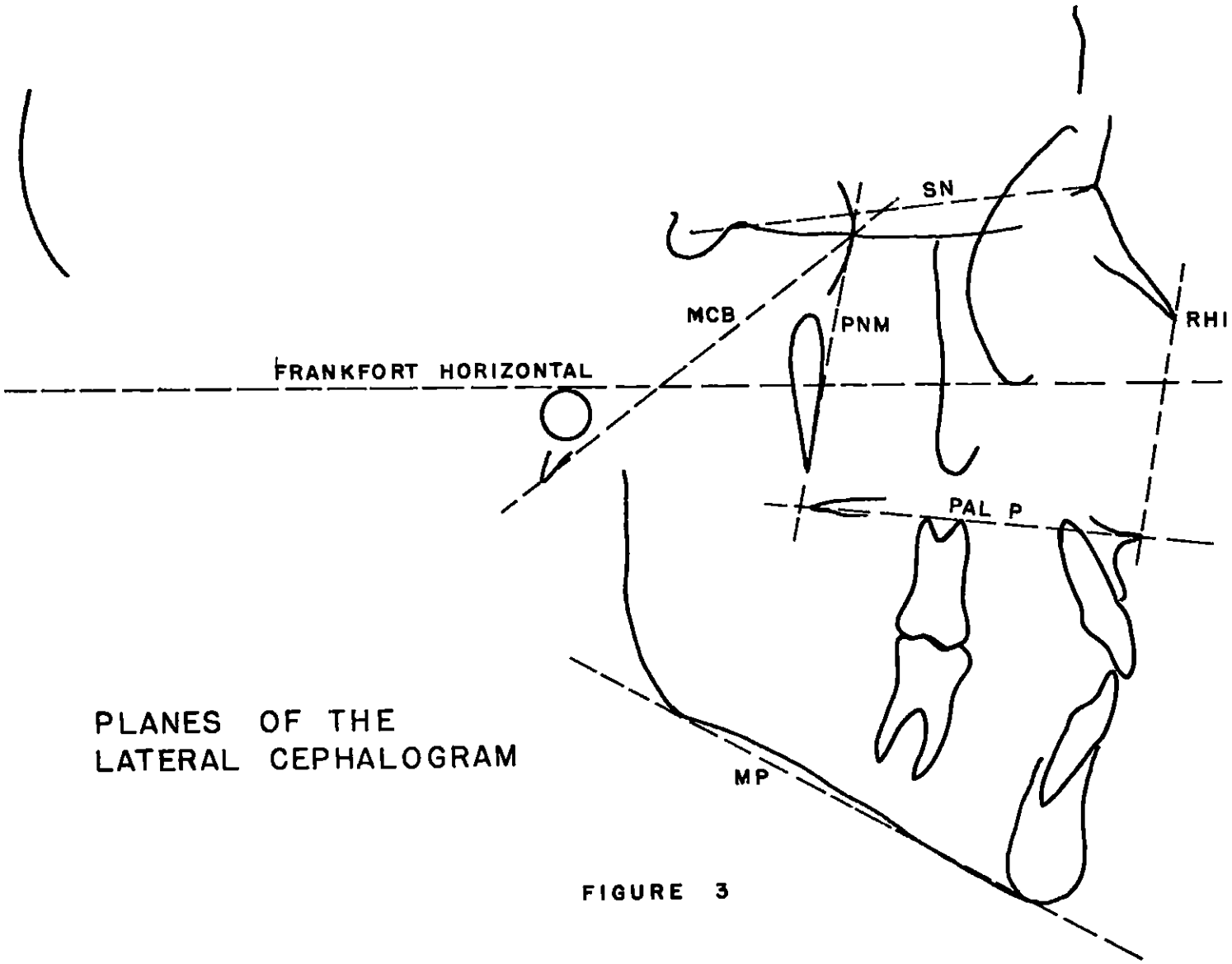
The anterior nasal margin (ANM) was constructed between the most anterior points of the superior and inferior bony elements. These are the distal tips of the nasal bones superiorly and the tip of the anterior nasal spine inferiorly. It is realized that this describes a true dimension in the midsagittal plane only, as the

TABLE III

DEFINITION OF CEPHALOMETRIC PLANES
OF THE LATERAL CEPHALOGRAM

Points/ Planes	Definition
SN	Sella-Nasion--the plane connecting points sella and nasion.
FH	Frankfort Horizontal--the plane connecting Porion and Orbitale.
MP	Mandibular Plane--the plane through Me and tangent to the posteroinferior border of the mandible.
PalP	Palatal Plane --line through ANS and PNS.
ANM	Anterior nasal margin--line from Na Tip to ANS.
PNM	Posterior nasal margin--line passing from SE, along the anterior border of the Ptm.
MCB	Posterior cranial base--represented by a line from SE through Ba.

Figure 3. The broken lines represent the planes of the lateral cephalogram in this study. Detailed descriptions may be found in Table III



PLANES OF THE
LATERAL CEPHALOGRAM

FIGURE 3

TABLE IV

DEFINITIONS OF CEPHALOMETRIC PLANES OF THE POSTEROANTERIOR CEPHALOGRAM

Points	Definition
Midsag P	Mid-sagittal plane--after Cheney (1961), passes through CG and SPr.
HP	Horizontal plane--perpendicular to Midsag P and passing through the right Orb.

Figure 4. The broken lines represent the planes of the posteroanterior film utilized in this study. Detailed descriptions may be found in Table IV.

PLANES OF THE
POSTEROANTERIOR CEPHALOGRAM

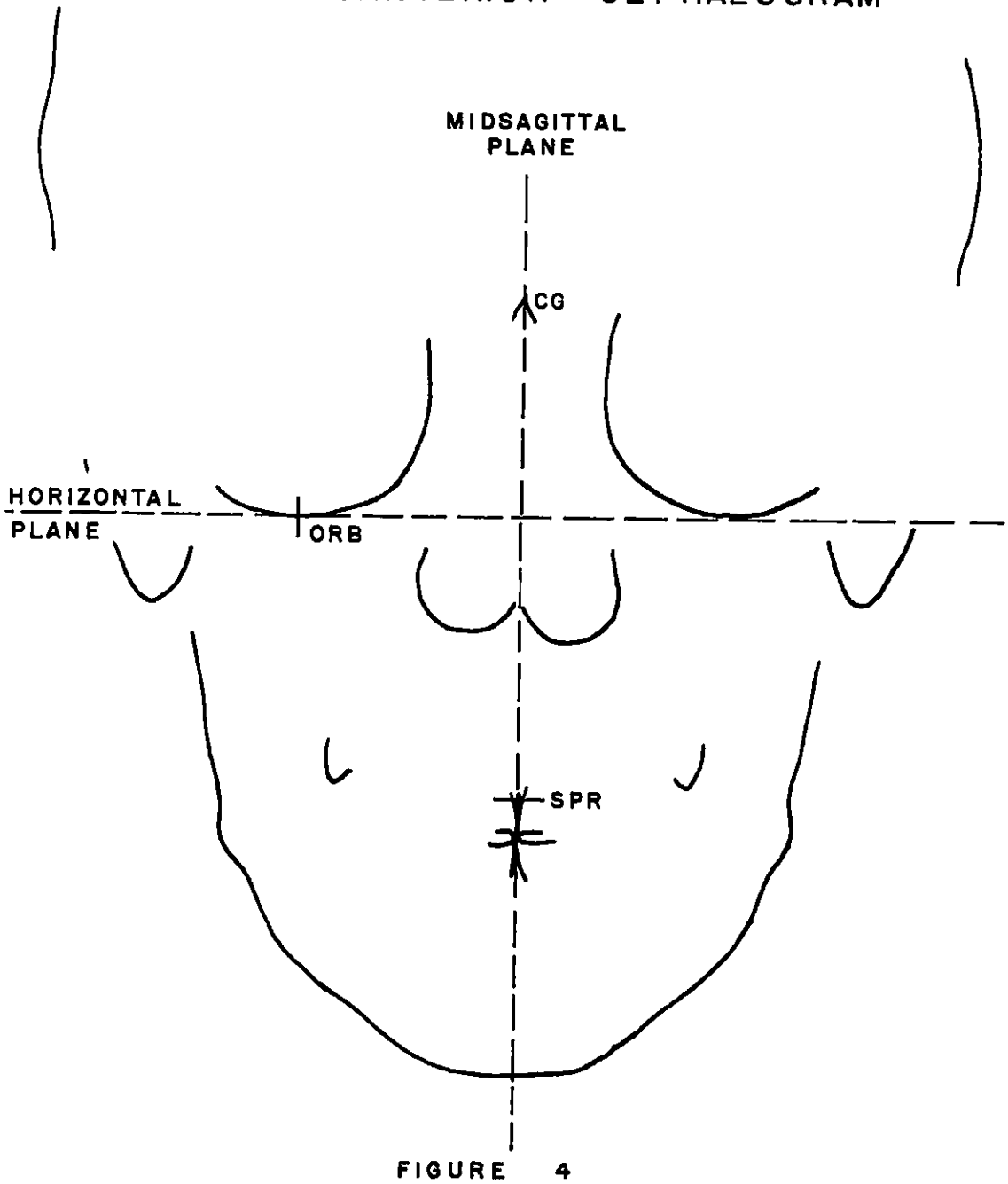


FIGURE 4

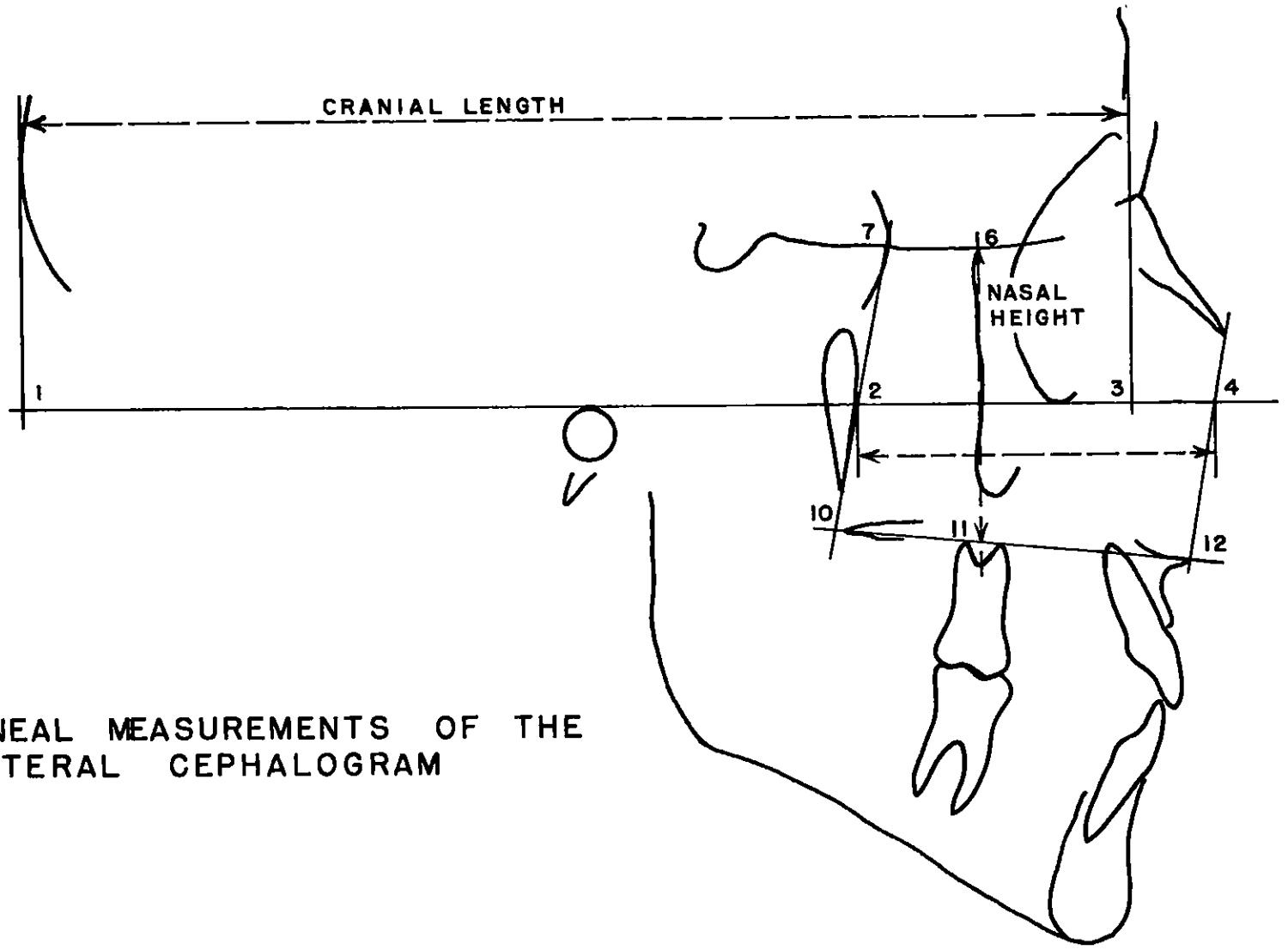
TABLE V

SUMMARY OF MEASUREMENTS

Simple distances (Program: SIMDIS)	Between points
1. Cranial length	1-3
2. Cranial width	20-33
3. Nasal airway length	2-4
4. Nasal airway width	25-27
5. Nasal airway height	6-11
6. Mid-facial height	5-13
7. Lower facial height	13-15
8. Inter molar distance	23-29
9. Mandibular width-intergonion distance	22-30
10. Interorbital distance	24-28

NOTE: Point numbers are the numbers assigned to the digitized points which were used in making the measurements for this study.

Figure 5. Lineal measurements made on the lateral cephalograms are shown in broken lines. Numbers are the digitized point numbers which were used for computations as described in Table V.



LINEAL MEASUREMENTS OF THE LATERAL CEPHALOGRAM

FIGURE 5

TABLE VI

ASYMMETRY COMPUTATIONS
(Program: SIMDIS)

All computations are from the midsagittal plane, first to the patient's right, then to the patient's left.

	Right Between Points	Left Between Points
1. Cranial width	20-26	26-33
2. Nasal airway width	25-26	26-27
3. Intermolar distance	23-26	26-29
4. Interorbital distance	24-26	26-28
5. Mandibular width	22-26	26-30

NOTE: Point numbers are the numbers assigned to the digitized points which were used in making the measurements for this study.

Figure 6. The lateral dimensions as measured on P-A cephalograms are shown in broken lines. Right and left dimensions are measured from the lateral extreme to the midsagittal plane. Numbers represent the digitized point numbers which were used for computations as referred to in Tables V and VI. Point 26 is the midpoint of the Horizontal Plane.

LINEAL MEASUREMENTS OF THE POSTEROANTERIOR CEPHALOGRAM

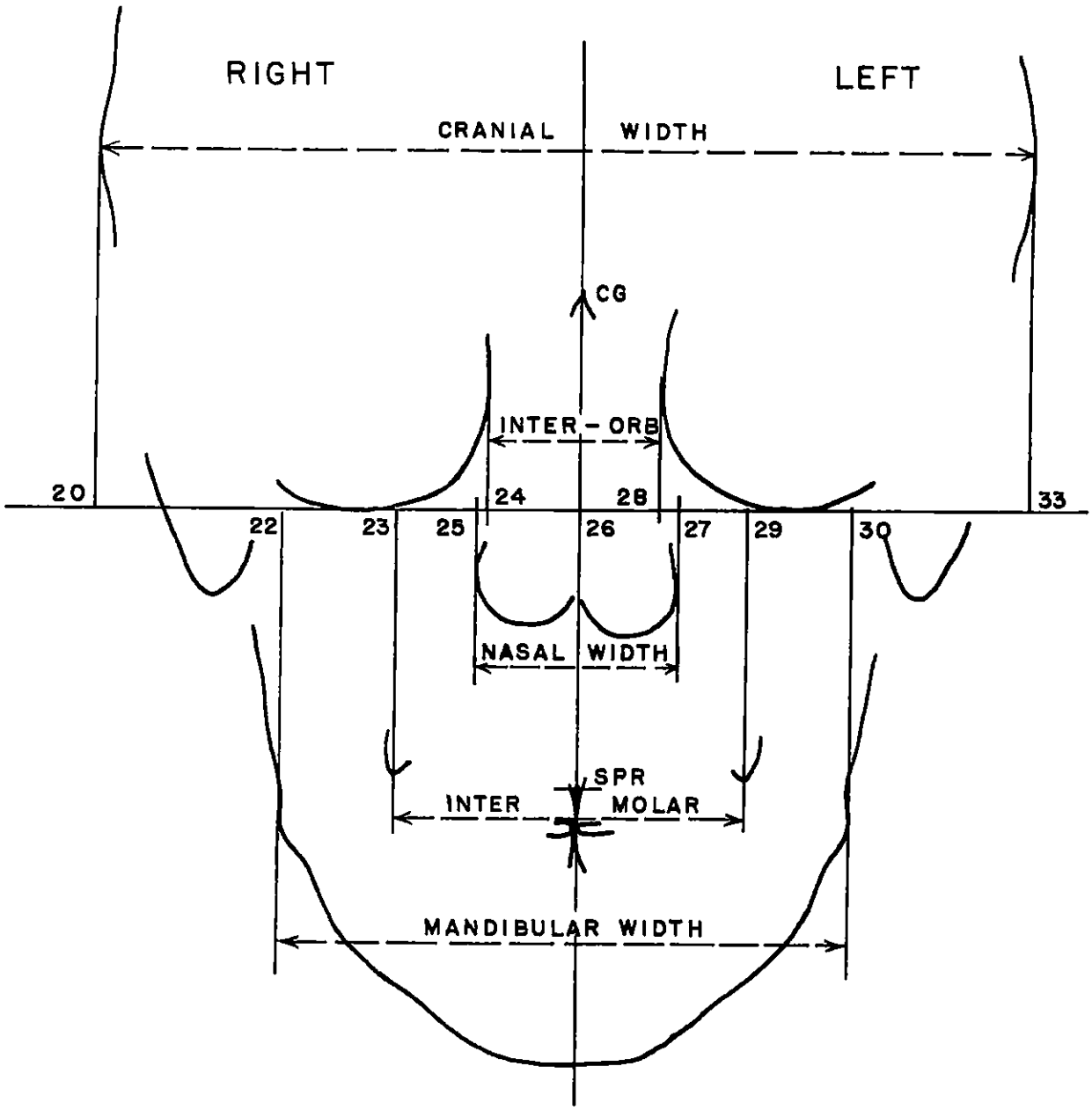


FIGURE 6

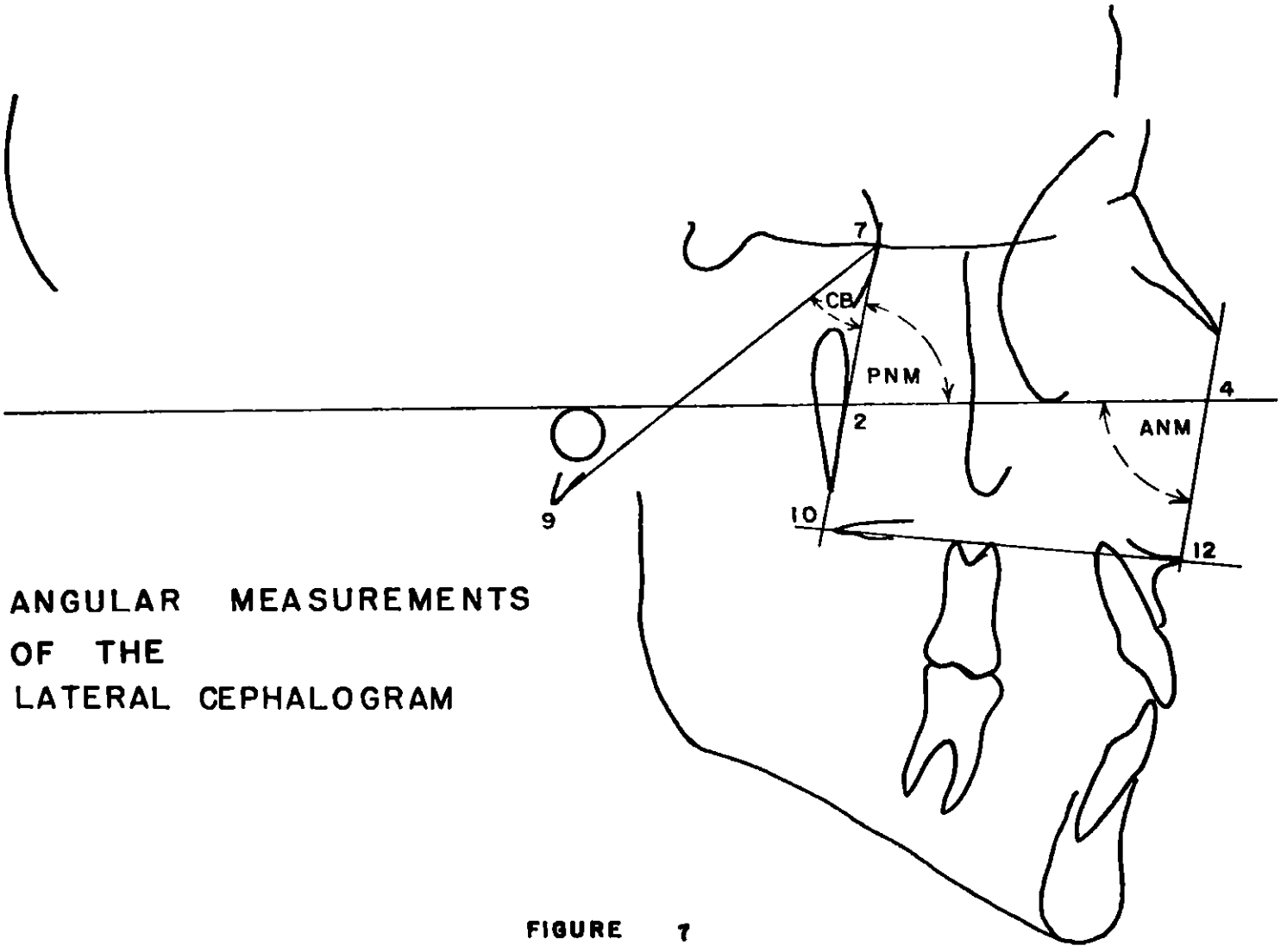
TABLE VII

ANGLE CALCULATIONS
(Between intersecting planes on cephalograms)
(Program: ANGL3)

Angle	Described by Points
1. MCB (to PNM) Midcranial base to posterior nasal margin	9-7-10
2. PNM (to FH) Posterior nasal margin to Frankfort	7-2-4
3. ANM (to FH) Anterior nasal margin to Frankfort	2-4-12

NOTE: Point numbers are the numbers assigned to the digitized points which were used in making the measurements for this study.

Figure 7. Angular measurements from the lateral cephalograms are indicated by broken line arcs. Numbers are the digitized point numbers which were used for angle computations as referred to in Table VII.



ANGULAR MEASUREMENTS
OF THE
LATERAL CEPHALOGRAM

FIGURE 1

lateral margins of the piriform aperture slope posteroirly. None the less, this seems to be a practical and fair method to describe the anterior margin.

The posterior nasal margin (PNM) was directed through the point SE and along the posterior borders (averaged) of the maxillary tuberosities. These are seen on the lateral cephalogram as the anterior margins of the pterygomaxillary fissures (PTM). This boundary was selected because anterior to it is clearly skeletal nasal airway and posterior to it would be soft palate and nasopharynx.

The midcranial base angle is similar to but should not be confused with that of Enlow (1971) in the Counterpart Analysis. The differences are in both the anterior and posterior legs. First, the PNM may not coincide with Enlow's PM line which passes from SE though the inferior point of the averaged PTM. Second, Enlow's cranial base leg goes from point SE to Bjork's Articulare, the point of intersection of the inferior surface of the cranial base and the averaged posterior border of the ramus.

Thus, one should not expect the same values to be obtained. However, there would probably be a very high correlation.

The mandibular plane passes through menton anteriorly and is tangent to the inferior margin of the mandible posteriorly.

Cranial length was obtained from the lateral cephalogram. Tangents from the most anterior and most posterior convexities of the neurocranium were dropped perpendicular to the Frankfort plane.

Length was measured on the Frankfort plane between the points of intersection of the tangent projections with the plane.

Cranial width was measured in a similar manner from the P-A cephalogram. Tangents to the most lateral convexities of the neurocranium were projected perpendicular to the Frankfort horizontal plane, as described below. Width was measured between these points on the Frankfort horizontal plane.

Horizontal measurements from the P-A cephalogram were all made on the horizontal plane between perpendicular projections from appropriate landmarks. For the orbits, the most medial point on the medial wall of each orbit was used for measuring interorbital dimension. This may or may not coincide with the medial point on the actual rim of the orbit. Likewise, the lateral walls of the nasal airway are the most lateral portions on the lateral wall of the nasal chamber and may or may not coincide with the piriform aperture.

RESULTS

For descriptive purposes, the control and experimental groups shall be designated as follows:

Bolton control group	BLTN	n = 20
Malocclusion groups:		
Angle Class I	CL1M	n = 20
Angle Class II	CL2M	n = 20
Angle Class III	CL3M	n = 12
Open Bite	OPBT	n = 12

See Tables VIII-X for the codes of the variables which were statistically analyzed. The measured variables were described in the previous section. Some variables were calculated and a discussion of these follows.

Cranial index (CI) is a ratio of cranial width (TCW) to cranial length (CL) multiplied by 100. While this ratio is quite similar to the anthropometric cephalic and cranial indices, the actual values computed might tend to be slightly larger due to a smaller denominator. This is due to the CL measurement being made in the horizontal plane. The formula for cranial index is:

$$CI = \frac{TCW}{CL} \times 100$$

Skeletal nasal airway index (NI) provides a ratio of the constructed frontal cross-sectional area of the airway to its

TABLE VIII

SUMMARY OF MEASURED LINEAR VARIABLES

Code	Definition
CL	Cranial length
RCW	Right cranial width
LCW	Left cranial width
TCW	Total cranial width
NL	Nasal airway length
NH	Nasal airway height
RNW	Right nasal airway width
LNW	Left nasal airway width
TNW	Total nasal airway width
ROW	Medial wall of right orbit to midline
LOW	Medial wall of left orbit to midline
TOW	Interorbital distance
RMW	Mesiobuccal cusp tip of right maxillary first molar to midline
LMW	Mesiobuccal cusp tip of left maxillary first molar to midline
TMW	Distance between mesiobuccal cusp tips of maxillary first molars
RMW	Lateral border of right mandible, at level of gonion, to midline
LMN	Lateral border of left mandible, at level of gonion, to midline
TMN	Width of mandible at level of gonion

TABLE IX

SUMMARY OF ANGULAR MEASURED VARIABLES

Code	Definition
ANM	Angle of anterior nasal margin to Frankfort plane
PNM	Angle of posterior nasal margin to Frankfort plane
MCB	Midcranial base angle

TABLE X

SUMMARY OF COMPUTED VARIABLES

Code	Definition
CI	Cranial index
NI	Skeletal nasal airway index
NAV	Skeletal nasal airway volume index
DELNM	ANM angle minus PNM angle
ACW	Cranial width asymmetry index
ANW	Skeletal nasal airway asymmetry index
AMW	Maxillary first molar mesiobuccal cusp asymmetry index
AOW	Interorbital asymmetry index
AMN	Maxillary width asymmetry index

length. "Constructed area" assumes a roughly triangular frontal cross-section of the skeletal nasal airway and the formula for its area is derived from the formula for the area of a triangle which is ½ its base times its height, i.e., ½ BH. Skeletal nasal airway width (TNW) is substituted for B in the formula and skeletal nasal airway height (NH) is used for H. This area is compared to skeletal nasal airway length (NL) in a ratio yeilding the following formula:

$$NI = \frac{TNW \times NH}{2NL}$$

Using the same values and rationale of the NI computation, a skeletal nasal airway volume index (NAV) was devised. The purpose is not to compute the volume per se, but to provide an index for comparison purposes. The formula used is:

$$NAV = \frac{TNW \times NH \times NL}{2000}$$

The factor of 2000 relates to the fact that measurements are in millimeters and a factor of 1000 (10 x 10 x 10) would convert these to centimeters. This also provides a more workable number. (The factor 2 is, of course, from the NI formula.)

A simple difference was calculated between the anterior nasal margin angle (ANM) and the posterior nasal margin angle (PNM). The resulting difference (DELNM) is determined by the subtraction below:

DELNM = ANM - PNM

An asymmetry index (after Mulick) was computed for right and left dimensions for certain craniofacial elements. These elements

are described in Table X. The formula used is:

$$\text{Asym.} = \frac{R-L}{R+L} \times 1000$$

Predominant deviation to the left produces a negative value; to the right, a positive value. A = 0 describes perfect symmetry.

Statistical Analysis

Various methods of analysis were utilized for this investigation. For this reason, a brief review of these methods seems appropriate.

Analysis of variance is a technique which breaks the total variation in a set of data into several components. The variance of each component is then analyzed to determine the degree of influence of that variance on the total variation. An F value is computed by the formula:

$$F = \frac{\text{among groups mean square}}{\text{within groups mean square}}$$

A critical F value is determined from printed tables or by computer. It is dependent upon the degrees of freedom associated with the numerator and denominator of the above formula and the desired confidence level.

If the computed F value exceeds the critical F value, one may conclude that the group means are significantly different.

In order to find out just which means are significantly different, multiple range tests, particularly the Scheffe procedure and Tukey Honestly Significant Difference (HSD) procedure, were

employed. These procedures are somewhat more stringent than the ANOVA. The ANOVA indicates the probability of differences in means. The Scheffe and HSD tests generate subsets of groups, no pair of which have means that differ by more than the shortest significant range for a subset of that size. Pairs of mesns not common to both subsets are deemed significantly different.

For assessing the relationship between two variables of a group, a Pearson correlation coefficient, r, measures the strength of the relationship. "r" values range from +1 (a perfect direct relationship) to a -1 (a perfect inverse relationship). If r = 0 there is no correlation whatever.

However, to get a true idea of a particular correlation, the "n" number must be considered. In this study, with our large value of n = 84, an r value of 0.3 is quite significant. This would not be true with a sample size of six or eight.

Table XI contains the ANOVA for certain measured variables. The means for each variable are listed under the appropriate group heading.

For this ANOVA, critical F values of 2.53 at p less than .05, and 3.65 at p less than .01 were determined. Significant findings are noted with the appropriate probability.

Similarly, an ANOVA for computed variables is shown in Table XII. The standard deviations are also shown because of their magnitude in the asymmetry index computations. These will be discussed later but it can be noted here that the significance of

TABLE XI

ANALYSIS OF VARIANCE FOR MEASURED VARIABLES

Variables	BLTN	CL1M	CL2M	CL3M	OPBT	Total Average	ANOVA	Significance*
CL	173.2	181.2	180.6	179.1	181.7	178.9	4.36	p less than .003
NL	58.7	57.4	58.3	58.9	59.2	58.4	0.68	NS
NH	46.5	46.3	45.8	47.9	47.6	46.7	0.93	NS
RCW	73.3	73.0	72.4	72.4	72.9	72.8	0.20	NS
LCW	74.2	70.1	70.8	72.8	68.3	70.9	3.28	p less than .05
RNW	15.3	15.1	14.9	15.1	14.2	15.0	0.94	NS
LNW	15.4	14.4	14.4	15.8	14.6	14.9	2.77	p less than .05
RMW	26.9	28.2	26.9	27.8	27.2	27.4	1.44	NS
LMW	26.9	26.1	26.5	28.9	26.7	26.9	3.03	p less than .05
ROW	11.8	11.2	11.2	12.4	11.7	11.6	1.17	NS
LOW	11.6	11.2	10.9	12.4	11.6	11.5	2.33	NS
RMN	47.5	49.3	47.9	48.0	50.6	48.5	1.86	NS
LMN	48.1	46.9	47.7	48.9	48.6	47.9	0.71	NS
ANM	78.4	80.4	82.8	77.8	85.6	80.8	5.29	p less than .01
PNM	75.1	78.2	81.3	74.6	83.0	78.4	5.66	p less than .01
MCB	39.8	41.4	43.0	39.5	45.3	41.7	3.36	p less than .05

*NS--No significant difference

TABLE XII

ANALYSIS OF VARIANCE FOR COMPUTED VARIABLES

Variable	BLTN n = 20		CL1M n = 20		CL2M n = 20		CL3M n = 12		OPBT n = 12		All Groups n = 84		ANOVA F	Significance*
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD		
ACW	5.9	34.2	20.4	38.6	11.1	32.4	-2.7	27.6	33.0	40.6	13.3	34.2	2.01	NS
ANW	-2.0	57.9	22.3	93.2	16.5	85.7	-21.9	68.7	14.0	82.2	3.6	77.2	0.90	NS
AMW	0.6	34.1	40.1	51.8	6.9	36.7	-18.7	59.2	10.5	64.1	10.1	46.9	3.25	$p < .05$
AOW	3.3	77.0	-0.5	77.2	12.0	62.4	-2.5	52.6	-4.1	62.9	3.3	67.1	0.15	NS
AMN	-6.9	31.2	25.8	38.4	1.8	36.7	-10.1	44.1	21.2	44.6	6.5	37.3	2.98	$p < .05$
NI	12.2	1.4	11.9	0.9	11.5	1.5	12.7	2.0	11.6	0.9	12.0	1.3	1.73	NS
CI	84.3	4.8	79.0	3.3	79.3	2.7	81.1	3.1	77.8	3.5	80.5	3.5	8.79	$p < .01$
DEL NM	3.3	5.7	2.1	5.2	1.5	5.4	3.2	4.8	2.6	6.4	2.5	5.4	0.33	NS
NAV	42.1	6.2	39.4	5.2	39.1	5.2	43.8	6.4	40.8	7.2	40.8	6.0	1.67	NS

* NS = No significant difference

the AMW and AMN variables must be suspect in the light of these huge variations.

The next step is to determine exactly which pairs of means are different. Both Scheffé's test and the HSD test were applied to those variables were found significant by ANOVA. The results of these tests are shown in Table XIII. Note that for LMW, the Scheffé test was slightly more stringent than the HSD test. This is probably due to the fact that the HSD is slightly more approximate when group n's are not equal. Also, note that upon the close scrutiny of the multiple comparison procedures, two of the variables, LNW and AMN, were found to have no significant differences.

Pearson correlation coefficients were computed for twenty-four variables, each to the other. Some of these variables obviously bear no relation to each other and these pairs were not considered, regardless of r values obtained. An example of such a pair would be right interorbital width (ROW) to left mandibular width (LMN). Instead, certain pairs were selected to answer specific questions.

Tables XIV, XV and XVI illustrate the extremely high direct correlations of right lateral variables to each other, the left lateral variables to each other, and the total bilateral variables to each other, respectively. Table XVII illustrates the relationships of the right lateral variables to the left lateral variables. Note there are almost no statistically significant

TABLE XIII

MULTIPLE RANGE TESTS* FOR VARIABLES SIGNIFICANT ON ANOVA

Variables	Significance	Test	Conclusions
CL	p .003	Both	BLTN is significantly smaller than CL1M, CL2M & OPBT.
LCW	p .02	Both	OPBT is significantly smaller than BLTN & CL3M.
LNW	p .03	Both	No significant difference between pairs.
LMW	p .02	Scheffé	CL1M is significantly smaller than CL3M
		HSD	CL1M & CL2M are significantly smaller than CL3M.
ANM	p .001	Both	CL3M & BLTN are significantly smaller than OPBT.
PNM	p .001	Both	CL3M & BLTN are significantly smaller than CL2M & OPBT.
MCB	p .01	Both	CL3M & BLTN are significantly smaller than OPBT.
AMW	p .02	Both	CL3M is significantly smaller than CL1M.
AMN	p .02	Both	No significant difference between pairs.
CI	p .001	Both	OPBT, CL1M & CL2M are significantly smaller than BLTN.

* Scheffé procedure and Tukey-HSD procedure

TABLE XIV

CORRELATIONS OF RIGHT VARIABLES

TO EACH OTHER

Variables	Variables				
	RCW	RNW	RMW	ROW	RMN
RCW	--	.46 ***	.31 **	.39 ***	.32 **
RNW	.46 ***	--	.42 ***	.26 **	.22 *
RMW	.31 **	.42 ***	--	.54 ***	.40 ***
ROW	.39 ***	.26 **	.54 ***	--	.22 *
RMW	.32 **	.22 *	.40 ***	.22 *	

r values shown above significance indicator
* = Significant at .05 level
** = Significant at .02 level
*** = Significant at .001 level
NS = No significant correlation

TABLE XV

CORRELATIONS OF LEFT VARIABLES

TO EACH OTHER

Variables	Variables				
	LCW	LNW	LMW	LOW	LMN
LCW	--	.52 ***	.24 *	.28 **	.45 ***
LNW	.52 ***	--	.47 ***	.26 **	.49 ***
LMW	.24 *	.47 ***	--	.31 **	.53 ***
LOW	.28 **	.26 **	.31 **	--	NS
LMN	.45 ***	.49 ***	.53 ***	NS	--

r values shown above significance indicator
* = Significant at .05 level
** = Significant at .02 level
*** = Significant at .001 level
NS = No significant correlation

TABLE XVI

CORRELATIONS OF TOTAL BILATERAL VARIABLES TO EACH OTHER

Variables	Variables				
	TCW	TNW	TMW	TOW	TMN
TCW	--	.44 ***	NS	.39 ***	.35 ***
TNW	.44 ***	--	.29 **	.27 **	.21 *
TMW	NS	.29 **	--	.48 ***	.34 ***
TOW	.39 ***	.27 **	.48 ***	--	NS
TMN	.35 ***	.21 *	.34 ***	NS	--

r values shown above significance indicator
* = Significant at .05 level
** = Significant at .02 level
*** = Significant at .001 level
NS = No significant correlation

TABLE XVII

CORRELATIONS OF RIGHT VARIABLES

TO LEFT VARIABLES

Variables	Variables				
	LCW	LNW	LMW	LOW	LMN
RCW	NS	NS	NS	.29 **	NS
RNW	NS	NS	NS	NS	-.26 **
RMW	NS	NS	.28 **	NS	NS
ROW	NS	NS	.30 **	.56 ***	NS
RMN	NS	NS	NS	NS	.48 ***

r values shown above significance indicator
* = Significant at .05 level
** = Significant at .02 level
*** = Significant at .001 level
NS = No significant correlation

correlations for these variables. These relationships will be evaluated in more detail in the Discussion.

Table XVIII shows the correlations of the angular variables ANM, PNM, and MCB. They are all highly significantly, directly, correlated. Also included are the computed values of CI and NI. It should be noted that the correlation of these variables to the angular variables are inverse, where correlations are significant.

TABLE XVIII

CORRELATION CRANIAL INDEX, NASAL INDEX AND ANGULAR VARIABLES TO EACH OTHER

Variables	Variables				
	CI	NI	ANM	PNM	MCB
CI	--	.30 **	-.26 **	-.23 *	-.34 ***
NI	.30 **	--	NS	NS	-.28 **
ANM	-.26 **	NS	--	.62 ***	.76 ***
PNM	-.23 *	NS	.62 ***	--	.42 ***
MCB	-.34 ***	-.28 **	.76 ***	.42 ***	

r values shown above significance indicator
* = Significant at .05 level
** = Significant at .02 level
*** = Significant at .001 level
NS = No significant correlation

DISCUSSION

An original intent of this study was to compute the volume of the skeletal nasal airway, without regard to soft tissues, from readily available lateral and P-A cephalograms. The difficulty of this task became increasingly apparent.

Montgomery (1979) had calculated nasal airway volumes using computed tomography, which provided him with fourteen to seventeen serial frontal radiographs, in addition to a lateral cephalogram. He reported a one percent error in his calculations. However, in calculating his error, the individual errors had been arithmetically averaged. That is, an error of +5% and an error of -5% would have been translated to a 0% error. If the individual errors were given absolute values, neither positive nor negative, an error of 6.43% would have been obtained.

This came to light after the present study had been started, however, and it was decided to continue. A simple feasibility study was undertaken to determine if more detailed and exacting study was warranted.

Three human adult skulls were utilized for the feasibility study. Lateral and P-A cephalograms were made. The nasal volumes were isolated with wax. Number 28 green casting wax sheets were used to reproduce the anterior nasal margin. At that time, the

anterior nasal margin was defined as a plane which was perpendicular to the midsagittal plane and passed through nasion and the anterior nasal spine. All smaller openings and foramina of the nasal airway were also sealed with the same wax. The nasal airway was then filled with very small (Number 9) lead shot inserted through the posterior choanae. The shot was levelled off in a plane which duplicated the posterior nasal margin as described earlier in this report. The lead shot was then removed and its volume was measured in milliliters, in a graduated cylinder, and the volumes were recorded. Although this method was somewhat approximate, it was considered to be accurate enough to determine the feasibility of the investigation.

The cephalograms were traced in the manner earlier described and submitted to the Computer Section of the Orthopedic Department of University Hospitals, Case Western Reserve Universty, Cleveland, Ohio. That department was selected becuase it had considerable experience in computing volumes from radiographs.

However, using Montgomery's methods of calculation and, later, supplementing with their own methods, an experimental error of no less than 20% could be obtained. The staff of the Computer Section suggested the only way to achieve greater accurary would be to have a third radiographic view. This was not pursued for two reasons:

1. a third view was not available from existing records, and,

2. the intention of the investigation was to make assessments from records which might logically be available in the office of a practicing orthodontist.

However, a skeletal nasal airway volume index (NAV) was suggested to provide some insight into the relationships of nasal volume.

Another original intention was to include variations vertical symmetry in the study. This was abandoned because of the difficulty in making precise measurements. Baumrind and Frantz (1971) have pointed out the error in making measurements which are not the result of crossing lines forming a definite intersection. Ramal length, for instance, often meant selecting a point along a tangent. This simply was not consistently accurate.

In evaluating the skeletal nasal airway as a whole, two computed variables were used, skeletal nasal airway index (NI) and skeletal nasal airway volume index (NAV). The analysis of variance (ANOVA) technique was employed to test the null hypothesis that these indices were from the same population. Rejection of the null hypothesis would indicate, at the 95% confidence level, that the means of the indices were significantly different, and that they were not of the same population. In other words, the intent is to establish whether or not the indices under investigation are truly different or only variations within a population. No significant differences in means were revealed at the .05 level. Therefore, one must conclude that the differences observed are those which might normally be expected within a given population and do not represent significantly different groups or populations.

With the computed variables showing no significant differences, an examination of the individual dimensions used in the formulae for the computed variables was undertaken. The idea was that if these evaluations of the airway as a whole showed no particular differences perhaps greater variation might be found in the individual dimensions of length, height and width. If airway width was very narrow in a dolichocephalic individual and very wide in a brachycephalic individual, would there be concommitant changes in the nasal length as a compensation?

ANOVA revealed only one dimension, left nasal airway width (LNW), as being significantly different. LNW was then subjected to the more exacting Scheffé's and HSD multiple range tests to determine in which group it was significantly different. These tests, however, revealed no significant differences. (The reader is referred to the Results section for a more detailed discussion of how this can happen.) Therefore, there does not appear to be any variation in individual dimensions which would be anything more than what would normally be expected in any group or population.

These are not the relationships the author had forseen. Associating brachycephalic head form with Class III occlusion and dolichocephalic head form with Class II or open bite occlusion, one would expect to see a consistent variation of nasal airway form to type of occlusion.

While the NI was found upon ANOVA not to be significantly different for various occlusion groups, it did correlate highly and

directly to cranial index (CI), using the Pearson correlation technique. This represents an expected relationship of the skeletal nasal airway and head form. NI also was found to correlate quite highly with the midcranial base angle (MCB) in an inverse relation. This means that as NI increases (nasal length decreases or nasal width increases), MCB decreases. However, NL and MCB were not significantly correlated and skeletal nasal airway width (TNW) was weakly and inversely correlated ($r = 0.17$, $s = 0.12$) to MCB. This correlation does not imply a direct cause and effect relationship, nor does it deny it. Logically, these correlated changes are the result of a set of other, multifactorial influences which affect both nasal width and midcranial base angle. These influences could include such things as brain development and flexure between the midventral brain axis and the cerebral hemisphere.

The value of asymmetry index as used in this study, is somewhat limited. In computing means and standard deviations for the indices, incredibly high standard deviations in relation to means, occurred quite routinely. Because this indicates extremely large ranges, the value of the asymmetry indices is somewhat limited. It does support Woo's (1931) observations of widespread craniofacial asymmetry and dominance of the right side. There are however, two trends which were consistent.

First, in the Class III malocclusion group, every single index is negative. That is, the left had dominance, i.e., was larger, than the right. While the magnitude of these differences

may not be highly significant, dominance is interesting. The author is unable to suggest why this might occur. Second, molar width asymmetry was found to be significantly less in Class III malocclusions than in Class I malocclusions. Again, however, the author would advise that, because of the large ranges of asymmetry, this evidence is probably of little clinical value.

Correlations of individual measurements of unilateral dimensions were more consistent. There were extremely high correlations of measurements within right and left groups. All correlations were direct so that if one dimension was larger, all tended to be larger. Again, this does not imply a cause and effect relationship but it would explain how the facial elements measured might follow the lead of width of the cranial base.

Correlations of total width dimensions were similarly high with the single exception of interorbital distance correlated to mandibular width at the level of gonion.

Right unilateral dimensions to left unilateral dimensions were generally not significantly related at all. Indeed, this is the whole basis for asymmetry. Only two were significantly related, right and left orbital distances and right and left mandibular width. The orbits are associated with cranial nerves and are closer to the cranial base and this might explain why there is less variation, right to left. It should be noted that two other correlations which were statistically significant were rejected as spurious results, occurring because of chance. They were right

orbital distance to left mandibular width and right cranial width to left orbital distance.

A few additional relationships should be mentioned which were not specifically being studied. They involve the angular measurements of anterior nasal margin (ANM), posterior nasal margin (PNM), and midcranial base (MCB) to the Frankfort horizontal plane.

These three angles correlated very significantly with each other in a direct relationship. Also, they were significantly, inversely, related to both CI and NI. The author believes that these relationships are influenced by many factors but that the brain and cranial base may be the primary influences by which these angles are varied.

SUMMARY AND CONCLUSIONS

There is much discussion of the part the airway plays in orthodontics. However, almost all "airway" literature concerns the nasopharyngeal and oropharyngeal region. Another area of increasing concern to the orthodontist is bilateral symmetry. Again, not a great deal of study had previously been undertaken in this area.

The question of whether the structure of the nasal airway area is related to types of occlusion gave rise to the present study. By not considering the soft tissues, we were looking at the framework of the nasal airway, much as one might look at the iron framework of a building under construction, before a facade is built. The notion of symmetry considerations began with observing the asymmetry of the airway and it was decided to include other craniofacial lateral dimensions as well.

Records of eighty-four individuals were selected and broken down into five groups. The first was a control group of Class I occlusions for whom orthodontic treatment was not indicated. The remaining four groups had malocclusions which were treated, however records for this study were obtained before treatment began.

Records consisted of lateral and P-A cephalograms. Measurements were made directly from the cephalograms and some computed variables were included. All variables were statistically

analyzed by analysis of variance, Scheffe's multiple range test and Tukey's HSD test, or Pearson correlation. Some variables were included in all tests. After evaluation of the data, the following conclusions were drawn:

1. In evaluating the skeletal nasal airway as related to control and malocclusion groups, no significant differences were found for either the computed variables, skeletal nasal airway index and skeletal nasal airway volume index; or the measured variables, skeletal nasal airway length, skeletal nasal airway height, and skeletal nasal airway width. The differences were not of sufficient magnitude to define separate populations. Rather, the differences were within the limits of variation which might be expected within a population.

2. There existed a high correlation of skeletal nasal airway index with the midcranial base angle. This may or may not be a direct cause and effect relationship. More logically, it is a mutual response to a multifactorial influence which could include such factors as development of the midbrain and cerebral hemisphere.

3. Craniofacial asymmetry is widespread and extremely variable. The only significant relation to the control or malocclusion groups of this study was that Class III malocclusions had larger dimensions to the left.

4. Unilaterally, right measurements are highly correlated, as are left measurements. Correlations of right measurements to left are not highly correlated except for the orbits and mandible. It is this low correlation which relates to asymmetry. The orbits are close to the cranial base and are associated with cranial nerves. This might explain the high correlation of right and left for the orbits. The rationale for mandibular symmetry is more conjectural but might be related to function. The mandible may function better with a higher degree of symmetry.

5. A high direct correlation exists between the angles of the anterior nasal margin, posterior nasal margin and midcranial base. The high correlation of the anterior and posterior nasal margins might be expected as they are associated with the nasomaxillary complex. The high correlation of the midcranial base angle is probably the result of a common, multifactorial influence to all elements of the angles.

6. The present study is an initial one and its general nature places some limitations on the interpretation of its results:
   a. In selecting the sample, differentiation of various types of Class II malocclusions (after Enlow et al., 1971), might have proved productive. Likewise, the open bite group could be broken down by Angle classification.

   b. The possibility exists that cephalometric landmarks of greater biologic significance could be selected. There may be different radiographic points which would more meaningfully assess the airway.

   c. No attempt was made to test the positional relationships of the skeletal nasal airway to the cranial base or dentition.

   d. A breakdown of the sample by sex could provide additional discriminatory data, because it is known that dimensional differences exist in the nasal region that relate to sexual dimorphism.

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