EVALUATION OF CRANIOFACIAL MORPHOLOGY AND OCCLUSION IN PATIENTS WITH NASAL OBSTRUCTION

by

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ABSTRACT

Impaired breathing is known to represent a significant factor contributing to the underlying etiology of malocclusion during childhood growth. However, not all breathing-compromised children develop a severe malocclusion or other facial deformity. The objective of this study is to determine if characteristic combinations of morphologic and occlusal features characterize those individuals who do develop facial dysplasia compared to controls. If such anatomic features are found to exist, the second objective is to test a hypothesis that specific types of malocclusions (shallow overbite, narrow upper arch) found in nasally-impaired patients relate to certain intrinsic morphologic combinations. Using lateral and PA cephalograms, models and rhinomanometric measurements, craniofacial morphology and occlusal pattern were evaluated in 71 patients having nasal obstruction as diagnosed by an otolaryngologist. These patients were compared with an equal number of age and sex matched controls from the Bolton Study without any history of nasal impairment. The patient group demonstrated characteristic combinations of craniofacial deformities and malocclusions which mainly comprised certain vertical and transverse morphologic components. The younger individuals showed a lesser

expression of malocclusion development and morphologic deformities. This point is significant, since an opportunity is thereby revealed for early prediction of a dysplasia that likely will develop later in childhood if these particular and characteristic combinations of morphologic components exist in a given child. Thus, an added goal of this study was to determine, using longitudinal data, if it is feasible to anticipate a future dentofacial deformity with an acceptable degree of accuracy. This would allow early clinical interception that could avert or minimize the severity of a variant growth pattern that otherwise would be expected to occur. From our limited data, the existence of statistically high correlations among certain anatomic combinations with specific malocclusion types suggests that such a predictive opportunity is feasible.

DEDICATED

to

My husband, Chiu-Po Chan, and my daughter, Ling-Yee Chan, for their endless love and understanding.

My sister, Man-Ting Cheng, and my brother, Uei-Cheng, for their constant encouragement and love.

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INTRODUCTION

Impaired breathing is known to represent a significant factor contributing to the underlying etiology of malocclusion during childhood growth. However, the results of several clinical studies (Huber and Reynolds, 1946; Leech, 1958; McNamara, 1981) indicate that the craniofacial relationships associated with mouth breathing are variable and can be associated with a number of facial patterns. Experimental studies using primates carried out by Harvold and associates (Harvold, et al., 1973, 1981; Harvold, 1975, 1979; Miller and Vargervik, 1979, 1980) also showed that varied dentofacial forms and malocclusions can result subsequent to the establishment of mouth-breathing. The variety of skeletal and dental configurations observed in animal experiments and human mouth breathers have been presumed to be secondary results of neuromuscular adjustments required to maintain adequate respiratory function (Miller and Vargervik, 1979; McNamara, 1981).

Individual neuromuscular activities have been reported to have close relationship with facial patterns. It has been observed by numerous clinicians that those facial types which exhibit the stronger musculature are characterized by deep bite, low mandibular plane, and a brachyfacial form (Bench, 1977). Brachyfacial persons having a larger mandibular curvature and a small gonial angle tend to show

a more anteriorly oriented and biomechanically efficient muscular pattern than among dolichofacial persons (Ingervall and Thilander, 1974). Since varied facial pattern showed different neuromuscular activities, a lack of a consistent type of malocclusion in nasally impaired patients might relate to their varied intrinsic facial patterns.

Varied facial patterns are composed of certain intrinsic morphologic combinations. Enlow (1982) qualitatively described the human face as the aggregate sum of all the many balanced and imbalanced craniofacial parts combined into a composite whole. A specific facial pattern has close association with a specific headform, basicranial flexure, nasomaxillary length, palate shape, ramus inclination and relative bony arch sizes (Enlow, 1982; Bhat and Enlow, 1985). Using both lateral and PA cephalograms to evaluate craniofacial morphology can provide more information about facial patterns rather than observing only single linear or angular measurements. Although PA cephalograms provide valuable information on the transverse dimensions of facial pattern, there is presently inadequate information for the quantitative measures of the transverse craniofacial variables in nasally impaired patients. Using lateral, PA cephalograms and models to evaluate craniofacial and occlusal patterns 3-dimensionally, and to further examine the relationships between certain types of malocclusion and

specific craniofacial morphologic combinations may help us better understand the effects of nasal airway impairment on craniofacial form and occlusion.

Lack of objective quantification of the respiratory mode was found to be related to the inconsistent, individualized craniofacial and occlusal patterns noted in patients with nasal obstruction (Vig, et al., 1981; Warren, et al., 1984). Rhinomanometry was regarded as able to provide clinicians with a more quantitative and accurate means to diagnose nasal obstruction in nasally impaired patients (Vig, et al., 1981). The purpose of the present study, therefore, is to utilize lateral and PA cephalograms, models and rhinomanometry to anatomically and functionally address the following two points.

1. Determine if characteristic combinations of morphologic and occlusal features characterize those individuals who do develop facial dysplasia compared to controls.
2. Test a hypothesis that specific types of malocclusions found in patients with nasal obstruction relate to certain intrinsic morphologic combinations.

LITERATURE REVIEW

The classical description of dentofacial morphology in a nasally impaired patient has been titled an "adenoid face" or a "long face syndrome". Such patients usually present with a mouth-open posture, nostrils that are small and poorly developed, a short upper lip, prominent-appearing upper incisors, a pouting lower lip, and a vacant facial expression. Mouth breathers have been classically described as possessing a narrow, V-shaped maxillary arch, a high palatal vault, a steep mandibular plane angle, and a vertically long lower one-third facial height. Early explanations of the etiology of malocclusion and the "adenoid face" were on the basis of a positive causal relationship between adenoids and mouth breathing leading to dental and facial changes. These explanations can be grouped into three general catagories: 1) compression, 2) disuse atrophy, and 3) altered air pressure.

1) Compression. The classical compression theory was first proposed by Tomes in 1872. He suggested that the characteristic narrowing of the upper arch associated with enlarged adenoids was the result of an unbalanced musculature related to low tongue position, a position in which it could not exert adequate buccal pressure to counteract inward forces from the lips and cheeks on the

maxilla. This explanation was based on clinical experience without attempting to measure differences in characteristic relationships. Harvold (1972), however, by the placing of an acrylic block under the palate to permanently depress the tongue in experimental animals, found an increased lower facial height and Class II malocclusions.

2) Disuse Atrophy. The second mechanism said to cause an alteration in the maxillary arch was that of inactivity of the nasal cavity. Nordlund (1918) stated that obstruction of nasal breathing due to adenoids causes the nasal cavity to undergo disuse atrophy. "Primacy of the functional matrix in orofacial growth" (Moss,1968) supported the idea of inactivity as a mechanism by which mouth breathing could alter dentofacial form. He stated that, in the case where congential bilateral choanal atresia caused an absence of naso-respiratory function, marked underdevelopement of the functional space occurs. Linder-Aronson (1979) also found that the cephalometric sagittal depth of the bony nasopharynx was influenced by the mode of breathing. In children who were predominantly mouth breathers, bony nasopharynx depth was smaller than that found in nasal breathers of the same age. Following a change to nasobreathing, the depth of the bony nasopharynx became normalized. However, using otolaryngologic, respiratory and cephalometric examinations, Bushey (1979) found the mean

for linear and angular bony nasopharyngeal depth to be similar in normal and mouth breathers. Instead of nasopharyngeal depth, he found that the nasopharyngeal anglular height was smaller in mouth breathes than in normal breathers, and he suggested that sagittal height in mouth-breather groups might be a more significant factor in restricting nasopharyngeal space for the adenoids than sagittal depth.

3) Altered Air Pressure. An explanation of a third mechanism by which adenoids and mouth breathing can affect dentofacial form is that air pressure within the nasal and oral cavities becomes altered. Kantorowicz (1916) believed that the increased negative air pressure difference between the oral and nasal passages in mouth breathers leads to the development of a deep palatal vault. The increased negative air pressure in the nasal cavity or oral air pressure against the palate was presumed to be sufficient to interfere with normal palatal development. This statement was descriptive in nature without measuring the amount of airflow or direct inspection of (radiographically) the nasopharyngeal area. Hinton and his associates (1986) could not verify this theory in their study. They used a simple mechanical model of the airway to describe pressures during simulated normal and impaired respirations, and the results showed that when nasal cross-

sectional area was greater than 0.1 cm^2, pressures associated with breathing were not excessive.

Recent studies of head posture and craniofacaial morphology (Solow and Tallgren, 1976; Solow, et al., 1984; Vig, et al., 1980) suggested that a changed head posture might also be responsible for the characteristic craniofacial morphology of nasally impaired patients. The similarity of the morphologic characteristics of subjects with obstructed airway due to adenoids and subjects with a large craniocervical angulation led Solow and Kreiborg (1977) to propose a soft-tissue stretching theory to account for the association between head posture, craniofacial morphology, and airway obstruction. This theory was supported by a later study of Solow and Greve (1979). Solow and Greve examined 24 children, aged 4 to 12 years, before and after adenoidectomy. Cephalometric recordings of natural head position and rhinomanometric recordings of nasal respiratory resistance were obtained for each subject. Before adenoidectomy, a large craniocervical angulation was seen in connection with a large nasal respiaratory resistance and a narrow passage between the adenoid tissue and the choanae. After adenoidectomy, reduction of craniocervical angulation occured in the children in whom nasal respiratory resistance was reduced. Woodside and Linder-Aronson (1979) also support the soft tissue stretching theory in an

examination of a group of 16 children before adenoidectomy and then four months postsurgically compared these to a matched control group of 16 children. Presurgically, the position of the head in relation to true vertical was about 2° higher in the adenoid children than in the controls. Postsurgically, the difference had disappeared. Vig and colleagues (1980) showed that experimentally induced interruption of both nasal respiration and visual feedback in humans resulted in reflex adaptations of head posture. They felt that permanent changes in musculoskeletal relations might be produced if the postural adaptation is sustained for a sufficient time during growth.

Even though the above theories present functional and morphologic explanations of mechanisms related to the etiology of adenoid face, a controversy still exists as to whether there is an actual, direct causal relationship between mouth breathing and altered dentofacial form. Reviewing previous studies, Shaughnessy (1983) pointed out that the reason there has been much debate on this topic is because alterations of nasorespiratory function during growth do not predictably and consistently alter dentofacial morphogenesis. Linder-Aronson (1970) found that only 26 percent of 81 mouth-breathers had adenoid faces. Leech (1958), in a study of 500 patients being treated for upper respiratory problems, found that 19 percent were classified as

mouth breathers. More than 60 percent of the mouth breathing patients were Class I, 25 percent were Class II, and 10 percent were Class III. Thus, the occlusions of patients with obstructed respiratory function covered the entire spectrum, with Class I malocclusion rather than a Class II malocclusion occurring most frequently. Linder-Aronson (1970) also found normal anteroposterior relationships between upper and lower jaws in mouth breathers. Watson, et al., (1968), in a study of relationships among nasal resistance, skeletal classification, and mouth breathing, found that both the magnitude of nasal resistance and the presumed or clinically determined breathing pattern was independent of skeletal classification. The animal experimental studies performed by Harvold and associates (1973, 1981) also demostrated the pronounced individual variation in skeletal and dental changes. Harvold placed latex plugs into the nasal openings of a group of young rhesus monkeys, and the animals gradually adapted from a nasal respiratory pattern to an oral one. The first noticeable changes were functional in nature in that the animals altered their neuromuscular activity to accomplish oral breathing. Although some skeletal traits were common among the experimental group (such as increased face height and a steeper mandibular plane with a large gonial angle), the occlusal and muscular adaptations were not uniform or

consistent among the experimental animals. The specific morphologic change depended on the preferred positioning and movements of the tongue and mandible to accommodate oral respiration. In other words, when the monkeys rotated their mandible posteriorly, they developed Class II malocclusions and skeletal open bites; when they postured their tongue and/or mandible forward, they developed Class III malocclusions, anterior cross-bites, and bi-alveolar protrusions.

Individual neuromuscular activities have been reported to have close relationship with facial patterns. Tomer and Harvold (1982) induced oral respiration in 8 growing rhesus monkeys which led to a lowering of the chin, steeper mandibular plane angle, and an increase in the gonial angle as compared with 8 control animals. However, because the posterior border of the ramus underwent gradual remodeling and maintained normal inclination, it was assumed that the masticatory muscles were not significantly affected by the altered respiratory function. Since the position of the chin and the inclination of the mandibular plane were controlled by the balance between the suprahyoid and the orofacial muscles, they concluded that the ramus with its masticatory muscles and the chin with its suprahyoid and orofacial muscles represent two relatively independent systems. Holik (1968) has reported a teleroentgenographic study of

the relationship between mouth breathing and development of the oral musculature. In 85 percent of the children who were habitual mouth breathers, underdevelopment of the oral musculature and varying degrees of distocclusion were observed. Holik concluded that a definite relationship existed between habitual mouth breathing and a lesser degree of neuromuscular development in the oral cavity which might be a causative factor in distoclusion. Möller (1966) found in adults that the amplitudes of temporal and masseter muscle contractions were greater in cases with anterior inclination of the mandible and a small gonial angle. Tallgren (1970) found greater alveolar bone resorption in those wearers of complete dentures who had a rectangular shape of the face with a large mandibular curvature and a small gonial angle. Ingervall and Thilander (1974) also reported that brachyfacial persons having a large mandibular curvature and a small gonial angle tended to show a more anteriorly oriented and biomechanically more efficient muscular pattern than among dolichofacial persons. According to clinical observation, Bench, et al., (1977) pointed out that facial types which showed the stronger musculature were characterized by a deep bite with a low mandibular plane type of brachyfacial structure. While those with a high mandibular plane angle, vertical pattern, open bite, and dolichofacial charcteristics had a weaker

musculature and were less able to overcome the adverse orthodontic treatment forces that tended to open the bite and rotate the mandible.

Varied facial patterns tend to show a close association with specific combinations of composite regional counterparts. Enlow (1982) qualitatively described the dolichocephalic head form as associated with a leptoprosopic facial type, obtuse cranial base flexure, long narrow maxillary arch, and a deeper, more narrow palate. On the other hand, the brachycephalic head form is associated with a euryprosopic facial type, closed basicranial flexure, a short, wide maxillary arch and a wide palate. Bhat and Enlow (1985) used the cephalometric counterpart analysis to evaluate relationships between head form and their related anatomical counterparts. They found that the dolichocephalic head from had a significantly higher incidence of mandibular retrusive effects as a result of the inclination of the middle cranial fossa, ramus orientation, relative vertical nasomaxillary length and relative bony arch sizes. Cranial base flexure was also reported to have a close relationship with specific types of craniofacial morphology and malocclusion. Ricketts (1954) and Bergland (1963) demonstrated a positive correlation between the cranial base and nasopharyngeal depth. The more obtuse the cranial base, the greater was the nasopharyngeal depth.

By measuring transverse, anteroposterior and vertical dimensions from lateral and PA cephalograms, Bushey (1977) found that an upward deflection of the anterior cranial base and a forward positioning of the glenoid fossae were common anatomical characteristics in the Class III skeletal facial form and in posterior crossbite.

Some authors also described the varied degree of influence of the obstructive airway on different facial patterns. Linder-Aronson (1970) using cephalometric analysis, an otolaryngologic evaluation and measurements of nasal resistance, demonstrated that enlarged adenoid restriction of the airway would result in mouth breathing if the individual had a high, narrow face. In his study, the group with large adenoids without symptoms of mouth breathing had the widest facial width, and the group with large adenoids with obstructed nasal breathing had the narrowest facial width. Linder-Aronson and Backström (1960) showed that children with long, narrow faces and high, narrow palates tended to have a greater nasal resistance to airflow than those with short, wide faces and low, broad palates. Bushey (1979) observed that nasally obstructed patients with long narrow facial patterns, a high lower anterior facial height, a smaller facial axis and a tapered face had poorer prognosis following adenoidectomy compared with nasally obstructed patients with normal facial

patterns.

Not only because of an individual's unique adaptation to aberrant muscle function, but also because of a lack of objective quantification of the respiratory mode in both normal subjects and clinical patients was confusion about the effects of nasal airway impairment on facial growth considered to exist (Vig et al., 1981; Warren, 1984). Clinically observed lip posture and the existence of lip separation were not accepted as valid criteria for the determination of mouth breathing or nasal obstruction Bushey, 1979; Vig et al., 1981; O'Ray, 1982). They suggested the use of a simultaneous nasal and oral respirometric technique (SNORT) to quantify the respiratory mode. In studies of airway obstruction it has been customary to express degrees of obstruction in terms of nasal resistance. A modification of Ohm's law (resistance = pressure/flow) can be applied to such airflow studies (Watson et al., 1968; Vig, et al., 1981). Watson and colleagues (1968) reported that the incidence of clinically observable mouth breathing was found to be much greater among 13 subjects with a nasal resistance above 4.5 cm. H_2O/liter/second (77 percent) than among the remaining 38 subjects with a nasal resistance below 4.5 cm. H_2O/liter/second (26 percent). McCaffrey (1979) used uninasal anterior active mask rhinomanometry to assess the

nasal airflow of clinical patients. He found that clinical symptoms of nasal obstruction usually occur when total nasal resistance (after 1 percent phenylephrine) is greater than 3.0 cm. H_2O/liter/second. Although the critical threshold of nasal resistance that produces mouth breathing is still uncertain, most researchers are agreed that the nasal airway resistance (NAR) is a useful index for nasal airway efficiency (Vig, 1985).

Varied facial patterns and malocclusions found in patients with nasal obstruction are considerd to be related to individualized, unique neuromuscular adaptations to aberrent muscle function and a lack of a objective way to determine the level of nasal obstruction. The close relationship between the facial patterns and their neuromuscular activities suggest that a pre-existing, specific facial pattern might have a tendency to result in certain types of malocclusion. If such relatioships exist, it suggests the possibility that a future dentofacial deformity can be anticipated with an acceptable degree of accuracy. This early diagnosis of a likely future dentofacial deformity could prevent or minimize continuing detrimental effects of nasal impairments on craniofacial morphology and occlusion with appropriate clinical intervention.

METHODS AND MATERIALS

Sample

In order to characterize craniofacial and occlusal patterns in nasally impaired patients and to evaluate the relationships among certain craniofacial combinations and specific types of malocclusion, 71 nasally impaired patients and an equal number of controls from the Bolton Study were utilized in this study.

The nasally impaired sample comprised of 41 male and 30 female patients. The age range was 3.8 to 35.8 years, with a mean of 11.1 years (Table I). The records included 71 lateral and 55 PA cephalograms, 70 models and 46 cases having rhinomanometry examination. The sources of these samples were varied. Twenty-five cases were obtained from the Case Western Reserve University Orthodontic Department; 22 cases were obtained from private orthodontic practitioners; 14 cases were referred from otolaryngologists, and 10 cases responded directly to notices posted in our school's dental clinics. Cephalometric cephalograms and models were taken from Case Western Reserve University Orthodontic Clinic for 49 cases, and 22 cases were obtained from four private orthodontic practitioners.

All of the cases in the nasally impaired sample have been evaluated by otolaryngologists to confirm passive

airway obstruction resulting from at least one of the following airway pathologies: (1) adenoid hyperplasia; (2) tonsil hyperplasia; (3) turbinate hyperplasia; (4) deviated nasal septum; (5) allergic rhinitis. The nasally impaired sample was further grouped into two subsamples on the basis of having received or not received orthodontic treatment. Subsample A compromised of 37 cases having no history of any orthodontic treatment. All of the cases in subsample A had lateral cephalograms, models, and rhinomanometric data, and PA cephalograms were available in 34 cases. Subsample B comprised of 34 cases, all of whom were under orthodontic treatment. All of the cases in subsample B had lateral cephalograms, 33 cases had models and 21 cases had PA cephalograms available. Initial cephalometric radiographs and models were taken before orthodontic treatment was started. Nine cases in subsample B had rhinomanometric records available, and these were taken during the period of orthodontic treatment.

The control sample was selected from the longitudinal records of the Bolton Study (Case Western Reserve University, Cleveland, Ohio), and had age and sex distributions comparable with the nasally impaired sample (Table I). The age range was 3.9 to 33.1 years, with a mean of 11.0 years. The control sample met the following criteria: (1) no history of orthodontic treatment; (2) no

TABLE I DISTRIBUTION OF SUBJECTS BY AGE, SEX AND RACE

	Age (years)		Sex		Race	
	Mean ± SD	range	Male	Female	Black	Caucasian
Nasally impaired Subjects	11.1 ± 4.6	3.8 to 35.8	41	30	15	56
Control Subjects	11.0 ± 4.4	3.9 to 33.1	41	30	0	71

history of mouth breathing or any airway impairments; and (3) each case had a complete set of records available including lateral and PA cephalograms, and maxillary and mandibular models.

Cephalometric measurements

All tracing was done by the same investigator. Tracings of all cephalograms were made on .005 matte acetate tracing paper using a Pental pencil with 0.5 mm drawing leads. All of the angular and linear values were made using a Baum protractor. In cases of double head film shadows, geometric means were used for determining the course of the lines. The linear values were measured and read to the nearest 0.5 mm and the angular values to 0.5 degree. The following landmarks were identified on each lateral (Fig. 1) and posteroanterior (Fig. 2) cephalograms: Ad, Psp, Rhi, Oc, Ar, Se, Pm, Ba, Na, S, Or, Po, Me, Ans, Pns, Go, Ro, Pog, Gn, A, B, IPr, Cg, Lo, Om, Zy, Nc, Sp, Ga. Definitions for these various landmarks are presented in Table II.

From the above landmarks, 49 linear, angular or ratio values were derived. These variables included one linear measurement (ND) related to the nasopharyngeal airway size; 33 linear, angular and ratio measurements related to the craniofacial structures; 6 linear and angular measurements

Figure 1. Anatomic Landmarks on the lateral cephalogram

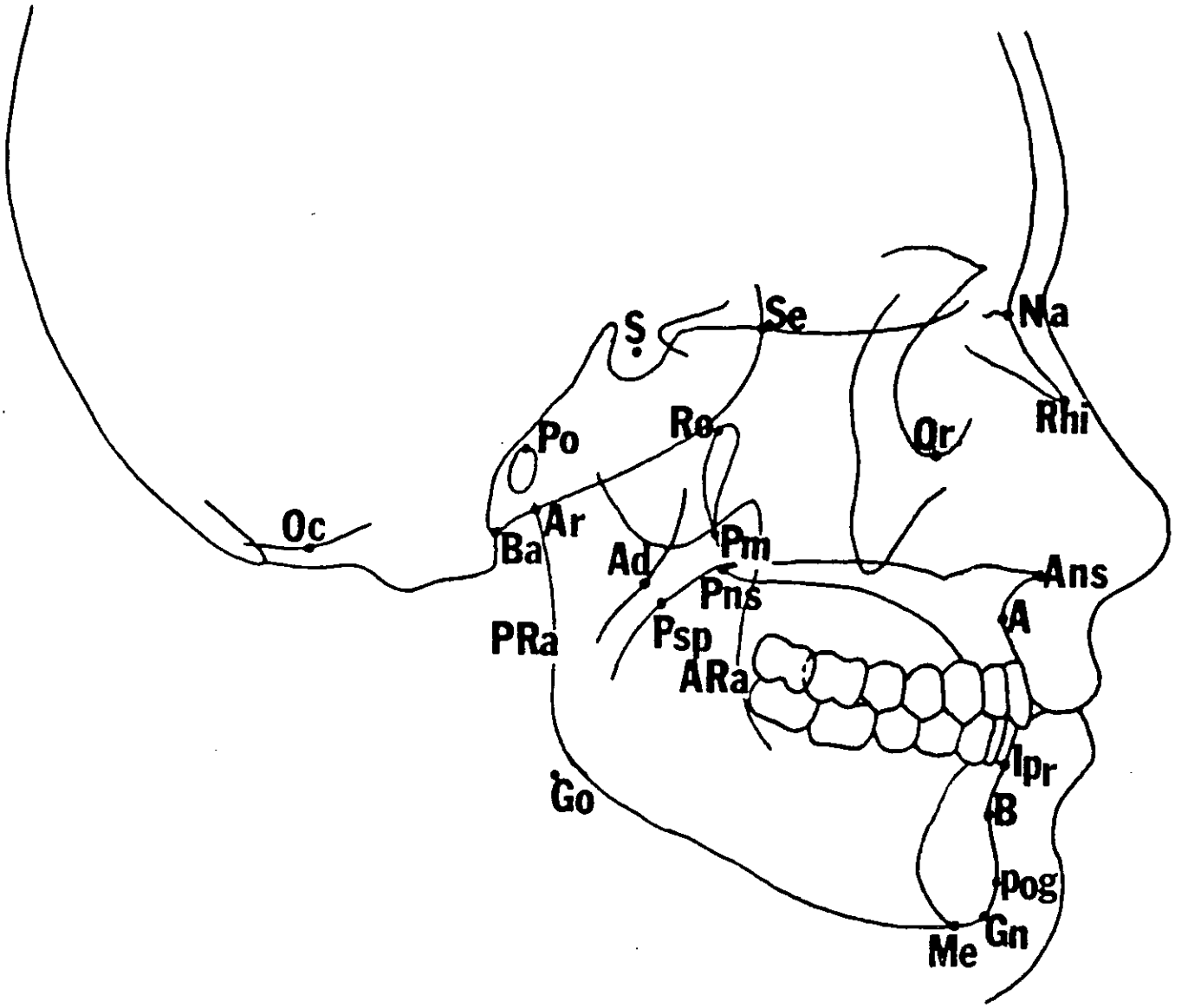


Figure 1. Anatomic Landmarks on the lateral cephalogram

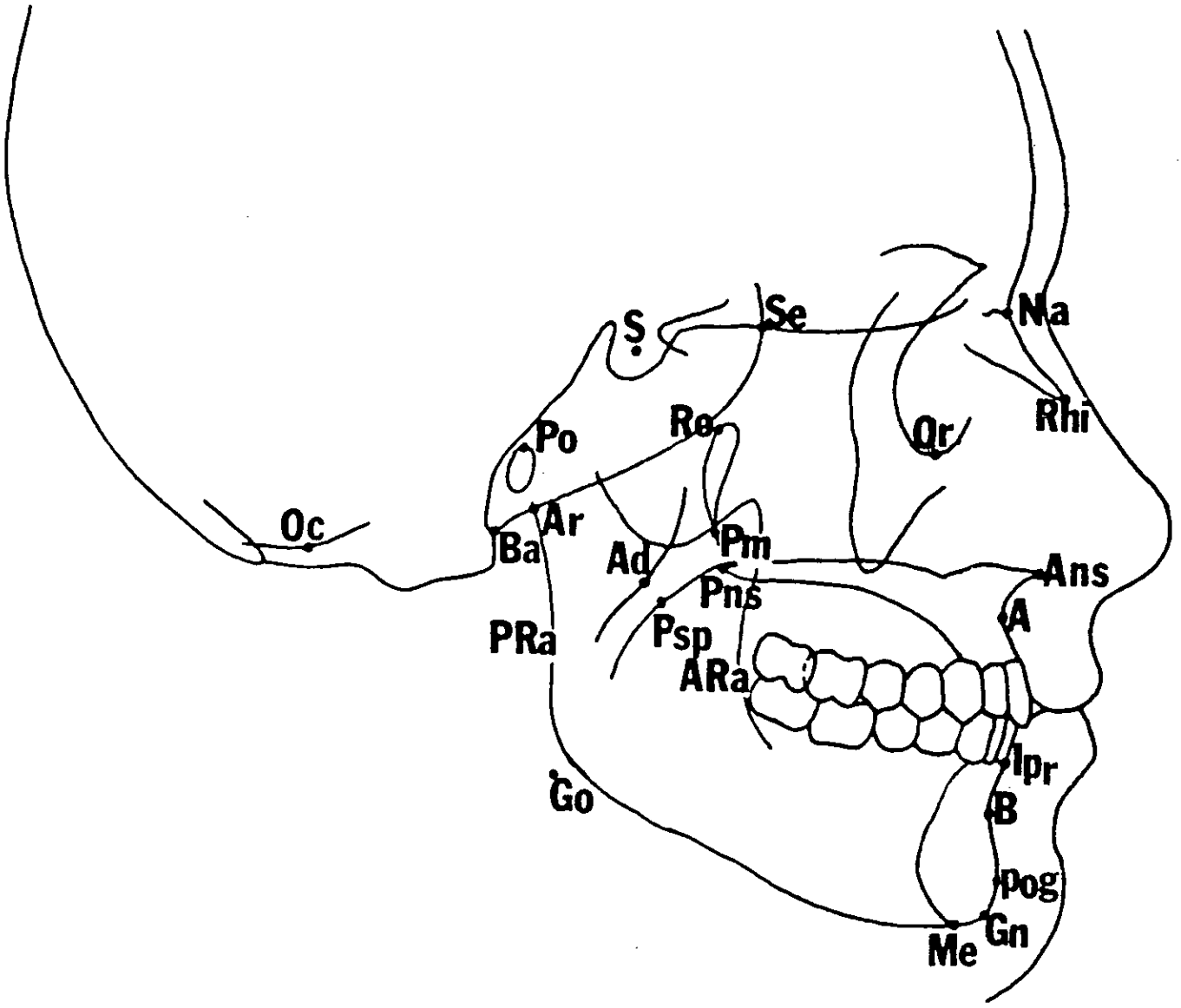


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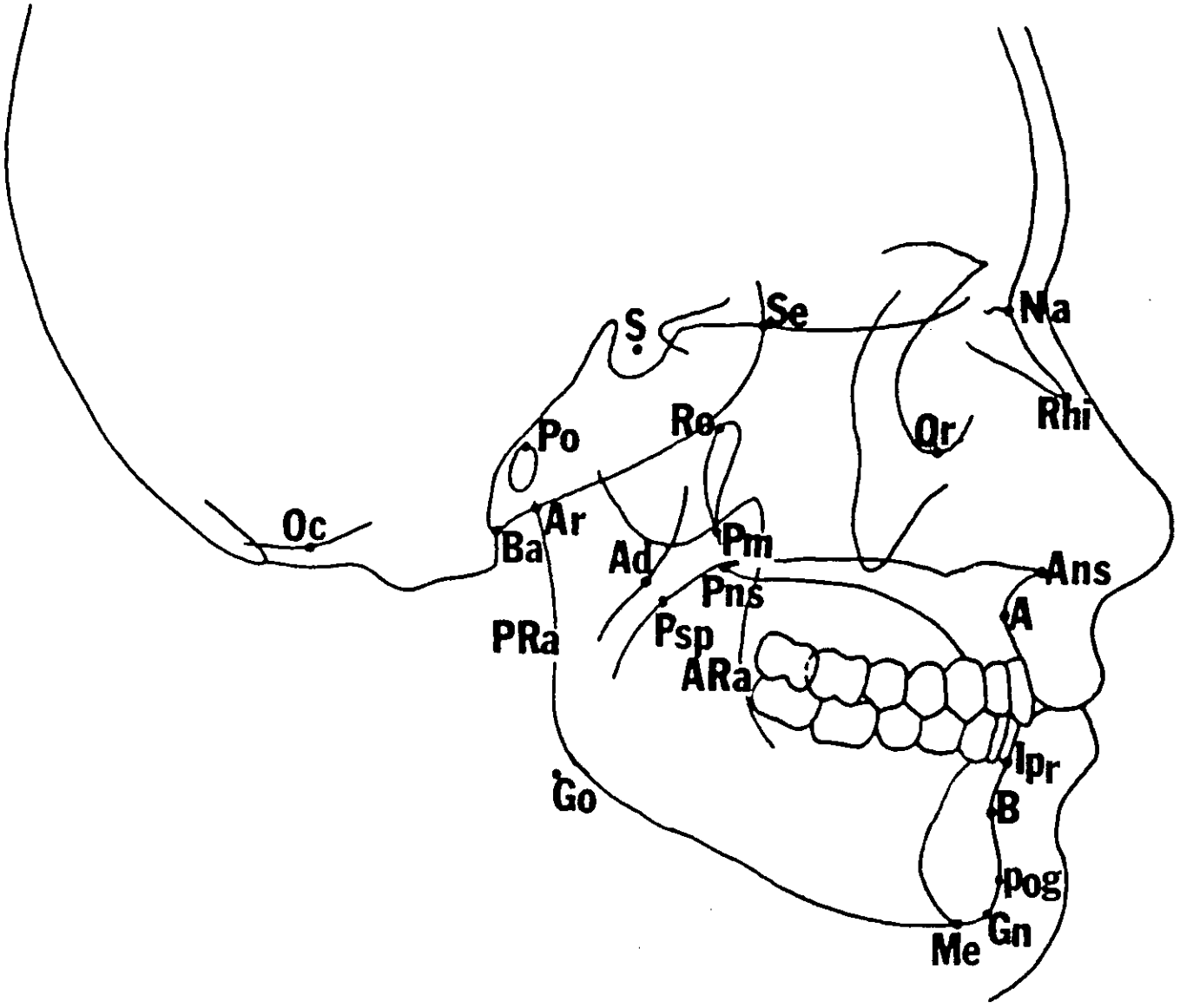


Figure 1. Anatomic Landmarks on the lateral cephalogram

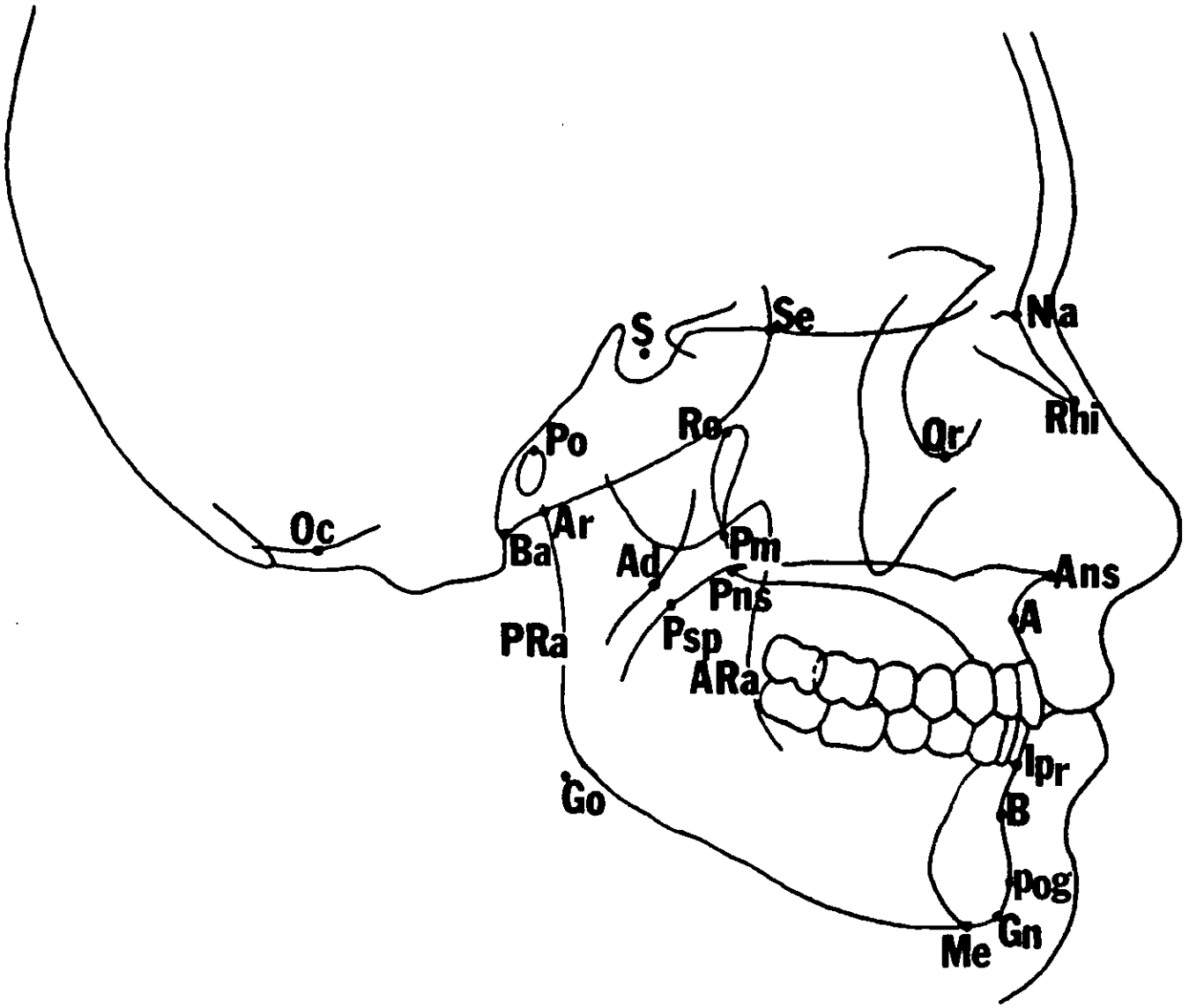


Figure 2. Anatomic Landmarks on the posteroanterior cephalogram

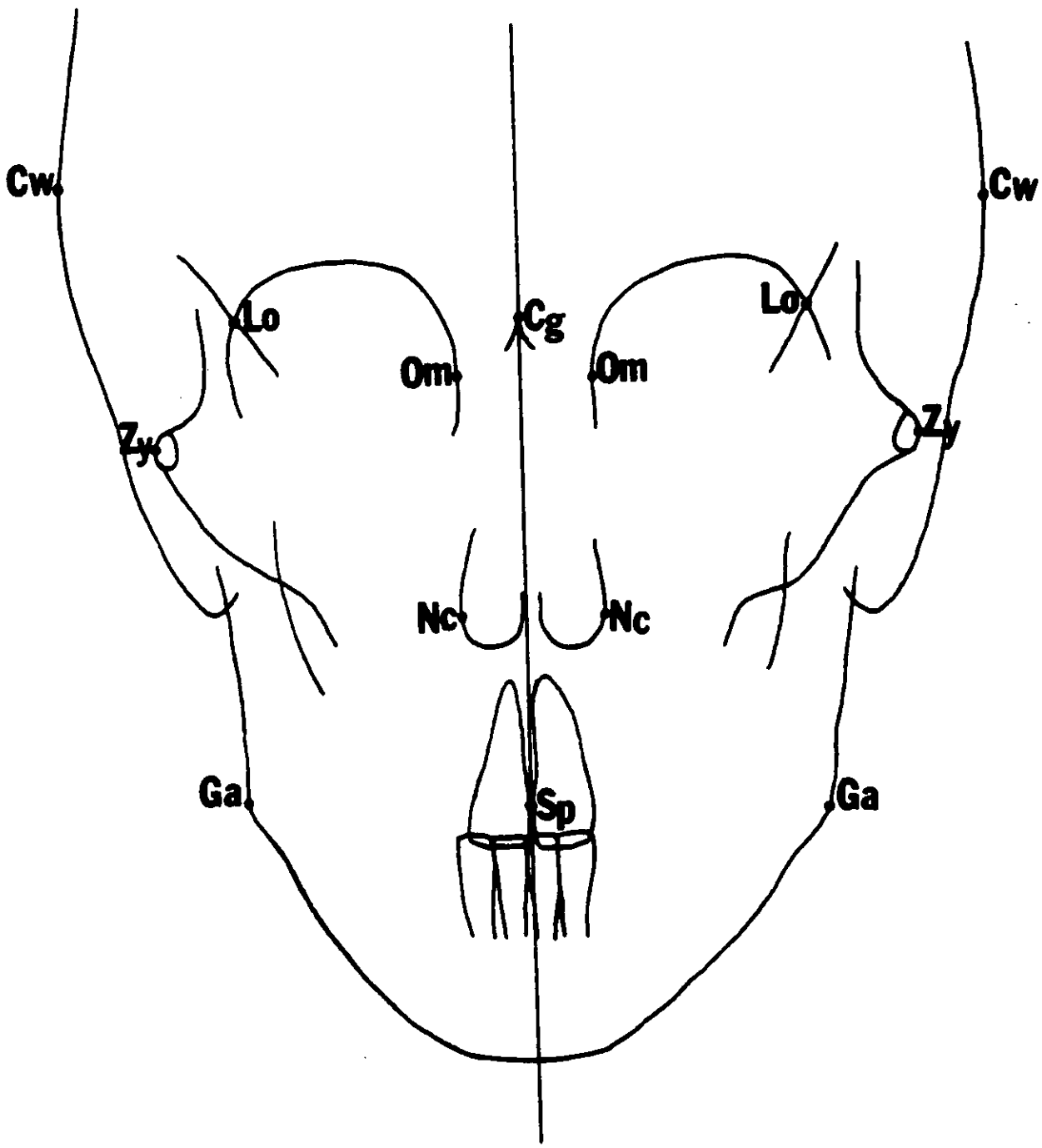


TABLE II

DEFINITIONS OF ANATOMIC LANDMARKS ON THE LATERAL AND PA CEPHALOGRAMS

Landmarks	Definition
Ad	The point on the posterior pharyngeal wall to have a shortest distance to the posterior outline of the soft palate.
Psp	The point on the posterior outline of the soft palate to have a shortest distance to the posterior pharyngeal wall.
Rhi	Rhinion--most anterior point of the shadow of nasal bone.
Oc	Occipital point, the inferior most point on the endocranial surface of the occipital fossa.
Ar	The point of intersection of the external inferior surface of the basicranium and the posterior margin of the condylar neck.
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.
Pm	The lowest point of Pterygomaxillary fissure.
Ba	Basion--the median point of the anterior margin of the foramen magnum.
Na	Nasion--the most anterior point on the naso-frontal suture.
S	Sella--the center of the sella turcica.
Or	Orbitale, averaged--the most inferior point on the averaged tracing of the orbits.
Po	Porion--mechanical porion--the most superior point on the ear rod shadow.
Me	Menton, the most inferior point on the symphysis of the mandible.

TABLE II (continued)

Ans	Anterior nasal spine, the tip of the spinous process of the maxilla forming the most anterior projection of the bony floor of the nasal cavity.
Pns	Posterior nasal spine, the tip of the spinous process formed by the most posterior projection of the junction of the palatine bones in the midline of the roof of the oral cavity.
Go	Construction gonion, intersection of lines tangent to the posterior border of the ramus and inferior border of the mandible.
Ro	Foramen rotundum
Pog	Most anterior point on the symphysis of the mandible in the median plane when the head is viewed in Frankfort relation.
Gn	Lowest, most anterior midline point on the symphysis of the mandible .
ARa	Anterior ramus, the point of intersection of the anterior margin of the ramus with the functional occlusal plane.
PRa	Posterior ramus, the point of intersection of the posterior margin of the ramus with the functional occlusal plane.
A	A point, the deepest middle point on the labial premaxillary surface between the anterior nasal spine and superior prosthion.
B	B point, the deepest middle point on the anterior surface of the symphysial outline of the mandible between infradentale (inferior prosthion) and pogonion.
IPr	Inferior prosthion, the point of contact of the alveolar process between the mandibular central incisors.
Cg	Crista galli--most superior point of crista galli of ethmoid bone.

TABLE II (continued)

Sp	Superior prosthion--the most anterior anteroinferior point on the maxilla at its labial contact with the maxillary central incisor.
Lo	The intersection point between the orbital margin and the temporal line.
Om	The most medial point on the medial wall of the orbit.
Zy	The most outest point on the outer border of the zygomatic arch
Nc	The widest lateral point of the aperture of the nasal cavity.
Ga	The most lateral point of the mandible in the gonial region.

related to the dentoalveolar morphology and 9 linear measurements related to the counterpart analysis. Definitions for these linear, angular and ratio measurements are given in Table III. Explanations of how each measurement relates to the counterpart analysis are illustrated in Figures 3 to 12, and the definitions of variables are presented in Tables IV and V.

Model Measurements

Impressions of the maxillary and mandibular dental arches were taken and measurements performed on study casts by using a Vernier Caliper (Fig. 13) and a 3-dimensional sliding caliper (Fig. 14). Reference points for and descriptions of dentoalveolar morphology (M_1-M_{16}) are given in Table VI and Figures 15 and 16. Variables M_1 to M_{10} are related to overjet, overbite, maxillary and mandibular dental arch widths and palate widths as measured on the study casts using a Vernier Caliper. Variables M_{11} was the palatal height as measured on study casts using a 3-dimensional sliding caliper. The values of M_{12} are indicated by category from 1 to 3 depending on the Angle classification. Variables M_{13} to M_{16} are indicated by positive (+) or negative (-) signs depending on the existence of crossbite or crowding, or not.

TABLE III

DEFINITIONS OF VARIABLES DERIVED FROM CEPHALOMETRIC RADIOGRAPHS

Variable	Definition
A. Adenoid area:	
ND	The narrowest distance from the posterior outline of the soft palate to the closest point on the posterior pharyngeal wall.
B. Craniofacial area:	
1. $N_pD^{(o)}$	Nasopharyngeal depth (N_pD) = angle between Ba-S-Pns.
2. $N_pH^{(o)}$	Nasopharyngeal height (N_pH) = angle between S-Ba-Pns.
3. $NW^{(mm)}$	Nasal width (NW) as measured between the widest points of the aperature of the nasal cavity (Nc) on the posteroanterior cephalogram. NW = Nc to Nc.
4. $NH^{(mm)}$	Nasal height (NH) as measured between the roof of the anterior cranial fossa and the floor of the 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.
5. $NL^{(mm)}$	Nasal length (NL) as measured between the intersection points of nasal plane anteriorly and PM vertical posteriorly to the Frankfort horizontal plane.

TABLE III (continued)

Variable	Definition
6. NAI	Nasal airway index (NAI) as calculated by the formula: $NAI = \frac{NW}{NH} \times 100$
7. NAV	Skeletal nasal airway volume index (NAV) as calculated by the formula: $NAV = \frac{NW \times NH \times NL}{2000}$
8. CW(mm)	Cranial width (CW): the distance between tangents to the most lateral convexities of the neurocranium projected perpendicular to the Frankfort horizontal plane on the posteroanterior cephalogram.
9. CL (mm)	Cranial length (CL): the distance between tangents to the most anterior and most posterior convexities of the neurocranium projected perpendicular to the Frank fort horizontal plane
10. CI	Cranial index (CI) as calculated by the formula: $CI = \frac{CW}{CL} \times 100$
11. MCBA(o)	Midcranial base angle (MCBA) = angle between Ar-Se-Pm
12. CBT(o)	Cranial base tipping (CBT) angle is the upper right angle between the intersection of Na-Ba plane and Frankfort horizontal plane.

TABLE III (continued)

Variable	Definition
13. ILO(o)	Interlateral orbital width (ILo) as measured from right Lo to left Lo on the posteroanterior cephalogram. (ILo = Lo - Lo)
14. IOm(mm)	Interorbital (IOm) width as measured from the most medial point on the medial wall of each orbit (Om). IOm = Om - Om
15. FW(mm)	Facial width (FW) as measured from the outer border of the zygomatic arch (Zy) on the posteroanteriorly cephalogram. FW = Zy - Zy
16. AFH (mm)	Anterior facial height (AFH) as measured between the distance from Na to Me.
17. FI	Facial index (FI) as calculated by the formula: $FI = \frac{AFH}{FW} \times 100$
18. LAFH (mm)	Lower anterior facial height (LAFH) as measured by the distance from Ans to Me.
19. AFHI	Anterior facial height index (AFHI) as calculated by the formula: $AFHI = \frac{LAFH}{AFH} \times 100$
20. PFH(mm)	Posterior facial height (PFH) as measured by the distance from S to Go.

TABLE III (continued)

Variable	Definition
21. PFHI	Posterior facial height index (PFHI) as calculated by the formula: $PFHI = \frac{PFH}{AFH} \times 100$
22. $FA^{(o)}$	Facial axis angle (FA): the lower left angle between the intersection of Na-Ba plane and Ro-Gn plane.
23. $SN\text{-}OP^{(o)}$	SN to occlusal plane angle (SN-OP) = Sella - Nasion to functional occlusal plane.
24. $SN\text{-}MP^{(o)}$	SN to mandibular plane angle (SN-MP) = Sella - Nasion to Gonion - Menton plane.
25. $RP\text{-}PP^{(o)}$	Ramal plane to palatal plane angle = Articulare - Gonion to Ans-Pns plane.
26. $GA^{(o)}$	Gonial angle (GA) = Articulare Gonion to Gonion - Menton plane.
27. $ML^{(m_m)}$	Mandibular length (ML) as measured by the distance from Ar to Gn.
28. $MW^{(mm)}$	Mandibular width (MW) as measured between the widest points of each mandibular angle (Ga) on the posteroanterior cephalogram. MW = Ga - Ga
29. MI	Mandibular index (MI) as calculated by the formula: $MI = \frac{MW}{ML} \times 100$

TABLE III (continued)

Variable	Definition
30. RL(mm)	Mandibular ramal length (RL) as measured by the distance from Ar to Go.
31. BL(mm)	Mandibular body length (BL) as measured by the distance from Go to Pog.
32. AG(mm)	Height of the antegonial notch (AG) as determined by the shortest distance between the Go-Me plane to the most concave point of the mandibular lower border.
33. CP(mm)	Chin protuberance (CP): the shortest distance between the IPr-Pog plane to the B point.
C. Dentoalveolar:	
1. UADH(mm)	Upper anterior dental height (UADH) as measured by the distance from Ans to the maxillary central incisal edge.
2. UPDH (mm)	Upper posterior dental height (UPDH) as determined by the shortest distance from the mesial occlusal contact point of first permanent molars to the outline of the palatal vault.
3. LADH(mm)	Lower anterior dental height (LADH) as measured by the distance between the lower central incisal edge to Me.
4. LPDH(mm)	Lower posterior dental height (LPDH) as measured by the shortest distance between the mesial occlusal contact point of first permanent molars to the outline of the mandibular lower border.

TABLE III (continued)

Variable	Definition
5. U1-SN(o)	U1-SN angle = The angle between the intersection of the long axis of the maxillary central incisor to the Sella-Nasion plane.
6. LI-MP(o)	LI-MP angle = the angle between the intersection of the long axis of the mandibular central incisor to the Go-Me plane.
D. Counterpart analysis (mm)	Table V

Figure 3. The points and planes used in the Counterpart Analysis are illustrated. Solid lines represent the individual's own anatomic positions, while the dashed lines represent neutral positions. This diagram includes additions to the original constructions and procedures presented by Enlow (1971).

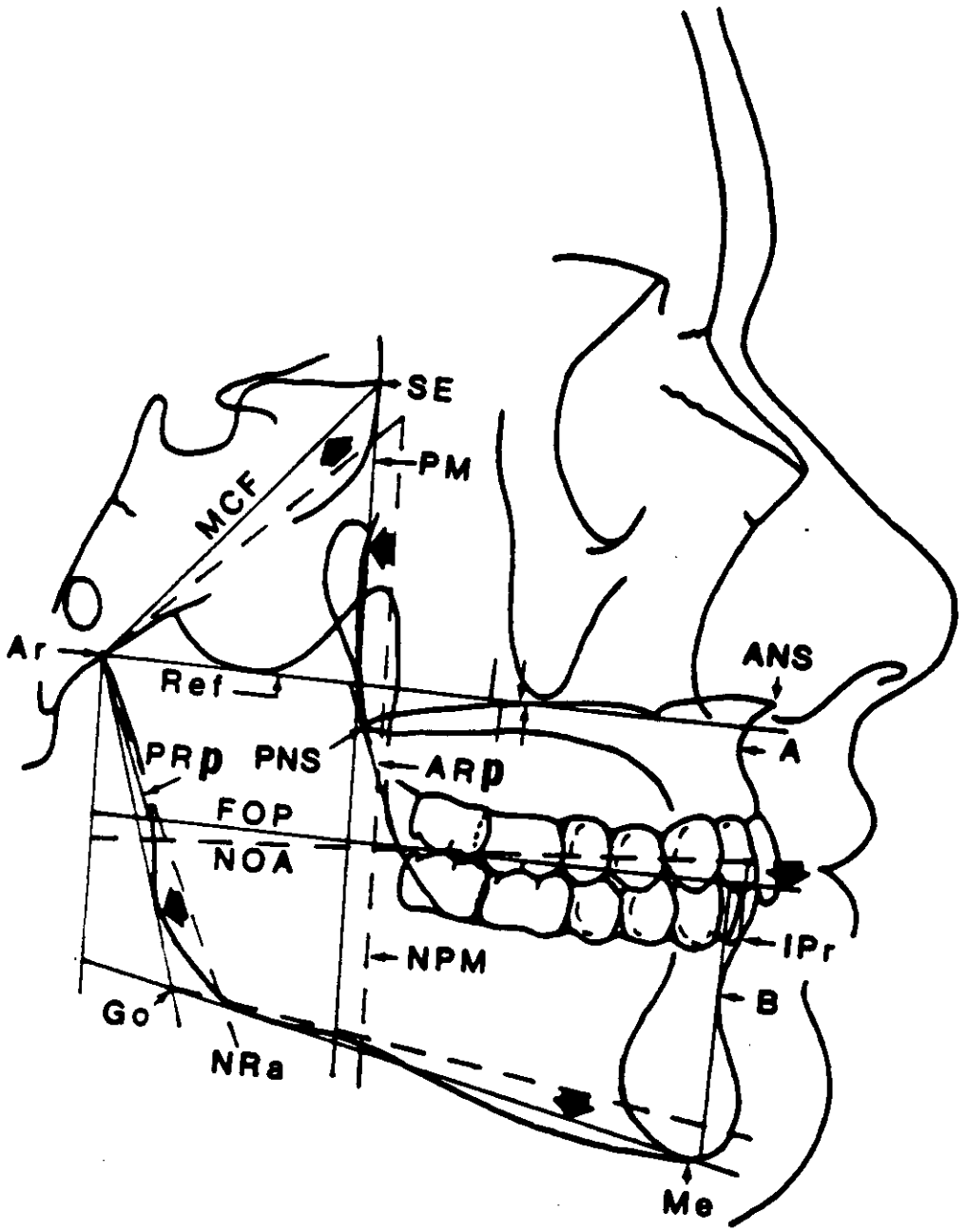

SE
PM
MCF
Ar
Ref
ANS
A
PRp
PNS
ARp
FOP
NOA
NPM
IPr
B
Go
NRa
Me

Figure 4. Aggregate cranial floor/maxilla and ramus/corpus horizontal dimensions at A and B points. This diagram demonstrates the comparison of cumulative maxillary length from Ar to A point with cumulative mandibular length from Ar to B point. The lines from A point to Ref, and B point to Ref are drawn perpendicular to Ref. Measurements are made in millimeters along Ref. If A point is ahead of B point, a mandibular retrusive (+) effect occurs. If behind, a mandibular protrusive (-) effect is present. If both lines coincide, a neutral (0) effect exists.

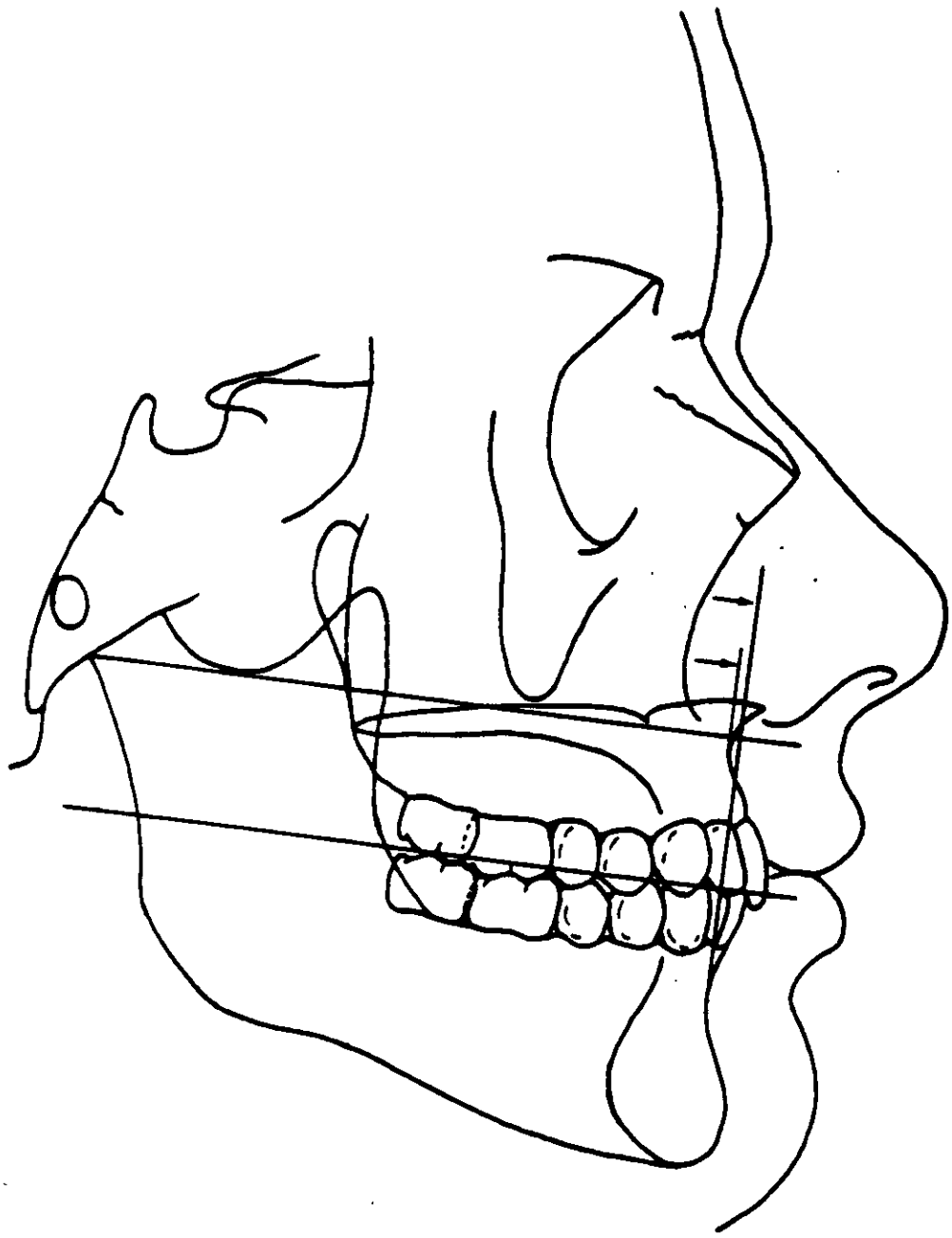


Figure 5. Middle Cranial Fossa (MCF) alignment. This diagram demonstrates the effects of rotational alignment of the individual's own MCF compared with the neutral MCF on corresponding maxillary and mandibular placement. A backward alignment (shown here) when compared with the neutral plane (dashed line) has a mandibular protrusive (-) effect. A forward alignment has a mandibular retrusive (+) effect. If the neutral MCF plane coincides with the individual's own MCF, a neutral (0) effect is present. To construct neutral MCF/PM, a separate preconstructed template is made consisting of two lines forming an internal angle of 40.3°. With dividers, determine the length of the individual's own MCF plane, then transfer this measurement to the corresponding line on the template. This step assures that the length of the individual's MCF and the neutral MCF will be the same. Place the tracing of the subject over the template superimposing on Ar and orienting the subject's PM vertical and the neutral PM parallel to each other. Draw the neutral MCF/PM with a dashed line on the subject's tracing. The distance between the neutral PM and the subject's PM vertical can now be measured along Ref in millimeters. When the subject's PM vertical lies behind the neutral PM, it is recorded as a (-) value, and mandibular protrusive effect is present. When it is in front of the neutral PM, it is recorded as a (+) value, and a mandibular retrusive effect is present. When they coincide, it is recorded as (0).

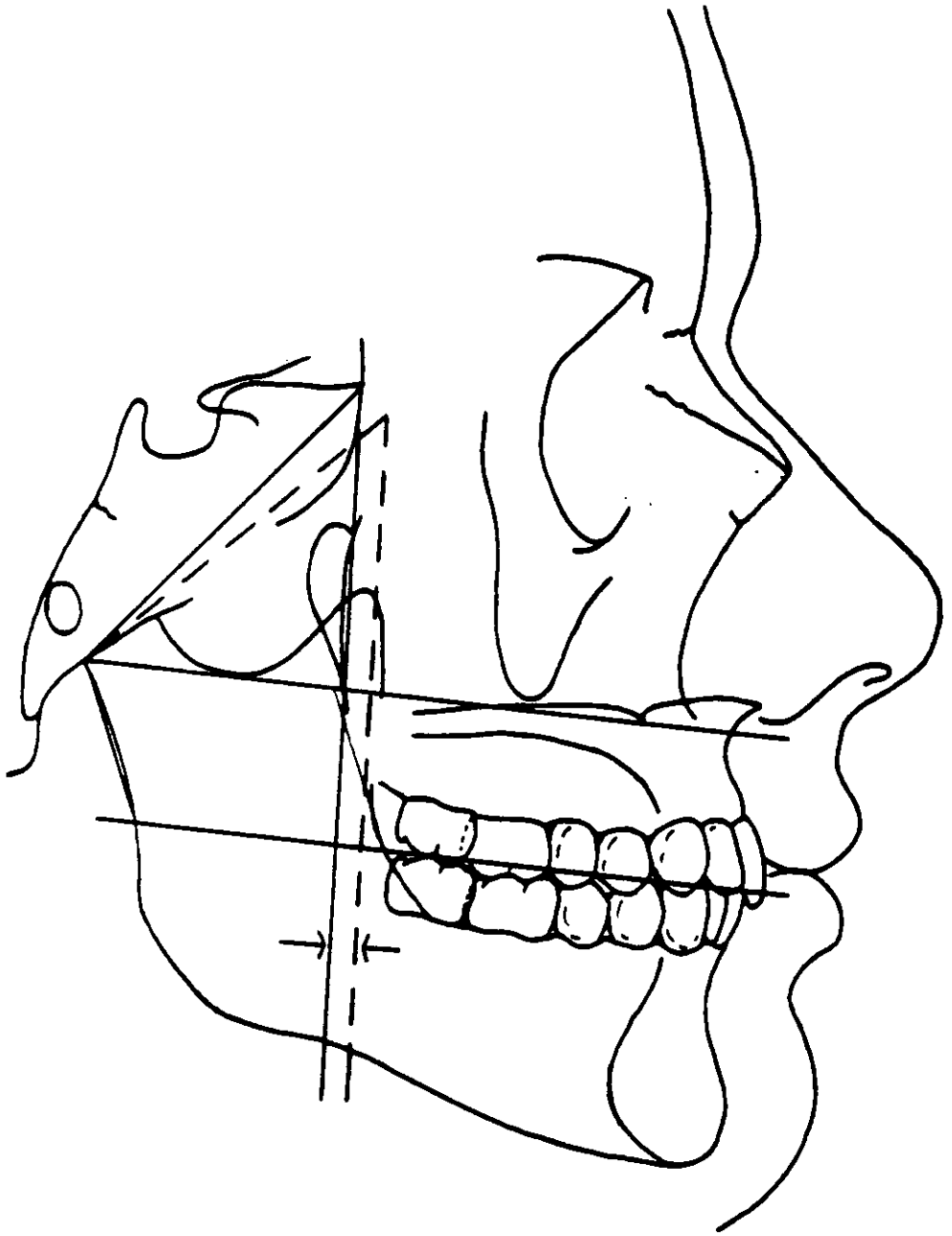


Figure 6. Ramus alignment. This measurement determines the direction and magnitude of ramus rotational alignment. The magnitude is determined by measuring the distance between the individual's ramus plane (Ar to Go) and the neutral ramus plane (NEa) where they intersect the functional occlusal plane (FOP). If the subject's ramus plane (Ar to Go) lies anterior to the neutral line (mandibular protrusive), it is given a (-) value, and if posterior to the neutral line (mandibular retrusive), a (+) value. If the value is negative, mandibular protrusive effect occurs. If the value is positive, a mandibular retrusive effect occurs.

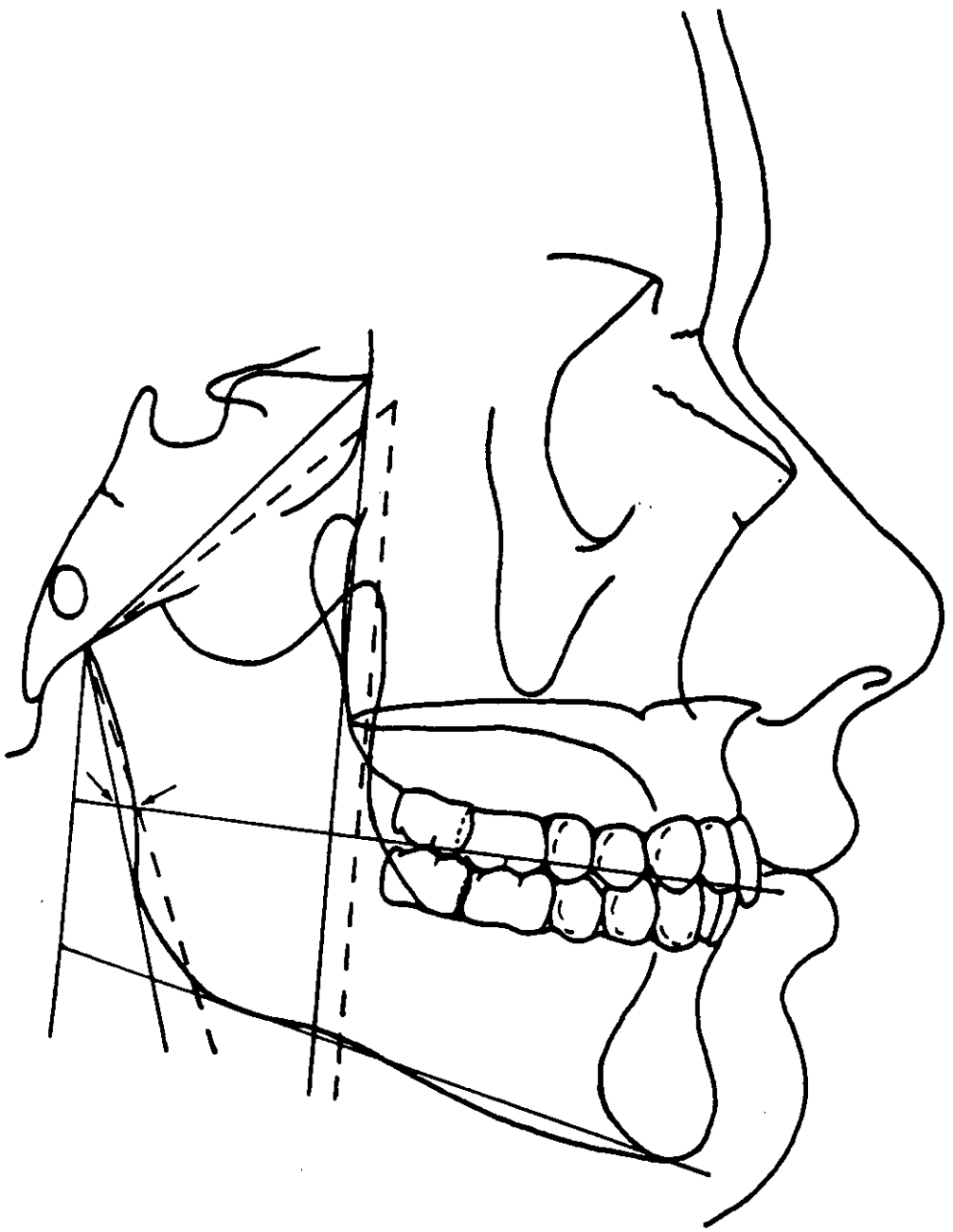


Figure 7. Ramus/MCF horizontal dimensions (skeletal). This diagram demonstrates the comparison of the horizontal dimensions of the middle cranial fossa with the width of the ramus. The distance from Ar to ARa and Ar to neutral PM are measured along Ref. A (-) effect occurs when the ramus width is greater than Ar to neutral PM, and a (+) effect when less. When the measurements are the same, a neutral (0) effect results.

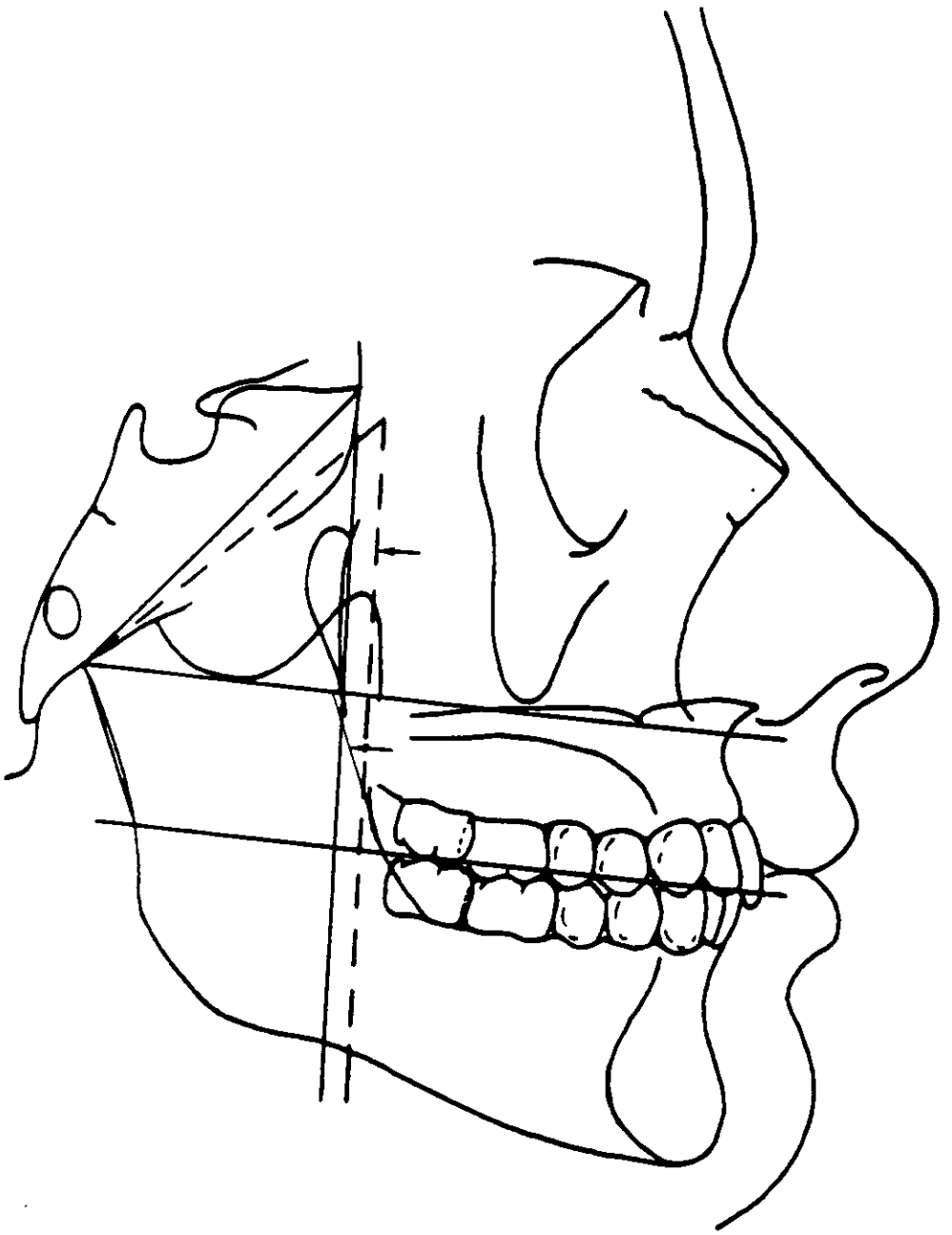


Figure 8. Posterior Maxillary (PM) vertical dimension compared with Ramus/MCF vertical dimensions. The individual's own relative vertical length of PM is determined simply by comparing the direction and the extent of MCF rotation with the direction and extent of ramus rotation. The MCF rotation is determined by measuring the difference between PM and neutral PM along FOP. If Pm is ahead of neutral PM, MCF has a forward and downward rotation. If PM is behind the neutral PM, the MCF has an upward and backward rotation. Ramus rotation is determined by measuring the difference between PRa and NRa along FOP. If PRa is ahead of NRa, the ramus has a forward rotation and if behind NRa, it has a backward rotation. Now, these two values (MCF value and ramus value) are compared with each other, and the composite effect is recorded as a "long" (+) or "short" (-) PM vertical dimension relative to the middle cranial fossa and the ramus. A schematic explanation is provided in Table III. This is a different consideration from any population tendency toward a vertically long or short midface as seen in various ethnic groups.

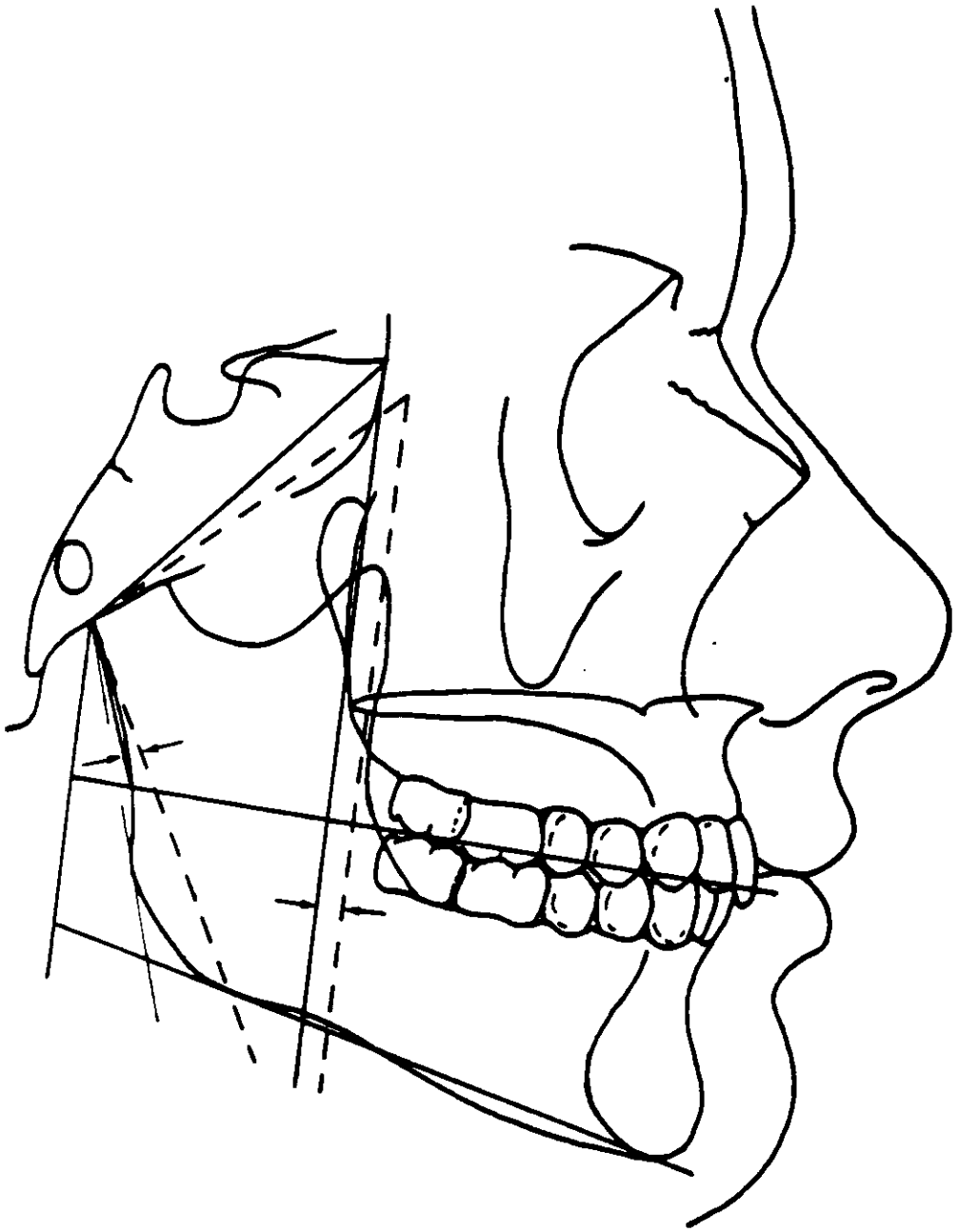


Figure 9. Maxillary/Mandibular arches, skeletal dimensions. A point compared with B point. This diagram compares the horizontal lengths of the maxillary and mandibular skeletal arches. The maxillary arch is measured from PM (solid line) to A point along Ref. The mandibular arch is measured along REf from ARa where it intersects Ref to B point. If the distances are equal it is recorded as (0). If either a mandibular retrusive or protrusive effect exists, a (+) or (-) value is recorded, respectively.

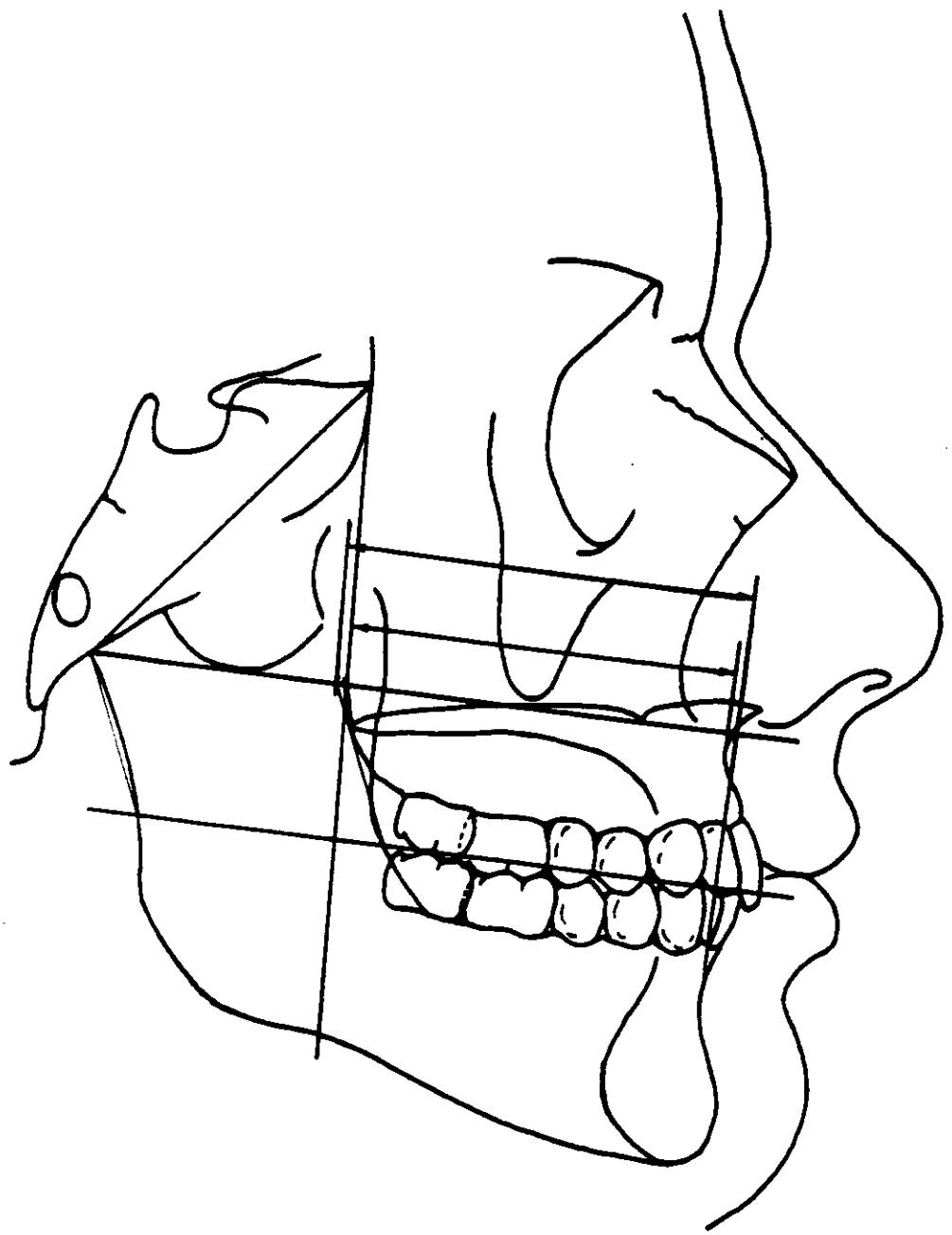


Figure 10. Palatal plane alignment. This diagram demonstrates the alignment between the palatal plane and is represented by a line from ANS through PNS projected posteriorly. The distance and direction of this plane relative to occipital point is determined. If the palatal plane is above occipital point, it is a (+) value. If it is below occipital point, it is a (-) value. Positive and negative values represent clockwise and counterclockwise rotations, respectively.

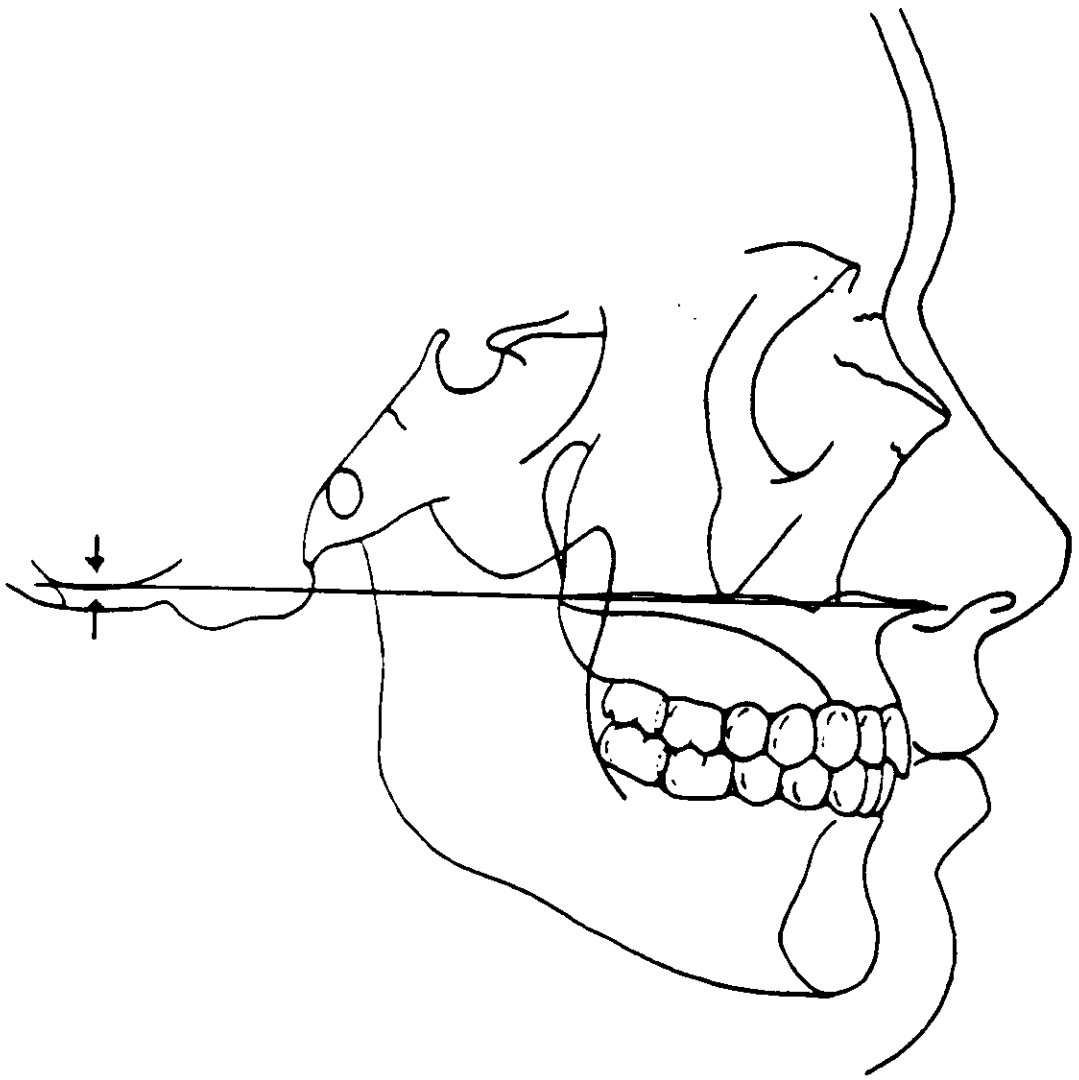


Figure 11. Occlusal Plane alignment. This diagram demonstrates the direction and the amount of occlusal plane rotation. The measurement is made between FOP and NOA along a perpendicular from IPr to FOP. If FOP is above NOA, it is a (+) value, if below NOA, it is a (-) value. Positive and negative values indicate counterclockwise and clockwise rotations, respectively.

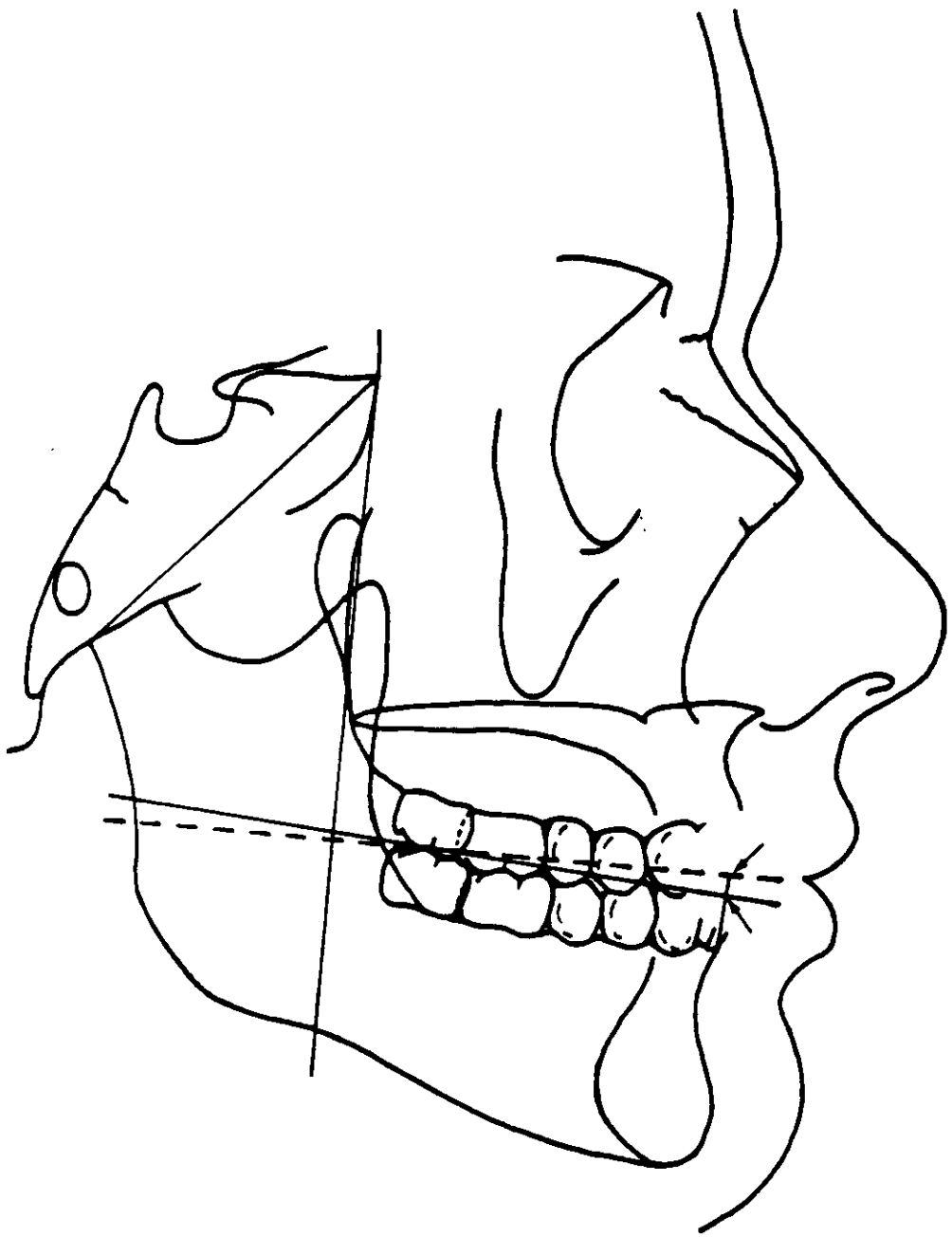


Figure 12. Curve of Spee. This is demonstrated by measuring the distance between the incisal edge of the mandibular central incisors and FOP. If the central incisors are above FOP it is a positive number, if below FOP it is a negative number.

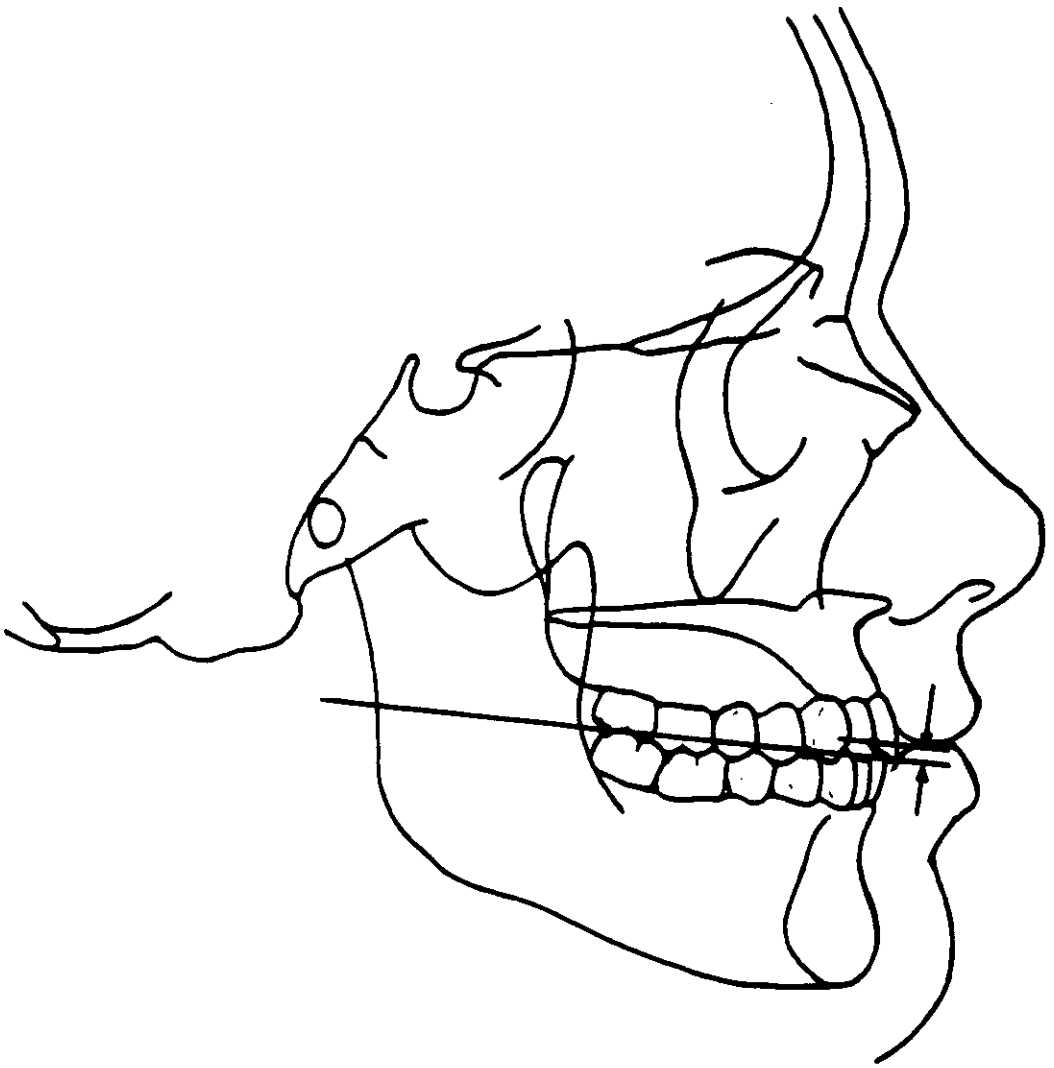


TABLE IV

DEFINITIONS OF CEPHALOMETRIC PLANES USED IN THE COUNTERPART ANALYSIS

Line	Description
Ar to Go	A line from Ar to constructed Go used to determine the alignment of the ramus.
ARP	Anterior ramus plane, a line from the intersection of FOP and the anterior border of the ramus drawn parallel to PRa up to Ref.
FOP	Functional occlusal plane, a line from the most posterior occlusal contact point to the last fully erupted maxillary and mandibular molars to the most anterior maxillary-mandibular first premolar occlusal contact.
MCF	Middle cranial fossa plant, represented by a line from SE to Ar.
NOA	Neutral occlusal axis, a line perpendicular to PM through the most posterior occlusal contact point of the last fully erupted maxillary and mandibular molars.
NRa	Neutral ramus, a line from Ar to a point midway between Ar and neutral PM line at the level of gonion.
PRP	Posterior ramus line, from Ar to the posterior margin of the ramus where it intersects FOP.
Ref	Reference line, a line parallel to FOP from Ar anteriorly.

TABLE V

NINE VARIABLES EVALUATED IN THE COUNTERPART ANALYSIS

	Abbreviation	Definition
1.	ArAB	Aggregate cranial floor/maxilla and ramus/corpus horizontal dimensions at A and B points.
2.	MCF	Middle cranial fossa (MCF) alignment.
3.	RAM	Ramus alignment
4.	RMCF	Ramus/MCF horizontal dimensions (skeletal).
5.	PMV	Posterior maxillary (PM) vertical dimensions compared with ramus/MCF vertical dimensions.
6.	MXMD	Maxillary/Mandibular arches, skeletal dimensions, A point compared with B point.
7.	PPAL	Palatal plane alignment.
8.	OPAL	Occlusal plane alignment.
9.	COSP	Curve of Spee

Figure 13. Vernier caliper for measuring intermolar, interpremolar, intercanine distances and palatal widths

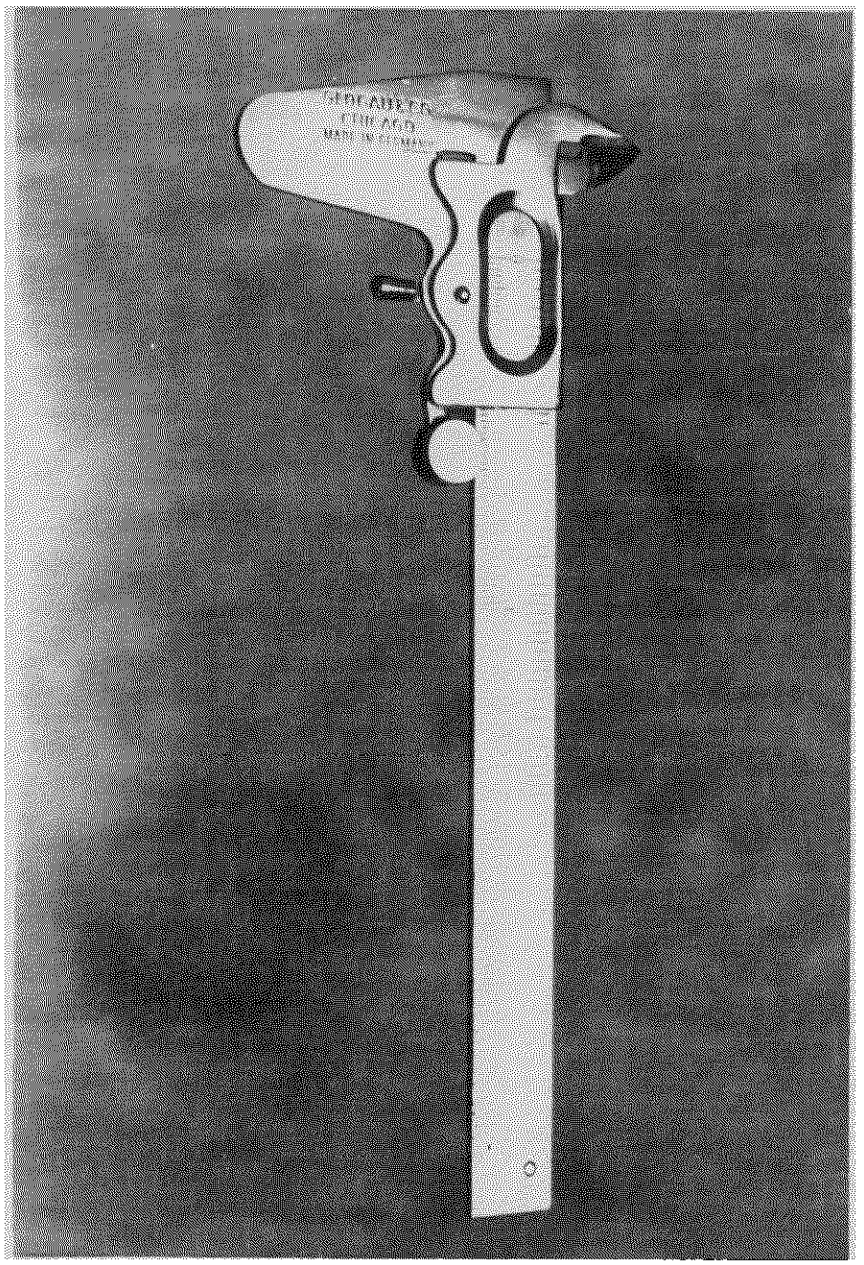


Figure 14. Three dimensional caliper for measuring palatal height

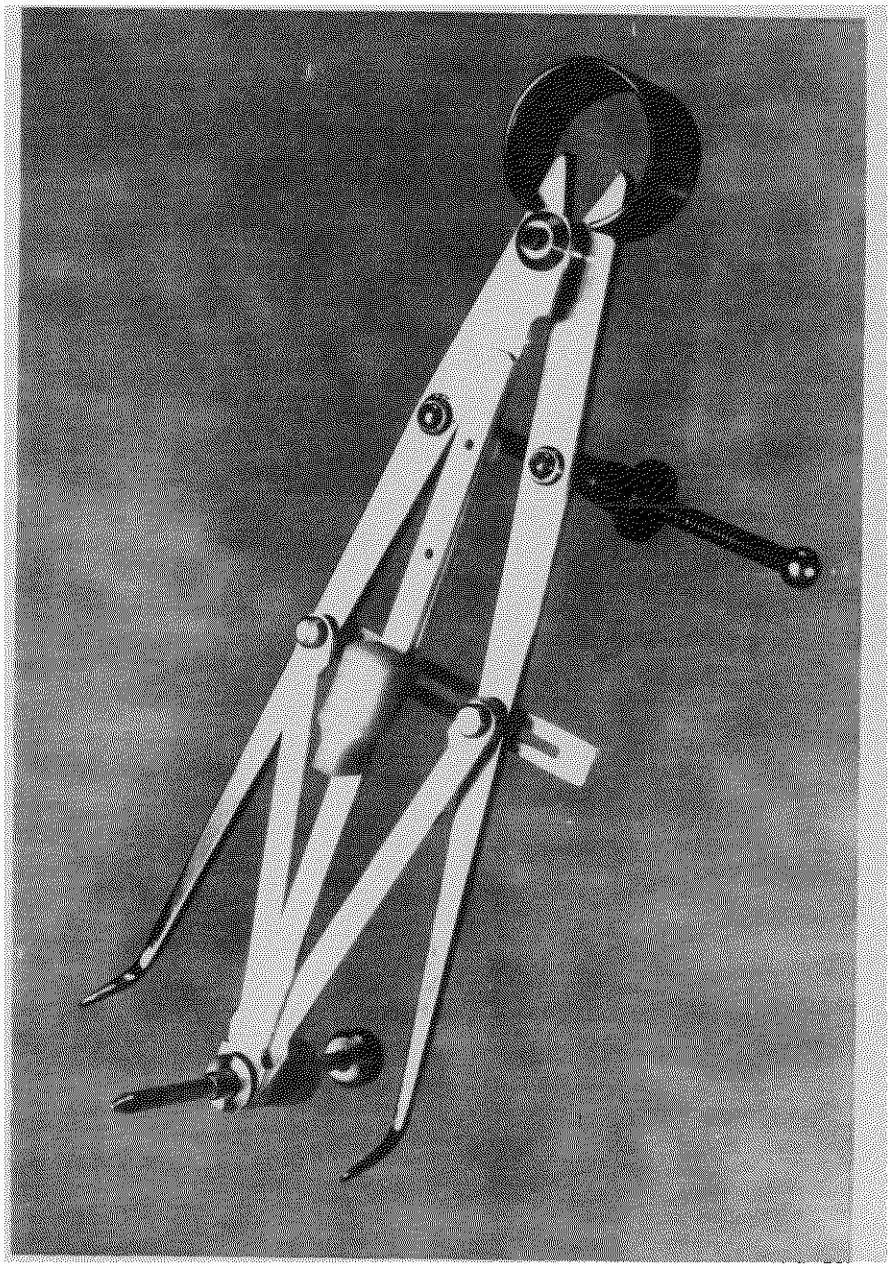


TABLE VI

VARIABLES FOR ASSESSING DENTOALVEOLAR MORPHOLOGY ON STUDY CASTS

Abbrev.	Variable	Definition
M_1	Overjet	The distance between the labial surface of the most prominent mandibular incisor to the most anterior point of the incisal edge of the most protruding maxillary central incisor.
M_2	Overbite	The distance between the incisal edge of the lower incisor and the point of the labial surface upon which the incisal edge of the maxillary central incisor is projected. An open bite is indicated by negative value.
M_3	Intermolar distance Maxilla (Fig. 17)	The distance between the central fossae of the occlusal surfaces of the first permanent maxillary molars.
M_4	Intermolar distance Mandible (Fig. 18)	The distance between the central fossae of the occlusal surfaces of the first permanent mandibular molars.
M_5	Interpremolar distance Maxilla (Fig. 17)	The distance between the midpoints of the occlusal surfaces of the first premolars or the first deciduous molars in the maxilla.
M_6	Interpremolar distance Mandible (Fig. 18)	The distance between the midpoints of the occlusal surfaces of the first premolars of the first deciduous molars in the mandible.
M_7	Intercanine distance Maxilla (Fig. 17)	The distance between the cusp tip of the permanent or deciduous canines in the maxilla.

TABLE VI (continued)

Abbrev.	Variable	Definition
M_8	Intercanine distance Mandible (Fig. 18)	The distance between the cusp tips of the permanent or deciduous canines in the mandible.
M_9	Palatal width (M)	The distance between the most lingual margin of the gingival border of the maxillary first molars.
M_{10}	Palatal width (P)	The distance between the most lingual margin of the gingival border of the first permanent maxillary premolars or the first deciduous maxillary molars.
M_{11}	Palatal height	Height of the palatal vault, measured from the intermolar distance line to the palatal vault.
M_{12}	Molar relation	1: Angle Class I molar relationship 2: Angle Class II molar relationship 3: Angle Class III molar relationship
M_{13}	Posterior crossbite	The buccal cusp of the maxillary premolar, deciduous molar, or permanent molar occluded lingually to the buccal cusps of a mandibular premolar, deciduous molar, or permanent molar. -: no posterior crossbite +: at least one tooth with posterior crossbite
M_{14}	Anterior crossbite	The incisal edge of an upper incisor occluded lingually to the incisal edge of a lower incisor. -: no anterior crossbite +: at least one toothe with anterior crossbite

TABLE VI (continued)

Abbrev.	Variable	Definition
M_{15}	Maxillary anterior crowding	-: no crowding from maxillary canine to canine area +: with crowding from maxillary canine to canine area
M_{16}	Mandibular anterior crowding	-: no crowding from mandibular canine to canine area +: with crowding from mandibular canine to canine area

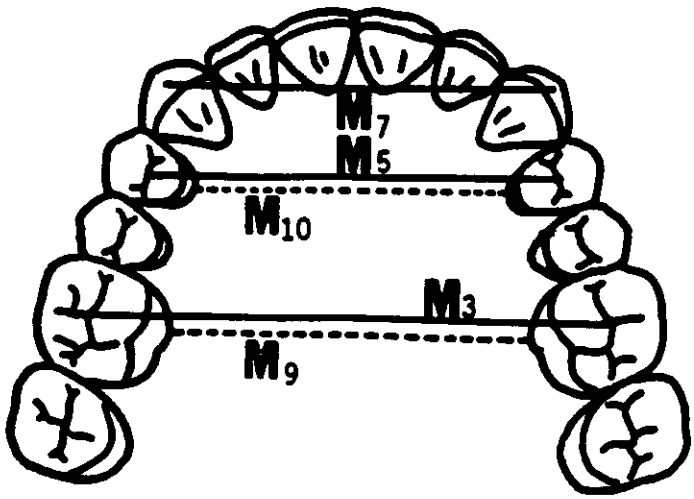


Figure 15. Maxillary intermolar (M_3) , interpremolar (M_5) , intercanine (M_7) distances and palatal widths (M_9 and M_{10}).

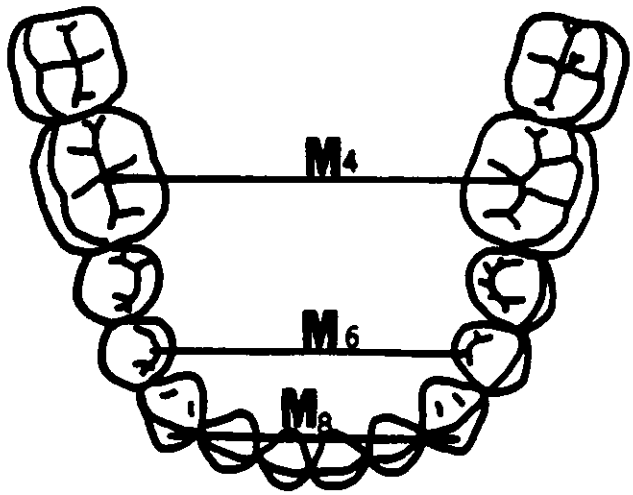


Figure 16. Mandibular intermolar (M_4) , interpremolar and intercanine (M_8) distances.

Rhinomanometric measurements

To provide an objective quantification of nasal airway resistance, the rhinomanometric measurements were performed by a trained rhinomanometry applicator using a Mastr rhinomanometer (Fig. 17). Forty-six cases in the nasally impaired sample had rhinomanometry examinations. The percentage error of the rhinomanometry measurements at different intervals was within 5%. To provide the expiratory nasal resistance values, the following procedure was used.

1. A pressure nozzle and a flow tube were placed onto the surface opening of each nostril side (Fig. 18).
2. The patient was instructed to relax and breath normally through the nose while sitting quietly for a few moments.
3. A dual-channel recorder allowed visualization of the recorded transnasal airflow (V) and pressure (P).
4. Once the depth and frequency of breathing had become stabilized, a sequence of 5 similar breathes, which were seen on the graph readout, was used to obtain average peak expiratory airflow and pressure values during quiet breathing.

Figure 17. Equipment for measuring total nasal resistance

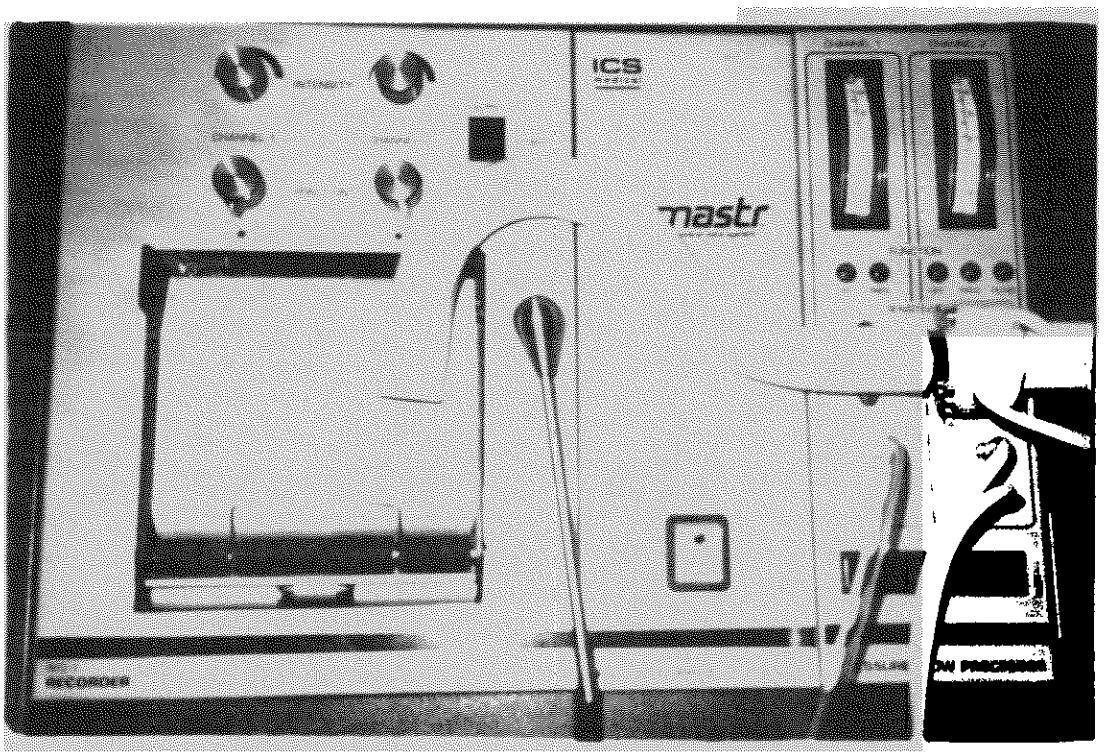
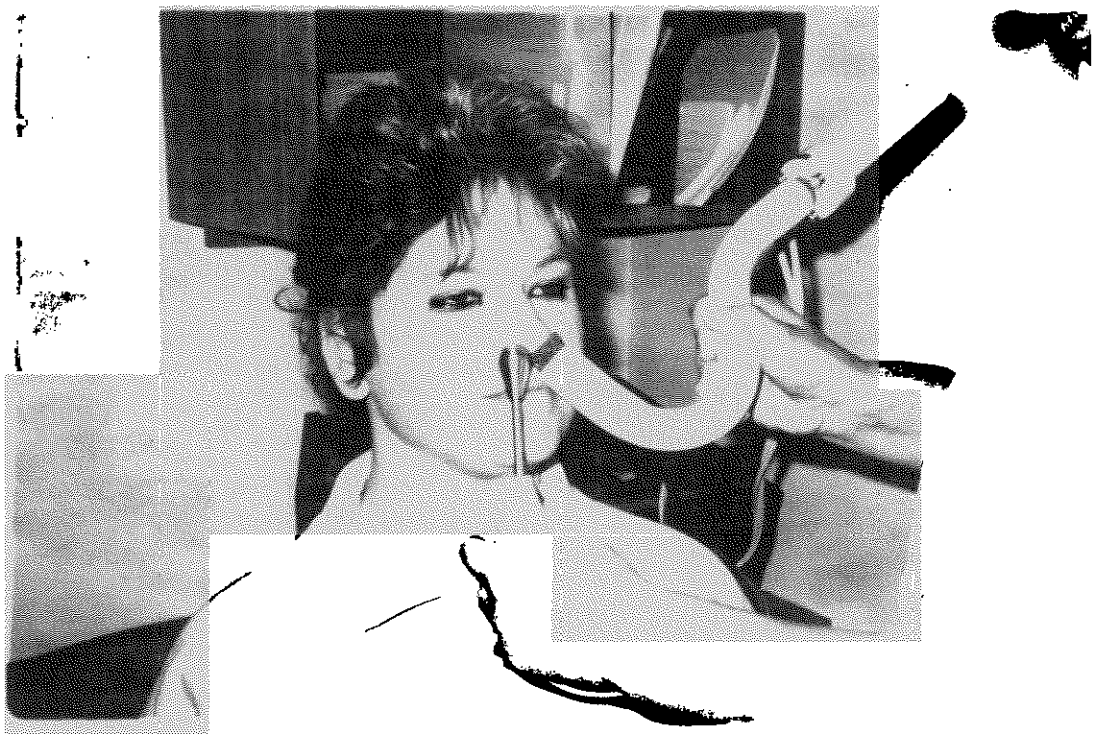

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Figure 18. Patient and equipment set-up for total nasal resistance recording



5. These peak transnasal airflow and pressure values were used to calculate the unilateral resistance by the following equation:

$$\text{Resistance} = \frac{\text{Transnasal pressure difference}}{\text{Airflow}} = \frac{P}{V}$$

6. To obtain a resistance value for the contralateral nostril, the pressure nozzle and the airflow tube were then transferred to the other nostril, and steps 1 through 5 were repeated.

Once the unilateral resistance values for the right and left sides had been obtained by the above sequential steps, the values for unilateral airway resistances of the right and left sides (Rn right and Rn left) were inserted into the following equation in order to calculate total nasal airway resistance (Rn total).

$$\underset{(cm \cdot H_2O/liter/second)}{\text{Rn Total}} = \frac{(\text{Rn right}) \times (\text{Rn left})}{(\text{Rn right}) + (\text{Rn left})}$$

Statistical Analysis

The statistical analyses were performed at the Jennings Computer Center, Case Western Reserve University using SPSSX (Statistical Package for Social Science) in a DEC 20 mainframe computer.

Conventional statistical methods were used for calculation of means and standard deviations. In order to characterize the craniofacial and occlusal patterns in nasally

impaired patients, differences between the variables of nasally impaired and control groups were tested using the Student's t-test if the variables were continuous data, and the Chi-square (x^2) test if the variables were categorical data (eg. the types of Angle classification). Student's t-test and Chi-square test were also used to compare craniofacial and occlusal patterns between black and caucasian subjects in the nasally impaired group.

Craniofacial and occlusal variables showing a significant difference ($p \leq 0.05$) between the patient and control groups were further selected to test the following relationships in the patient group only. The relationships between these selected craniofacial, occlusal and age variables were tested by means of the Pearson correlation method. The rhinomanometric data in subsample A (N = 37) were chosen to evaluate its relationships with these selected craniofacial, occlusal variables by means of the Spearman correlation method. A Spearmen correlation was also calculated to evaluate the associations between the rhinomanometric data and ND values in cases diagnosed as having adenoid hyperplasia in subsample A (N = 30). MANOVA was also used to determine differences between subsample A and subsample B groups simultaneously.

To test whether specific types of malocclusions in nasally impaired patients have close relationships to certain

craniofacial combinations, univariate and multivariate analyses were performed sequentially to obtain multiple regression equations or discriminate functions. The univariate tests were used first to select the significant craniofacial variables to be used in the multivariate test. In these multivariate analyses, the occlusal variable was the dependent variable (regressand) and the craniofacial variables were the independent variables (regressor). If the occlusal variable was continuous data, stepwise multiple regression was used. If the occlusal variable was dichotomous data, stepwise discriminate analysis was used. The prediction power of the craniofacial combinations (regressors) to the occlusal variable (regressand) in the stepwise multiple regression could be explained by the R^2 value. The discriminant score calculated from the discriminate analyses were used to obtain a Bayes' rule for classifying cases into one of two groups (eg., crossbite group or no crossbite group).

RESULTS

The means and the standard deviations for all the cephalometric and occlusal variables are presented in Tables VII, VIII, IX and X. As seen in Table VII, the nasally impaired subjects showed significantly smaller values for the ND variable ($p = 0.000$), higher nasopharyngeal height ($p = 0.000$), leptorhine nasal type ($p = 0.011$), larger midcranial base angle ($p = 0.030$), more upward tilt of the cranial base ($p = 0.043$), narrower interlateral orbital distance ($p = 0.049$), a more dolichocephalic head form ($p = 0.000$) and a more leptoprosopic face ($p = 0.000$). Vertically, the facial axis, anterior facial height index, SN-mandibular plane angle and palatal plane-ramal plane angle were all increased in the nasally impaired subjects. The variables relating to the shape of the mandible demonstrated a longer mandibular whole length, deeper antegonial notch and a larger gonial angle for the nasally impaired patients. All of the upper dental heights and the lower anterior dental heights were significantly greater than the control subjects ($p = 0.000$). The lower incisors were also more upright in nasally impaired subjects, with the L1 - mandibular plane angle being smaller.

The results of the counterpart analysis (Table VIII) show that the nasally impaired subjects had more B facial

TABLE VII MEAN VALUES ($\bar{x}$), STANDARD DEVIATIONS (S.D.) AND VALUES P FOR THE CEPHALOMETRIC VARIABLES RECORDED FROM NASALLY IMPAIRED AND CONTROL SAMPLES

Cephalometric variable	Nasally impaired sample (N = 71) $\bar{x} \pm$ S.D.	Control sample (N = 71) $\bar{x} \pm$ S.D.	P value (T test)
A. ND	4.85 ± 4.67	9.95 ± 3.03	0.000***
B. 1. N_pD	58.49 ± 5.99	60.00 ± 4.87	0.101
2. N_pH	64.59 ± 5.48	60.48 ± 4.53	0.000***
3. NW	25.75 ± 2.78	26.51 ± 3.18	0.163
4. NH	43.70 ± 5.28	42.24 ± 3.90	0.064
5. NL	53.89 ± 4.17	54.01 ± 4.51	0.862
6. NAI	59.81 ± 6.67	62.97 ± 6.87	0.011*
7. NAV	31.06 ± 7.82	30.88 ± 7.61	0.897
8. CW	145.67 ± 6.07	150.90 ± 6.58	0.000***
9. CL	193.52 ± 8.73	188.40 ± 8.28	0.000***
10. CI	75.37 ± 3.87	80.22 ± 3.88	0.000***
11. MCBA	41.61 ± 4.46	40.19 ± 3.16	0.030*
12. CBT	26.55 ± 2.88	25.60 ± 2.63	0.043*
13. ILo	88.17 ± 5.47	89.97 ± 4.65	0.049*
14. IOm	20.54 ± 2.48	21.16 ± 2.38	0.155
15. FW	121.67 ± 6.60	125.52 ± 7.62	0.004**
16. AFH	115.52 ± 10.70	107.33 ± 8.20	0.000***
17. FI	93.75 ± 6.82	85.41 ± 5.06	0.000***
18. LAFH	67.84 ± 7.94	60.32 ± 4.92	0.000***
19. AFHI	58.66 ± 2.98	56.25 ± 2.19	0.000***

TABLE VII (continued)

Cephalometric variable	Nasally impaired sample (N = 71) $\bar{x} \pm$ S.D.	Control Sample (N = 71) $\bar{x} \pm$ S.D.	P value (T test)
20. PFH	69.77 ± 6.95	70.44 ± 6.83	0.564
21. PFHI	60.80 ± 5.40	65.49 ± 3.52	0.000***
22. FA	86.75 ± 4.87	89.80 ± 7.47	0.005**
23. SN-MP	39.06 ± 5.80	32.19 ± 4.10	0.000***
24. RP-PP	81.29 ± 7.22	79.17 ± 5.13	0.046*
25. GA	130.08 ± 6.53	125.55 ± 6.10	0.000***
26. ML	100.87 ± 7.82	97.98 ± 8.01	0.031*
27. MW	90.07 ± 8.15	90.97 ± 8.40	0.550
28. MI	89.75 ± 6.13	92.96 ± 6.00	0.004**
29. RL	40.38 ± 4.81	40.88 ± 4.76	0.535
30. BL	72.04 ± 5.90	71.21 ± 7.64	0.473
31. AG	2.13 ± 0.99	1.25 ± 0.61	0.000***
32. CP	1.85 ± 1.17	2.06 ± 0.91	0.250
33. ANB	3.61 ± 3.03	3.18 ± 2.14	0.340
C. 1. UADH	28.34 ± 3.83	25.80 ± 2.74	0.000***
2. UPDH	16.77 ± 2.20	15.07 ± 1.45	0.000***
3. LADH	40.68 ± 4.43	37.72 ± 3.28	0.000***
4. LPDH	30.08 ± 3.41	29.48 ± 2.82	0.250
5. UI-SN	102.33 ± 7.90	103.03 ± 7.32	0.586
6. LI-MP	86.94 ± 8.13	91.82 ± 6.01	0.000***

* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$

TABLE VIII MEAN VALUES ($\bar{x}$), STANDARD DEVIATIONS (S.D.) AND VALUES P FOR THE COUNTERPART VARIABLES RECORDED FROM NASALLY IMPAIRED AND CONTROL SAMPLES

Counterpart variable	Nasally impaired sample (N = 71) $\bar{x} \pm$ S.D.	Control sample (N = 71) $\bar{x} \pm$ S.D.	P value (T test)
1. ArAB	- 3.76 ± 3.42	- 1.27 ± 2.65	0.000***
2. MCF	0.53 ± 2.87	- 0.25 ± 2.15	0.071
3. RAM	2.47 ± 1.94	1.59 ± 1.40	0.002***
4. RMCF	- 1.09 ± 3.58	- 0.01 ± 3.18	0.058
5. PMV	0.83 ± 3.25	0.92 ± 2.67	0.848
6. MXMD	- 2.88 ± 4.64	- 0.59 ± 3.68	0.001***
7. PPAL	- 0.32 ± 6.53	1.18 ± 5.62	0.145
8. OPAL	- 4.34 ± 4.29	- 1.49 ± 2.65	0.000***
9. COSP	1.89 ± 1.60	2.27 ± 1.48	0.144

* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$

types, a greater extent of backward rotation of the mandibular ramus, a relatively longer mandibular arch length and a more steep occlusal plane. From the model measurements (Tables XI and X), nasally impaired subjects demonstrated a more shallow vertical overbite, more narrow maxillary dental widths of the intermolar, interpremolar and intercanine distances, a narrower and deeper palate, a more severe posterior lingual crossbite, an anterior crossbite, and crowded maxillary and mandibular anterior arches as compared with the control subjects.

The relationships among cranial width (CW) and other transverse facial dimensions are shown in Table XI. Cranial width showed highly significant associations with most transverse facial dimensions such as interorbital width ($p = 0.007$), interlateral orbital width ($p = 0.000$), facial width ($p = 0.000$) and mandibular width ($p = 0.000$). As seen in Table XII, the cranial index also shows significant relationships with several craniofacial and dental variables ($p \leq 0.05$). The results indicate that the dolichofacial headform is associated with a longer nasal length (NL), a longer anterior facial height (AFH), a more leptoprosopic face (FI), and a higher mandibular plane angle.

As seen in Table XIII, in the nasally impaired sample, black subjects had larger values for midcranial base angle, anterior facial height index, mandibular body length,

TABLE IX MEAN VALUES ($\bar{x}$), STANDARD DEVIATIONS (S.D.) AND VALUES P FOR THE CONTINUOUS OCCLUSAL VARIABLES RECORDED FROM NASALLY IMPAIRED AND CONTROL SAMPLES

Model variable	Nasally impaired sample (N = 71)	Control sample (N = 71)	P value (T test)
	$\bar{x}$ ± S.D.	$\bar{x}$ ± S.D.	
M_1	3.47 ± 2.87	3.01 ± 1.17	0.120
M_2	1.04 ± 2.70	3.61 ± 1.37	0.000***
M_3	43.10 ± 3.34	45.52 ± 2.62	0.000***
M_4	40.20 ± 3.00	39.93 ± 2.84	0.618
M_5	32.44 ± 3.39	34.50 ± 2.58	0.000***
M_6	28.82 ± 2.89	29.44 ± 2.19	0.163
M_7	30.92 ± 3.76	32.43 ± 2.74	0.012*
M_8	25.10 ± 2.62	25.32 ± 1.85	0.594
M_9	29.95 ± 3.63	32.15 ± 2.21	0.000***
M_{10}	24.37 ± 3.43	26.79 ± 2.35	0.000***
M_{11}	16.17 ± 1.61		

* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$

TABLE X X^2, DEGREE OF FREEDOM (D.F.) AND VALUES P FOR THE CATEGORICAL OCCLUSAL VARIABLES RECORDED FROM NASALLY IMPAIRED AND CONTROL SAMPLES

Model variable	x^2	D.F.	P value
M_{12}	1.09	2	0.580
M_{13}	25.02	1	0.000***
M_{14}	16.43	1	0.000***
M_{15}	34.58	1	0.000***
M_{16}	5.48	1	0.019*

* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$

TABLE XI IN NASALLY IMPAIRED SAMPLE, PEARSON CORRELATION COEFFICIENTS (r_1) FOR THE TRANSVERSE VARIABLES AS REGRESSORS AND CRANIAL INDEX AS REGRESSAND

(CW) Regressand / Regressor	IO	ILo	FW	NW	MW
r_1	0.33	0.46	0.49	0.22	0.40
p	0.007**	0.000***	0.000***	0.059	0.001***

* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$

TABLE XII IN NASALLY IMPAIRED SAMPLE, PEARSON CORRELATION COEFFICIENTS (r_1) FOR THE CEPHALOMETRIC VARIABLES AS REGRESSORS AND CRANIAL INDEX AS REGRESSAND

Regressor No.	Variable	Regressand CI r_1	Regressor No.	Variable	Regressand CI r_1
1	NL	-0.48***	9	MI	0.36**
2	CW	0.47***	10	RL	-0.25*
3	CL	-0.65***	11	BL	-0.23*
4	AFH	-0.34**	12	SN-MP	-0.23*
5	FI	-0.44***	13	UADH	-0.22*
6	LAFH	-0.32**	14	LADH	-0.37**
7	PFH	-0.26**	15	LPDH	-0.38**
8	ML	-0.46***	16	OPAL	0.25*

* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$

TABLE XIII IN NASALLY IMPAIRED SAMPLE, A COMPARISON OF VARIABLES SHOWING SIGNIFICANT DIFFERENCES ($p \leq 0.05$) BETWEEN BLACK AND CAUCASIAN PATIENTS

Variable	Black Patients (N = 15) $\bar{x} \pm$ S.D.	Caucasian Patients (N = 56) $\bar{x} \pm$ S.D.	P Value (T test)
ND	2.16 ± 2.15	5.56 ± 4.91	0.000***
MCBA	43.89 ± 3.74	41.00 ± 4.47	0.025*
AFHI	60.32 ± 2.24	58.22 ± 3.02	0.014*
BL	75.47 ± 4.69	71.12 ± 5.88	0.010*
AG	2.63 ± 0.97	1.99 ± 0.95	0.025*
RP-PP	86.57 ± 5.77	79.88 ± 6.95	0.001***
GA	126.50 ± 5.22	131.04 ± 6.55	0.016*
ANB	5.40 ± 3.06	3.13 ± 2.87	0.009**
LADH	43.60 ± 4.61	39.89 ± 4.07	0.003**
LPDH	31.73 ± 3.67	29.64 ± 3.22	0.034*
UI-LI	125.83 ± 12.44	133.54 ± 10.73	0.020*
LI-MP	90.80 ± 7.55	85.91 ± 8.03	0.038*
IOm	21.83 ± 2.81	20.04 ± 2.18	0.016*
MCF	1.87 ± 2.05	0.17 ± 2.96	0.041*
RAM	3.90 ± 2.20	2.09 ± 1.68	0.001***
RMCF	-4.61 ± 3.76	-0.15 ± 2.90	0.000***
UIM	45.55 ± 2.07	42.42 ± 3.31	0.002**
LIM	41.82 ± 3.08	39.75 ± 2.85	0.027*
UIP	34.72 ± 3.26	31.84 ± 3.19	0.004**
LIP	30.43 ± 2.65	28.42 ± 2.83	0.023*
UIC	32.84 ± 3.21	30.34 ± 3.76	0.042*
LIC	26.68 ± 2.80	24.62 ± 2.39	0.011*
PW_1	32.34 ± 2.38	29.28 ± 3.65	0.006**
PW_2	26.41 ± 3.23	23.83 ± 3.30	0.011*

antegonial notch, ramal plane to palatal plane angle, lower dental height, ANB angle, interorbital distance, dental arch and palatal widths than caucasian subjects. Black subjects also showed a more narrow airway, a more posterior rotation of the mandibular ramus, a relatively larger mandibular arch length and a smaller gonial angle.

The results of MANOVA test demonstrated that there is no significant difference of craniofacial ($p = 0.289$) and occlusal ($p = 0.112$) variables between subsample A and subsample B groups.

As shown in Table XIV, all of the linear measurements of ND, CL, ILo, FW, AFH, LAFH, ML, UADH, UPDH, LADH, intercanine distance (M_7) and palatal height (M_{11}) of nasally impaired patients showed significantly positive correlations with the age variable ($p \leq 0.05$). The younger patients also showed less crowded maxillary and mandibular anterior dentitions, a more brachycephalic head form, and a more euryprosopic facial pattern. The smaller midcranial base angle, less upward tilt of the cranial base, larger facial axis angle, smaller mandibular plane angle and the smaller ramal plane-palatal plane angle were also noted in the younger subjects. The relationships among the total nasal resistance (TNR) and the selected craniofacial dental variables showing significant differences compared with controls ($p \leq 0.05$) are given in Table XV. The results indicate that smaller

TABLE XIV IN NASALLY IMPAIRED SAMPLE, PEARSON CORRELATION COEFFICIENTS (r_1) FOR VARIABLES SHOWING SIGNIFICANT DIFFERENCES BETWEEN PATIENT AND CONTROL GROUPS AS REGRESSORS AND AGE VARIABLE AS REGRESSAND

Regressor No.	Variable	Regressand Age r_1	Regressor No.	Variable	Regressand Age r_1
1	ND	0.60**	22	AG	-0.18
2	N_pH	0.08	23	UADH	0.31**
3	NAI	-0.00	24	UPDH	0.48***
4	CW	0.06	25	LADH	0.41***
5	CL	0.26*	26	LI-MP	0.19
6	CI	-2.34*	27	ArAB	0.04
7	MCBA	-0.52*	28	RAM	0.07
8	CBT	-0.78	29	MXMD	-0.12
9	ILo	0.33**	30	OPAL	-0.07
10	FW	0.59***	31	M_2	0.24*
11	AFH	0.52***	32	M_3	-0.09
12	FI	0.30*	33	M_5	-0.16
13	LAFH	0.33**	34	M_7	0.23*
14	AFHI	-0.20*	35	M_9	-0.05*
15	PFHI	0.06	36	M_{10}	-0.17
16	FA	-0.07	37	M_{11}	0.52***
17	SN-MP	0.01	38	M_{13}	0.13
18	RP-PP	0.14	39	M_{14}	0.09
19	GA	-0.18	40	M_{15}	0.46***
20	ML	0.54***	41	M_{16}	0.50***
21	MI	0.05			

* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$

TABLE XV IN SUBSAMPLE A WITH AGE OLDER THAN 6 YEARS OLD, SPEARMAN CORRELATION COEFFICIENTS (r_2) FOR VARIABLES SHOWING SIGNIFICANT DIFFERENCES BETWEEN PATIENTS AND CONTROL GROUPS AS REGRESSORS AND TOTAL NASAL RESISTANCE (TNR) AS REGRESSAND

No	Regressor Variable	Regressand TNR r_2	No	Regressor Variable	Regressand TNR r_2
1.	ND	-0.01	22.	AG	0.17
2.	N_pH	0.16	23.	UADH	-0.21
3.	NAI	-0.23	24.	UPDH	-0.17
4.	CW	0.04	25.	LADH	-0.13
5.	CL	0.17	26.	LI-MP	-0.29
6.	CI	-0.16	27.	ArAB	0.00
7.	MCBA	-0.30	28.	RAM	-0.16
8.	CBT	-0.03	29.	MXMD	0.12
9.	ILo	-0.07	30.	OPAL	0.02
10.	FW	0.04	31.	M_2	0.15
11.	AFH	-0.42	32.	M_3	-0.42*
12.	FI	0.01	33.	M_5	-0.14
13.	LAFH	-0.09	34.	M_7	-0.09
14.	AFHI	-0.17	35.	M_9	-0.43*
15.	PFHI	0.01	36.	M_{10}	-0.20
16.	FA	-0.22	37.	M_{11}	-0.08
17.	SN-MP	0.23	38.	M_{13}	0.15
18.	RP-PP	-0.08	39.	M_{14}	-0.20
19.	GA	0.19	40.	M_{15}	0.23
20.	ML	-0.33*	41.	M_{16}	0.29
21.	MI	0.54**			

* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$

rhinomanometric values were associated with a shorter mandibular length and a more narrow maxillary intermolar distance and palate width.

In order to evaluate the reliability of radiographic diagnosis for nasal obstruction in adenoid hyperplasia patients, the subjects of subsample A with adenoid hyperplasia (N=30) where utilized to determine the relationship between the rhinomanometry (total nasal resistance) and ND. The Spearman correlation coefficient between them demonstrated no significant relationship (r_2 = -0.17, p = 0.19). The distributions of the rhinomanometry and ND variables of the tested subjects are presented in Figure 19.

As seen in Table XVI, the results of multivariate analyses show that vertical overbite (M_2); maxillary intermolar, interpremolar, intercanine distances (M_3, M_5, and M_7); palatal width (M_9, M_{10}); palatal height (M_{11}); crossbite (M_{13}, M_{14}) and crowding (M_{15}, M_{16}) had very significant correlations (p = 0.000) with certain craniofacial combinations. The R^2 value of these 7 multiple regression functions varied from 0.20 to 0.65. The high R^2 value (0.65) for equation M_{11} indicates that 65% of the variations in palatal height (M_{11}) could be explained by the variations in mandibular corpus length (BL), the Ramus/MCF horizontal dimension (RMCF) and anterior facial height (AFH). As

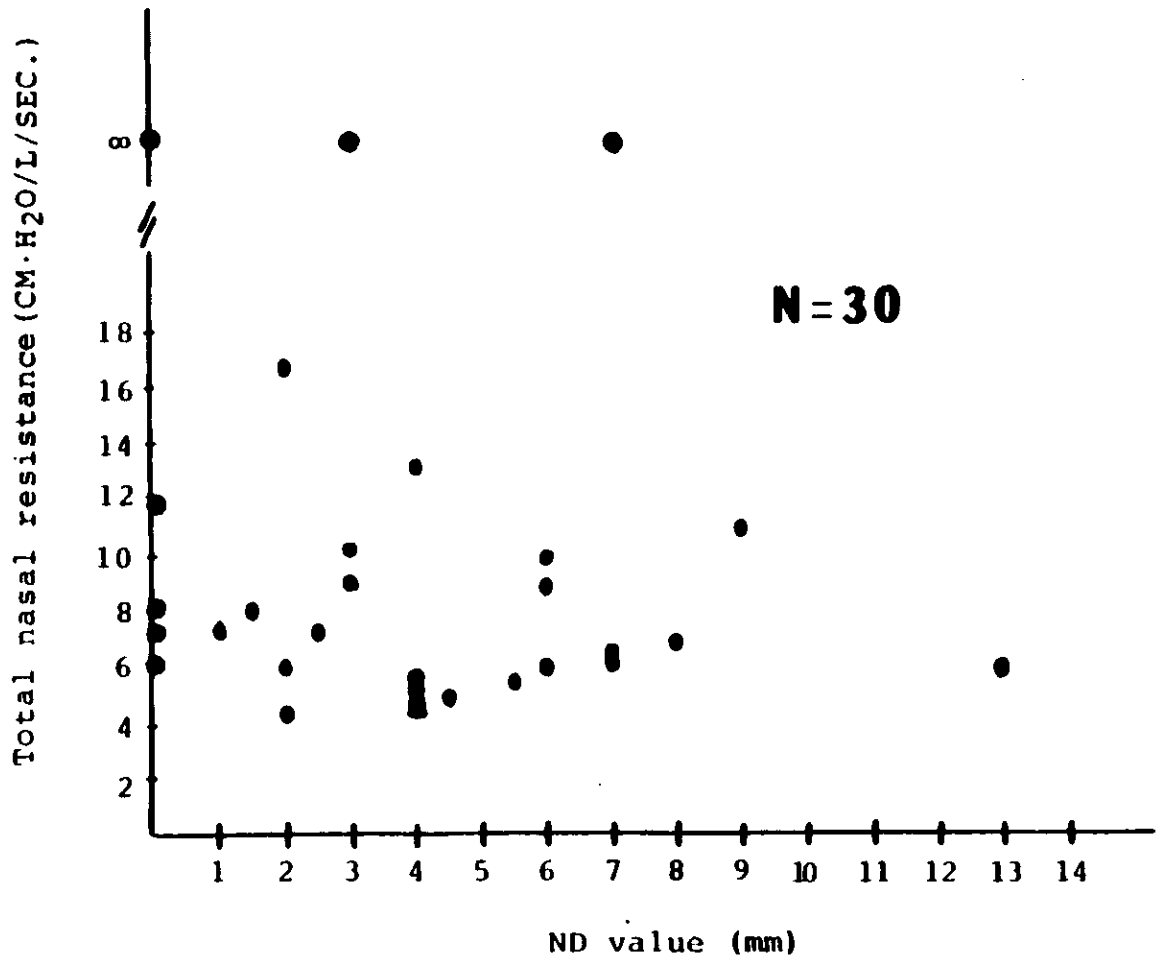


Figure 19. Relationship between total nasal resistance and ND variables of subsample A

seen in Table XVII, four discriminant score functions demonstrate that the high percentage of accurate groupings of the crossbite and anterior crowding incidences were reached from 63.24% to 89.58%.

TABLE XVI MULTIPLE REGRESSION FUNCTIONS, R, R^2 AND P VALUES OF M_2, M_3, M_5, M_7, M_9, M_{10}, and M_{11} VARIABLES OF NASALLY IMPAIRED SAMPLE

Multiple regression functions	R	R^2	P
M_2 = 24.92 - 0.41 AFHI	0.45	0.20	0.000***
M_3 = 21.41 + 0.17 BL - 0.85 AG + 0.27 MCBA	0.54	0.29	0.000***
M_5 = 24.73 - 0.30 RMCF - 1.21 AG + 0.24 MCBA	0.61	0.37	0.000***
M_7 = 35.52 + 0.27 NpH - 0.26 MI + 1.09 CP	0.69	0.48	0.000***
M_9 = 6.41 + 0.19 BL - 0.90 AG + 0.29 MCBA	0.53	0.29	0.000***
M_{10} = 16.08 - 0.98 AG - 0.32 RMCF + 0.25 MCBA	0.64	0.40	0.000***
M_{11} = -10.17 + 0.13 BL + 0.24 RMCF + 0.14 AFH	0.81	0.65	0.000***

TABLE XVII DISCRIMINANT SCORE FUNCTIONS AND PERCENTAGE OF ACCURATE PREDICTION OF M_{13}, M_{14}, M_{15}, and M_{16} VARIABLES OF NASALLY IMPAIRED SAMPLES

Discriminant score functions	Percentage of accurate prediction (%)	P
$D_{(M13)} = -19.44 + 0.13$ RMCF $+ 0.09$ PFH $+ 0.15$ $N_pH + 0.11$ N_pD	63.24	0.004**
$D_{(M14)} = 4.27 + 0.32$ ANB $- 0.20$ CBT	69.12	0.000***
$D_{(M15)} = -6.58 + 0.18$ RMCF $+ 0.53$ CP $- 0.11$ LAFH $+ 0.07$ PFH $+ 0.15$ FI $- 0.15$ MCBA $- 0.11$ NAV $+ 0.07$ NpH	86.96	0.000***
$D_{(M16)} = -1.19 + 0.09$ RMCF $+ 0.05$ MI $- 0.13$ LAFH $- 0.162$ FA $+ 0.15$ AFH $- 0.09$ MCBA $+ 0.10$ N_pD	89.58	0.000***

DISCUSSION

The classical description of dentofacial morphology as seen in the nasally obstructed patient has been termed "adenoid face". However, not all breathing-compromised children have the dentofacial characteristics found in such faces (McNamara, 1981; Linder-Aronson, 1986). Most researchers have suggested that pronounced individual variations in neuromuscular adaptations result in individual variations in the craniofacial and occlusal patterns of nasally impaired patients (Harvold, 1975, 1979; Miller and Vargervik, 1979, 1980). The individual neuromuscular activities have been reported to have close relationship with facial patterns (Ingervall and Thilander, 1974; Bench, 1977). A given, specific facial pattern is composed of several craniofacial components three-dimensionally. Anteroposterior and vertical craniofacial characteristics of nasally impaired patients have been discussed extensively (Linder-Aronson, 1979; Watson, et al., 1968). However, there is presently inadequate information for quantitative measures of transverse craniofacial dimensions in patients with nasal obstruction. In our study, 55 PA cephalograms in the patient group and 71 PA cephalograms in the control group provided basic information about transverse dimensions of certain craniofacial morphologies and facial proportions.

Vig, et al. (1981), and O'Ray, (1982) mentioned that clinically observed lip posture and the existence of lip separation are not valid criteria for the determination of nasal obstruction. All the nasally impaired patients in our study were diagnosed as such by an otolaryngologist. The suspected cases in whom nasal obstruction couldn't be confirmed by the examination of an ENT specialist and rhinomanometry were excluded from this study. We exclusively used nasal obstructed cases in order to evaluate differences in craniofacial and occlusal patterns between nasal obstructed cases and controls.

Of the variables studied, 30 cephalometric and 11 model variables showed significant differences between the patient and control groups ($p \leq 0.05$). The nasally impaired subjects demonstrated smaller sagittal depths and larger sagittal height angles of the bony nasopharynx than the controls. These findings support the observations in Linder-Aronson's study (1979), who concluded that the sagittal depth of the nasopharynx is less in the mouth-breathing patient. Bushey (1979) found that the sagittal height of the nasopharynx was less in the nasally impaired patients and suggested that the angular height of the nasopharynx appears to be a more discriminating factor among different respiratory groups. The conflicting findings with regard to nasopharyngeal height in nasally impaired

patients need to be further studied. Nasally impaired patients also showed significantly larger midcranial base angle ($p = 0.030$) and cranial base tipping angle ($p = 0.043$). The larger midcranial base angle has a more maxillary protrusive effect in the nasally impaired patients. Schulhof and colleagues (1977) found that the upward deflection of the anterior cranial base was one of the common characteristics of severe posterior crossbite. In the present study, the larger cranial base tipping angle might be related to the higher incidence of posterior crossbite in the patient group.

All the vertical variables, such as anterior total and lower facial heights, SN to mandibular plan, and facial axis angle, were larger in the patient group. However, the ANB angle and the Angle groups did not show any significant differences between the two groups. These findings tend to confirm the theory that the deleterious effects of impaired nasal function are mainly related to the vertical craniofacial morphologic components (Harvold et al., 1973; Bushey, 1979; McNamara, 1981; Linder-Aronson, 1986). Leech (1958), Watson and colleagues (1968) could not find significant effects of airway obstruction on craniofacial morphology. The reason is likely that they evaluated the ANB angle and Angle classifications only, without considering the vertical components. Tarvonen and Koski (1987) proposed that a

dorsal rotation of the mandibular ramus relative to the palate was a diagnostically useful characteristic associated with the occurrence or a past history of enlarged adenoids. A similar finding was obtained in our study. Tomer and Harvold (1982), inducing oral respiration in 8 growing rhesus monkeys, noted that the posterior border of the ramus underwent gradual remodeling while maintaining its normal inclination. This suggested that the large RP-PP angle found in the present study may be due to an upward cant of the palatal plane. However, the palatal plane alignment as determined by the counterpart analysis did not show any significant differences between the two groups.

The influence of nasal obstruction on the transverse craniofacial components has received less attention in the literature. Our study revealed that more narrow cranial and facial widths are found in the nasally impaired patient. These effects also contributed to the long face appearance of the mouth breathers. In the nasally impaired patients, cranial width demonstrated significant associations with the interorbital ($p = 0.007$), interlateral orbital ($p = 0.000$), facial ($p = 0.000$) and mandibular ($p = 0.000$) widths. This result supports the theory of Enlow (1982) that the boundary of the midface coincides with respective brain boundaries. The cranial index also shows high correlations with dentofacial morphology ($p \leq 0.05$). The more dolichocephalic the head

form, the more leptoprosopic is the face, with longer nasal and mandibular whole lengths, and longer facial and dentoalveolar heights. Steeper mandibular and occlusal planes are also related to the dolichocephalic headform. These 3-dimensional relationships further demonstrate the close relationship of headform with facial morphology (Enlow, 1982, Bhat and Enlow, 1985).

The shape and size of the mandible in nasally impaired patients showed significant differences as compared with controls ($p \leq 0.05$). Their mandibles were longer with larger gonial angles and deeper antegonial notches. The counterpart analysis demonstrated a more "B" facial type tendency (i.e., mandibular B point protrusive relative to maxillary A point as determined perpendicular to the functional occlusal plane). Also, there exists a relatively larger mandibular arch and more backward rotation of the mandibular ramus. However, there was not a higher incidence of Class III malocclusion in the nasally impaired patients. These overall mandibular protrusive effects might be compensated by the vertically increased face height and backward rotation of the whole mandible (Bushey, 1979).

All dentoalveolar heights were increased in the patient group. This appears to be a dental compensation to excessive mid-facial height (Enlow, 1982). Narrower maxillary dental arch and palate widths were noted in

patient group. Palatal height could not be determined for the models of the control sample because of the limitation of the impression material. A high correlation between the palatal height and the posterior dental height ($r = 0.93$) obtained from the lateral cephalograms permitted substitution of palatal height for UPDH. Since the UPDH was significantly higher in the patients ($p = 0.000$), they thus had higher palatal heights than the control cases. The higher incidence of posterior lingual crossbite in our study supports a similar finding by Melsen et al. (1987). In our study, the nasal impaired subjects showed more upright lower anterior teeth and anterior crowding than the controls. Linder-Aronson et al. (1986), suggested that some forms of incisor crowding previously attributed to tooth-jaw size discrepancy might represent environmental crowding which could be managed without permanent tooth extraction. The higher incidence of anterior crowding in nasally impaired patients might be due to the narrowed maxillary arch and an aberrant muscular pattern. Early correction of the nasal obstruction might decrease the relapse tendency of the lower incisor crowding after orthodontic treatment.

There are 15 black and 56 caucasian patients included in the nasally impaired group. These black patients showed a relatively longer mandibular arch length, wider dental arch and palatal widths than the caucasian patients. These

findings might be related to the larger tongue size in a black population (Drummond, 1968). A greater lower anterior facial height, more procumbent maxillary and mandibular incisors and more backward rotation of the mandibular ramus found in black patients also supported the findings of Alexander and Hitchcock (1978). They found that the American Negro population have a more bimaxillary dentoalveolar protrusion, more anterior placement of the maxilla and a greater lower anterior facial height than the Caucasian population. Since the control group was composed of caucasian subjects only, the differences of craniofacial and occlusal characteristics between black and caucasian subjects should be taken into account in the comparison between the caucasoid-only control and the racially mixed patient groups.

It was very interesting to find that the younger a patient, the less the adenoid facial characteristics were noted. The younger patients, naturally, demonstrated a lesser degree of a "leptoprosopic" face. They also had less of an open bite tendency and a lesser extent of anterior crowding. These conditions relate to growth stage in younger children as well as detrimental effects of an obstructive airway not yet fully expressed. This also underscores the importance of early diagnosis and treatment of the nasally impaired patient.

Since younger patients showed less marked breathing impairment characteristics, which were usually more recognizable in the nasally impaired older patients, the age factor should be considered when evaluating relationships between rhinomanometry and the craniofacial or occlusal variables.

Only patients older than 6 years of age in subsample A were chosen for evaluation of these relationships. The results demonstrated that a relationship existed between rhinomanometry and mandibular length ($r = -0.33$, $p \leq 0.05$), maxillary intermolar distance ($r = -0.42$, $p \leq 0.05$) and palatal width at molar area ($r = -0.43$, $p \leq 0.05$). A higher total nasal resistance value was associated with a shorter mandibular length, a more narrow maxillary intermolar and palatal widths. Most of the other craniofacial and occlusal variables did not show a significant linear relationship with the rhinomanometric value. This finding is at variance with that of Holmberg and Linder-Aronson (1979), who suggested that a negative relationship exists between the size of the adenoids, as measured on lateral cephalograms, and nasal airflow. However, Martin, et al., (1981) had similar findings with our study. He could not find significant correlations between nasal resistance values and 14 vertical dental and skeletal-facial dimensions in 42 children between 10 and 15 years of age. Vig, et al.,

(1981) examined the relationship between facial morphology and nasal respiration in 28 adults. While he found the long-face subjects demonstrated the highest nasal airway resistance and the lowest over-all amount of nasal airflow as a group, individual variations were large enough to preclude categorizing breathing mode according to facial morphology. In the present study, nasal obstructive cases diagnosed by rhinomanometry all had a total nasal resistance larger than 3.5 cm. H_2O/liter/second. They also showed significant vertical and transverse dentofacial deformities. However, the serverity of nasal obstruction did not have a significant linear relationship to most of the craniofacial and occlusal variables. Shaughnessy (1983) believed that the activity of the associated musculature necessary to facilitate oral respiration might be more important than the quantitative measure of nasal resistance. The rhinomanometric data was limited in that it was obtained at one point in time and did not reflect dynamic changes which may be occurring. A longitudinal study will be needed to clarify the association between nasal resistance and dentofacial morphology.

Relationships among the total nasal resistance and ND variables were also evaluated in our study. Only the patients in subsample A diagnosed as adenoid hyperplasia were chosen for this examination (N=30). The results

showed that there is no significant association among them. Vig (1980) mentioned the inadequacy of cephalometric radiographs for airway assessment, and Montgomery (1979) used computed tomography to study the nasal airway 3-dimensionally. He found that the most constricted part of the airway was not necessarily at the location of the turbinates. McNamara (1983) pointed out that apparent airway obstruction is indicated by an opening of 5 mm or less in the upper pharyngeal measurement of lateral cephalograms. When we further selected the nasal obstructive cases with ND variable smaller than 5.0 mm, total nasal resistance value showed a significant negative relationship with ND value ($r = V\ 0.39$, $p = 0.044$). Weimert (1986) suggested that a normal x-ray did not rule out the possiblity of significant underlying nasal obstruction. Adenoid hypertrophy is not the only pathology which can cause nasal obstruction. Turbinate hypertrophy, deviated nasal septum, infective rhinitis, and allergy can also be involved in the etiology of nasal obstruction. Most of these pathologies cannot be diagnosed clearly from a lateral cephalogram. Lateral cephalograms are not reliable indicators of nasal obstruction unless the adenoid hypertrophy is severe. Although the computed tomography is an effective method for evaluating nasal airway volume, the problem of increased radiation exposure and the high

cost of the procedure limits its clinical application. Weimert (1986) reported that the nasal airway could best be evaluated by direct visualization with a nasal speculum. Nasal examination with rhinomanometry may be the most effective method for diagnosing nasal obstruction.

In order to test the hypothesis that specific types of malocclusions found in nasally impaired patients relate to certain intrinsic morphologic combinations, multivariate analyses were used.

Results from the multiple regression equations (Table XV) showed that vertical overbite (M_2), maxillary intermolar width (M_3), interpremolar width (M_5), intercanine width (M_7), and palatal width at the molar (M_9) and premolar (M_{10}) areas all had high correlations with certain intrinsic morphologic combinations ($P = 0.000$).

Equation $M_2 = 24.92 - 0.41$ AFHI ($R = 0.45$, $P = 0.000$) demonstrated that the anterior facial height index (AFHI) had a negative association with the overbite variable. The larger of the AFHI, the more shallow the vertical overbite.

Equation $M_3 = 21.41 + 0.17$ BL $- 0.85$ AG $+ 0.27$ MCBA ($R = 0.54$, $P = 0.000$) showed that longer the mandibular body length (BL), the lower the depth of the antegonial notch (AG) and the larger the midcranial base angle (MCBA), the wider the intermolar distance (M_3) would be.

The equation M_5, M_7, M_9, M_{10}, and M_{11} also

demonstrated a close relationship with the combinations of RMCF, AG, MCBA, NpH, MI, CP; BL, AG, MCBA; AG, RMCF, MCBA and BL, RMCF, AFH, respectively. The height of the antegonial notch (AG) and the midcranial base angle (MCBA) were both noted in four of the equations M_3, M_5, M_7, M_9, M_{10}. Since the variables M_3, M_5, M_7, M_9, M_{10} are all related to the transverse dimensions of the maxillary dental arch or palate, the high incidence of AG, MCBA found in these equations suggests that an intimate relationship exists between the AG, MCBA variable and the transverse maxillary dimension. The higher value of the AG, the greater the chance to have a narrowed maxillary dental arch or palate. The higher the value of the MCBA, the greater is the tendency to have a wider maxillary dental arch or palate. This finding conflicts with other results (Table V), which showed that the nasally impaired patients had a larger midcranial base angle in conjunction with a narrowed maxillary dental arch and palate. The nature of the influence of the MCBA on the malocclusion thus is in need of further investigation.

Equation M_{11} = -10.17 + 0.13 BL + 0.24 RMCF + 0.14 AFH had a very high R^2 score (0.65). This high value suggests that by using mandibular body length (BL), RAMUS/MCFS horizontal skeletal dimensions (RMCF) and anterior facial height (AFH) to predict the value of palatal

height (M_{11}), an acceptable degree of accuracy to predict palatal height can be obtained. This equation also showed that the patients with larger BL, RMCF and AFH values had a tendency for a higher palatal vault (M_{11}).

Since the crossbite and anterior crowding data were dichotomous variables, discriminant analysis was used to test the relationship between the existence of crossbite or anterior crowding with the craniofacial variables. A discriminant score was calculated first, and then Bayes' Rule was further used for classifying cases into one of the two groups. The relationship among the + or - sign of the craniofacial variables and the grouping of the crossbite or anterior crowding was determined by the results. The results also showed a high correlation between posterior lingual crossbite (M_{13}) and RMCF, PFH, NpH, NpD ($p = 0.004$); anterior crossbite (M_{14}) and ANB, CBT ($p = 0.000$); maxillary anterior crowding (M_{15}) and RMCF, CP, LAFH, PFH, FI, MCBA, NAV, NpH ($p = 0.000$); mandibular anterior crowding (M_{16}) and RAM, MI, LAFH, FA, AFH, MCBA, NpD ($p = 0.000$). Based on our study sample, the correct prediction percentage was 63.24% for grouping posterior lingual crossbite; 69.12% for grouping anterior crossbite; 86.95% for grouping maxillary anterior crowding and 89.58% for grouping mandibular anterior crowding. These high accuracy rates for grouping crossbite and anterior crowding

and the high r^2 score for equation M_{11} (palatal height) suggest that future, specific types of malocclusion (palatal height, crossbite and anterior crowding) can be expected if these characteristic <u>combinations</u> of morphologic components exist in a young child.

SUMMARY AND CONCLUSIONS

The objectives of the present study were to characterize the craniofacial morphology and occlusal pattern of nasally impaired patients and to test a hypothesis that specific types of malocclusions (shallow overbite, narrow upper arch) found in patients with nasal obstruction relate to certain intrinsic morphologic combinations.

Seventy-one patients recognized as having nasal impairment were evaluated. Their mean age was 11.1 years. An equal number of control subjects matched for age and sex were obtained from the Bolton Study records. All records included lateral cephalograms and models. Posteroanterior cephalograms were available in 55 cases, and 47 cases in the patient group had rhinomanometry measurements. Fifty-eight cephalometric and 16 model variables were measured and their mean values compared. The relationships among the craniofacial and occlusal variables in nasally impaired patients were further evaluated by multivariate analyses. The influence of age and rhinomanometric levels on craniofacial morphology and occlusion in patient group were also evaluated by Pearson or Spearman correlation methods.

The findings led to the following conclusions:

1. Craniofacial morphology and occlusal patterns in the nasally impaired sample were significantly different from those in the control sample. The discrepancies were related to the vertical components associated with a longer face and dentoalveolar and palatal heights. Transversely, they also showed more narrow cranial and palatal widths. The mandibles in these patients were characterized by longer whole mandibular lengths and more prominent antegonial notching.
2. In the nasally impaired group, black patients showed a larger mandibular length, wider dental arches and palates, a larger midcranial base angle and a more backward rotation of the mandibular ramus. These differences of the craniofacial and occlusal characterists between black and caucasian subjects should be taken into account in comparisons of variables between the racially mixed patient and caucasian only control groups.
3. The younger the nasally impaired patients, the less the expression of these craniofacial and occlusal characteristics.
4. Total nasal resistance is a reliable indicator of the magnitude of nasal obstruction. Nasal obstructive cases diagnosed by rhinomanometry with total nasal resistance value larger than 3.5 cm. H_2O/liter/second

show a significant vertical and trnasverse dentofacial deformities. However, the severity of nasal obstruction does not have a clear-cut linear relationship with the severity of dentofacial deformities.

5. Nasal examination with rhinomanometry is the most effective method for diagnosing nasal obstruction. Lateral cephalograms may be useful in this regard if the adenoid hypertrophy is severe.

6. The results of the multivariate analyses showed that certain types of occlusal variables had high correlations with specific combinations of craniofacial structures.

7. The high prediction rates of palatal height (R^2 = 65%) and accurate groupings of posterior lingule crossbite (R^2 = 63.24%), anterior crossbite (R^2 = 69.12%), maxillary anterior crowding (R^2 = 86.96%) and mandibular anterior crowding (R^2 = 89.58%) were achieved by using certain combinations of craniofacial morphologic variables.

8. A multidisciplinary approach involving the otolaryngologist and the orthodontist is advantageous for patients having nasal obstruction to curtail or reduce future or continuing detrimental effects of breathing impairments on craniofacial morphology and occlusion.

9. An added goal of this study was to determine, using longitudinal data, if it is feasible to anticipate a future dentofacial deformity with an acceptable degree of accuracy. From our limited data, the existence of statistically high correlations among certain anatomic combinations with the specific malocclusion types (e.g., high palatal height, posterior lingual crossbite, anterior crossbite and anterior crowding) suggests that such a predictive opportunity is feasible.

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