A COMPUTER AIDED CEPHALOMETRIC INVESTIGATION OF CRANIAL BASE DIFFERENCES BETWEEN CLEFT AND NONCLEFT INDIVIDUALS

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INTRODUCTION

Physical anthropologists first implicated the importance of the cranial base as an influencing factor in facial growth and form in the early part of this century.[1] The methods used by early investigators for determining growth changes in cranial base have been criticized due to the impossible task of accurately measuring cranial landmarks that are covered by skin and soft tissue in the living person. With the development of the Broadbent-Bolton cephalometer in 1931, a standardized roentgenographic technique was introduced that made it possible to accurately record cranial landmarks and growth changes in the living head. Despite the numerous cranial base studies which have been reported since then, to date the literature has not revealed a rigorous standardized definition of the cranial base which is universally accepted.

In general terms the cranial base is defined as an angle formed by cranial landmarks which divides the cranium from the facial structures. Brodie and Broadbent have regarded the angle formed by the landmarks nasion, sella, bolton point as the saddle angle or cranial base[4,5] (Figure 1). However, the use of bolton point as the posterior terminal landmark for cranial base has been considered less than ideal for study because it is difficult to accurately locate in lateral cephalometric radiographs. As a consequence it has been suggested that basion be substituted for bolton point as an alternate point for the cephalometric evaluation of the cranial base. In 1947 Bjork advanced articulare as the most ideal posterior terminal point from which to study growth changes in the cranial base.[6]

Since then numerous investigations have targeted the cranial base structures for study, but the aforementioned reference points used to define the posterior limits of the cranial base have received little concern in the literature. The interchangeable use of different landmarks in cranial base studies has implied a constancy between these points and associated structures which has not been adequately tested and confirmed. In part, the purpose of this report is to determine the relative constancy or lack of between the anatomic landmarks basion and articulare in a sample of males and females possessing Angle Class I molar occlusion.

The importance of the cranial base has long been recognized in orthodontics as well as other fields due to its unique location which places it between the border of the cranium and the face. This position necessarily places the anterior cranial base in intimate association with the upper facial structures and the posterior cranial base is closely related to the mandible. Thus it has been frequently suggested that changes in the size and shape of the cranial base during growth and development are accompanied by changes in the relationship and positions of upper and lower facial structures, i.e. the maxilla and mandible.

Unfortunately, the cranial base dimensions as described by the saddle angle has never been advocated for routine description of craniofacial form in the practice of orthodontia although it is frequently used in the description and identification of some cranial dysplasias. In fact, all recognized cephalometric analyses currently in clinical use by orthodontists have neglected any consideration of the cranial base for the purpose of description, diagnosis or treatment planning.

In light of the importance of the cranial base as an influence on facial form, it is conceivable that a description of the normal range of variation in the saddle angle could be an adjunct in the diagnosis and subsequent treatment of "routine" orthodontic cases. At the very least it will aid all practitioners in the screening of lateral cephalometric radiographs for craniofacial pathology, an important but often overlooked aspect of roentgenography.

Therefore, this investigation also proposes to develop cephalometric standards for cranial base (saddle angle) as part of a computerized cephalometric analysis which has been described and developed in a previous report.

REVIEW OF THE LITERATURE

Early research by Keith and Campion[1] investigating the growth of the human face emphasized the role of the skull in determining facial proportions. Their results based on measurements taken from the face indicate that "the base of the skull is transformed in size and conformation between the fifth and 18th years to a much greater degree than is usually realized."

Hellman[2] conducted a similar investigation of the living head and developed standards for Angle Class I occlusions. He contended that "measuring individuals directly has an advantage over measuring complex curves of a three-dimensional object on a flat photograph or illusive shadows on a roentgenograph." These early investigative methods are often criticized due to the inaccurate identification and measurement of cranial landmarks through soft tissue. Keith and Hellman adequately outlined the general nature of the cranial base structure but it remained for later studies to elicit a quantitative description of growth and morphology of the skull base. This was realized with the development of the Broadbent-Bolton[3] cephalometer in 1931 which made possible longitudinal serial studies of the living head.

Broadbent[4] was the first investigator to describe the cranial base with cephalometric data using a method of superimposing series of headplate tracings on an assumed base and making comparisons of the entire head. The bolton-nasion plane was introduced as a stable base for the orientation and registration of subsequent roentgenograms of the same individual. Since this work numerous investigators have documented the growth characteristics of the cranial base with the aid of cephalometrics.

Brodie[5] complemented the work of Broadbent by breaking down the human head into its various parts and studying each entity quantitatively. His study of the growth pattern of the human head from age three months to eight years reveals that the conformation of the cranial base is determined by the third month of life and remains relatively constant thereafter.

Using material from the Bolton Study of Western Reserve University, Brodie[6] studied the growth changes of individuals from age three years to 18 years. The incremental growth of the cranial base was measured as was the relative contribution made by each part of the cranial base to the whole. For each individual the ratio of each component of the cranial base to the whole remained nearly constant during the period of study. The angle of the cranial base was also noted to remain unchanged on the average through this time.

In 1955 Bjork[7] analyzed the growth mechanism of the cranial base during the adolescent period of Swedish boys from age 12 to 20 years. The study examines the deflectional changes that occur in the cranial base angle and indicates that changes in the shape of the cranial base with age are a normal occurrence. The two cranial base angles N-S-Ar and N-S-Ba were found to be closely correlated in regards to magnitude and direction of growth changes. As early as 1947 Bjork[8] argued that the use of articulare was preferable to basion for quantitative studies of the cranial base because it was more easily identified on lateral headplates and therefore was more reliable. The reliability of articulare coupled with its stable relationship to basion greatly increased its use as the posterior terminus in cranial base studies.

Coben[9] also recognized a seemingly stable relationship between basion and articulare in face development. He noted little change in the basion-articulare dimension in the cases studied and suggested that the position of the mandibular fossa relative to basion is nearly constant.

Observations by Ricketts[10] have also indicated that changes in the cranial base are consistent to a degree with changes in the position of the glenoid fossa.

A recent investigation of the relationship of basion and articulare was conducted by Seward[11] in 1981. The distance between the two landmarks was evaluated on serial cephalometric radiographs in a longitudinal study of boys and girls between the ages of five and 20 years. It was concluded that the distance from basion to articulare remains essentially constant and makes articulare a reliable alternative cranial base landmark.

In short, the accumulated results of these investigators have helped establish articulare as a fundamental reference point in the description of cranial base morphology.

Much of the interest in the cranial base complex has evolved from the attempts to find a stable region in the craniofacial area from which growth and treatment changes could be evaluated. The work of Bjork[7] implicated the cranial base components as factors in determining the degree of maxillary and mandibular prognathism. This inspired a multitude of comparative studies between the cranial base morphology of normal individuals and of individuals affected by congenital or developmental anomalies of the craniofacial structures. Craniofacial disorders which have been investigated include among others, cleido-cranial dysostosis,[12] cerebral palsy,[13] microcephaly,[14] and cleft palate.[15] Of these, the orthodontist is most closely involved with the care of the cleft palate patient. Successful rehabilitation of an individual with clefting often involves input from the orthodontists in regard to diagnosis and treatment of malocclusions. This has created a need to establish diagnostic criteria based on the craniofacial patterns of these individuals as compared to persons without clefting. In particular, it is important to distinguish between those conditions that are due to skeletal dysplasias and those resulting from dento-alveolar causes.

Deviation of the craniofacial pattern of cleft individuals from noncleft individuals has been documented extensively in the literature. Where deviations have been present they have often been considered secondary to the surgical repair of the cleft.[16,30] Less attention has been directed towards deviations which may be primarily related to the cleft conditions. A deviation in the position and/or morphology of the cranial base has been implicated as a primary factor in the occurrence of clefting of the lip and/or palate by some researchers.

Moss[17] believes that the cleft palate deformity may be but one of a series of cephalic malformations which differ in their degree but not in kind. Common to these malformations are changes in the skull base which have collectively been termed "dysostosis sphenoidalis." Studies by Moss indicate that all types of cleft palate deformities show significant malformations characterized by an increased flexion of the skull base.

Ross[18] studied the morphology of the cranial base in 342 children with clefts of the lip and palate and found no evidence of dysostosis sphenoidalis. Minor angular differences of the cranial base were thought to be of no practical significance. Ross concluded that there is no evidence to support the contention that clefts of the lip and palate are related to other cranial malformation which have an abnormality of the sphenoid bone.

I. Clefts of the Primary Palate (Cleft Lip)

Relatively little attention has been given to the craniofacial development of persons afflicted with clefting of the primary palate only. Possibly, it is because this type of clefting presents fewer treatment difficulties than other types of clefting.

In a study of the cranial base in cleft children, Ross[18] reported great similarity between cleft subjects and normals and only minor angular differences in cranial base.

In 1970 Dahl[19] studied a sample of 62 males with isolated cleft of the primary palate. When compared with normal controls the linear measurements in the cranial base did not reveal significant differences except the posterior cranial base which was significantly shorter in the cleft group. No significant change was noted in the angle of the cranial base.

Bishara et al[20] (1976) studied the facial growth of eight individuals of Asian descent with unoperated clefts of lip and alveolus. Their findings showed a significant difference in the cranial base angle indicating a tendency toward a larger angle in the cleft group than in the normal group.

Cronin and Hunter[21] investigated the craniofacial structure of 44 pairs of like-sexed twins discordant for cleft of the lip and/or palate using lateral cephalometric radiographs. The cleft group with involvement of the primary palate only differed from their noncleft cotwins in one cranial base dimension: a significantly shorter S-Ar length.

In summary, examination of the literature has for the most part indicated that the cranial base angulation does not differ substantially in subjects with clefting of the primary palate and subjects without clefting. The other cranial base dimensions also are essentially the same in cleft subjects as compared to normal subjects with the possible exception of the posterior cranial base which has been reported as shorter in the cleft subjects.[19,21]

II. Clefts of Secondary Palate (Isolated Cleft Palate)

A detailed analysis of cranial base characteristics in the cleft palate only (CPO) patient has been conducted by only a few researchers. Some have indicated that the cleft of the palate is a local defect and that facial development does not differ from that in noncleft individuals. Others believe the defect is influenced by changes in other elements of the craniofacial skeletal complex.

Ross[18] reported that in a group of 138 CPO individuals, the cranial base was smaller in size than in the control group, although the proportions of the component areas were similar in the two groups. Ross states this is due to the smaller size of the cleft children and is not a reflection of an abnormality in the cranial base.

This view is supported by Bishara[22] who has reported that normal individuals are larger in terms of absolute dimensions of the cranial base when compared to CPO groups. However, there were no significant differences found in the relative measures of the cranial base between cleft and normal groups. Also the cranial base flexure angle (N-P-O) in the CPO individuals was not significantly different from the normal individuals.

In a comparison of CPO subjects with normal control subjects Brader[23] has also stated that there is no basis for judging the two groups of subjects as being from different populations in regard to cranial base flexure.

Dahl[19] found the cranial base of CPO individuals to differ on the average from the control in both size and shape. The total linear measurement (N-Ba) as well as the anterior and posterior segments were significantly shorter in the CPO group. Changes in the shape of the cranial base were manifest as a general tendency toward flattening of the cranial base.

Cronin and Hunter[21] reported that in a sample of 10 CPO subjects the cranial base angle (Ar-S-N) was an average of 3.8 degrees larger than in noncleft cotwins. Other parameters of cranial base morphology did not differ significantly between cleft and noncleft twins.

Krogman and others[24] conducted a mixed longitudinal study of the craniofacial growth pattern in children with CPO from birth to six years of age. The data accumulated in this study has led Krogman to conclusions that are in general disagreement with previous studies. Their data indicate that, compared to normals, clival length (Ba-S) and anterior cranial base length (S-N) are longer in the CPO individual. Compared to normals the angle Ba-S-N showed greater flexion in the cleft sample.

Smahel[25] studied a series of 90 Czech males ranging in age from 20 to 40 years with repaired isolated cleft palate. This sample was further subdivided into three groups: complete clefts, incomplete clefts and clefts of the soft palate only. As compared to controls, the complete cleft subjects showed deviations in cranial base morphology while the incomplete cleft and soft palate cleft groups did not. These changes were manifest as a significant decrease in the N-S-Ba angle and shorter posterior cranial base (S-Ba) dimensions. Smahel reported that these changes in cranial base configuration were not substantial and not an essential characteristic of the craniofacial pattern of the CPO subject.

In summary, most investigators have indicated that there is no difference in the angulation of the cranial base in CPO subjects as compared to normals (Ross,[18] Bishora,[22] Brader[23]). Others have reported a decreased cranial base flexure (Dahl,[19] Cronin[21]) and some have reported an increased cranial base flexure (Krogman,[24] Smahel[25]). Investigators have generally agreed that the linear dimensions of the cranial base are smaller in the CPO individual (Ross,[18] Bishora,[22] Dahl,[19] Smahel[25]), although one investigator has reported no difference (Conin[21]) and another has reported larger dimensions (Krogman[24]).

III. Clefts of Primary and Secondary Palate (Combined Cleft Lip and Palate)

Combined cleft lip and palate is the most common type of cleft and the type which presents the greatest clinical and anatomical problems. For this reason the craniofacial morphology in combined clefts of the lip and palate has been investigated in a number of cephalometric studies. Most researchers have emphasized the development of the maxilla and other facial bones, while some have studied the structures of the cranial base.

In regard to cranial base, Broder[23] reported no significant aberrations in subjects with cleft lip and palate. Broder's findings have been supported by the findings of Engman and others[25] who studied the cranial base angle in 24 male subjects with clefting of the lip and palate. Comparison of the cleft group with normals revealed no statistically significant differences in any of four measures of cranial base angulation.

Dahl[19] has presented a detailed discussion of the craniofacial morphology of 153 male subjects with cleft of the lip and palate. The cranial base was found to be significantly different in both length and shape. There was a significant shortening of both the anterior and posterior cranial base. Changes in the shape of the cranium manifest themselves as a flattening of the angle Ba-S-N.

Ross[18] studied the cranial base in 342 children with clefts including 201 cases of combined cleft lip and palate. Ross found the cranial base to be shorter in the cleft subjects which he assumed was due to a difference in head size and standing height of the cleft and control groups. Angular measurements were significantly greater in the cleft subjects but he did not consider these variations to be clinically significant.

Krogman's[24] longitudinal study which included 43 cleft lip and palate cases found these individuals to have cranial base patterns that differed significantly from normals. Clival length and anterior cranial base are both longer in the cleft sample than in the controls. The cleft group also showed a greater flexion in the cranial base.

The craniofacial relationships of 12 subjects with unoperated clefts of the lip and palate were studied by Bishara et al[26,20] in 1976. This study reported no significant differences in any of the cranial base parameters. Later, Bishara and others[27] conducted a longitudinal cephalometric study of 18 subjects with surgically repaired unilateral clefts of the lip and palate, followed from age five years to age 10 years. Comparisons between normal and cleft groups indicated a significantly larger cranial base in normals of all ages. No significant differences were noted in the linear dimensions of the cranial base among the two groups.

Johnson[28] evaluated the craniofacial development in young adult male and female subjects with complete clefts of the lip and palate. The data revealed no differences in the angle Ba-S-N when males and females in the cleft group were compared. Statistically significant changes in the cranial base angulation could not be demonstrated in the cleft and normal groups.

Cronin's[21] investigation of craniofacial morphology in 44 pairs of like-sexed twins included 19 pairs which were discordant for cleft lip and palate. The cleft and noncleft cotwins could not be shown to differ significantly from one another with respect to any of the cranial base parameters studied.

Smahel[25,29,30] has conducted a series of studies of craniofacial deviations in adults with different types of clefts. One study is concerned with 58 adult males of Czech origin with unilateral cleft lip and palate. The results indicate that the anterior part of the cranial base (N-S) was shortened in the cleft group while the length of the posterior part (S-Ba) and curvature of the base (N-S-Ba) did not differ from controls. In a similar investigation, a sample of 26 adult Czech males with bilateral cleft lip and palate were studied. The posterior cranial base dimension (S-Ba) was significantly smaller in the cleft group as compared to controls. Other angular and linear measurements of the cranial base were essentially the same for the cleft and control subjects.

As might be expected, the combined cases of cleft lip and palate share characteristic morphological features common to the isolated cleft palate subjects. The literature seems to indicate that subjects with combined cleft lip and palate show additional differences in the morphology of the cranial base than did subjects with isolated cleft palate or cleft lip. Any comparisons of the cited studies beyond a superficial overview is difficult due to the differences in composition of the cleft and control groups, and differences in method of analysis. Perhaps the most important point is the nonhomogenous character of many of the samples used. Some investigators did attempt to increase sample homogeneity by grouping according to age, sex, and/or type of cleft but others did not even indicate whether or not the sample was operated on.

MATERIALS AND METHODS

The control group was comprised of patients from the Oregon Health Sciences University Department of Orthodontics between the ages of 12 and 16 who possessed Angle Class I molar occlusion and were primarily of northern European ancestry. Forty-nine females and 30 males were included. These individuals had no evidence of clefting of the lip or palate or any other apparent craniofacial anomaly. This represents the sample as used by Fry in his development of computerized cephalometric norms.[32]

The experimental group consisted of 44 cleft individuals, 25 males and 19 females between the ages of eight years one month and 18 years nine months. The case records kept at the Crippled Children's Division (CCD) of the OHSU were the source of sample material collected for 20 individuals of the cleft group. Sample material for the other 24 cleft individuals originated from records taken from the private orthodontic practice of Douglas Buck, chairperson of the Department of Orthodontics, OHSU. Apart from personal data, the case records gave information concerning the type and extent of cleft and in some cases a brief surgical history. Examination of the records indicated that all individuals were surgically treated at an early age to repair the appropriate cleft defect. However, detailed information concerning the type, number and timing of surgical procedures was not available. The cleft group was also believed to be primarily of northern European ancestry.

These data were subsequently used to divide the cleft group into three main categories according to Kernajan and Stark's classification system.[33]

I. Clefts of the primary palate

II. Clefts of the secondary palate

III. Clefts of the primary and secondary palates

Type I comprises clefts involving the primary palate and are limited posteriorly by the incisive foramen. This includes the upper lip and the associated part of the alveolar process.

Type II clefting represents developmental defects in the embryonic secondary palate. Defects of this type always occur in the midline but differ in extent and shape. Palatal clefts may be restricted to the soft palate but often include the hard palate and may extend as far anteriorly as the incisive foramen.

Type III consitutes a combination of Types I and II. These defects may be unilateral or bilateral and may be interrupted by bridges of hard or soft tissue.

The cleft lip group was comprised of seven persons with clefts of varying extent in the structures anterior to the incisive foramen. It may be difficult to establish the exact extent of the cleft in the structures of the primary palate, since even minor clefts of the lip may be associated with a defect of the alveolar process or dental anomalies in the region of the cleft. Accordingly, no attempt was made to divide the group by extent of cleft (see Figure 2).

A total of three patients with isolated cleft palate were investigated. This group was comprised of clefts of varying extent but did not include clefts restricted to the uvula or soft palate.

Thirty-four subjects with cleft lip and palate, 15 unilateral and 19 bilateral were investigated. Detailed information about the appearance and extent of the original defect could not be obtained for all subjects. Subdivision by extent of cleft was therefore limited to unilateral or bilateral.

Lateral cephalometric radiographs were collected from the patients' records and four landmarks were located on each headfilm as outlined in the following procedure by Johnson.[34]

> An 8½ x 10-inch transparency was affixed to the cephalometric radiograph. Each point was marked by placing a small hole in the transparency corresponding to the landmarks used in the study. These landmarks are identified in Appendix A. The data were then digitized by orienting the transparency films such that the S-N plane was registered at sella on a predetermined point and horizontal line on the Apple Graphics Tablet. Once the orientation was established, the landmarks were sequentially located and entered into the computer. The anatomic landmark basion was entered first, followed by sella, nasion and articulare in that order.

Using the data entered, calculations for the following angles and distances were computed for each individual:

1. Ba-S-N - The angle formed by the intersection of the three points basion, sella and nasion with sella being at the apex.

2. Ar-S-N - The angle formed by the intersection of the three points articulare, sella and nasion with sella being at the apex.
3. Ba-S - The linear distance between points basion and sella.
4. Ar-S - The linear distance between points articulare and sella.
5. S-N - The linear distance between points sella and nasion.

Angular measurements are given in degrees and linear measurements in millimeters.

For each of the two angular and three linear dimensions the following statistical data were determined:

1. mean
2. standard deviation
3. variance
4. standard error of the mean
5. coefficient of variation
6. third moment about the mean

The data collected were statistically examined in the following groups:

- The control group was tested for male-female differences in all angular and linear dimensions of the cranial base.
- The control group as a whole was compared to the cleft lip and palate group in regards to angular measurements only. Comparisons of linear measurements were not considered valid and therefore were not analyzed.

In comparison of two means, the difference was assessed by using the Student's t-test. The null hypothesis was rejected where $p \geq 0.05$.

The method used for determination of error was checked by evaluating data for gross measurement errors (more than ± 1 mm or ± 2 degrees) and by calculating the standard error of the measure.

If by inspection of the data a gross measurement error was suspected, the landmark location markings were checked for accuracy and redigitized if an error was detected.

Operator error with regard to landmark location was determined by replicate measurements of the angle Ba-S-N from 15 randomly selected lateral cephalograms on two separate occasions. The standard error of the measure was calculated by using the formula:

$$SE_{meas} = \sqrt{\frac{\Sigma(X_1 - X_2)^2}{2N}}$$

The standard error of the measure for the angle Ba-S-N was (Figure 3):

$$SE_{meas} = 0.47^{o}$$

A consideration of the radiographic technique involved in this study may also be of importance in the interpretation of the results obtained.

With respect to the control sample, all lateral cephalometric films were taken using the Bolton-Broadbent cephalometer at the Department of Orthodontics, OHSU. Exposures were taken by a single radiology technician using a standardized department technique. Films of the cleft group were taken at different locations. Some were taken at the dental department of the CCD, OHSU, and some at private offices in the Portland area, all using a Wehmer cephalometric unit. Because of this a different technique and operator were used for these exposures.

Since error resulting from equipment variation could not be accurately determined and compensated for it was decided to reduce the impact of projection errors, at least in part, by using angular rather than linear measurements when comparing the control and cleft groups. This technique is effective because values of angular measures remain constant regardless of enlargement factor.[35] Linear measurements could not be appropriately adjusted for differences in enlargement factor inherent to the different types of cephalostats and therefore, valid comparisons could not be made.

It should be pointed out that radiographs taken of the control group were of superior quality as compared to those of the cleft group. This difference in quality is not suspected to result from differences in projectional errors, head orientation errors, or the quality of the apparatus. Rather, it is most likely the result of poor handling and processing of films after exposure. This finding has not been evaluated quantitatively, although an increase in measurement error of the cleft sample may result due to the greater difficulty in landmark identification, particularly basion.

RESULTS

Statistical data for the control group are presented in Tables I and II, and for the cleft groups in Tables III, IV and V. The results of comparisons within the control group appear in Table I, and comparisons between the control group and cleft lip and palate group in Table VI. All comparisons were evaluated by means of Student's t-tests and significant differences recorded at the 0.05 probability level.

With regard to the control group, the findings indicate that differences in the cranial base flexure of males and females are not of practical importance. Neither cranial base angle studied (Ba-S-N, Ar-S-N) was shown to be significantly different between the male group and female group. This is supported by similar findings reported by other investigators.[18,28]

Two of the three linear dimensions of the cranial base reflected size differences between the sexes in the control group. The male group was significantly larger than the female group in both the S-N and Ar-S dimensions, but no sex difference in the Ba-S dimension was evident. Nanda[37] and Ross[18] have also reported generally larger linear cranial base dimensions in males as compared to females from four years to 17 years of age.

The statistical data compiled for the cleft lip and alveolus group and cleft palate only group is graphically presented in Tables

III and IV respectively. Unfortunately, the small sample number in these two groups makes them unsuitable for statistical comparison with the control group.

Table V is a graphic representation of the statistical data for the cleft lip and palate group. The measure of cranial base angle Ba-S-N determined in this study compares favorably with values reported by Dahl,[19] Johnson,[28] and Smahel[29] for their cleft lip and palate samples. Other investigations of the cranial base in cleft individuals have infrequently utilized articulare as a landmark; however, Cronin and Hunter[21] have reported a value for the cranial base angle Ar-S-N that is nearly identical to the measurement derived in this investigation.

Of the three linear cranial base measurements, the S-N and Ar-S dimensions were within the range of values reported by others[19,21,28,29] but the Ba-S dimension was substantially shorter as compared to other reported values.

Table VI is a comparison, by means of Student's t-tests, of the angular measurements observed in the control group to those observed in the cleft lip and palate group, without regard to sex. The findings indicate the cranial base angle Ba-S-N is significantly larger in the cleft lip and palate group (132.8^{o}) as compared to the control group (130.8^{o}). However, comparison of the angle Ar-S-N did not reveal a significant difference in the cranial base flexure between the control group (122.3^{o}) and cleft lip and palate group (124.4^{o}).

In the control group the relationship between the Ba-S-N angle and the Ar-S-N angle was evaluated by correlation of the two angles.

The appropriate values for the male group, female group, and control group as a whole are listed in Table VII. The correlation value computed for the male group (r = 0.90) compares closely with the value determined by Bjork[7] for his male sample (r = 0.89).

DISCUSSION

The cephalometric landmark articulare was originally introduced by Bjork as an alternative to the anatomic landmark basion.[8] He argued that articulare was more clearly visible on lateral headfilms than basion and therefore could be identified with less error. With the passage of time articulare has become increasingly useful in cephalometric studies and its stability in relation to basion has been suggested frequently. The magnitude of the cranial base angles, Ba-S-N and Ar-S-N, were closely correlated in this study, which lends further support to the theory that the medial and lateral portions of the cranial base maintain a constancy in relation to one another.

This relationship is more fully appreciated after consideration is given to the multitude of physiologic and postural changes that could potentially disrupt it. The anatomic point basion may change position indirectly as a result of growth at the spheno-occipital synchondrosis subsequent to closure or directly through resorptive or appositional remodeling at the anterior border of foramen magnum. Articulare, which is an artificially constructed point, may be affected by positional changes of the mandible or remodeling of either the inferior border of the basi-occiput or posterior border of the mandibular ramus. Additionally, the squamo-occipital suture is a sight of potential change that may affect the relationship of occipital and temporal bones.

If the relationship between basion and articulare is indeed stable, it may have practical applications in a variety of future studies as suggested by Seward.[11]

1) For the precise detection of mandibular displacements such as may occur subsequent to prosthetic, surgical or orthodontic treatment.

2) As a test for constancy of mandibular positioning in serial cephalometric studies.

3) To probe the comparability of the cephalometric radiographs of two different groups.

4) To review the accuracy of existing growth study data.

The main thrust of this paper has been devoted toward the determination of cranial base differences particularly angular, between a control group with Angle Class I malocclusions and an experimental group comprised of cleft lip and palate individuals.

For the purpose of this study distinctions between the control and experimental groups with reference to sex were eliminated. The potential value of assessing sex differences between the two groups does not appear to be warranted based on the findings of this study as well as previous investigations. Historically, some researchers have either assumed that growth and development patterns of males and females do not differ or that any differences that do occur are not of clinical significance.[24,38,39]

Studies aimed at determining cranial base differences in regard to sex have shown linear dimensions to be greater in males than females although the relative sizes of the cranial base structures are similar.[18,28,40]

This pattern is reflected by the results of comparisons between males and females in the control group of this study. The linear dimensions S-N and Ar-S are significantly larger in the male sample, but the cranial base flexure as measured from Ba-S-N or Ar-S-N reveals no significant difference. Based on these findings it is unlikely that sex differences exist in the saddle angle of individuals with cleft lip and/or palate and therefore are not a factor in the etiology or development of clefting.

Although the control and experimental groups in this study were matched as closely as possible, there is a clear discrepancy between the ages of the two groups. Due to the difficulty in procuring a cleft sample with adequate records, it was necessary to sacrifice strict age matching in lieu of adequate sample size. The impact of incongruent age matching on the validity of the results is believed to be minimal since angular dimensions rather than linear measurements are used for comparison. Previous studies indicate that while the shape of the cranial base does vary with age in regard to increased or decreased flexion of the cranial base, it can, on the average, be considered to remain stable with age.[5,7] In light of this apparent stability with age, a lack of identical age matching may not be a critical factor as it pertains to this study.

The author is fully aware that use of angular measurements to compensate for differences in age and sex may distort means and variances to an extent that make comparisons unreliable. Because of this, conclusions drawn from the present findings should be weighted accordingly.

It seems evident that the cleft malformation must have an affect on the growth and development of the craniofacial complex, but to demonstrate what is wrong or abnormal has been difficult. Previous studies have shown that in the presence of cleft lip and palate aberrations of size and shape occur in the maxilla, mandible and cranial base structures. The results, however, are far from consistent and in some cases, conflicting. To date it is not clear if clefts of the lip and palate can be interpreted solely as local defects of the maxilla and palatine bone or if there is an association with changes in cranial base development.

In the present study both cranial base angles were larger in the cleft lip and palate group than in the control group. The difference in the Ba-S-N angle (2.0°) between clefts and normals was significant, however, the difference in the Ar-S-N angle (2.1°) was not. These findings are consistent with other studies in both degree and direction of change. Whether or not the minor angular differences found in this study are of any practical significance is open to debate. Their presence, nevertheless, appears to confirm to some extent the theory that alterations in the morphology of the cranial base are a primary part of the cleft anomaly.

It was suggested by Bishara in 1973 that differences in the facial morphology between cleft and noncleft populations might be the result of any of the following factors:[41]

a) inherited trait, i.e. genetic influences

b) acquired traits, i.e. obligatory adaptive changes

c) induced traits, i.e. changes in growth induced by surgery

d) combinations of these factors or others as yet unidentified

This clearly indicates that there are many abnormal environmental influences acting in an individual with clefting that may affect the morphology of the facial skeleton as well as the cranial base. At least initially there is an insufficiency of the palatopharyngeal musculature and a discontinuity of the lip musculature that accompanies clefting of the palate and alveolus. In this environment, neuromuscular compensation and adaptation by the tongue and other muscle groups may produce secondary facial distortions. Corrective lip and palate surgery also introduces nonphysiologic forces that act on the developing craniofacial structures, the effects of which are not clearly understood. Confusing evidence has been presented regarding the effects of surgery with some authors reporting severe developmental deformities in the craniofacial complex. The complex nature of the interactions between environmental and genetic influences on the growth process makes their outcome very difficult to evaluate in the cleft individual. The small differences in cranial base flexure reported in this study may be the result of secondary environmental factors and/or primary developmental factors.

A greater understanding of the etiology of clefting and its subsequent influence on the growth and development of craniofacial structures will require meticulous and dedicated research. Particularly there is a need for longitudinal studies of cleft subjects. This is not surprising since longitudinal studies are by design lengthy, costly, and dependent on long-term subject cooperation. Also, the recent surge of moral and legal issues aimed at protecting the health and well-being of subjects has made the initiation of new longitudinal studies a difficult if not unsurmountable challenge.

However, these studies are needed for acquiring knowledge of the individual variation that occurs in the growth of the cleft individual. Longitudinal information would also help determine the proper timing for management procedures including orthodontics and surgery.

SUMMARY

In part, this study established cephalometric standards for various cranial base dimensions in a sample of 12 to 16-year-old children from the Portland area with Angle Class I molar occlusion, using a previously developed computer-aided approach. The analysis of this group included comparisons of the male and female samples and the relationship of basion to articulare by correlation of two cranial base angles.

Additionally, a sample of cleft lip and palate individuals aged eight years one month to 18 years nine months was compared to the control group in search of cranial base flexure differences between the two groups.

The results of this study have not led to any original concepts concerning the growth and development of the cranial base structures or their influence on other skeletal components of the face. Nor have the results contributed significantly to the resolution of controversy concerning the possible cranial base differences in normal and cleft individuals. However, this investigation has spotlighted some points of interest that are worthy of restatement:

1) Based on the high correlation of the cranial base angles Ba-S-N and Ar-S-N it is possible for the anteroposterior relation of basion and articulare to remain stable.

2) The cranial base structures of males appear to be significantly larger than females in terms of absolute size, but in relative terms they are not different in shape, as indicated by similar cranial base flexure angles.

3) The results of this study confirm to some extent the theory that alterations in the morphology of the cranial base are a primary part of the cleft anomaly.

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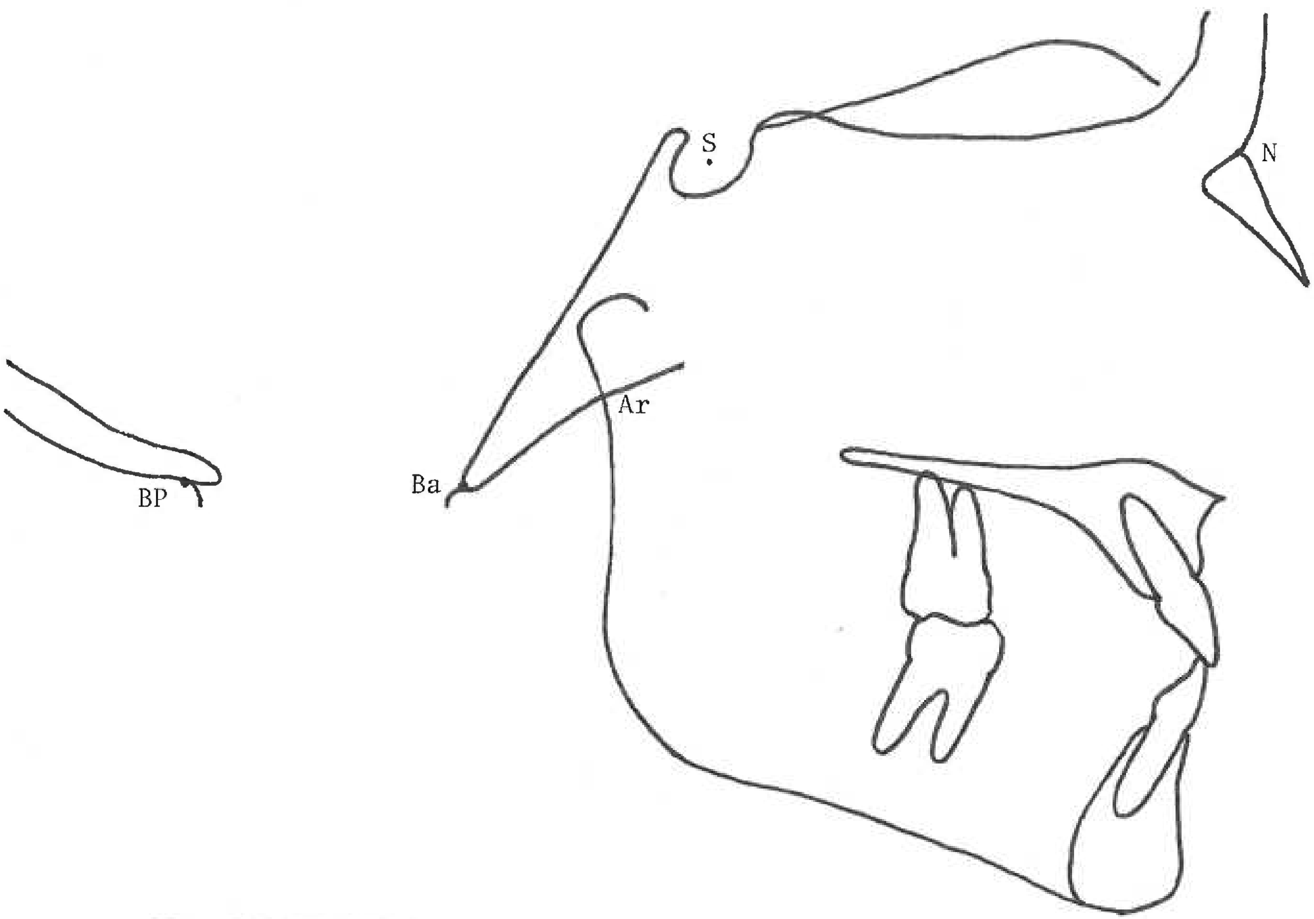
FIGURE 1



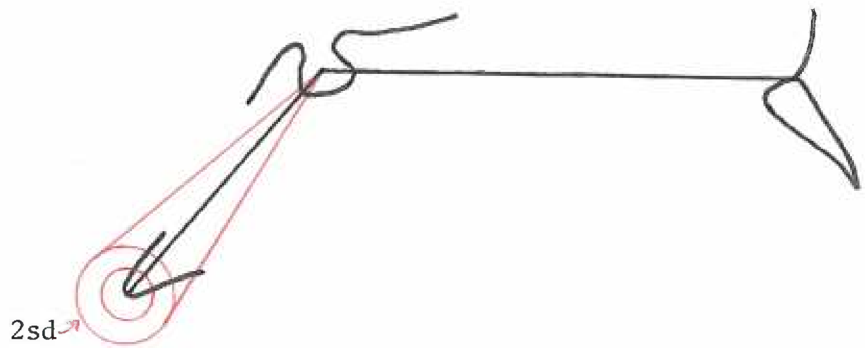
BP - Bolten Point
Ba - Basion
Ar - Articulare
N - Nasion
S - Sella

FIGURE 2

CLEFT SAMPLE

Cleft Type	Male	Female	Total
I. Cleft lip	5	2	7
II. Cleft palate	1	2	3
III. Cleft lip and palate	19	15	34

FIGURE 3



$$\theta = .94^{o}$$

$$S.E.Meas. = \sqrt{\frac{\Sigma d^2}{2N}} = .47^{o}$$

TABLE I

CONTROL

	Female (N = 49)				Male (N = 30)				
	$\overline{X}$	S.D.	S.E.M.	Range	$\overline{X}$	S.D.	S.E.M.	Range	t-value
Ba-S-N	131.2	4.6	0.66	121.7-139.5	130.1	4.9	0.92	116.7-137.4	1.05
Ar-S-N	122.1	4.8	0.69	112.4-132.9	122.8	5.7	1.06	109.4-132.2	0.58
(measurement in degrees)									
Ba-S	44.7	3.2	0.46	36.9-52.1	46.2	3.9	0.73	37.8-53.1	1.85
S-N	71.4	2.8	0.40	66.8-77.2	73.2	3.9	0.65	67.0-80.9	2.45*
Ar-S	34.0	2.8	0.40	26.7-39.3	36.9	3.5	0.65	29.1-43.3	3.67*
(measurement in millimeters)									

$\overline{X}$ = Mean
S.D. = Standard Deviation
S.E.M. = Standard Error of the Mean
N = Number included in sample
* = Significant at 0.05 probability level

TABLE II

CONTROL (N = 79)

	$\overline{X}$	S.D.	S.E.M.	Range
Ba-S-N	130.8	4.7	0.54	116.7 - 139.5
Ar-S-N	122.3	5.2	0.59	109.4 - 132.9

(measurement in degrees)

Ba-S	45.3	3.6	0.41	36.9 - 53.1
S-N	72.1	3.2	0.36	66.8 - 80.9
Ar-S	35.1	3.7	0.41	26.7 - 43.3

(measurement in millimeters)

$\overline{X}$ = Mean
S.D. = Standard Deviation
S.E.M. = Standard Error of the Mean
N = Number included in sample

TABLE III

CLEFT LIP AND ALVEOLUS (N = 7)

	$\overline{X}$	S.D.	S.E.M.	Range
Ba-S-N	133.2	4.1	1.69	128.3 - 140.4
Ar-S-N	124.6	4.0	1.62	120.6 - 133.0
(measurement in degrees)				
Ba-S	41.0	5.3	2.18	34.7 - 48.7
S-N	69.5	4.7	1.91	63.0 - 75.7
Ar-S	32.1	4.4	1.80	26.3 - 39.9
(measurement in millimeters)				

$\overline{X}$ = Mean
S.D. = Standard Deviation
S.E.M. = Standard Error of the Mean
N = Number included in sample

TABLE IV

CLEFT PALATE (N = 3)

	$\overline{X}$	S.D.	S.E.M.	Range
Ba-S-N	137.6	1.3	0.91	135.9 - 139.0
Ar-S-N	127.1	2.5	1.80	124.2 - 130.4
(measurement in degrees)				
Ba-S	39.7	0.9	0.66	38.4 - 40.6
S-N	68.1	2.5	1.79	64.7 - 70.7
Ar-S	30.7	1.8	1.28	28.2 - 32.4
(measurement in millimeters)				

$\overline{X}$ = Mean
S.D. = Standard Deviation
S.E.M. = Standard Error of the Mean
N = Number included in sample

TABLE V

CLEFT LIP AND PALATE (N = 34)

	$\bar{X}$	S.D.	S.E.M.	Range
Ba-S-N	132.8	5.2	0.90	124.8 - 140.6
Ar-S-N	124.4	5.2	0.90	115.2 - 135.5
(measurement in degrees)				
Ba-S	43.2	4.1	0.71	36.8 - 52.6
S-N	71.0	3.7	0.63	63.6 - 78.5
Ar-S	33.2	3.8	0.66	25.9 - 41.6
(measurement in millimeters)				

$\bar{X}$ = Mean
S.D. = Standard Deviation
S.E.M. = Standard Error of the Mean
N = Number included in sample

TABLE VI

	Control (N = 79)			Cleft Lip and Palate (N = 34)			
	$\overline{X}$	S.D.	Range	$\overline{X}$	S.D.	Range	t-value
Ba-S-N	130.8	4.7	116.7 - 139.5	132.8	5.2	124.8 - 140.6	2.01*
Ar-S-N	122.3	5.2	109.4 - 132.9	124.4	5.2	115.2 - 135.5	1.88

(measurement in degrees)

$\overline{X}$ = Mean
S.D. = Standard Deviation
N = Number included in sample
* = Significant at 0.05 probability level

TABLE VII

CONTROL

Correlation of the Ba-S-N angle with the Ar-S-N angle

	N	r
Male	30	0.90
Female	49	0.83
Total	79	0.85

APPENDIX

Reference points on lateral cephalometric films.

Unless otherwise stated, the definitions are those given by Fry.[32]

1. N - Nasion - the intersection of the internasal suture with the nasofrontal suture in the midsagittal plane
2. S - Sella turcica - the midpoint of sella turcica as determined by inspection
3. Ar - Articulare - the point of intersection of the dorsal surface of processus articularis mandible and os temporale. The midpoint A is used where double projection gives rise to two images, A_1 and A_2.
4. Ba - Basion - the most posterior inferior point on the clivus (Solow)[36]