A STUDY OF CRANIOFACIAL ASYMMETRY

Abstract

by

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The intent of this thesis was to study the normal range of asymmetry in the human facial skeleton, primarily those regions involved with mastication, and specifically the mandible. By assessing the range of variability of landmarks selected to represent boundaries of functional areas, the effective contribution of these areas in creating, maintaining, or reducing facial asymmetry could be analyzed. For methodological reasons, three-dimensional analysis of asymmetry was attempted to more accurately portray the factors involved in creating asymmetry.

The selected landmark coordinates of 73 human crania were collected with an Oyen-Walker Stereoplotting Craniostat. Means and standard deviations for each coordinate of each landmark were calculated, tabulated, and projected using a stereographic net. Results obtained showed a small but consistent difference between right-side mean coordinates and left-side mean coordinates. Right-side mean coordinates were larger. The standard deviations were examined and inferences drawn about

the relative effect of each. Sagittal variability of porion, and transverse variability of orbital were the most pronounced. Means and standard deviations were also used to analyze individual skull landmark coordinates. Any landmark located in a position more than one standard deviation from its contralateral equivalent's position (side differences ignored) was compared to the corresponding mean. A qualitative assessment was made of the displacement in position of that landmark. Several patterns of displacement were noted.

Based on these results the following conclusions were drawn:

1. There is a tendency toward right-side dominance in size and/or tendency for right frontopetalia and right temporopetalia.

2. In relation to the subspinale-basion midline the poria show a sagittal variability, which can effect analyses based on transporionic axis orientation.

3. The mandibular area defined by the boundaries of the anterior surface of the condyle and the lingual tuberosity may be involved in reducing the adverse effect of cranial base asymmetry on facial asymmetry and occlusion.

4. The dentoalveolar component, both maxillary and mandibular, can also be involved in reducing the adverse occlusion effect produced by asymmetrical skeletal relationships.

These conclusions indicate that clinically the mandibular ramus, as defined by condyle/lingual tuberosity is a logical target for any therapy intended to alter sagittal relationships between the maxilla and mandible where the mandible is the problem.

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DEDICATED

TO

Betsy and Jonathan

because no one deserves it more

TABLE OF CONTENTS

	Page
ABSTRACT	ii
ACKNOWLEDGEMENTS	iv
DEDICATION	vi
LIST OF TABLES	viii
LIST OF FIGURES	ix
INTRODUCTION	1
REVIEW OF THE LITERATURE	3
METHODS AND MATERIALS	19
RESULTS	43
DISCUSSION	54
SUMMARY AND CONCLUSIONS	60
LITERATURE CITED	62

LIST OF TABLES

Table		Page
I.	Definition of Anatomic Landmarks	26
II.	Means and Standard Deviations for Azimuth Coordinates	44
III.	Means and Standard Deviations for Elevation Coordinates	45
IV.	Means and Standard Deviations for Radial Distance Coordinates	46

LIST OF FIGURES

Figure		Page
1.	Landmarks; basilar view of skull	21
2.	Landmarks; occlusal view of mandible	23
3.	Landmarks; frontal view of skull	25
4.	Oyen-Walker Stereoplotting Craniostat	31
5.	Sample Data Sheet	34
6.	Meridional Stereographic Net (Wulff Net)	37
7.	Principle of Stereometric Projection	39
8.	Projection of landmarks in anterior, middle section	48
9.	Projection of landmarks in lateral, middle section	50
10.	Projection of landmarks in middle and anterior, middle sections	52

INTRODUCTION

In the orthodontic and orthopedic treatment of malocclusion and facial dysharmony the correction of sagittal relationships receives the greatest attention. Correction of transverse and vertical malrelationships is also addressed by many. The concepts behind appropriate therapy are relatively straightforward and directed against the perceived problem. The treatment of asymmetrical relationships is not so straightforward, and unfortunately, not always successful. The reason is that there is an incomplete knowledge of the biological basis of asymmetric growth. The questions raised by the occurrence of differences in growth of the left versus right side of a face parallels the basic questions of facial growth. By examining the different results of facial growth in asymmetric individuals, the location and degree of component differences may be determined. This information reduces the number of factors that must be examined to answer the questions, "how, when, and why?"

The present study concerns the occurrence and extent of skeletal component's contribution to the creation or reduction of facial asymmetry. The position of landmarks representing boundary points of these components is recorded with a stereoplotting craniostat. The means and standard deviations calculated for individual landmark coordinates indicate general tendencies

about the skull and variability of skull landmarks. The individual skull is compared with mean values determined from all the skulls to determine relative displacement of landmark positions. Inter-relationships between landmarks are examined and conclusions are drawn about components demarcated by pairs of landmarks.

REVIEW OF THE LITERATURE

There are three major areas of research represented in this literature review. The first deals with description of craniofacial asymmetry and methodology for assessment. The second, briefly, deals with the theoretical division of the mandible into functional components. The final section deals with craniometric, or indirect metric, techniques.

Craniofacial Asymmetry

Many studies dealing with craniofacial asymmetry have been carried out. These studies present a great deal of information on the incidence and methods for assessing asymmetry. The significance of asymmetry has been evaluated from both clinical and morphogenic perspectives. Some descriptive reports of craniofacial asymmetry are as follows.

One of the earliest, and most exhaustive, studies was carried out by Woo (1931). He made 53,400 measurements on approximately 800 Egyptian skulls and found nearly all to be asymmetrical, with the right side larger as a unit. Right side individual bones were also larger than left side bones with the exception of the zygoma. Woo attributed these findings to right cerebral hemisphere dominance not extending to the zygoma, which does not contribute to forming the cranial vault. The mandibles were not evaluated.

Hadziselimovic and Cus (1966) studied the relationship of the brain and the skull using 250 Yugoslavian skulls, and 17 specially selected and preserved cadavers. They found absolute conformity between the type of asymmetry in the preserved brain and its skull. Their skull sample was 98 percent asymmetric, with the most frequent type a combined left occipitopetalia, right temporoparietopetalia, and right frontopetalia (28 percent). Gundera and Zivanovic (1968) made nearly identical observations of 297 East African skulls.

Based on cerebral computerized transaxial tomography studies (CTT), LeMay (1977) noted that brain asymmetries were reflected in calvarial outline. The most common asymmetries noted, for right handed individuals, was left occipital and right frontal protrusion. Left handed individuals, with reversed orientation, showed asymmetrical measurements less frequently and with reduced degree. No percentages were given for combined features, only individual protrusions. Right frontal protrusion and left occipital protrusion occurred in 66 and 77 percent, respectively, for right handed individuals.

In order to study functional interactions during cephalic growth, Moss (1958) measured lateral cephalometric radiographs of 65 artificially deformed skulls of North and South American Indians and 54 radiographs of infants diagnosed as possessing "postural flattening" of the head. He concluded that cranial

deformation was the result of redirected growth vectors without change in vector magnitude. He stated:

> As there is a good reason to believe that purely mechanical factors can alter the expression of this potential shape in the development of artificial cranial deformation, it is reasonable to assume that analogous mechanical factors similarly determine the attainment of normal skull shape.

Plagiocephaly, or "oblique skull" was defined by Grieg (1925) as "a deformation of the skull in which one frontal region protrudes unduly forwards while the opposite occipital region projects unduly backwards". He felt that such distortion was a common birth defect as well as a response to external pressure such as the binding of heads practiced by American Indians.

Watson (1971) found the incidence of plagiocephaly to be 14 percent among normal adults. The actual percentage of normal adults having a slight plagiocephaly maybe even greater since the instrument used for this determination only detected gross asymmetry.

In a case presentation, Root and Price (1977) pointed out that the most important feature of the effect of plagiocephaly on the cranial base was the relative anterior position of the petrous temporal bone, the mandibular fossa, and the zygomatic arch on the unaffected side [the side of occipital protrusion is the affected side by convention]. The recognition of such clinically important aspects of asymmetry was regarded as a requirement for the proper diagnosis and treatment of the patient.

Recognizing the clinical importance of asymmetry, Cheney (1961) described four component types which he felt require attention in treating malocclusion: unilateral antero-posterior displacements; vertical displacements; lateral displacements; rotary displacements.

Lundstrom's study of asymmetry listed the following types as important orthodontically:

A. Qualitative asymmetry

1. Number of teeth
2. Cleft palate

B. Quantitative asymmetry

1. Size of teeth
2. Location of the teeth in the arches
3. Location of the arches in the head

Lundstrom concluded that the etiology of asymmetry could be genetic or non-genetic and most likely a combination.

Smith and Bailit (1979) reported on the prevalence and severity of occlusal asymmetry in a sample selected for intact dentition. They were unable, based on their data, to determine the effect of genetics in producing or reducing dental asymmetry. They felt that the high degree of dental asymmetry could be related to either lack of controlled development or a control system that allows for adjustments to environmental variation.

Various methods of assessing asymmetry have been used. Some researchers established a midline thought to represent the interaction of the median sagittal plane with the plane of projection used.

Sollas (1933) presented the following observations:

> The value of the median sagittal section as an aid to the comparative study of the human skull has long been recognized, yet notwithstanding many attempts, no satisfactory method of determining the precise relations which may exist between its morphological features has so far been discovered. Throughout the history of craniology we may trace a constant endeavor to find some fixed line, i.e., a line which by maintaining a constant position in human skulls might provide us with a secure basis for comparison. The result of this endeavor would appear to be the discovery that the only constant factor of the skull is its variability.

In a report on craniological technique Buxton and Morant (1933) stated, "The median sagittal plane has generally been presumed without being defined." They selected a plane passing through nasion, bregma and lambda but realized that many other "median" points would probably not lie within this plane. They pointed out that there would be a great advantage if a valid median sagittal plane could be constructed actually perpendicular to the standard horizontal and transverse planes. They distinguished a "median plane" that referred only to a particular region, such as the palate. It was felt, however, that the use of this term could be misleading, since asymmetries were common features of even small regions.

In 1951 Harvold studied asymmetry of the human facial skeleton utilizing both skulls and posteroanterior headfilms. The lateral borders of the zygomatico-frontal sutures were used to construct a horizontal reference line and a perpendicular to it through the root of crista galli (his "X-line"). He found that the

main features of the facial skeleton are usually symmetric about this line. Using this technique on unilateral cleft palate children, and also patients with other skeletal anomalies, Harvold suggested that there was a high degree of independence between dental arches and underlying skeletal components.

Kulaga (1965) defined the mid-sagittal plane as a plane bisecting the transporiance axis at right angles in a postero-anterior cephalometric radiograph. He concluded that basion and sella are true mid-sagittal points but that nasion is not.

Other researchers used a third perpendicular orientation of the skull for radiographic analysis, the basilar projection.

In 1961 Berger recommended the basilar cephalometric radiograph for determining a skull midline. He used the anterior tubercle of the atlas, the odontoid process of the axis, and outlines of the vomer and crista galli to construct a midline plane. Where these points were not on the same line he interpolated. As additional points he used crista frontales and crista occipitalis interior (presumably for radiographs of dried skulls).

Marmary, Zilberman and Mirsky (1979) also used the basilar radiographic projection to describe a skull midline and test its validity. They constructed a skull midline by drawing the perpendicular bisector of the line connecting the two foramina spinosa. To check the validity of this reference line they measured the perpendicular distance of several "median" land-

marks to this line. They also measured the perpendicular distance to homologous landmarks and used one-half the difference as a measure of point asymmetry. They concluded that this was a valid midline since these two measures showed that the deviation of landmarks from this line was no greater than the experimental error in locating them.

Other researchers have used methods of assessing asymmetry that do not use a midline representing the mid-sagittal plane. Furthermore, there are those who do not use any midline.

In a case report, Evans and Christianson (1979) showed a basilar headfilm of a North American Indian skull with a posterior cranial base defect, assumed to be congenital. They divided the skull into three zones, and drew individual midlines (method of construction unspecified). The midline of the palate and of the occipital bone, posterior to foramen magnum, were found to be parallel. The midline for the posterior cranial base, anterior to foramen magnum, diverged approximately 10 degrees from the other two. The pattern of occlusal wear indicated essentially normal, symmetrical intercuspation. Evans and Christianson hypothesized that compensatory restraining influences of surrounding soft tissues prevented a more severe facial malformation from occurring.

Letzer and Kronman (1967) developed an analysis of anterior cranial base and mandibular asymmetry based on angular

measurements, between various landmarks, taken from a postero-anterior cephalometric radiograph. Their results showed no statistically significant correlation between asymmetry of the anterior cranial base or the mandible and the presence of malocclusion. However, they pointed out that facial asymmetry is a normal finding, even in a patient with excellent occlusion.

Vig and Hewitt (1975) described a method for analyzing facial asymmetry using posteroanterior cephalometric radiographs. They characterized midface to mandibular asymmetry by measuring the divergence of longitudinal axes drawn separately for each. The midfacial axis deviated to the left of the mandibular axis in 67 percent of subjects with a mean angle of 1.9 degrees (± 0.25). To assess the contribution of individual components they used triangulation and comparison of homologous areas. The left side was larger in all mean areas except middle maxillary (determined by lateral position of alveolus and dento-alveolar height) and mandibular. Their conclusion was that:

> To enable bilaterally symmetrical function and maximum intercuspation of teeth to occur, compensatory changes seem to be operating in man in the growth and development of the dento-alveolar structures which minimize the underlying symmetry in the spatial arrangement and size of the jaws.

Using a similar method of analysis, Shah and Joshi (1978) also concluded that symmetrical faces with excellent occlusion can, and often do, exhibit skeletal asymmetry. However, their results indicated a right side dominance, but with dento-alveolar sym-

metry.

In his study of craniofacial asymmetry Cook (1980) described three categories:

1. Minor, subclinical asymmetry. This exists in most, if not all, otherwise normal individuals and has no effect on normal occlusion.

2. Gross asymmetry associated with trauma, pathology, or genetic anomaly. Compensatory dento-alveolar asymmetry may or may not reduce the effect on the occlusion.

3. Clinically apparent asymmetry with occlusal manifestation but not related to (2) above. These individuals often exhibited curvature of the skull base.

Cook studied this third category using submentalvertex (basilar) cephalometric radiography. He did not construct an arbitrary midline but drew lines between homologous points. According to Cook the relationship of these lines indicated a lateral curvature of the cranial base in many cases.

> This curvature resulted in an offset transcondylar axis, and the mid-point of the mandibular incisors were displaced towards the inside of the curvature. The maxilla, indicated by a triangle joining the landmarks, on the junction of the pterygoid plates with the maxilla and the point between the maxillary cerebral incisors, could deviate in either direction relative to the curvature.

When there was no such curvature, he felt asymmetry was the result of asymmetric mandibular length, or a shift of condyles or pterygoid plates laterally. Cook suggests that different mechanisms may be responsible since the main growth periods for these regions do not coincide.

In a study relating mandibular asymmetry to pain dysfunction, Williamson and Simmons (1979) measured submentovertex and posteroanterior cephalometric radiographs to assess mandibular asymmetry. They defined horizontal asymmetry as a difference in length between right and left halves of the mandible measured from the midpoint of the posterior of the condylar head to the most anterior part on the mandible. They defined vertical asymmetry as a difference in length measured from the most superior point on the condyle to menton. For the 53 orthodontic patients in the study a mean horizontal asymmetry of 2.67 mm was calculated. The standard deviation was 2.91 mm and the range was 0 to 11 mm. One-third showed 3 mm or more horizontal asymmetry. Vertical asymmetry was calculated to a mean of 2.80 mm, standard deviation of 2.08 mm, and a range of 0 to 8 mm. Again one-third showed 3 mm or more vertical asymmetry. They noted that not all patients with horizontal asymmetry displayed vertical asymmetry and the converse. It was felt those cases showed compensation in ramal height or corpus length. Williamson and Simmons also noted that not all patients with significant (3 mm) asymmetry showed occlusal asymmetry and hypothesized dental or skeletal (glenoid fossa) compensation.

Having completed the review of methods of analysis based on two-dimensional projection, without orthogonal integration, it is pertinent to return to Cook (1980). He found that a 5 degree

horizontal rotation of the headholder could reverse the apparent dominant side of asymmetry as determined by posteroanterior cephalometric radiography. Similar investigation of vertical rotation in submentalvertex cephalometric radiography showed no change in asymmetrical dominance but a relative shift of points. A 5 degree rotation is equivalent to less than 5 mm of movement of the earposts, well within the range of human anatomical variability, and patient-positioning error.

In an attempt to analyze the skull in three dimensions, Nahoun et al. (1964) used oriented lateral, posteroanterior, and verticulosubmental (basilar) cephalometric radiographs. They based their analysis on the three reference planes determined by the transporionic axis and Frankfort Horizontal. They noted that possible asymmetry in the transporionic axis would distort their measurements since different magnification errors could not be corrected. The points farthest away from the midpoint of the axis showed conflicting position coordinates.

Mulick (1965) also used oriented headfilms to study craniofacial asymmetry. His sample consisted of serial lateral and posteroanterior cephalometric radiographs of identical and fraternal twins. Rather than direct point to point measurement Mulick used orthogonal measurement which he adjusted for size distortion. Measurements were calculated between anatomic points and not to a reference line or plane. The maxillary registration

point was the anterior nasal spine; mandibular was menton; cranial was the ethmoid triad point. To compare triangular areas that were different sizes he used an index of asymmetry (relative rather than absolute). Mulick concluded that:

1. Heredity alone does not determine the occurrence or extent of asymmetry.
2. Relative asymmetry does not change with dimensional increase associated with growth.
3. An individual's mean asymmetry is not effected by age.

In an article leading to the conceptual basis for the present study, Bjork and Bjork (1963) studied artificially deformed crania of ancient Peruvians. The method used was direct metric measurement with calipers, which by its nature is three-dimensional. However, components vectors are not separated. The dimensions used were:

1. Length of cranial base; Nasion to a posterolateral point in the glenoid fossa.
2. Length of maxilla; Subspinale to maxillary tuberosity pterygoid plate junction.
3. Length of mandible; Prognathion to condylion.

Bjork and Bjork showed a relationship between asymmetrical deformation of the cranial vault, the cranial base, the maxilla, and the mandible. They concluded that in distinction from dysplastic asymmetry that the mandible can exhibit an asymmetry that is compensatory in nature.

The measurements used by Bjork and Bjork encompass more than one functional area. The present study is concerned with describing the component differences that result in asymmetry.

Mandibular Functional Division

The studies by Bjork and Williamson both viewed the mandible as a whole only divided into right and left halves. The division of the mandible into functional components or counterparts is of significance to this researcher because proper selection of landmarks defining these areas will help suggest the role of the components in asymmetry.

According to Moss et al. (1952, 1954, 1959, 1960, 1968 and 1968) the mandible is composed of ten skeletal units:

1. the continuous alveolar process
2. the paired coronoid processes
3. the paired angular [gonial] processes
4. the bilateral body, basal neurovascular areas
5. the paired condylar processes
6. the chin or symphyseal area.

Based on interspecies comparisons five inferences were drawn about these units:

1. neither the size, shape nor spatial position of any ramal component bears any causal relationship to the existence of the ramus;

2. there is no necessary relationship between size, shape, or spatial relationship of the several ramal components to each other;

3. a ramus may exist without the presence of the usual number of ramal components;

4. the expressivity of form and spatial position of the ramus is independent of that of the mandibular body;

5. there is no causal relationship between the vertical position of the condylar head and any other aspect of mandibular morphology.

Evidence was presented showing that the chin could be included as a basal structure along with the body (neurovascular region) in length measures since a constant proportionately existed between the midpoint to mental foramen segment. The remaining component of mandibular length is the condylar process and condylar head. Moss and his colleagues feel that this area is functionally compensatory in nature. Growth here is secondary to the displacement of the whole mandible and thus TMJ disarticulation. The condyle grows to sustain functional articulation.

Enlow et al. (1964, 1969, 1971, 1973, 1975, and 1982) also views the role of the condyle as adjustive. However, he differs from Moss in the delineation of the mandibular compensatory structure. In Enlow's terms it is not just the condyle that is involved, however, but the ramus as a whole. The mandibular rami are key adaptive structures that establish functional mandibular fitting with the nasomaxillary complex and the basicranium, and they also represent direct targets for many clinical procedures. The dimensions that Enlow uses for analysis of mandibular ramus vs. corpus dimensions keys on the lingual tuberosity. This corresponds to the maxillary tuberosity as an anatomic boundary and divides the horizontal dimension of the

mandible into corpus and ramus. The lingual tuberosity also is necessary for determining effective ramal height.

Craniometric Technique

There are a variety of ways to derive three-dimensional coordinates for landmarks on a human cranium (see Oyen and Walker, 1977). This review includes only those that directly relate to the technique used in this study. Calipers can be used for direct point-to-point determination of distance. Furthermore, geometrical manipulation can generate position coordinates for the landmarks used to determine distances. The craniostatic technique is basically the reverse in concept. In the craniostatic technique coordinates for each landmark are plotted directly but mathematic manipulation is necessary to calculate the distance between landmarks.

Benfer (1975) used direct measurement from left and right porion and apex to 35 landmarks (including paired lateral points). A computer program (SKULL) calculated three-dimensional coordinates for each landmark. The cartesian coordinates generated could be used to calculate linear and angular relationships between landmarks.

The Western Reserve Craniostat was developed and described by Todd (1923). This device required precise positioning of the skull using the two poria and the Frankfort Horizontal Plane. Use of the craniostat involved moving a pointer

along the three perpendicular planes defined by the two poria pointers and left orbitale pointer.

Taylor (1962) used the Western Reserve Craniostat in his study of the palate. He also used a direct measurement technique but found that there were physical difficulties in measuring or in estimating projections. Taylor observed that it was not always possible to place both tips of the calipers at the same time on the anatomical points. Taylor felt that the craniostat permitted a true record of asymmetry.

Oyen (1974) and Oyen and Walker (1977) describe a different three dimensional measuring device, a Stereoplotting Craniostat. While both devices measure three dimensional co-ordinates, the methodology and instrumentation differ markedly. With the Stereoplotting Craniostat coordinates are recorded in terms of azimuth, elevation, and radial distance from a selected point. Coordinates obtained in this fashion can be used in conventional analytic ways, just as cartesian coordinates. However, they can also be plotted on a Wulff net, a meridinal stereographic net. This produces a two-dimensional representation of a three-dimensional cranium. A complete description of this device is in the methods section.

METHODS AND MATERIALS

Source

The skulls utilized in this study were obtained from two sources. The first source was the Case Western Reserve University School of Dentistry, Department of Anatomy. The other source was the T. Wingate Todd Osteological Collection housed in the Cleveland Museum of Natural History.

Sample

A total sample of 73 skulls was measured in this study. The Anatomy Department provided 48 and the Todd Collection provided 25. The criteria for selection were:

1. all skulls had to be free of osteological damage or pathological distortion;
2. all skulls had to have an unsectioned mandible;
3. the skull had to be horizontally sectioned superior to orbits;
4. sufficient posterior teeth had to be present to permit establishment of homologous anterior premolar occlusal contact points and posterior molar occlusal contact points;
5. a stable centric occlusion must be possible as determined by occlusal wear and maximum intercuspation.

No data as to age, sex, or race was available for the sample provided by the Anatomy Deparment. However the usual source of the skulls is Asian, and the dentition suggests dental adulthood. The Todd Collection skulls had age, sex, and race record-

Figure 1.--Basilar view of human skull, mandible removed, with landmarks indicated.

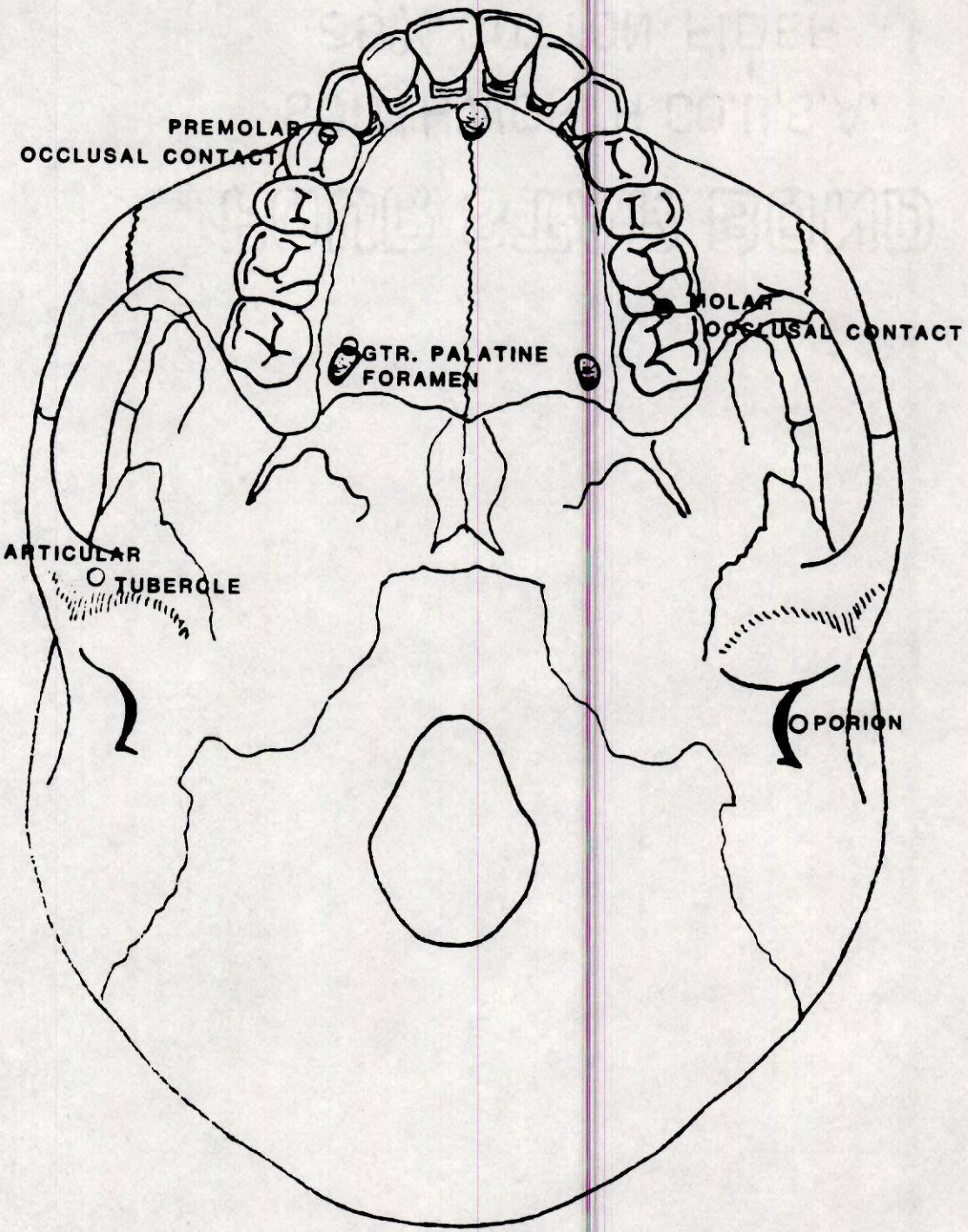

PREMOLAR
OCCLUSAL CONTACT
MOLAR
OCCLUSAL CONTACT
GTR. PALATINE
FORAMEN
ARTICULAR
TUBERCLE
PORION

Figure 2.--Occlusal view of human mandible with landmarks indicated.

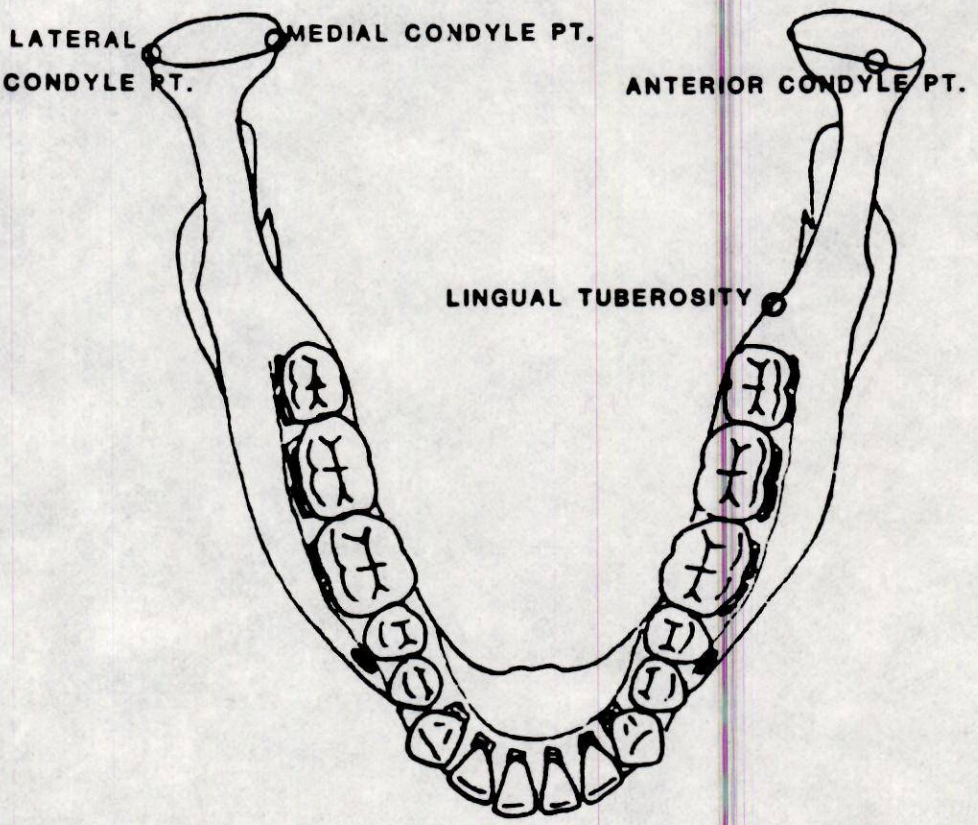

LATERAL CONDYLE PT.
MEDIAL CONDYLE PT.
ANTERIOR CONDYLE PT.
LINGUAL TUBEROSITY

Figure 3.--Frontal view of human skull with landmarks indicated.

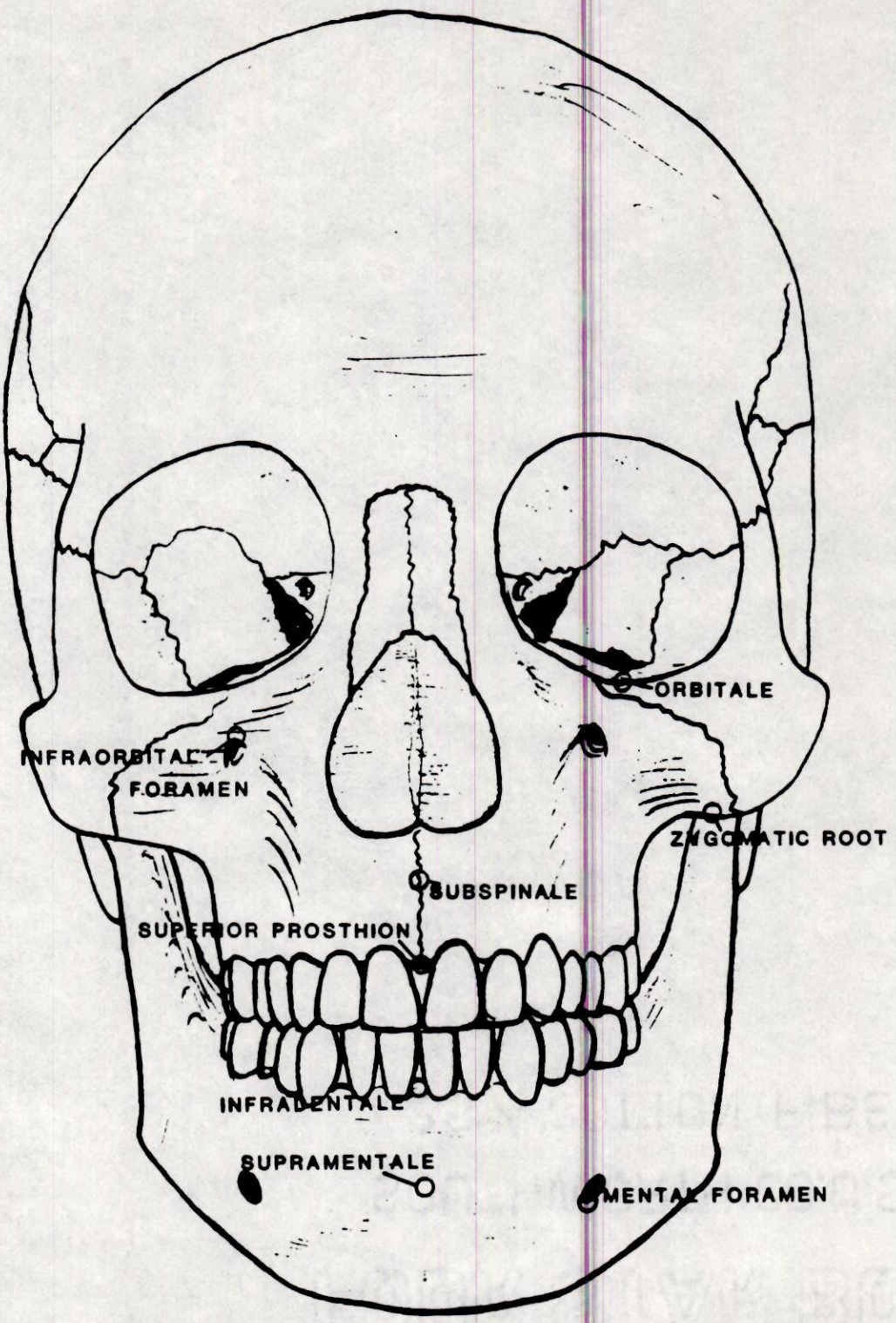

ORBITALE
INFRAORBITAL FORAMEN
ZYGOMATIC ROOT
SUBSPINALE
SUPERIOR PROSTHION
INFRADENTALE
SUPRAMENTALE
MENTAL FORAMEN

TABLE I

DEFINITION OF ANATOMIC LANDMARKS

Landmark	Definition
Anterior Condyle Point	The point where the central axis of the condylar neck intersects the anterior inferior edge of the articular surface.
Articular Tubercle	The most inferior point of the zygomatic process of the temporal bone at the anterolateral border of the glenoid fossa.
Greater Palatine Foramen	The most anterior point of the greater palatine foramen
Infradentale	The most anterior and superior midline point between the lower central incisors.
Infraorbital Foramen	The superior margin of the infraorbital foramen.
Lateral Condyle Point	The most lateral point on the articular surface of the mandibular condyle.
Lingual Tuberosity	The point where the functional occlusal plane and central fossa (Pm1, Pm2, M1) line intersect the internal oblique line.
Medial Condyle Point	The most medial point on the articular surface of the mandibular condyle.
Mental Foramen	The inferior margin of the mental foramen.
Molar Occlusal Contact Point	The most posterior occlusal contact point on the maxillary first molar (or anterior of second molar where necessary).

TABLE I continued

Landmark	Definition
Orbitale	The most inferior point of lower margin of orbit.
Porion	The most superior point of the external auditory meatus directly posterior to the postglenoid tubercle.
Premolar Occlusal Contact Point	The most anterior premolar occlusal contact point.
Subspinale	The most posterior point along the bimaxillary suture between anterior nasal spine and superior prosthion.
Superior Prosthion	The most anterior and inferior midline point between the upper central incisors.
Supramentale	The most posterior median point in concavity between infradentale and pogonion (referenced to FOP).
Zygomatic Root	The most anterior-inferior point of attachment of the masseter.

ed but since any single group represented so small a percent of the total sample no use was made of this data. Missing teeth and Angle classification were recorded for each, also any obvious asymmetry.

Point Selection

The landmarks were chosen to represent defining landmarks for each specific component area. Additional points were chosen on the facial skeleton and dentition to describe their relative position. These points are illustrated in Figures 1-3, and defined in Table I.

Technical Details

Skull Preparation

The position of both the lingual tuberosities and anterior condylar points were marked on the mandible with pencil. The skulls were positioned within the Oyen-Walker Stereoplotting Craniostat (Oyen, 1974) on a height-adjustable platform. A rice-filled cloth bag was used on top of the platform to stabilize and position the skull. The skull was inverted and positioned with respect to the following parameters:

1. The position of Basion was set at 90 degrees elevation and 100 mm radial distance (azimuth reading irrelevent).
2. The position of Subspinale was adjusted to 0/360 degree azimuth.

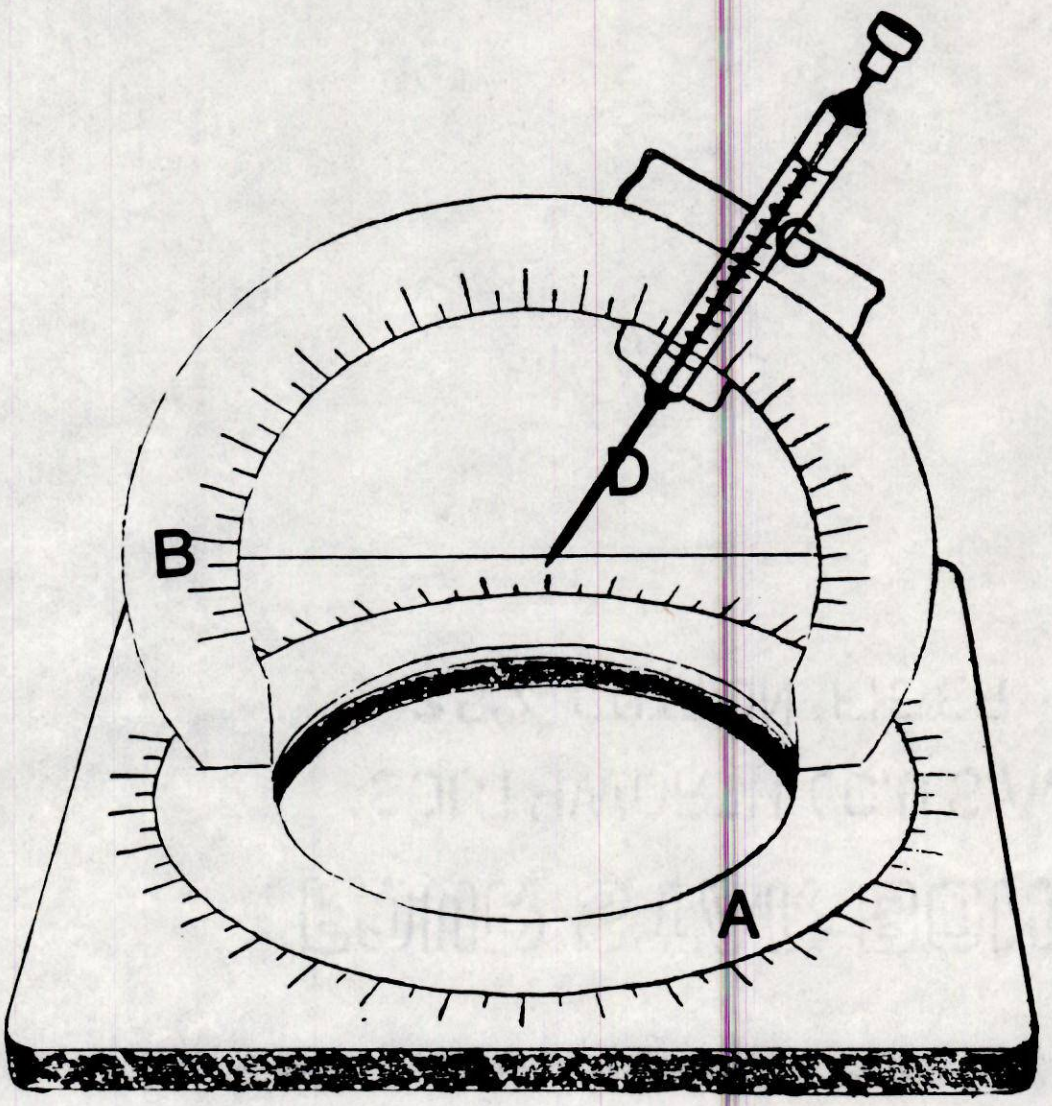
3. Skull position was adjusted until a circular level on an adjustable tripod base showed Frankfort plane to be horizontal (more easily and accurately done if mandible not in position).

Adjustments in position and orientation of each skull were made by raising or lowering the skull, rotating the skull in a horizontal plane, and tipping the skull with wedges, until all three parameters were met. The lower jaw was then attached to the cranium in centric occlusion. The maxillary and mandibular occlusal planes were carefully checked with regard to any irregularities of the positions of individual teeth. In addition to occlusal relations, the position of the mandibular condyles to their articular fossae were checked. When the proper maxillo-mandibular relationship had been determined, the mandible was securely taped to the cranium.

Location of Points

In order to describe the location of points a detailed description of the Oyen-Walker Stereoplotting Craniostat is necessary. As described by Oyen and Walker (1977) the stereoplotting craniostat (Figure 4) consists of an open rotatable circle (A) to which is attached perpendicularly an arc (B). Attached to the arc is a movable needle mount (C) with a retractable, radially pointing needle (D). Calibrations on the needle and/or mount permit direct reading from the needle point to the originating center point of the sphere partially defined by the arc and circle.

Figure 4.--The Oyen-Walker Stereplotting Craniostat


C
D
B
A

Both the arc and the surface into which the circle is recessed are marked to indicate degrees of elevation (0-180°), through which the needle mount will move, and degrees of azimuth (0-360°), around which the arc may be rotated. Through movement of the needle through its mount, rotation of the mount through the arc, and rotation of the arc around the circle, any point within the partial sphere described by the arc can be defined in terms of radial distance and degrees of azimuth and elevation.

The needle is adjusted by rotation of the circle and movement through the arc, as well as sliding of the needle until it makes point contact with the chosen landmark. The position of the landmark is recorded in terms of azimuth, elevation, and radial distance.

In several cases certain landmarks were not accessible with the standard pointer. Two different point extensions were constructed. A 90 mm extension with two offsets and a 60 mm extension with one offset, when coupled to the pointer tip, permitted access to otherwise inaccessible landmarks. Azimuth and elevation were recorded to the nearest 0.5 degree and radial distance was recorded to the nearest whole millimeter. Each measurement was repeated twice and any differences resolved by a third repetition. After all points were recorded the skull was checked to insure that it still conformed to the positioning parameters, if not it was repositioned and replotted. (See Figure 5 for sample data sheet.)

Figure 5.--A sample data sheet.

SKULL ID# 393 ♂W 56

MISSING TEETH 87654321 12345678

None 87654321 12345678

DENTAL RELATIONSHIP

Class III Sub (R)

↓ Midline to (R)

	azimuth	elevation	radial distance
R PORION	265.5	56.5	102
R ARTICULAR TUBERCLE	318.0	55.0	112
R ZYGOMATIC ROOT	324.0	55.0	129
R INFRAORBITAL FORAMEN	335.0	50.0	123
R ORBITALE	328.5	47.0	120
R GREATER PALATINE FORAMEN	342.0	64.0	121
L PORION	092.0	57.0	101
L ARTICULAR TUBERCLE	073.0	55.0	112
L ZYGOMATIC ROOT	027.5	54.5	131
L INFRAORBITAL FORAMEN	022.5	50.0	125
L ORBITALE	029.5	46.5	122
L GREATER PALATINE FORAMEN	011.0	64.5	121
PHARYNGEAL TUBERCLE	355.0	84.0	094
SUPRAMENTALE	352.0	61.0	125
INFRADENTALE	352.0	59.5	168
SUPERIOR PROSTHION	000.0	56.5	153
SUBSPINALE	000.0	54.5	146
RIGHT ANTERIOR PREMOLAR CT	344.5	60.5	153
RIGHT POSTERIOR M1 CONTACT	332.0	66.5	141
LEFT ANTERIOR PREMOLAR CT	014.5	61.5	155
LEFT POSTERIOR M1 CONTACT	023.5	66.5	143
L MENTAL FORAMEN	017.5	64.0	178
L LATERAL CONDYLE PT	076.0	52.5	180
L ANTERIOR CONDYLE PT	072.5	59.5	164
L MEDIAL CONDYLE PT	078.0	64.5	098
L LINGUAL TUBEROSITY PT	041.0	27.0	140
R MENTAL FORAMEN	339.5	63.5	179
R LATERAL CONDYLE PT	280.0	55.0	162
R ANTERIOR CONDYLE PT	283.5	59.0	162
R MEDIAL CONDYLE PT	271.0	65.0	098
R LINGUAL TUBEROSITY PT	216.0	70.0	138

Data Reduction

Means and standard deviations were computed for each coordinate of every landmark. All calculations were performed by the Department of Biometry, Case Western Reserve University, by a Digital Equipment Corporation Computer, model PDP 11/45. These data were then converted into two-dimensional representations by stereographic projection using a stereographic net.

According to Phillips (1954), a meridional stereographic net, known also as Wulff net (Figure 6), consists of three "circles" and one plane. The primitive circle represents the equator itself, the plane of which is the plane of the stereographic projection. A great circle represents any plane which intersects the center of the sphere; a small circle represents the intersection of a sphere by a plane which bypasses its center. Figure 7 shows what actually happens when a stereoprojection is made onto a two-dimensional plane of the equator.

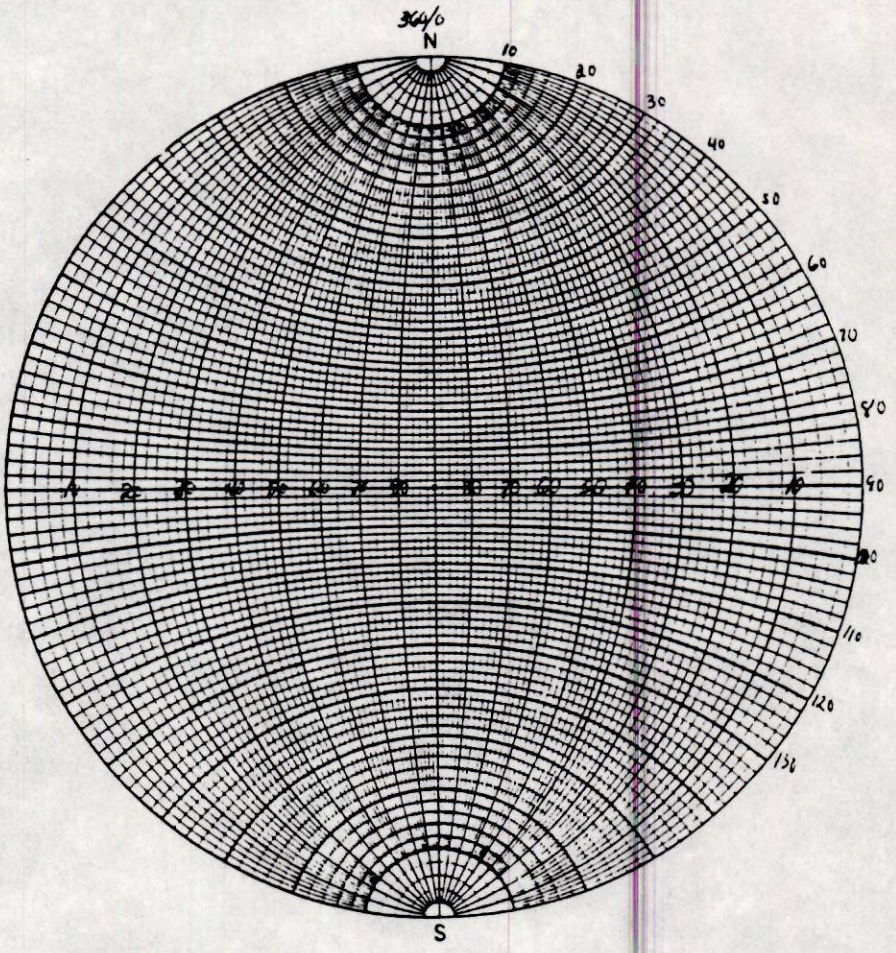
According to Oyen (1974) a stereographic projection is made in the following steps:

1. An overlay is centered and fixed with a single pin to the net; all work will take place on this thin, rotatable sheet rather than on the net itself.

2. A point is marked on the overlay to indicate North, 0/360°.

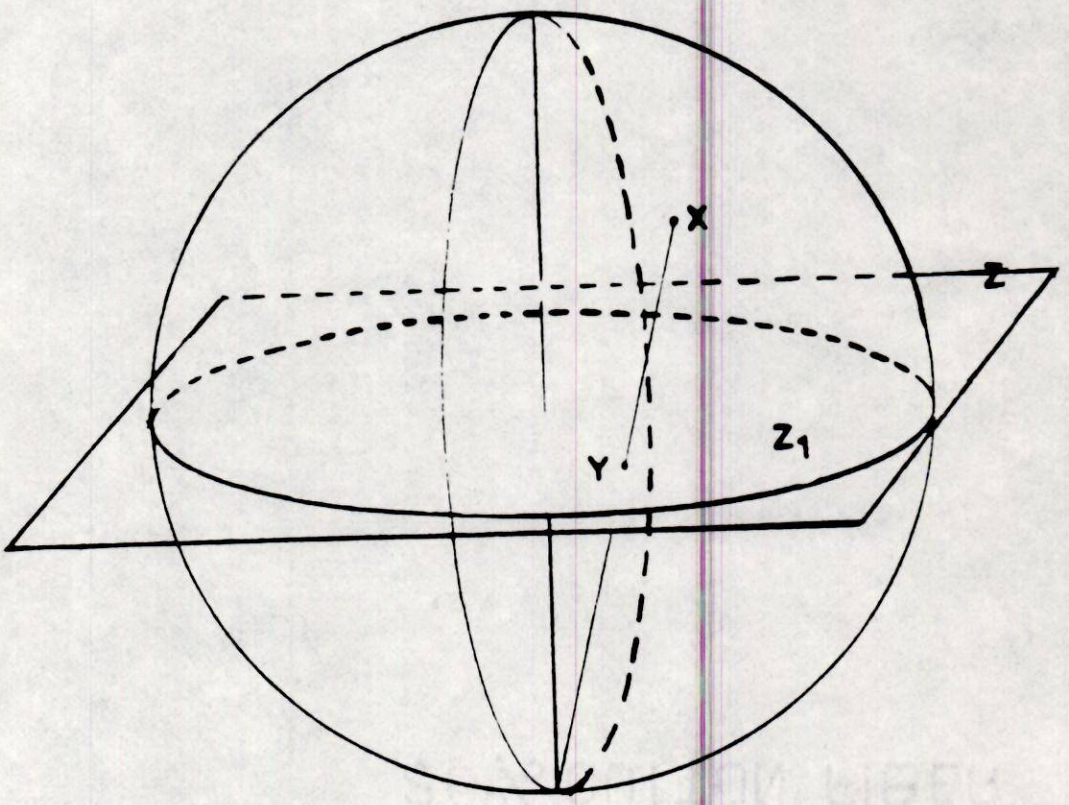
3. The degree of azimuth of a given landmark ascertained with the Craniostat is found along the primitive and lightly marked on the overlay.

Figure 6.--Meridional Stereographic Projection of the Hemisphere



WULFF NET

Figure 7.--The principle of stereometric projections: A line drawn from point X to the Polar point (P) of the opposite hemisphere will intersect the plane of the equator (Z, Z_1) at Y. The equatorial primitive of the Wulff net is formed by the intersection of the sphere and the equatorial plane (Z_1). Great and small circles are used to determine and define the two-dimensional location of point Y on the equatorial plane in terms of azimuth and elevation of point X (After Phillips, 1954).


X
Z
Y
Z_1

4. The overlay is rotated until the point marked in step three is at the end of the vertical great circle, North.

5. The degree of altitude is then found along this line at the proper distance from the center of the circle.

6. The point found in step five is permanently marked on the overlay and identified with the radial distance which was determined for that landmark with the Craniostat. The point now is a stereographic description, with a distance qualification, of a three-dimensional point (landmark) determined by use of the Stereoplotting Craniostat (Phillips, 1954).

In the evaluation of coordinate differences it is necessary to consider the effect of polar recording of data. Changes in azimuth in lateral (60-120° from N) sections are related to basically sagittal changes in position. These changes in azimuth gradually result in less sagittal and more transverse change in position until in the anterior sections (0-30° from N) the change becomes almost totally transverse. Changes in elevation are more complicated.

Changes in radial distance interact directly with elevation so they can best be explained together. Elevation in the lower sections (0-30° elevation) and radial distance in the upper sections (60-90° elevation) are both principly vertical components. Conversely, elevation in the upper sections and radial distance in the lowers are both horizontal phenomena, varying from transverse to sagittal changes as the azimuth changes from lateral to anterior sections. The component changes are combined in the middle elevation sections (30-60° elevation). By dividing a hemi-

spherical quadrant into three azimuth divisions and three elevation divisions the component effects are then defined within the nine sections by a matrix of the preceding variations.

The means and standard deviations can be used to assess individual patterns in the following manner. Each coordinate of each landmark is compared to the contralateral equivalent. If the difference between values is greater than one averaged standard deviation for that landmark coordinate, then the coordinate of each is compared to the corresponding mean value. The differences between coordinates and mean values are also compared to one standard deviation. If only one landmark differs by more than one standard deviation from its mean that is determined to be displaced. The effect of displacement in that coordinate can be assessed based on the matrix described previously. If neither coordinate differs from its mean by more than one standard deviation, then each landmark is partially involved in creating the asymmetry. The displacement is then assessed by splitting the difference of the matrix changes. Finally both coordinates may differ from their respective means by more than one standard deviation in which case the one showing greater deviation is treated as if it alone were displaced. The effective displacements of all three coordinates are then combined based on relative values from the matrix. The position of that point relative to the reference plane (Frankfort Horizontal) and reference line (Sub-

spinale-Basion) is compared to the contralateral homologous landmark. This can also be done by stereoprojection of the individual on the plot of mean and standard deviation, except radial distance which is done mathematically. This process, is repeated for each landmark.

The next step involves the assessment of mandible asymmetry. The existence of mandibular landmark displacements is checked sequentially; porion, articular tubercle, all three condylar points, lingual tuberosity, mental foramen, and supramentale. A qualitative assessment is then made.

RESULTS

Statistical Data

The means and standard deviations for each coordinate of each landmark were calculated. The results of these calculations were recorded in Table II (azimuth), Table III (elevation), and Table IV (radial distance). These results are discussed in a latter section.

Stereographic Projection

The means and standard deviations of azimuth and elevation of individual landmarks were plotted (Figures 8 to 10). The range of variation was more inclusively represented by including all values within two standard deviations of the mean. An ellipse was drawn around the area defined by the mean and double standard deviations of these two coordinates. The greater and lesser axes of the ellipse correspond to the effectively greater and lesser coordinate standard deviations. The mean and doubled standard deviation for radial distances were recorded next to the landmark ellipse.

Individual Assessment

Landmark displacements observed in individuals were categorized into several qualitative patterns. In one displacement pattern the poria were sagittaly asymmetric, subspinale and sup-

TABLE II

MEANS AND STANDARD DEVIATIONS FOR
AZIMUTH COORDINATES

Landmark (N=73)	Right		Left		Median	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Porion	268.6	3.2	91.2	3.4	. .	. .
Articular Tubercle	288.7	2.9	71.2	2.9	. .	. .
Lateral Condyle Point	285.3	3.0	74.3	3.4	. .	. .
Anterior Condyle Point	287.3	3.4	72.4	3.5	. .	. .
Medial Condyle Point	284.4	4.0	73.9	4.5	. .	. .
Greater Palatine Foramen	342.7	2.2	16.2	2.8	. .	. .
Lingual Tuberosity	320.6	3.5	38.1	3.6	. .	. .
Zygomatic Root	324.6	2.3	35.1	2.4	. .	. .
Infraorbital Foramen	340.8	1.4	19.0	1.5	. .	. .
Orbitale	334.2	2.4	24.9	2.7	. .	. .
Premolar Occlusal Contact Point	347.0	1.2	12.8	1.2	. .	. .
Mental Foramen	342.3	1.8	17.7	2.0	. .	. .
Molar Occlusal Contact Point	336.9	2.1	22.3	1.9	. .	. .
Subspinale	. .	. .	. .	. .	360.0	0.0
Superior Prosthion	. .	. .	. .	. .	360.0	0.4
Infradentale	. .	. .	. .	. .	359.9	1.0
Supramentale	. .	. .	. .	. .	359.8	1.1

TABLE III

MEANS AND STANDARD DEVIATIONS FOR ELEVATION COORDINATES

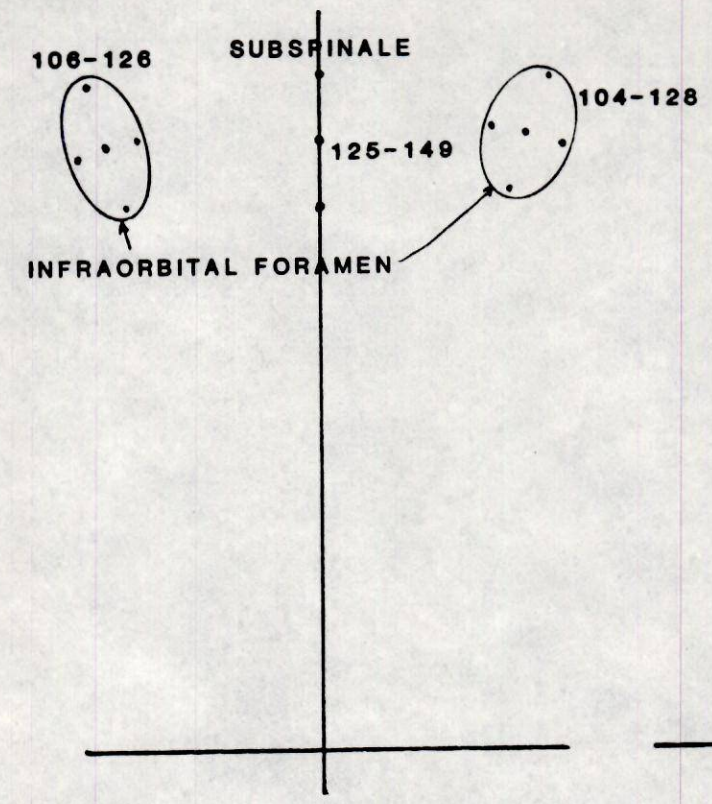
Landmark (N=73)	Right		Left		Median	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Porion	58.6	2.3	58.5	2.2	. .	. .
Articular Tubercle	55.9	2.0	55.6	1.8	. .	. .
Lateral Condyle Point	57.0	2.4	56.8	2.1	. .	. .
Anterior Condyle Point	60.0	2.1	59.7	1.9	. .	. .
Medial Condyle Point	66.1	1.8	66.0	2.0	. .	. .
Greater Palatine Foramen	62.8	1.7	62.7	1.8	. .	. .
Lingual Tuberosity	69.2	1.6	69.1	1.5	. .	. .
Zygomatic Root	52.3	1.8	51.6	1.7	. .	. .
Infraorbital Foramen	47.2	2.0	46.6	1.8	. .	. .
Orbitale	44.4	1.9	43.9	1.7	. .	. .
Premolar Occlusal Contact Point	56.7	2.1	56.6	2.1	. .	. .
Mental Foramen	63.1	2.0	62.7	1.9	. .	. .
Molar Occlusal Contact Point	62.3	1.9	62.2	1.8	. .	. .
Subspinale	. .	. .	. .	. .	49.5	2.1
Superior Prosthion	. .	. .	. .	. .	51.5	2.1
Infradentale	. .	. .	. .	. .	56.6	2.3
Supramentale	. .	. .	. .	. .	59.2	2.2

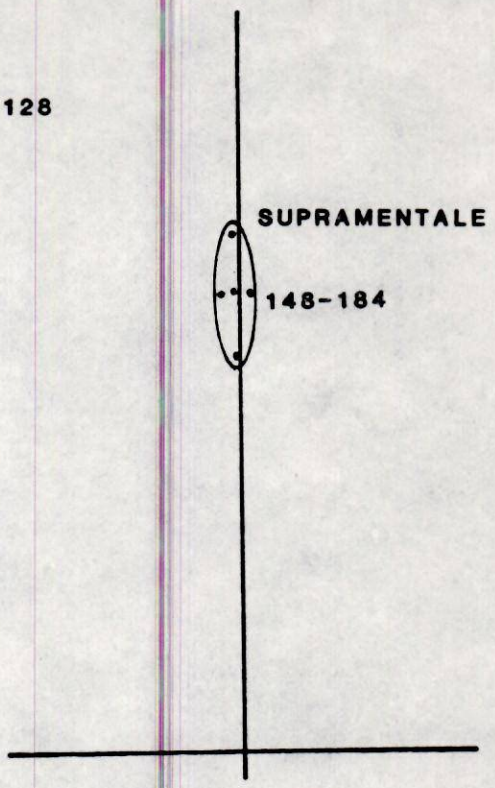
TABLE IV

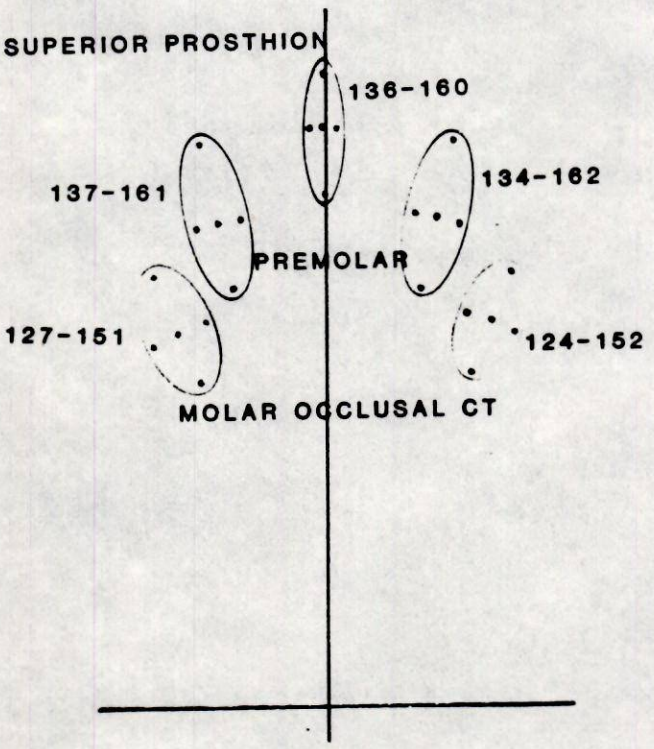
MEANS AND STANDARD DEVIATIONS FOR
RADIAL DISTANCE COORDINATES

Landmark (N=73)	Right		Left		Median	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Porion	95	4	94	4	. .	. .
Articular Tubercle	106	5	105	5	. .	. .
Lateral Condyle Point	104	4	103	5	. .	. .
Anterior Condyle Point	99	4	98	5	. .	. .
Medial Condyle Point	96	3	95	4	. .	. .
Greater Palatine Foramen	114	5	114	5	. .	. .
Lingual Tuberosity	132	6	131	7	. .	. .
Zygomatic Root	125	6	124	6	. .	. .
Infraorbital Foramen	116	5	116	6	. .	. .
Orbitale	115	5	114	6	. .	. .
Premolar Occlusal Contact Point	149	6	148	7	. .	. .
Mental Foramen	168	8	167	9	. .	. .
Molar Occlusal Contact Point	139	6	138	7	. .	. .
Subspinale	. .	. .	. .	. .	137	6
Superior Prosthion	. .	. .	. .	. .	148	6
Infradentale	. .	. .	. .	. .	161	7
Supramentale	. .	. .	. .	. .	166	9

Figure 8.--Stereographic projection of landmark means and standard deviations in the anterior azimuth, middle elevation section; Subspinale, Supramentale, Infradentale, Superior Prosthion, Premolar Occlusal Contact, Molar Occlusal Contact, and Infraorbital Foramen (scale reduced to 80%).


106-126
SUBSPINALE
104-128
125-149
INFRAORBITAL FORAMEN


SUPRAMENTALE
148-184


SUPERIOR PROSTHION
136-160
137-161
134-162
PREMOLAR
127-151
124-152
MOLAR OCCLUSAL CT

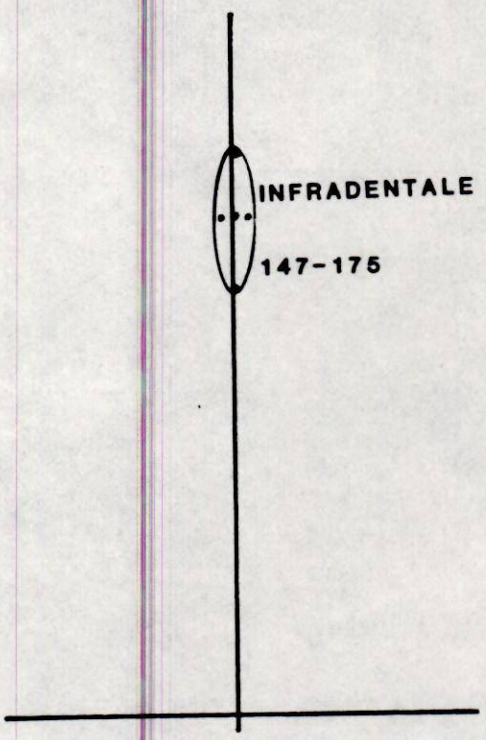

INFRADENTALE
147-175

Figure 9.--Stereographic projection of landmark means and standard deviation in the lateral azimuth, middle elevation sections; Porion, Articular Tubercle, Anterior, Medial and Lateral Condyle Points (full scale).

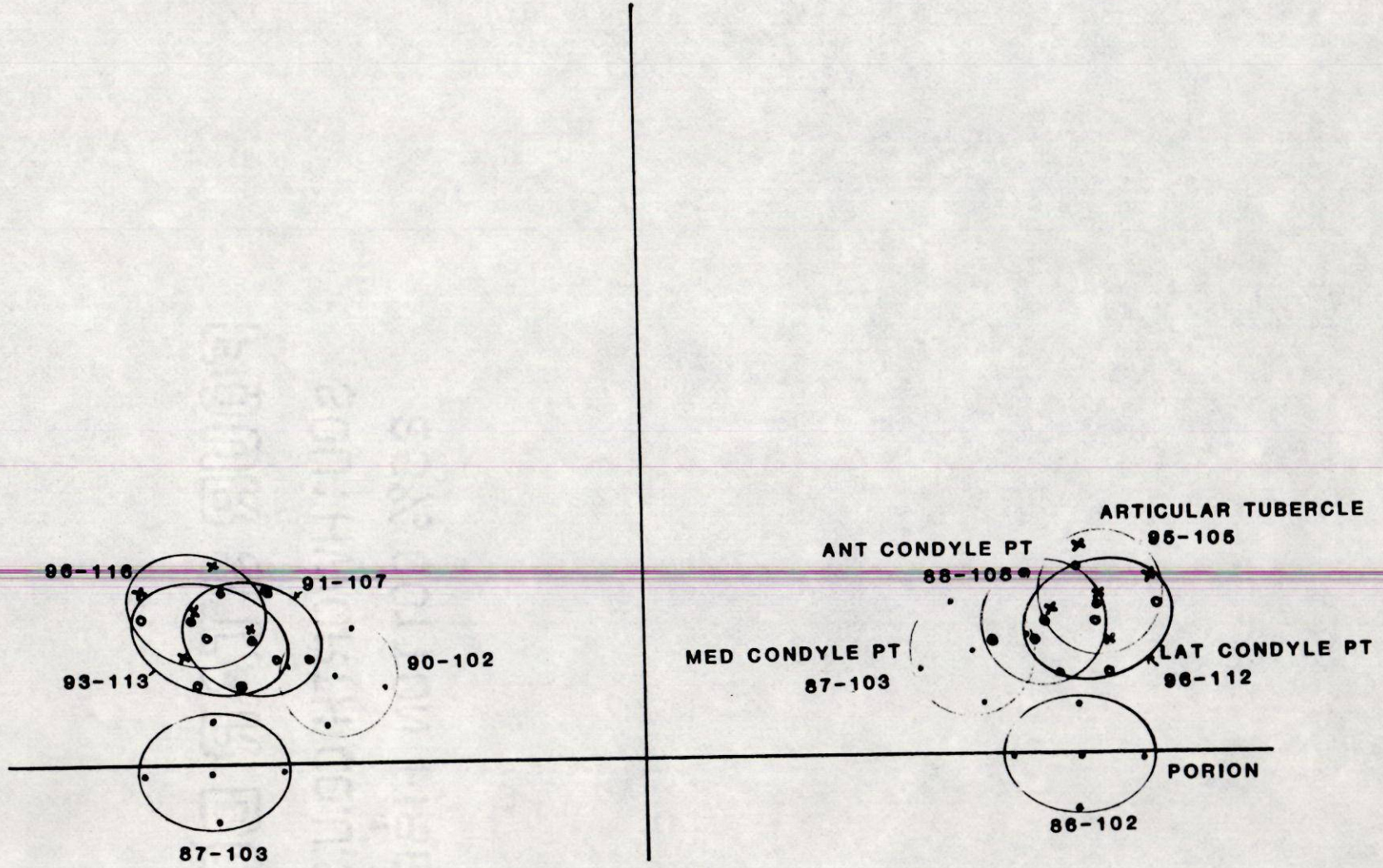
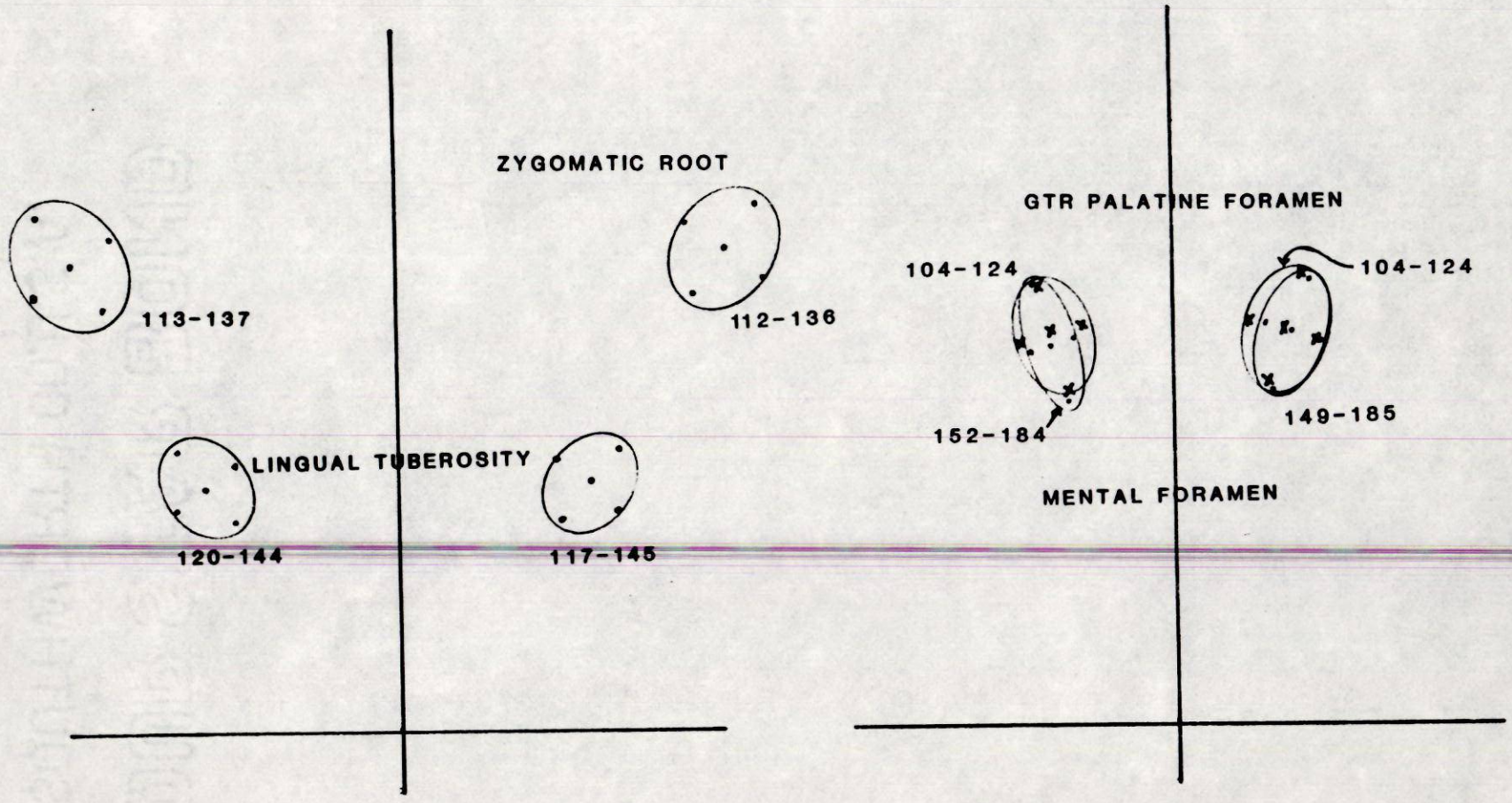

96-116
91-107
90-102
93-113
87-103
ARTICULAR TUBERCLE
95-105
ANT CONDYLE PT
88-108
MED CONDYLE PT
87-103
LAT CONDYLE PT
96-112
PORION
86-102

Figure 10.--Stereographic projection of landmarks, means and standard deviations in the middle azimuth, upper elevation sector (on left); Lingual Tuberosity and Zygomatic Root: anterior azimuth, upper elevation sector (on right); Greater Palatine Foramen and Mental Foramen (full scale).


ZYGOMATIC ROOT
113-137
112-136
LINGUAL TUBEROSITY
120-144
117-145
GTR PALATINE FORAMEN
104-124
104-124
152-184
149-185
MENTAL FORAMEN

ramentale showed no relative displacement, and the lingual tuberosity displayed no displacement as determined above. In another displacement configuration the poria were laterally asymmetric and again the lingual tuberosity showed no displacement. Also associated with this second configuration no condylar displacement was observed, but this did not always occur. Lateral displacement of the premolar contact point occurred as an isolated displacement and in conjunction with the sagittal porion pattern, but not always.

DISCUSSION

The means and standard deviations previously listed have been used for interpretation on two levels; the general tendencies, and individual landmark variabilities. Means and standard deviations have also been used to assess individual subject asymmetry.

General Tendencies

All right-side azimuth means show a general tendency toward values further away from the 0°/360° axis. This suggests that the right articular area is more posterior, and that anterior landmarks on that side are more lateral than the homologous landmarks on the left side. All elevation means are slightly larger on the right side. This suggests that, relative to corresponding landmarks on the left, the right-side points are positioned more inferior in relation to Frankfort Horizontal. All right-side radial distance means are larger, which suggests a relatively more inferior position for right-side landmarks. Although larger elevation means produce a centrally directed vector in the horizontal plane, radial-distance dominance in the horizontal plane (due to greater magnitude), results in the tendency for right-sided points to be more lateral in the posterior, and more anterior when near the midline, than corresponding left-side

points. In general, the magnitude of differences in means are not individually large relative to the mean value range. However, without exception, differences in the means of azimuth and elevation are consistent with a slightly larger right side and/or a right temporopetalia and face "suspended" from an anterior cranium exhibiting right frontopetalia.

Individual Landmark Variability

Standard deviations of azimuth and elevation can be interpreted as variability of landmarks, with consideration given to the effect of size difference on variability. Porion, the articular tubercle, and all three condylar points each shows large variations in sagittal position and less in transverse and vertical (porion had no vertical variability based on positioning criteria). The lingual tuberosity and zygomatic root both show about equal variation in sagittal and transverse position, but little vertical variability, that is not obscured by radial distance interaction. The mental foramen and greater palatine foramen show greater sagittal variation than transverse variation. The infraorbital foramen varies about equally in all three dimensions. Orbitale varies to a great extent in transverse position, and to less extent in vertical and sagittal positions. Orbitale is the only anterior facial landmark to show large transverse variability. All dental landmarks varied primarily in their sagittal position. Subspinale and supramentale varied primarily sagitally, but the transverse

variability may be a more accurate measure of true location variability.

Methodological Limitations

There are certain problems involved in determing the significance of polar coordinates. Characteristics of a landmark defined using polar coordinates are heavily influenced by position and orientation of the subject relative to the radial center, as well as by size of the subject. Variability in landmarks is affected accordingly. The effect of orientation between source, subject, and projection plane can be illustrated by the change in a shadow cast by the sun. The more oblique the angle between the line determined by the source and object, and the projection plane the greater the length of the shadow cast. This relates specifically to elevation changes in polar coordinate projections. For this reason only azimuth standard deviations are directly related to position variability.

If the variation in three dimensions is visualized it is represented by a cone of variability. The azimuth and elevation means and standard deviations define the position and axis dimensions of an ellipse. The long axis of the cone relates to the mean and standard deviation of the radial distance. The cones of variability described by the three coordinates of each landmark are fairly narrow. Variability within these cones is partially a function of the distance to the radial center. If narrow cones

were only observed in landmark in the lower anterior facial skeleton, then the coincidental approximation of the Bolton Growth Axis with the line from the radial center to the symphyseal area could explain the phonemena. However, all landmarks show relatively the same narrow spread. The resultant spread is analogous to the shadow cast by an object that is relatively distant from a light source. Because of the distance factor there is less distortion between true sagittal variation and azimuth variation.

A fixed radial center determined by the instrument makes orientation and distance a function of skull position. A skull position low to the horizon unevenly magnifies variability between central and peripheral landmarks. Generally elevation differences are more closely related to true vertical differences. The accuracy of the instrument is poorest near the radial center. Skull positions away from the horizon reduce projection magnification differences and allow for better control of angular distortion. These factors were taken into consideration when determining position criteria for the skulls, with the upper limit being dictated by physical interference of the skull and stereoplotter.

Given these possible distortions attributable to methodology, individual assessments of asymmetry were based primarily on azimuth differences. Elevation and radial distance, in combination, were used only for porion since the orientation of the skull

assured no vertical components.

Individual Subject Assessment

Sagittal asymmetry of porion either associated with a midline shift and displacement of the condyles, lingual tuberosity, and mental foramen, or with a condylar displacement only. This suggests that the mandibular corpus may vary slightly in sagittal position. This also suggests that effective ramal dimensions may be dictated by the position of the condyle and lingual tuberosity, themselves subject to functional position requirements. Transverse asymmetry of porion shows no consistent pattern. This may indicate a problem in distinguishing a true lateral displacement of porion from an apparent shift due to lateral displacement of subspinale, arbitrarily on the midline. This suggests that the lateral position of the condyle may not be closely related to the lateral position of porion. And also suggests that the lateral position of porion has no effective relationship with the position of lingual tuberosity. Lateral displacements of the greater palatine foramen yield no consistent displacements elsewhere. The choice of subspinale to represent the anterior determinant of the midline reduces the ability to differentiate palatal rotation, palatal shift, porion shift and combinations. For this reason no consistent results elsewhere should be expected. The last displacement of interest is transverse dentoalveolar. Occurring alone, and randomly in other asymmetric situations suggests that this is an

area also influenced by non-skeletal factors. The frequency and range of such displacements indicates a somewhat limited variability from skeletal base units. Based on the landmarks used no further displacements are noted.

The facial landmarks showed a tendency to similar displacements of points on the same side of the face. This would indicate that facial landmarks, on or near the same frontal plane would be bilaterally symmetric around the perpendicular bisector of a line constructed between homologous points. This is consistent with several of the variations on Harvold's "X-line" method.

Finally, there are two general comments concerning the literature previously reviewed. The first is that the sagittal variability of porion is large enough that any postero-anterior cephalometric analysis of asymmetry could yield totally incorrect information. And second, that any study of asymmetry uses a specific reference plane and a midline whether the author acknowledges it or not, and his results reflect such a midline.

SUMMARY AND CONCLUSIONS

The intent of this thesis was to study the normal range of asymmetry in the human facial skeleton, primarily those regions involved with mastication, and specifically the mandible. By assessing the range of variability of landmarks selected to represent boundaries of functional areas, the effective contribution of these areas in creating, maintaining, or reducing facial asymmetry could be analyzed. For methodological reasons, three-dimensional analysis of asymmetry was attempted to more accurately portray the factors involved in creating asymmetry.

The selected landmark coordinates of 73 human crania were collected with an Oyen-Walker Stereoplotting Craniostat. Means and standard deviations for each coordinate of each landmark were calculated, tabulated, and projected using a stereographic net. Results obtained showed a small but consistent difference between right-side mean coordinates and left-side mean coordinates. Right-side mean coordinates were larger. The standard deviations were examined and inferences drawn about the relative effect of each. Sagittal variability of porion, and transverse variability of orbital were the most pronounced. Means and standard deviations were also used to analyze individual skull landmark coordinates. Any landmark located in a position more than one standard deviation from its contralateral equi-

valent's position (side differences ignored) was compared to the corresponding mean. A qualitative assessment was made of the displacement in position of that landmark. Several patterns of displacement were noted.

Based on these results the following conclusions were drawn:

1. There is a tendency toward right-side dominance in size and/or tendency for right frontopetalia and right temporopetalia.

2. In relation to the subspinale-basion midline the poria show a sagittal variability, which can effect analyses based on transporionic axis orientation.

3. The mandibular area defined by the boundaries of the anterior surface of the condyle and the lingual tuberosity may be involved in reducing the adverse effect of cranial base asymmetry on facial asymmetry and occlusion.

4. The dentoalveolar component, both maxillary and mandibular, can also be involved in reducing the adverse occlusion effect produced by asymmetrical skeletal relationships.

These conclusions indicate that clinically the mandibular ramus, as defined by condyle/lingual tuberosity is a logical target for any therapy intended to alter sagittal relationships between the maxilla and mandible where the mandible is the problem. And, finally, further research in this area using this technique may produce more significant results by plotting grossly asymmetrical skulls such as those Bjork and Bjork studied.

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