A POSTERO-ANTERIOR CEPHALOMETRIC EVALUATION OF CRANIOFACIAL ASYMMETRY

A Thesis
Presented to
The Faculty of Graduate Studies
University of Manitoba

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by

Ayman Moustafa Chamma
Department of Preventive Dental Science

April 1978

A POSTERO-ANTERIOR CEPHALOMETRIC EVALUATION OF CRANIOFACIAL ASYMMETRY

BY

AYMAN MOUSTAFA CHAMMA

A dissertation submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

ACKNOWLEDGEMENTS

The successful completion of this research project depended on the cooperation and helpfulness of many different people. To all of these people who have contributed in one way or another to this study, I wish to express my sincere appreciation.

I am especially grateful to Dr. F. S. Chebib, Professor and Biostatistician for his guidance and encouragement throughout the course of this study. The many hours he spent in discussion of this work and the aid he extended during the preparation of this study, are especially appreciated.

It gives me great pleasure to express my sincere gratitude to Dr. A. T. Storey, Professor and Head, Department of Preventive Dental Science, Faculty of Dentistry, University of Manitoba, under whose guidance this work was carried on. His encouragement, constructive criticism and generous help during the entire period of this study is deeply appreciated and gratefully acknowledged.

I wish also to express my sincere appreciation to my research supervisor, Dr. F. J. Hechter, for his supervision, valuable suggestions and sincere encouragement throughout the preparation of this research project.

I would also like to thank Drs. L. C. Melosky, E. Cohen, M. Rudisaille and J. T. Winburn III, Department of

Preventive Dental Science, who have made my stay at the University of Manitoba both a true learning and enjoyable worthwhile experience.

Special thanks to the support staff of the Department of Preventive Dental Science and to the students in the Orthodontic Program, both past and present. Particular thanks and sincere appreciation to my classmates, Dr. T. D. Carlyle and Dr. R. W. Moir, whose encouragement, suggestions and stimulations have been continuous and whose friendship will be treasured.

Grateful appreciation is extended to Mr. A. Domokos and his staff for the many hours involved in the preparation of the art work and photography.

Special acknowledgement is also extended to Drs. I. Hassan and C. G. Baker who provided me with invaluable aid and encouragement during the development and preparation of this thesis.

Special thanks to Ms. M. Reid for the time and effort involved in the excellent typing services provided.

Finally, I would like to express my sincere gratitude and thanks to my parents, in-laws, family and my wife Fayza for their constant encouragement, assistance and understanding throughout the entire program.

DEDICATION

This thesis is dedicated to
my parents, whose many sacrifices
and inspiration made possible my
education.

A POSTERO-ANTERIOR CEPHALOMETRIC EVALUATION OF CRANIOFACIAL ASYMMETRY

by

Ayman M. Chamma

ABSTRACT

Few investigators of the human craniofacial structures have employed the postero-anterior (P-A) film in assessing facial asymmetry. A major obstacle to its use has been the difficulty in defining a suitable "midline".

The objectives of this study were 1) to establish a method of assessment of craniofacial asymmetry, 2) to quantitatively assess the degree of asymmetry, and 3) to examine the effect of sex on the degree of craniofacial asymmetry.

The sample consisted of 32 male and 31 female dental and dental hygiene students at the Faculty of Dentistry, University of Manitoba. The entire sample were adult Caucasians and exhibited no craniofacial abnormalities, crossbite, mandibular deviation, missing teeth (no more than one per quadrant) or previous orthodontic therapy. Postero-anterior cephalometric radiographs were obtained of both

sexes using a conventional technique, but with slight adjustment for the head position (i.e., a line connecting the tragus of the ear and nasal wing being parallel to the floor).

Six major indices measuring various aspects of craniofacial asymmetry were mathematically developed and calculated through the use of a specially designed P-A coordinate analysis computer program for each of the 63 subjects. The indices were termed lateral expansion asymmetry, oblique motion, vertical disharmony, vertical distortion, mid-sagittal distortion and lateral distortion. The indices were based on the calculation of two best fit lines (mid-sagittal and bilateral structures). Furthermore, the site and/or magnitude of craniofacial asymmetry for any structure can be assessed (i.e., measuring the horizontal and/or vertical deviation for any landmark based to the best fit line). In addition, 10 paired selective angular and 10 paired selective linear measurements were used to evaluate the degree of craniofacial asymmetry. All the measurements used in this study were statistically analyzed to assess the significant difference between the right and left side of the face and between the two sexes.

The significant findings were as follows:

1. The six major asymmetry indices of the craniofacial

structures showed, significantly, that the left side of the face was larger than the right, but with no significant diagonal expansion or vertical disproportion. The degree of asymmetry was less evident along the mid-sagittal structures as compared to the bilateral structures.

2. The specific indices of the mid-sagittal structures exhibited significant asymmetry only for the maxillary dentoalveolar midline structures and for the chin point (menton).

3. Indices of the bilateral craniofacial structures, provided the following:

   a) No significant asymmetry (horizontally or vertically) of the orbital region.

   b) The lower nasal region exhibited a greater degree of symmetry (horizontally and vertically) as compared to the remaining bilateral craniofacial structures.

   c) Significant horizontal left side facial asymmetry was present for the structures with major muscle attachment; those structures were: temporal (temporalis), condyle (lateral pterygoid), maxilla (buccinator), zygoma (zygomatic), mastoid (sternocleidomastoid) and gonial region (masseter and medial pterygoid).

4. The linear measurements were additionally supportive of the above mentioned findings that the left side of the face was larger.
5. The angular measurements provided less information of craniofacial asymmetry as compared with the other measurements and indices used.
6. Differences between the two sexes with respect to all the indices and linear and angular measurements were not significant.

TABLE OF CONTENTS

CHAPTER Page

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

CHAPTER I

INTRODUCTION

It has been about forty-seven years since Hofrath of Germany and Broadbent of the United States independently introduced cephalometric radiographs (lateral and frontal views) to the orthodontic profession. During this period cephalometrics has grown from an isolated laboratory experiment to a valuable clinical and research tool in daily use by orthodontists.

The postero-anterior cephalometric radiograph (P-A film) is a clinical diagnostic tool that supplements the lateral radiograph in craniofacial diagnosis. Its prime role is that of assessing the frontal facial pattern and the degree of symmetry. Other uses of the P-A film include assessment of quantitative widths of the maxilla, mandible, and other facial structures, shape and deformations of the turbinates, vertical heights of the sinuses, and vertical height of dento-alveolar structures (Marshall 1969). Archer (1966) in addition, has stated that the P-A radiograph is very useful in diagnosing fractures of the mandible and nasomaxillary complex.

Asymmetry in the craniofacial region can be recognized as a difference in the size or form of individual bones, as in the case of condylar hyperplasia of the mandible. It can also be recognized as a difference in positional relationship of a bone or bones in the cranium or face as in unilateral complete cleft palate.

In orthodontics, asymmetry of the craniofacial structures is of great interest. In some cases of facial asymmetry one may find a different growth pattern on the right and left sides, for example in the mandible, "a class III pattern on one side and a class I growth pattern on the other" (Barnett 1971). Cheney (1961) subjectively classified dentofacial asymmetry into four categories:

1 - Unilateral antero-posterior asymmetry

2 - Vertical asymmetry

3 - Lateral asymmetry

4 - Rotary asymmetry

Each of the above mentioned categories is associated with particular clinical problems. In spite of this, little has been written concerning the quantitative assessment and study of the effect of craniofacial asymmetry in the developing of malocclusions. This neglect may be due to the two reasons:

1. The assumption that malocclusion affects the face in the sagittal plane more than it does in the transverse plane.

2. Difficulty in locating suitable landmarks and base lines on postero-anterior (P-A) film.

Considering the foregoing, it was therefore decided to undertake the following investigation. Sixty-three dental students and dental hygienists (32 male and 31 female) were examined clinically as well as radiographically (postero-anterior radiographs). The P-A radiographs were taken for each subject by rotating the ear rods of a Moss Cephalometrix* cephalometer 90 degrees so that the central x-ray beam would pass through the head along the mid-sagittal plane and at a right angle to the transmeatal axis. The subject was oriented in the cephalostat so that he or she was facing the film cassette.

---

* Moss Corporation, Chicago, Illinois, U.S.A.

The specific purposes of this study were as follows:

1) To establish a method of assessing craniofacial asymmetries (horizontally and vertically) in the bilateral and midline structures.
2) To quantitatively assess the degree of craniofacial asymmetries in the sample.
3) To examine the effect of sex on the degree of craniofacial asymmetry.

REVIEW OF THE LITERATURE

CHAPTER II

REVIEW OF THE LITERATURE

Asymmetry in the craniofacial region was first recorded by the artist. Hasse's investigations (1887) of early Greek statuary reveals that sculptors of the classic period duplicated nature in the creation of artistic works which showed light to moderate asymmetries. Since then, biologists and anatomists - among them Hilton (1963), Duncker (1904), Sumner and Huestis (1921), Ludwig and Wette (1958), Huxley (1932) and Woodger (1937), have found asymmetry of form, functions and proportions in their studies of invertebrates and mammals. Yet, as Thompson (1943) stated, "normal asymmetry is not very evident, whereas abnormal asymmetry is quite obvious". According to Ward and Lerner (1947) "marked asymmetry is probably much more common than a review of the literature would indicate" and Fisher (1954) said that "facial asymmetry is a natural phenomenon and there is nothing abnormal about it".

Etiology of Craniofacial Asymmetry

A wide variety of explanations have been suggested to explain the etiology of craniofacial asymmetry. Gruneberg (1942) said that genes, their substratum (cytoplasmic environments) and interaction between genes and substratum accounted for the combination of asymmetry seen in nature. Landauer (1939) stated that slight asymmetries were consequences of "imperfections in the morphological mechanism which creates symmetry" during early development. Such asymmetry, expressing a chance distribution to either right or left, would be regulated by growth - gradient differences on the right and left sides. Lundstrom (1961) proposed that the biological principle of bilateral asymmetry is never manifested with mathematical precision and attributes right - left difference to genetic and non-genetic influences during the development of the individual.

Clinical and laboratory studies of the etiology of asymmetries range from gross observation to more precise anthropometric studies (Moore and Dannis, 1925; Greene, 1931; Reiss and Broder, 1940). Moloy (1942) studied the effects of "moulding" of the head at birth, attempting to relate the resulting asymmetries to the degree of calcification of the calvarium and face. Parmelee (1952) suggested that extreme intra-uterine flexion of the head with pressure of the shoulder continuously against the jaw produces the "moulding". However, none of these studies have used radiographs in measuring the degree of asymmetry. Conclusions were drawn from clinical observations alone.

Yates (1928), Balyeat and Bower (1934), and Todd (1939) related facial and dental deformity to chronic nasal infections and allergic manifestations, but no quantitative evidence was presented to substantiate their findings. Chalk (1975), who tested the functional stimulus of nasal air flow by means of surgical unilateral nasal blockage on rats, reported that the asymmetry following surgery was not significant and appeared to be mediated through sutural adjustments in the craniofacial complex.

To test the influence of muscle and bone in the production of craniofacial asymmetries, animal investigations of form and function were conducted by Pottof (1916), Koch (1917), Fell and Robison (1929), Pratt (1943), Horowitz and Shapiro (1951), Sarnat and Engel (1951), and Ryll (1972). Results of these and other studies are summarized by Scott (1954, 1958) who stated that muscles are capable of exerting a modifying action and are not independently responsible for the total form of a bone or bone complex. If the skeleton itself is abnormal, as in the case of pathology, normal muscle forces could produce abnormalities of bone growth.

In contrast to Scott's beliefs, Moss (1962) suggested in his functional matrix hypothesis that functional matrices of muscles and soft tissue structures are the primary factors in determining the shape and form of the facial bones.

Mulick (1965) suggested that damage to a nerve will result in varying amounts of asymmetry, dependent on the extent of injury and the developmental stage at which injury occurs. Actually, an injury to a motor nerve probably produces asymmetry indirectly because it is the alteration of individual muscle function or group of muscles in function which produces asymmetric change.

Washburn's (1947) experiments on rats describes neural damage (motor nerve) effects as two-fold in nature:

1) The reduction of function locally, with resultant deviations or asymmetries due to overt muscular action toward the opposite side.
2) Atrophic influences, which tend to cause deviation towards the affected side.

Thompson (1943) listed four categories as etiological factors in the production of abnormal facial asymmetry, namely:

1) Direct injuries to and loss of bone, e.g., infection, fractures, trauma, carcinoma.
2) Direct injuries of growth sites occurring pre- and post-natally.
3) Indirect effects upon growth sites of neuro-muscular afflictions - age factor is important in the resultant asymmetry; can occur pre- and post-

natally.

4) Idiopathic factors.

Plint and Ellisdon (1974) in a discussion of facial asymmetries with special reference to mandibular displacements, distinguished between "true" asymmetries (due to congenital and acquired malformations), and non-pathological asymmetry (which is possibly due to heredity factor). In their description of their "true" asymmetry, they identified:

a) first branchial arch dysplasia (congenital)

b) neuro-fibromatosis (acquired)

c) masseteric hypertrophy (acquired)

d) ankylosis of tempro-mandibular joint (acquired)

In summary, it has been demonstrated in both experimental and clinical studies, that certain environmental agents can produce decided right-left differences. Thus, the presence of unfavorable pressures, interruption of muscular balance, or damage to a growth site or growth center, can at a critical stage in development, exercise a powerful influence on the final morphologic and functional form of structures within the craniofacial complex.

There is also a great deal of speculation regarding the sub-clinical right-left differences which occur in the craniofacial complex. Whether differences of this degree are produced primarily by genetic or environmental control has not been established (Mulick 1965).

Assessment of Asymmetry

The median line of the face

In order to determine accurately the site and extent of facial asymmetry, a mid-sagittal plane from which lateral measurements could be obtained, had to be devised. Ideally, measures of the head should indicate a perfect division into two halves by a vertical line through the crista galli of the ethmoid bone, the nasal septum, the anterior nasal spine, the midline of the maxilla and the mandible (Yen 1960). Such a perfect, symmetrical face is very rarely, if ever, observed. Tildesley (1921), Buxton and Morant (1933), Sollas (1933), and Ray (1960) have identified difficulties which arise in investigations involving the use of this plane and Jackson (1937) considered that to determine the median sagittal plane of the skull "is not easy, if at all possible".

Most observers mentioning the median plane ignore the difficulty of establishing its position. Buxton and Morant said that the median sagittal plane has generally been presumed without being defined. Cheney (1961) said that it passes through nasion and anterior nasal spine. It would appear that this plane is usually considered to bisect all the central anatomical structures. However, investigation will readily show that such a plane, probably without exception, cannot be described through these "central" structures. Therefore, the term "plane" is merely an approximation which is convenient for descriptive purposes.

The dimensions of the skull usually measured are the same as those of the remainder of the body: length, height and width. A single film, however, can only be a two-dimensional representation of a three-dimensional object. A lateral cephalometric view reveals height and length, a postero-anterior radiographic view reveals only width and height.

Asymmetry, or, as Fisher (1954) defines it, "imbalances that occur between homologous parts of the face affecting the proportion of these parts to one another with regard to size, form and position on opposite sides of a plane, line or points", can also occur in any of the three-dimensions, antero-posteriorly, supero-inferiorly or medio-laterally. The lateral projection of the head will disclose antero-posterior irregularities, and to some extent supero-inferior ones. But to reveal medio-lateral and supero-inferior asymmetries, the use of a postero-anterior cephalograph is mandatory. In fact, Langestrom and Brodie (1967) have stated that "it is not safe to measure changes due to growth or to any other cause from the lateral head film alone, no matter how carefully it has been taken. The postero-anterior film is an indispensable adjunct".

Few investigations of the human skull have employed this approach because of the difficulty in identifying reproducible landmarks. "Postero-anterior skull radiographs are never easy to interpret, as they require concentration and careful study of anatomy" (Marshall 1969).

In their investigation of this problem, Krogman and Sassouni (1957) and Sassouni (1957, 1960) specifically identified suitable P-A landmarks. The superior and lateral contour of the orbits, crista galli, point gonion, the anterior cranial base, and the lesser wings of the sphenoid bone were some of the readily identified landmarks which they described.

Recently Bjork and Skieller (1974) used metallic implants to assess the transverse growth of the maxilla by means of P-A radiographs. The sample was studied longitudinally from ages 4 to 20 years. Anatomical landmarks were not used in assessment of the radiographs, presumably due to their confidence in the accuracy of locating the implants.

Studying cases of abnormal asymmetry, more closely related to deformities, Thompson (1943) constructed a vertical line that appeared to be midway between the medial aspects of the orbits and passed through the nasal septum. He did not take any measurements on his cephalograms, but rather drew conclusions directly by subjective observations. Harvold (1951, 1959) conducted several studies of facial symmetry and developed his "x" line method to establish the mid-sagittal plane. This line was constructed by drawing a perependicular to a line connecting the right and left zygomatic-frontal sutures, passing through the root of the crista galli. He stated, "the lack of some sort of reference base from which bilateral measurements may be derived has limited the use of this radiogram". In an examination of cleft palate patients Harvold (1954) demonstrated that in ninety percent of the cases, his median plane divided the distance between left and right zygomatic bones into two parts that differed by less than 2 percent of the total width. He found that the zygomatic-frontal suture was essentially unaffected in the severe growth disturbances of cleft palate patients. Harvold's index of symmetry obtained by measuring from his "x" line to the zygomatic-maxillary sutures on the malar process closely corresponded to previous anthropologic findings (Woo 1931). Viloria (1955) studied sixty-eight pairs of twins from age twelve to sixteen years in which one individual from each pair was used. His findings revealed that Harvold's X plane could be used in order to determine the position of "raphe palatinus" in relation to the upper facial skeleton.

Truque (1956) studied eight individuals in ages ranging from twelve to sixteen years. His results were supportive of those of Violoria. He also found that the maxilla as a rule deviates to the right and the "raphe palatinus" deviates with it.

In an anthropometric study Woo (1931) examined approximately eight hundred Egyptian skulls. He concluded that "the human skull from its very nature is asymmetrical". He found the leading feature of this asymmetry is the predominance of the right side. It was his feeling that this cranial predominance of the right side must be counter-balanced by a predominance somewhere else possibly in the cerebellar or basal portions of the skull. He could draw no conclusions from his data supporting this hypothesis and thus accepted the belief that the asymmetries of the cranial bones do not equalize each other so as to produce a symmetrical total head form. The malar bone was the only case in which the left side has dominance for all measurements taken, and this was felt to be due to its distant relation to the brain development. In a subsequent study (1938), Woo reported that the malar, occipital and sphenoid bones were larger on the left side than on the right side, while the frontal, temporal and parietal bones were smaller.

Sassouni, in 1958, proposed a mid-sagittal plane on the P-A cephalogram which was constructed by connecting the right and left latero-orbital points with a straight line and then drawing a line perpendicular to it from the neck of the perpendicular lamina of the ethmoid. The observer could then check all bilateral asymmetries on both sides of the perpendicular.

Later, Sassouni (1960, 1971) presented another method by which facial and dental asymmetries could be noted on the P-A film. He studied the dento-facial asymmetries by constructing five horizontal lines: the supra-orbital, the latero-orbital, the bi-zygomatic, bi-mastoid and bi-gonial lines. In an ideal situation, all these lines should be parallel. If not, he suggested selecting the three which were the most parallel and from their midpoint, dropping a perpendicular and assessing the transverse symmetry of the dentition and bones. Since facial asymmetry is possible in all three planes of the body, he suggested the use of both a lateral and a poster-anterior film to identify asymmetry in length, width and height.

Berger (1961) has reported on a third view in cephalometrics the basilar view which until then has received little if any, attention. It is his feeling that the most obvious use of a basilar film would be the determination of the midline and the assessment of asymmetry. There are a number of points which qualify as reference points for this purpose: the anterior tubercle of the atlas, the odontoid process of the axis and the outline made by the vomer and crista galli. In addition to these, two characteristic features on the inner walls of the frontal as well as the occipital bone can help in the determination of a midline from the basilar view.

A method of identifying, describing and evaluating dento-facial asymmetries has been proposed by Cheney (1961). His main interest centered on the use of points nasion and anterior nasal spine as reference points in determining the mid-sagittal plane for direct observations about asymmetries. He concluded that asymmetry was a major factor in certain types of malocclusion, and that each side necessitated a different treatment approach. In an earlier study, Thompson (1943) stated that "malocclusion is not one of the causes of asymmetry of the face, but rather is one of the symptoms. The orthodontic treatment may straighten the teeth, but it will not straighten the face".

Fisher (1964) developed a procedure to assess asymmetry when the crista galli is masked on antero-posterior projection. He connected the most distal aspect of both fronto-zygomatic sutures with a straight line and constructed a perpendicular bisecting that line. He reported this median plane to be just as reliable as Harvold's X-line.

In a serial study over a five year period, Robinson (1966) used Fisher's method to analyse asymmetries for a substantial number of subjects. He found that the left side generally was larger than the right side at age five years for certain landmarks: gonion, intersection of cranial base and ramus, condylar, mastoidal, zygoma and temporal point. Asymmetry tended to decrease from age five to ten years.

Letzer and Kronman (1967) utilized the postero-anterior cephalogram to explore the relationship between occlusion of the teeth and the presence or absence of mandibular or anterior cranial base asymmetry in the frontal plane. They used a system of angular measurements from a point on crista galli near the level of the sphenoid plane. They found no statistical evidence to corroborate any relationship between the occlusion of the teeth and symmetry or asymmetry of the face.

Mulick (1965), investigating craniofacial asymmetry in fraternal and identical twins, used orthogonal measurements (measurements of distance along perpendicular reference planes) on tracings of lateral and the postero-anterior cephalometric radiographs. He stressed the importance of correcting measurements due to size distortion, and also the use of anatomic landmarks rather than a reference axis system as a basis for the measurements of asymmetry, since anatomic landmarks show less variation than arbitrarily selected points in a coordinate system.

Due to overlapping of bones, anatomical landmarks however are also difficult to identify particularly in P-A radiographs. Mulick failed to show that heredity could be a significant factor in producing craniofacial asymmetry. He also concluded that age had no effect on an individual's mean asymmetry and the differences between left and right side did not increase with age. This was contrary to Moore (1944), who felt that heredity is operative in such facial asymmetries as lateral displacement of the chin or differences in mandibular angles, in levels of orbital points or anterio-posterior position of the malar bones, height of right and left rami, or of right and left corpal length of the mandible. He also thought that the frequency of asymmetry was three or four times greater in children whose parents demonstrated craniofacial asymmetry. However, further investigation is needed to answer the question of the impact of heredity on the production of craniofacial asymmetry, since Mulick's sample was rather small in size (6 identical same sex twin sets), while Moore's larger sample of 78 families involving 265 individuals was not assessed for asymmetry from P-A radiographs but strictly from clinical examination. Woods (1950) stated that asymmetry as judged clinically was not related to differences in sex, other than absolute size, the female being slightly smaller in all dimensions.

Kondo (1972) used Sassouni's method (1960) as a base line of investigating the transverse dimensions of various parts of the craniofacial complex and their inter-relationships using postero-anterior cephalograms and dental casts of 64 individuals (32 male and 32 female adults) possessing "excellent occlusion". He reported that the maximum head width and the widths of middle and lower face were more variable than that of the upper face. Therefore, it seemed that the variations of the individual's face pattern in the frontal aspect were influenced by the widths of those areas. Although a significant degree of symmetry was found in the upper, middle and lower face, the degree of symmetry of the lower face and the maximum head width, were more variable than the upper face. Thus, it seemed that the symmetry of the face is influenced by the variation of the midline shift of those parts.

A radiographic study of facial asymmetry was undertaken by Vig and Hewitt (1973) on "normal" growing children. A line of "best fit" was drawn through the points that represented the mandibular region and another line of "best fit" was drawn through the points that represented the maxillary region. The angle between these axes was proportional to the degree of asymmetry between the two regions. The reference points were joined to form triangles on both sides of the midline. These triangles represented the right and left mandibular region, the lower middle, and upper maxillary regions, and the cranial base region. The areas of the triangles were compared with the equivalents on the contra-lateral side. Facial asymmetry revealed horizontal and vertical componenets. The horizontal asymmetry was assessed by reference to a central axis system and the vertical disharmony was referred to an axis through the condyles that represents the cranial base. The preliminary investigation suggests an overall vertical and horizontal disproportion in most instances, with the left side being larger. The axis that represented the mandibular region was found to deviate to the left of the maxillary axis in 88 percent of the children examined. The cranial base and the mandibular regions also tended to be larger on the left side but the dento-alveolar region exhibited symmetry in most children, indicating the efficacy of adaptation during growth.

Hewitt (1975) applied the same method of assessing asymmetry. On 63 individuals aged 14-18 years he reported that the mandibular and dento-alveolar regions exhibited a greater degree of symmetry. He also pointed out that the maxillary regions were larger on the left side.

This finding would agree with Burke's (1971) results. Burke, however, used different techniques of assessing the facial asymmetry. He measured the face steriophotogrammetrically (plotting the soft tissue facial contours). He attributed this result to different rates of growth between the right and left sides at the maxillary region, suggesting that the control of growth of the two sides of the face is separate.

In summary, there has been a dearth of literature concerning the quantitative assessment of craniofacial asymmetry. Although no substantial evidence has been presented as to the actual sites of craniofacial asymmetry (right vs left sides of specific bones) some investigators (Woo 1938, Robinson 1966, Burke 1971, Vig and Hewitt 1973, and Hewitt 1975) using different methods of assessment, have reported that the left side of the face tended to be larger than that of the right side. Others have found that the right side, particularly in the maxillary region, was larger than that of the left (Viloria 1955 and Truque 1956).

It is evident from the literature cited, that no method is adequate to accurately define and assess the areas of asymmetries in the craniofacial complex. Such a method could be applied to such cases as cleft lip and/or cleft palate, condylar and facial dysplasia, and many of hereditary syndromes affecting the face and cranium such as Apert's syndrome and hemi-facial microsomia syndrome (Gorlin 1976). In addition, this method would also be beneficial in treatment planning the orthodontic and/or surgical management for these patients.

The establishment of a method of assessing the craniofacial asymmetry has been dependent upon the construction of reference planes or axes in order to assess the sites and/or magnitude of horizontal and vertical asymmetry. However, the reliability of previously employed methods for assessment of craniofacial asymmetry may be questioned as they have ignored some mathematical principles in the construction of reference axes and/or planes. As such, the derivation of the reference planes may be better understood if the concepts of symmetry are considered.

The following brief description presents the concept of mathematical symmetry, to allow the reader to become familiar with the process of relative asymmetry of a three dimensional object.

The Principles of Symmetry:

The principles of symmetry described are presented in such a manner as to eliminate the necessity of mathematical formulae, in order to avoid unnecessarily complicating the description of symmetry.

The term symmetry has slightly different usages, however, it means "the correspondence in size, form and arrangement of parts on opposite sides of a plane, line or point (The American College Dictionary, Webster 1977). Nevertheless, the principles of symmetry involve two aspects 1) the relative equality between two objects and 2) the geometric regularity (Geometric symmetry in regular manner) for one object.

1. Relative Equality as a Basis for the Theory of Symmetry

The concept of the relative equality of two objects is a fundamental principle in the theory of symmetry (Koptsik 1974). Two objects may be considered equal in relation to some particular feature if both objects possess that feature. For example, the vertices of a square are equal to one another in the sense that two edges at right angles meet in each of them. They are not, however, equal to one another with respect to their different orientation in space. All the sides of a scalene traingle are relatively equal to one another in that each is a section of a straight line. A right hand is equal to the left in all quanitative features, although the right hand cannot be made to coincide with the left by simple superimposition, i.e., without first reflecting one of them in a mirror. The faces of a piece of rock salt, which when broken along its cleavage planes, has the shape of a rectangular paralleloped, are not equal to one another in the ordinary geometric sense, but are equal with respect to their physical properties (Koptsik 1974).

One can see from these examples, first, that nature does not and cannot allow absolute equality between two objects separated in space or time, and second, that in real or relative equality it is essential to specify a criterion, or, more precisely, to specify the measure of equality. In the discussion of the measure of equality for each aspect of symmetrical feature, one can also mention the idea of two objects being more or less equal. For example, one may say that the corners of a square are more equal to one another than the corners of a parallelogram, since the corners of a square have more features in which they are equal than those of a parallelogram. Establishment of equality between two objects means estimating their qualitative as well as their quantitative features.

2. Geometric Regularity

An object is constructed in a geometrically regular manner if it may be divided without a remainder into equal parts with respect to a specific geometric feature. For example, a square is constructed in a geometrically regular manner since it may be divided without a remainder into eight geometrically equal right-angled triangles (figure 1).

A circle is constructed in a geometrically regular manner, since the figure as a whole may be made up of an infinite number of points equal to one another in that each lies at the same distance from the center (Koptsik 1974).

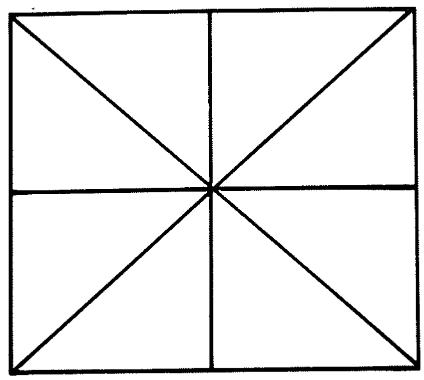
Symmetry as a special kind of Geometric Law: Geometric Equality

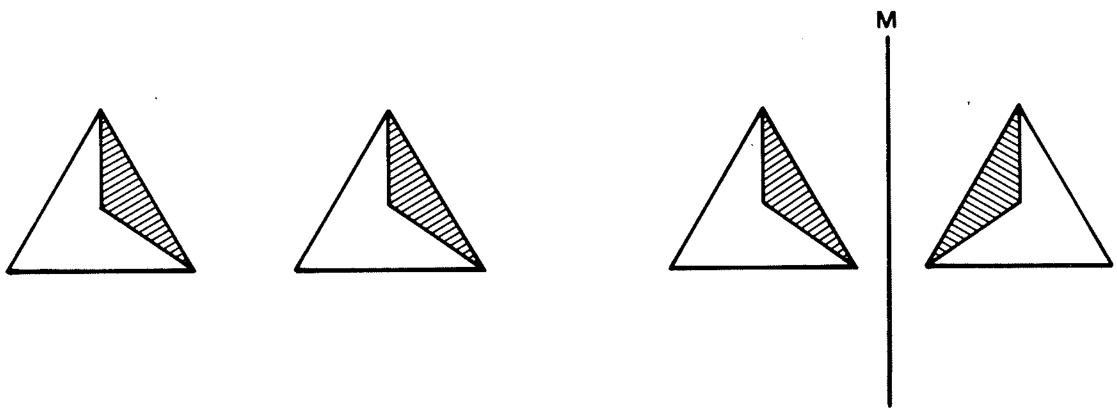
Geometric equality means two things, either compatible equality (congruence) or mirror equality (see figure 2). Shubnikov (1974) stated that neither in man made objects nor in nature (crystals, plants, animals, etc.) is symmetry ever achieved with mathematical precision. If the deviation from faultless symmetry is fairly small and unsystematic, one can accept the objects as symmetrical even when one is clearly able to see these deviations: circles drawn by hand or with compasses will both be regarded as symmetrical figures (figure 3). If the deviations increase in size, symmetry is lost.

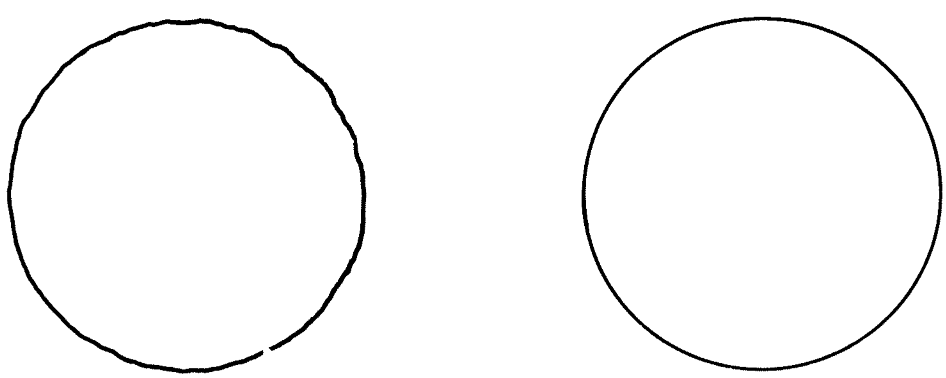
Figure 1. Geometric regularity of a square.

Figure 2. Compatible equality on left and mirror equality on right between two figures.
M: Imaging mirror plane.

Figure 3. Symmetrical figure of a circle drawn by: free hand on left and compass on right.




M



In crystallography, symmetry emerges as the special study of "real" crystals as opposed to "ideal" crystals, i.e., to theoretical models of crystals constructed in a mathematically precise manner. Thompson (1952) suggested that a crystal is the perfection of symmetry and of regularity; symmetry is displayed in its external form and regularity revealed in its internal lattices. At present, the symmetry of crystals is understood in terms of atomic dynamics: if equal atoms exert forces upon each other creating a definite state of equilibrium for the atomic ensemble, then the atoms in equilibrium will, of necessity, arrange themselves in a regular system of points (morphological symmetry) (Weyle 1972).

Planes and Axes of Symmetry

The symmetry plane is that imaginary plane which divides a figure into two mirror image parts. In nature (man, animals, crystals ...) mirror symmetry is, of course, only approximate. The symmetry axis on the other hand, is the line around which, when the figure rotates, the figure comes into coincidence with itself several times. Thus, one can distinguish between bilateral symmetry (in case of symmetry plane) and rotational symmetry (symmetry axis), (Stewart 1975).

The human figure is approximately symmetrical about a vertical plane, which is one of the reasons why mirrors seem to invert right and left. For example, a body with geometrical configuration, is symmetrical with respect to a given plane E (figure 4) if it is carried into itself by reflection in E. Take a line L perpendicular to E and any point P on L there exists one and only one point P', on L which has the same distance from E but lies on the opposite side. This kind of symmetry is know as bilateral symmetry. The Swastika on the other hand, possesses rotational symmetry (figure 5). There is also combination of bilateral and rotational symmetry.

A square is bilaterally symmetrical about a line through the center parallel to each side (figure 6). This line is constructed by joining the point M (mid point between AB or DA) and point M_1 (mid point between DC or CB). It also can be rotated 90° and still be symmetrical (figure 7).

In an attempt to relate the above mentioned concept of symmetry to the craniofacial complex, a polygon representing its structures can be drawn (figure 8). This polygon is defined by five skeletal points, four of which are paired bilateral points (bilateral craniofacial structures) and one which is the chin point of the midsagittal structure.

Figure 4. Bilateral symmetry

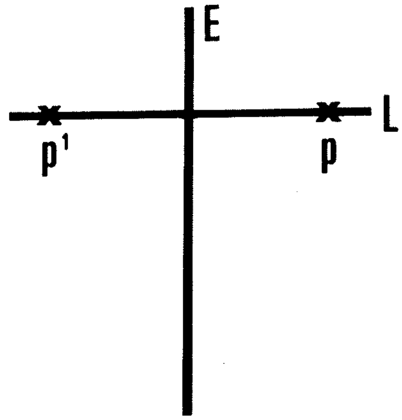
Figure 5. Rotational symmetry

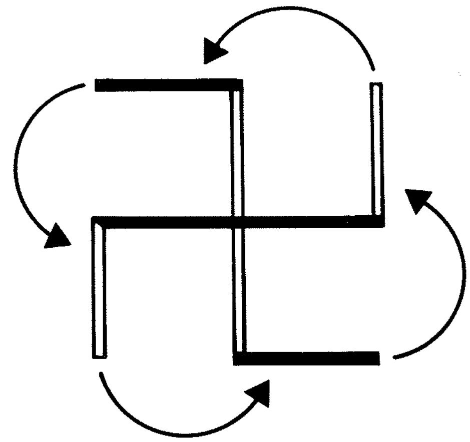
Figure 6. Symmetry axis of a square

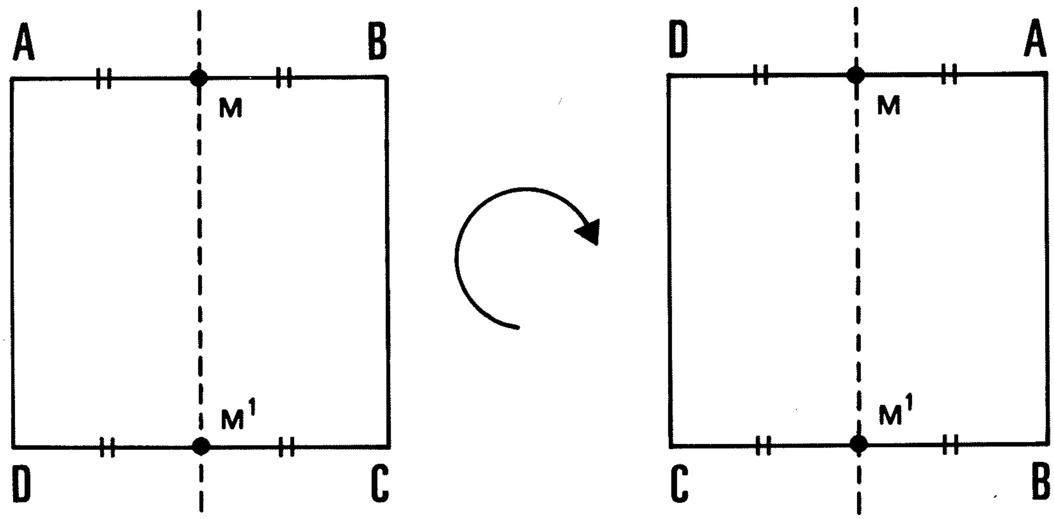
Figure 7. Symmetry axis of a square but after 90 degrees rotation

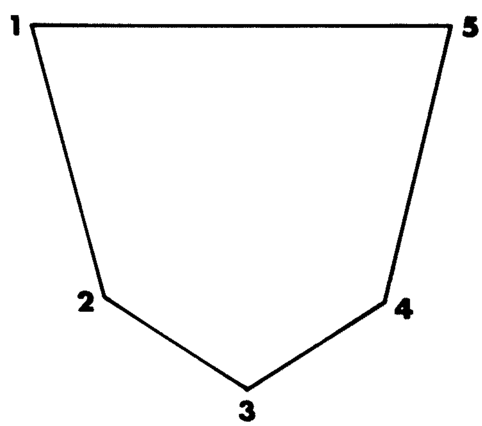
Figure 8. A polygon representing the craniofacial complex

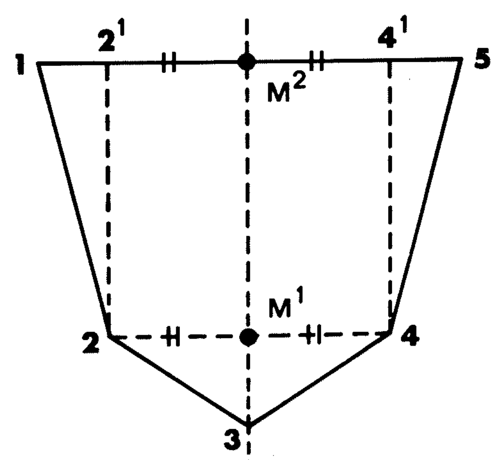
Figure 9. Symmetry axis of a craniofacial polygon


E
L
p1
p




A
B
M
M1
D
C
D
A
M
M1
C
B


1
5
2
4
3


1
21
41
5
M2
M1
2
4
3

Construction of this polygon was performed in order to simplify the picture of defining a single symmetry axis of the craniofacial structure where:

$$2_1 - 4_1 = 2 - 4$$

By bisecting $2_1 - 4_1$ and $2 - 4$, we have two midpoints, M_1 and M_2. By connecting M_1M_2 and extending the line superiorly as well as inferiorly, one can obtain a symmetrical axis X. Because this symmetry axis should represent the imagining mirror axis (since the polygon is ideally symmetrical), the figure $1M_232$ is identical with the figure $5M_234$ (figure 9). For that reason, point 3 (as well as any point on the midline structure) should fall on the axis X in case of ideal symmetrical polygon, while in case of asymmetrical polygon we have two axis, one representing the bilateral structure and the other the midline structures. There are two other ways of obtaining this X line, the first being a bisection of line 2 - 4 and connecting its midpoint M_2 to point 3 (since the X line in this case of perfect symmetry should pass by point 3). The second method is by bisecting the line 1 - 5 and connecting its midpoint (and in this case is also M_1M_2) to point 3.

It was hoped from this short presentation of mathematical symmetry, that the concept is understood for, as Weyle (1972) has stated, "symmetry is a vast subject, significant in art and nature. Mathematics lies at its root and it would be hard to find a better one on which to demonstrate the working of the mathematical intellect".

MATERIALS AND METHOD

CHAPTER III

MATERIALS AND METHOD

The Sample

The sample consisted of 32 male and 31 female dental and dental hygiene students at the Faculty of Dentistry, University of Manitoba. The age distribution of this sample is shown in Table I. The following criteria were used for the selection of the sample:

1) Adult caucasian
2) Absence of dental cross bites (anterior and/or posterior)
3) Absence of mandibular deviation (on closing and opening)
4) Absence of craniofacial anomalies, and/or previous trauma to the head and neck regions
5) No more than one missing tooth per quadrant
6) No previous orthodontic therapy
7) Good quality postero-anterior cephalograph

Each subject was examined clinically (intra and extra oral examination) to determine if he or she met the above mentioned criteria. In addition, the following records were obtained:

1 - Dental and medical history (see Appendix I)

Table I

Age distribution of the sample (years)

	Males	Females
Number	32	31
Mean	22.2	20.6
S.D.	1.9	1.4
Range	19.6 - 28.0	19.3 - 26.0

2 - Right and left 45° oblique radiographs

3 - Postero-anterior radiographs

4 - Lateral and frontal photographs

5 - Lateral cephalometric radiographs

6 - Dental study models

The oblique and lateral cephalograms, photographs, and the dental models mentioned above were not used in this study and have been retained for future investigations.

Cephalometric Techniques

The postero-anterior (P-A) radiographs were taken for each subject by rotating the ear rods of a cephalostat 90 degrees so that the central X-ray beam passed through the head along the mid-sagittal plane and at right angle to the transmeatal axis. The subject was oriented in the cephalostat, with the line connecting tragus of the ear and nasal wing parallel to the floor (Baker 1977). The anode or X-ray source was established at a distance of five feet (152.4 cm.) from the transmeatal axis, and the transmeatal to film cassette distance was fixed at 15 centimeters. All radiographs were taken using the Moss* Cephalometrix cephalometer at the University of Manitoba, Department of Preventive Dental Science. The exposure was 90 kV, 20 mA and varied between

* Moss Corporation, Chicago, Illinois, U.S.A.

1 second and 1¼ of a second depending on the size of the head.

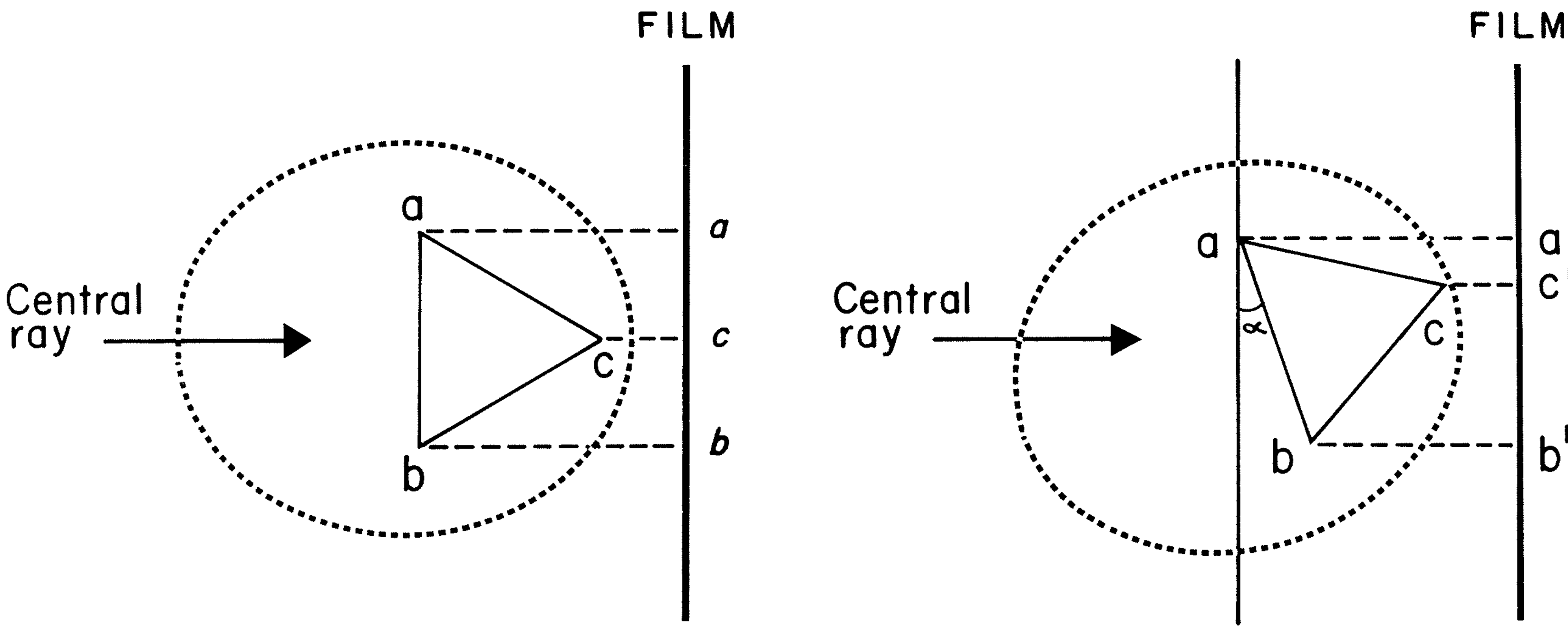
The magnification factors for this procedure had been previously established (Frostad 1969) and recently substantiated (Moir 1978) to be 9 percent. Although angular measurements were not affected by magnification and in order to simplify computer programming, the correction factor was directly applied to the coordinates of the individual landmarks. Hence, both angular and linear measurements were calculated from corrected coordinates.

Although the skeletal structures lying anterior to the transmeatal axis will be magnified less, as compared to structures posterior to the transmeatal axis, Alimchandani (1973) reported that the magnification error was relatively insignificant (i.e., < 0.6 percent).

The magnification error resulting from tipping the head in the cephalostat or laterally (beyond the standard positioning of the head established by the author), was investigated as a potential error in the method. In case of vertical tipping, no appreciable effect on midline or bilateral structures should occur. However, in case of lateral tipping of the head (rotation, as shown in figure 10), a horizontal distance will appear smaller than its real value. Mathematically, the error associated with such tipping (ab vs $a'b'$) expressed as a percentage of ab is: $100\ (1 - \cos\alpha)$.

Figure 10. Effect of head tipping on linear measurements.

Head free of lateral tipping on left; Lateral tipping (rotation) on right.


FILM
a
a
Central
ray
c
c
b
b
FILM
a
a'
c'
Central
ray
α
c
b
b'

where α is the angle of tipping. Thus, for a tipping of 5 degrees the error of any horizontal measurement is .38 percent and for 10 degrees is 1.52 percent. These values fall within the error of the method (1.68 percent) established by taking duplicate measurements on a dry skull (free of tipping).

Selection and Plotting of the Landmarks

Eight midline landmarks and twelve lateral pairs of landmarks were selected (figure 11). The selection was based on the following:

1) Relative ease of identifying the anatomical craniofacial structures
2) The age of the sample (1st permanent molar point is difficult to locate in adults due to overlap of the 2nd and 3rd molars)
3) Landmarks most commonly used in other studies

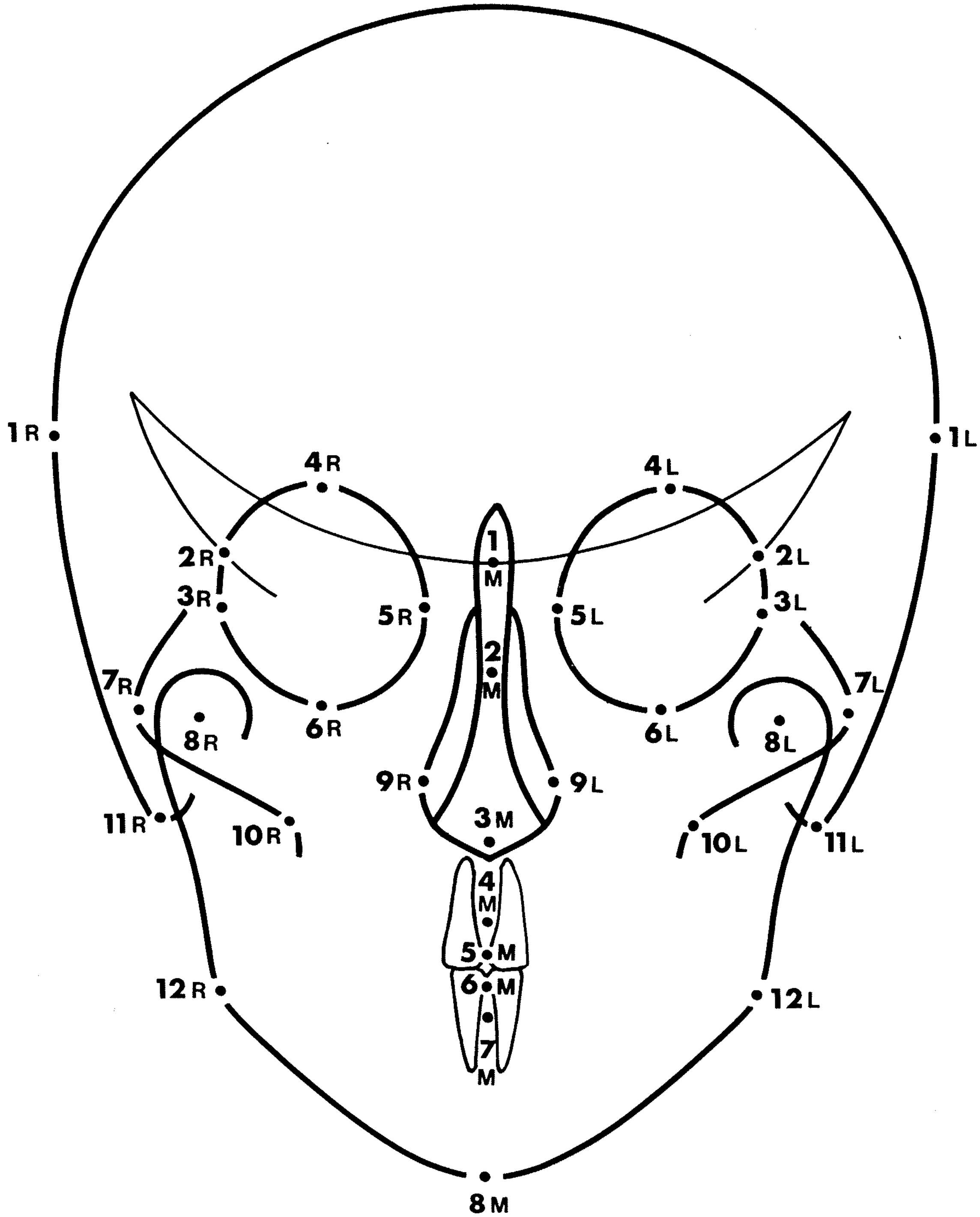
A detailed description of these landmarks is found in Appendix II.

The "X" and "Y" coordinates of each landmark were digitized in the preselected sequence (figure 11) and recorded directly onto 80 column punch cards, by means of a Ruscom* logistics strip chart digitizer connected to an IBM key punch machine (figure 12). Information from the punch

---

* Ruscom Logics Limited, Rexdale, Ontario, Canada

Figure 11. Numbering system of landmarks for digitization on the P-A radiographs


1R
1L
4R
4L
2R
2L
3R
3L
5R
5L
1M
2M
7R
7L
8R
8L
6R
6L
9R
9L
3M
11R
11L
10R
10L
4M
5M
6M
7M
12R
12L
8M

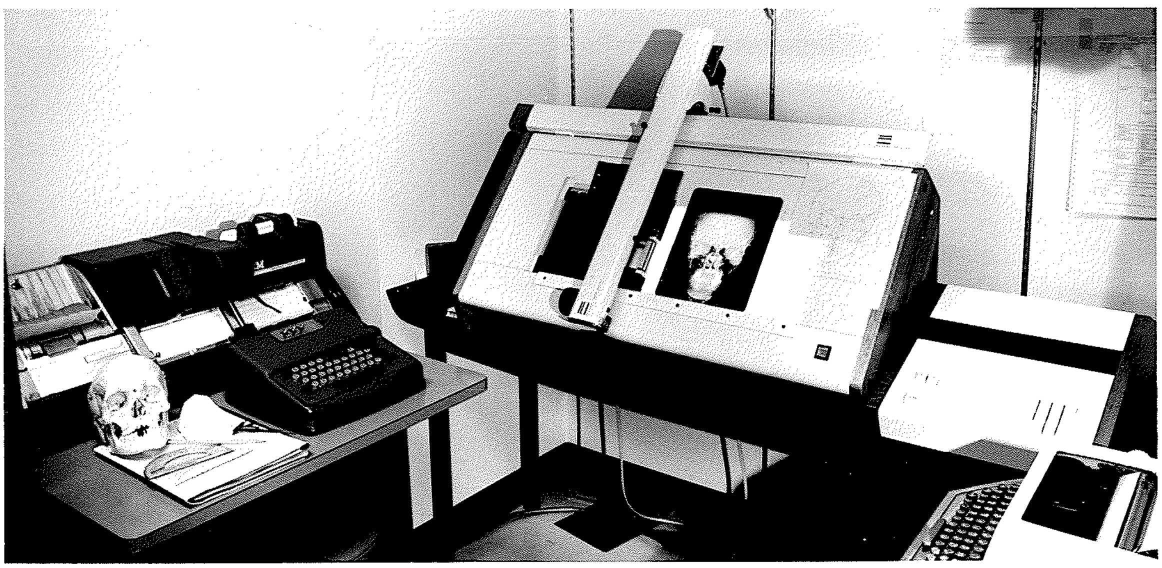


Figure 12. Digitization equipment used to record the coordinates of the landmarks from the P-A cephalometric radiograph

cards was then analyzed using the University of Manitoba IBM 370-68 computer by a specially written P-A coordinate analysis Computer Program (Chebib and Chamma, 1978).

Error of the Measurement

To examine the accuracy of the identification and digitization of the various landmarks used in this study, 15 randomly selected radiographs were digitized in duplicate on different days. A total of 9 angular and 9 linear measurements (shown in figure 13 and 14 and listed in Table II) were calculated for each set of coordinates and used to estimate the error of measurement as described by Chebib and Burdick (1973). These measurements were selected so as they involved landmarks which were difficult to locate due to overlapping bones.

The estimate of the measurement error included the calculation of the expected mean error ($\bar{e}$), the standard deviation of measurement error (s), and the maximum error (e_p) associated with 99 percent of the values, according to the following formulas:

$$(1) \qquad s = \sqrt{\frac{\Sigma\left[\Sigma\,(x - \bar{x})^2\right]}{\Sigma\,(n - 1)}}\ , \quad df = \Sigma\,(n - 1)$$

where 'n' is the number of times each radiograph was

Figure 13. Angular measurements used for the estimation of the error of measurement

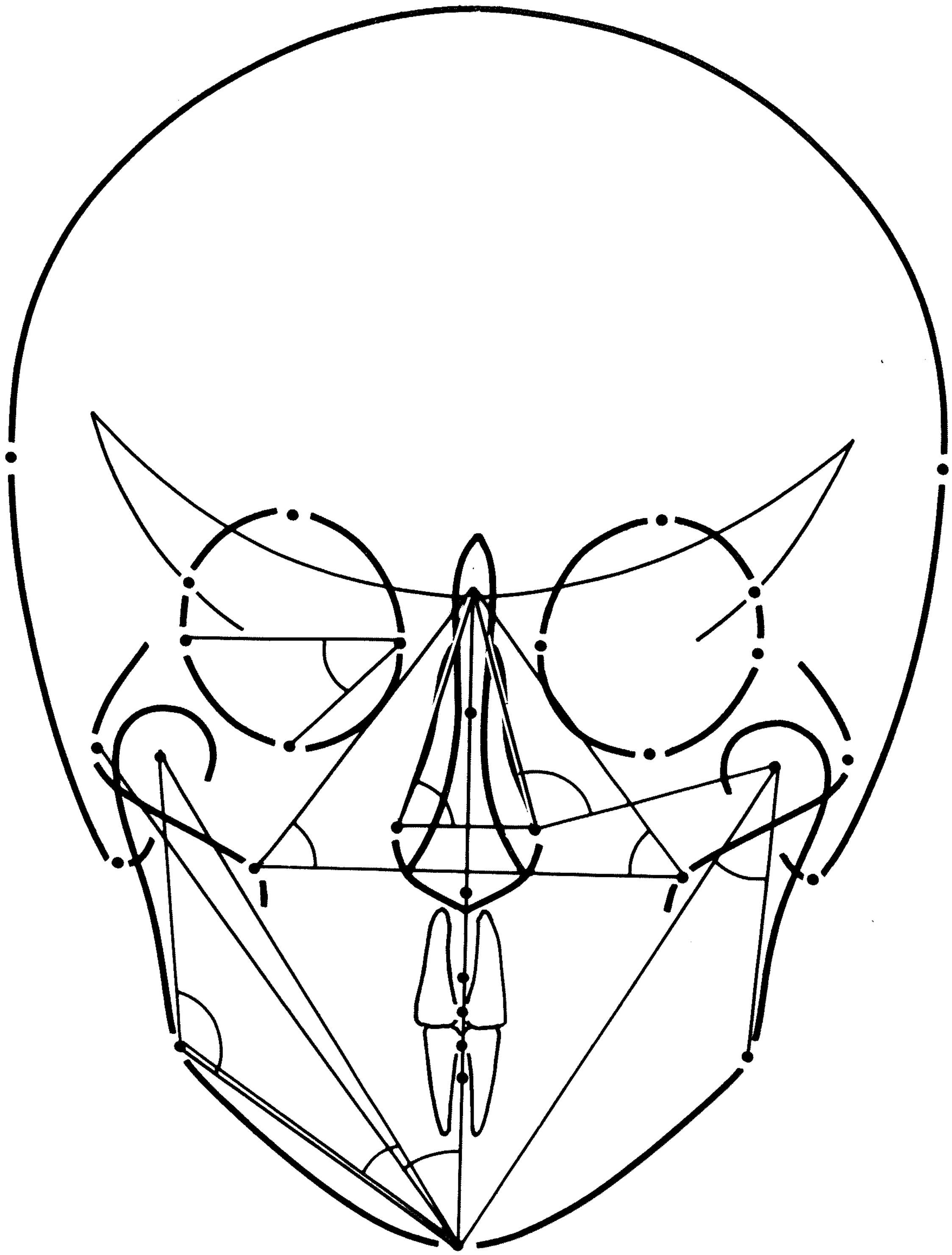


Figure 14. Linear measurements used for the estimation of the error of measurement

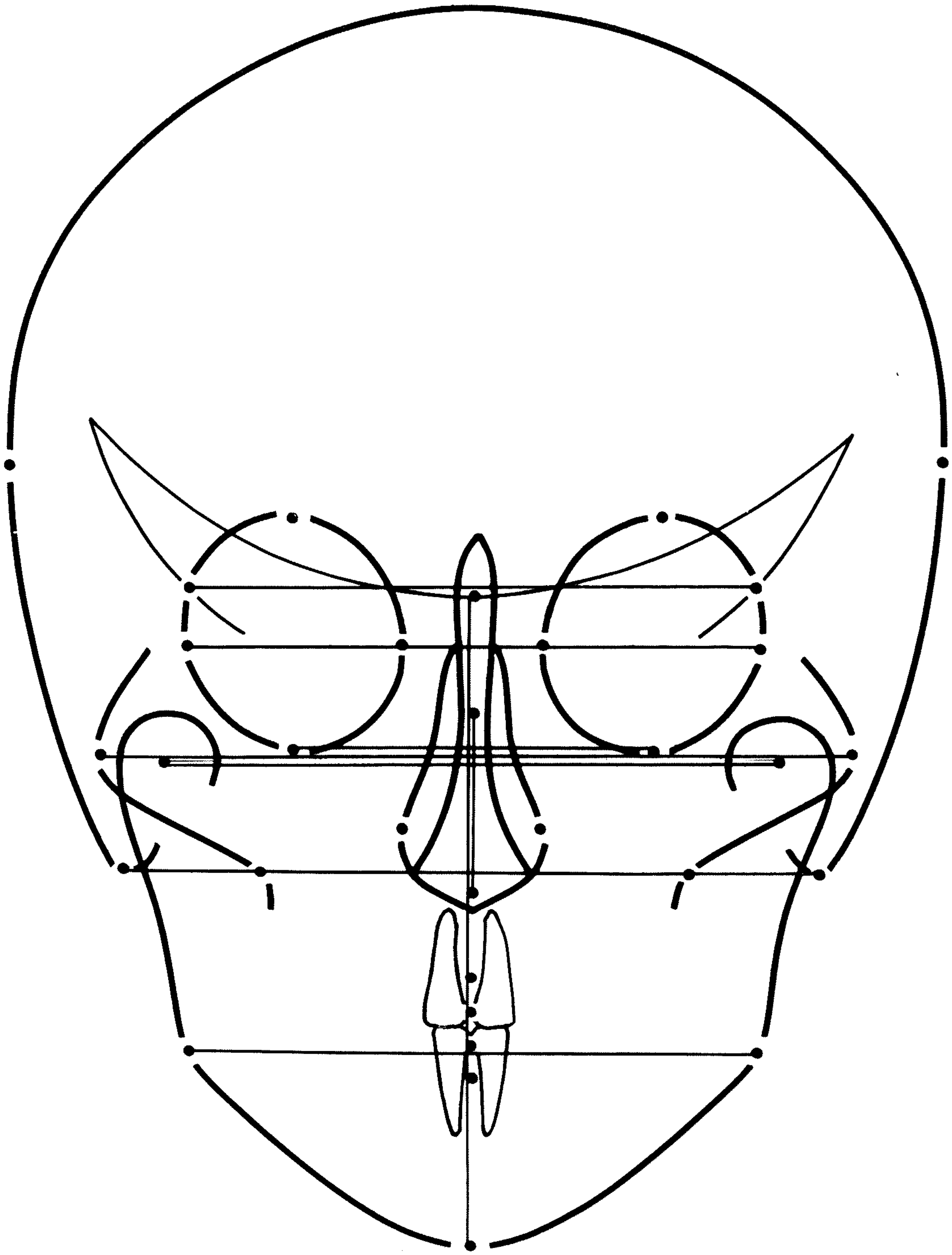


Table II

Expected mean error ($\bar{e}$), standard deviation of measurement error(s), 99% maximum error, for 18 P-A radiographic variables.

Variable	Mean Error ($\bar{e}$)	Standard Deviation of error(s)	99% maximum error (+/-)
Angles:			
1. 3R - 5R - 6R	2.842	2.532	7.203°
2. 8R - 8M - 12R	0.395	0.496	1.411°
3. 1M - 9L - 8L	1.093	1.371	3.900°
4. 1M - 9R - 9L	1.509	1.892	5.382°
5. 1M - 10L - 10R	0.741	0.929	2.643°
6. 1M - 10R - 10L	0.625	0.784	2.230°
7. 1M - 8M - 7R	0.485	0.608	1.729°
8. 8M - 8L - 12L	0.747	1.187	2.125°
9. 8R - 12R - 8M	0.879	1.102	3.135°
Distances			
1. 2R - 2L	.031	.039	.112 mm.
2. 3R - 3L	.059	.074	.213 mm.
3. 6R - 6L	.178	.224	.637 mm.
4. 7R - 7L	.120	.151	.430 mm.
5. 8R - 8L	.132	.165	.471 mm.
6. 11R - 11L	.454	.056	.162 mm.
7. 12R - 12L	.303	.038	.108 mm.
8. 2M - 3M	.095	.119	.340 mm.
9. 1M - 8M	.992	.124	.353 mm.

digitized for determination of the measurement error and in this case n = 2.

$$(2) \qquad \bar{e} = \pm \sqrt{\frac{2}{\pi}}\ s = \pm\ .7979\ s$$

$$(3) \qquad e_p = \pm\ t_{(99\%,\ df)}\ .s$$

where t = student's t value for degrees of freedom (df) and probability "p" (99 percent).

The maximum errors associated with 99 percent of the measurements for each of the variables are listed in Table II. In 99 percent of the measurements the error will be less than the reported value and only in rare occasions (one percent or less) will the error in the measurement exceed these values. It can be seen from Table II that the maximum error for the angular measurements ranged from 1.41 degrees (variable number 2) to 7.20 degrees (variable number 1) and for the linear distances from 0.10 mm. (variable number 7) to 0.63 mm. (variable number 3). The largest angular error was associated with inferior margin of the orbit. This was possibly associated with the difficulty in locating the inferior margin point (orbitale).

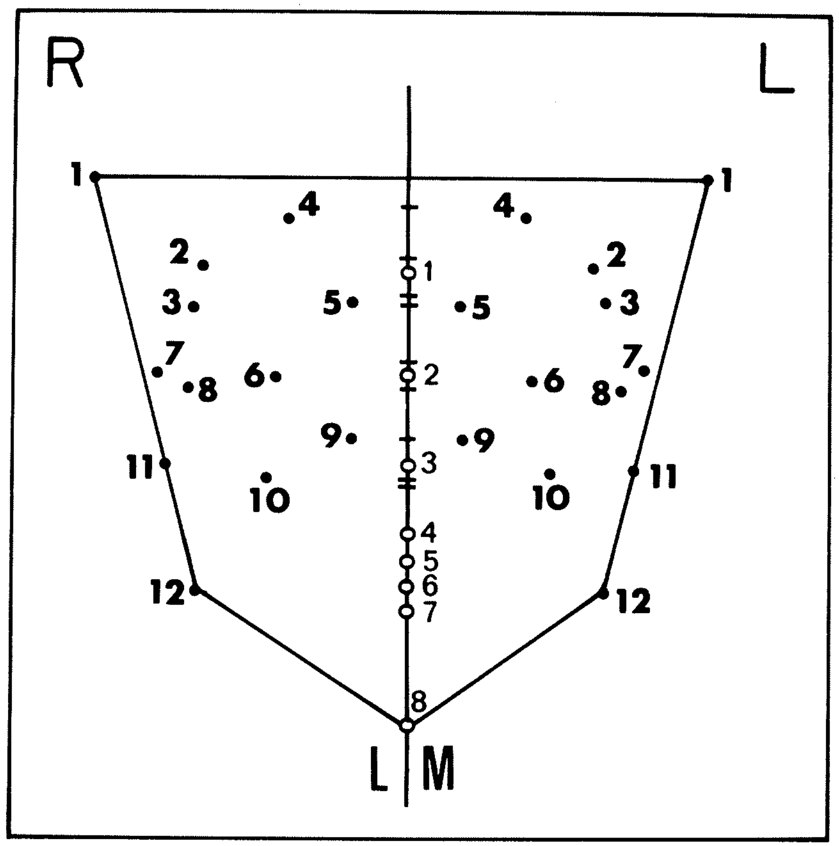
<u>Methods of Measuring Craniofacial Asymmetry</u>

For the measurement of the relative asymmetry of any given P-A radiograph, two axes, a mid-sagittal axis (M) and a lateral axis (L),were established. The mid-sagittal axis was defined as the best fit line (see Appendix III) for the midline structures (points M1 - M8 in figure 11). The lateral axis was taken as the best fit line for the bilateral structures. This axis was calculated from the midpoints of the 12 pairs of the lateral structures shown in figure 11.

These two axes (M and L) were used as the basis for the development of six indices for asymmetry according to the following rationale:

1) In the case of an overall perfect symmetry, the two axes will coincide (figure 15).
2) In the case of no deviation of midline structures from a straight line all the mid-sagittal structures will fall on the M axis (figure 15).
3) In the perfect case where all the pairs of the bilateral structures are equi-distant from a central axis, all the corresponding midpoints will fall on the L axis (figure 15).
4) In the case where no vertical disharmony exists, the vertical difference between any bilateral pair

Figure 15. A polygon representing perfect symmetry of the face



o Midline Points
— Midpoints of Paired Bilateral Points

of point, measured parallel to the M axis, will be zero (figure 15).

The following six indices were developed to assess the degree of asymmetry in its various concepts.

1. Index of Lateral Expansion

This index was calculated as twice the algebraic distance from the M axis to the L axis. In the general case these two axes are not parallel. This index, therefore, was calculated as twice the average algebraic distance between the two axis taken at orbitale (points 2R and 2L) and at gonial (points 12R and 12L). These two structures were selected because they define the total craniofacial region superiorly as well as inferiorly.

This index will, therefore, indicate the degree that one side of the face is expanded laterally relative to the other. A positive index indicates a left side expansion (figure 16) while a negative index indicates a right side expansion (figure 17).

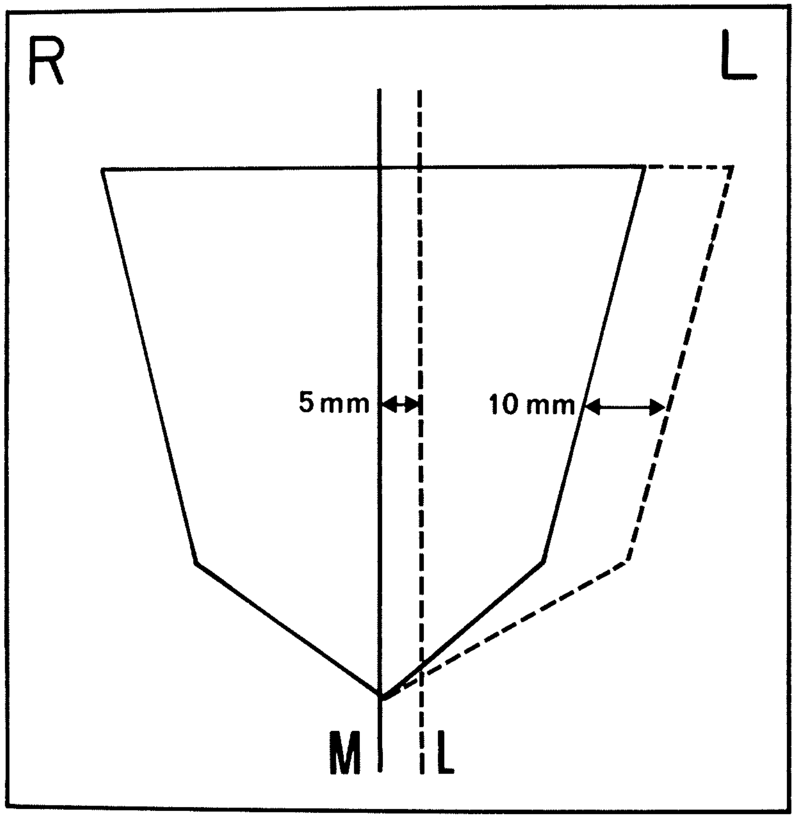
2. The Index of Oblique Motion

This index is measured as the angle formed between the two axes, arbitrarily taken clockwise from M to L. It measures the degree of diagonal expansion of facial components. A positive angle (figure 18) indicates a clockwise expansion of the facial structures. This would result, e.g., from the

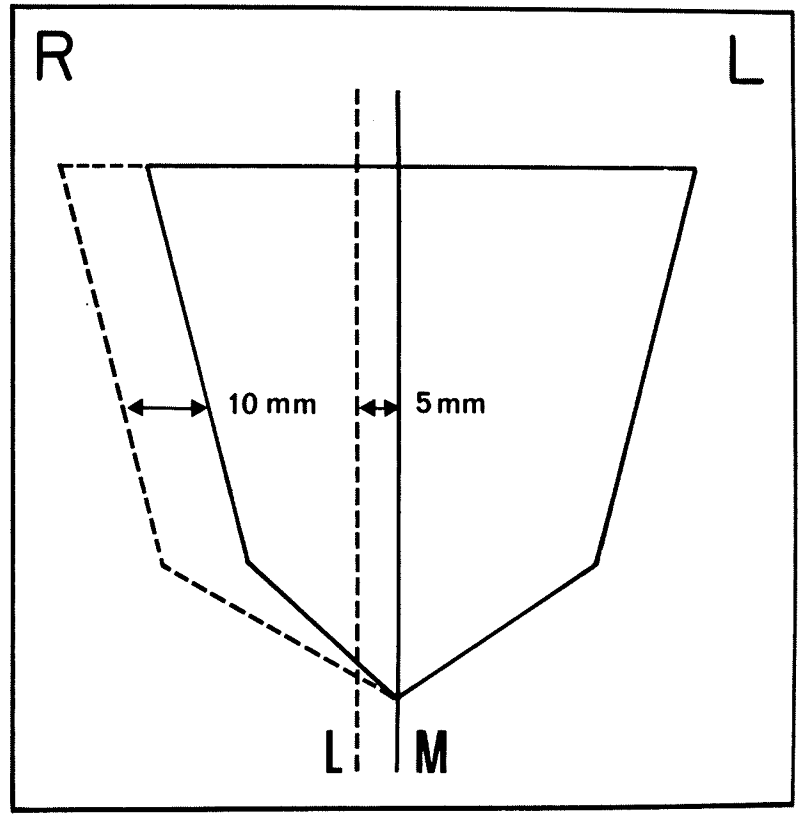
Index of Lateral Expansion

Figure 16. Lateral expansion of the left side of the face

Figure 17. Lateral expansion of the right side of the face



D = + 10 mm

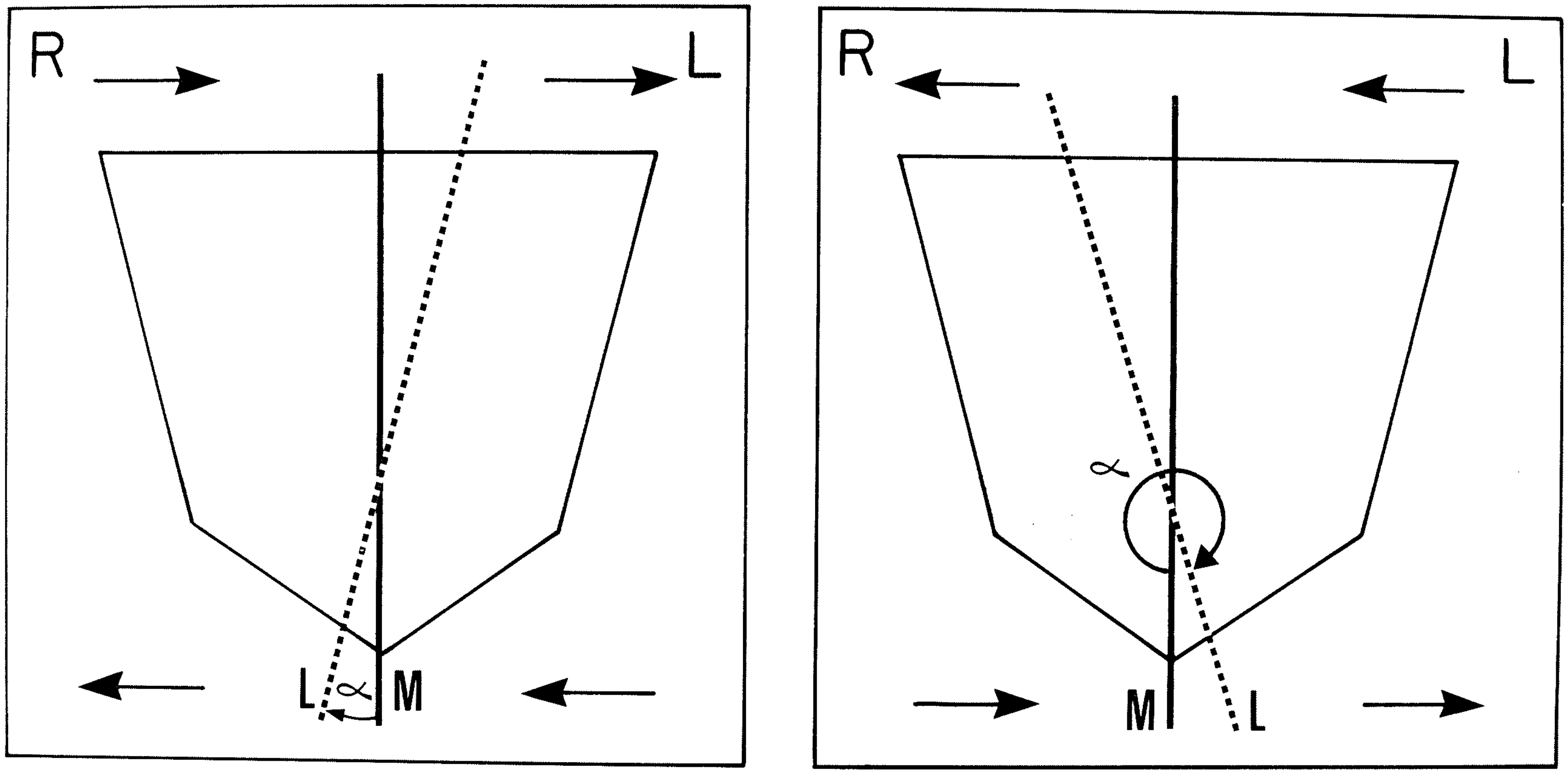


D = − 10 mm

Index of Oblique Motion

Figure 18. Clockwise oblique motion of the craniofacial structures

Figure 19. Counterclockwise oblique motion of the craniofacial structures



$\alpha > 0$ $\alpha < 0$

the expansion of the right side upper face and/or the left lower face. A reverse situation will result in a negative value for this index (figure 19).

3. <u>Index of Vertical Disharmony (V)</u>

This index was calculated as the mean algebraic vertical distance (parallel to the M axis) between pairs of lateral points and according to the following formula:

$$V = \frac{\Sigma Vi}{n}$$

where Vi is the distance between the projection of any pair of lateral structures taken parallel to the M axis.

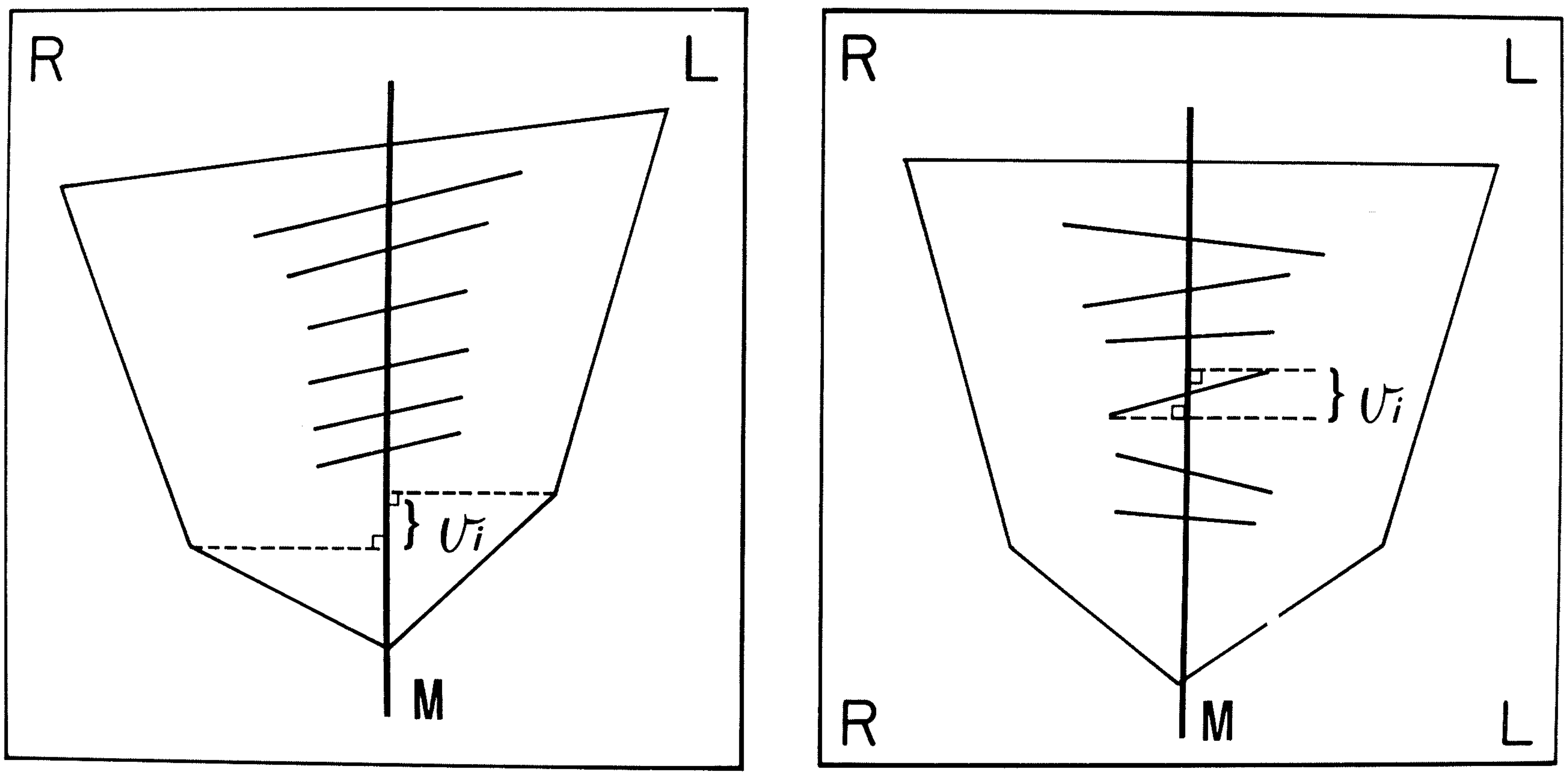
As a result of possible diagonal expansion (oblique motion) of the facial structures, the distances between the pairs of lateral points was taken parallel to the M axis rather than to the L axis. The individual distances were assigned negative values if the left side was cephalically higher than the right (figure 20). A positive value of this index, therefore, indicates that on the average, the left side of the face is higher cephalically than the right side while the converse is true.

4. <u>Index of Vertical Distortion (VD)</u>

This index was calculated according to the following formula:

Figure 20. Vertical disharmony of the craniofacial structures

Figure 21. Vertical distortion of the craniofacial structures


R
L
M
v_i
R
L
R
M
L
v_i

$$VD = \sqrt{\frac{\Sigma (Vi - \bar{v})^2}{n}}$$

where Vi and n are as defined earlier and $\bar{v}$ is the mean of Vi. This index provides a measure of the lack of vertical adaptation. A large value of the index would indicate that some structures are higher on the left side while others are higher on the right side (figure 21).

5. Index of Mid-Sagittal Distortion (MD)

This index is calculated according to the following formula:

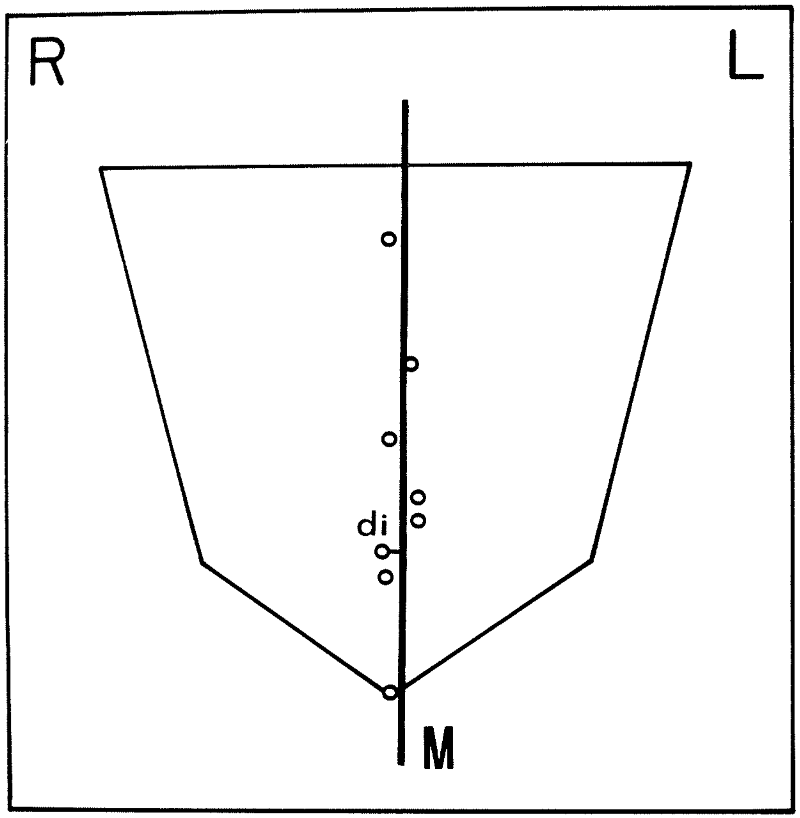
$$MD = \sqrt{\frac{\Sigma d_i^2}{n}}$$

where d_i represents the perpendicular distances from the mid-sagittal points to the best fit line (figure 22) and n is the number of points involved in the calculation of the best fit line (M axis).

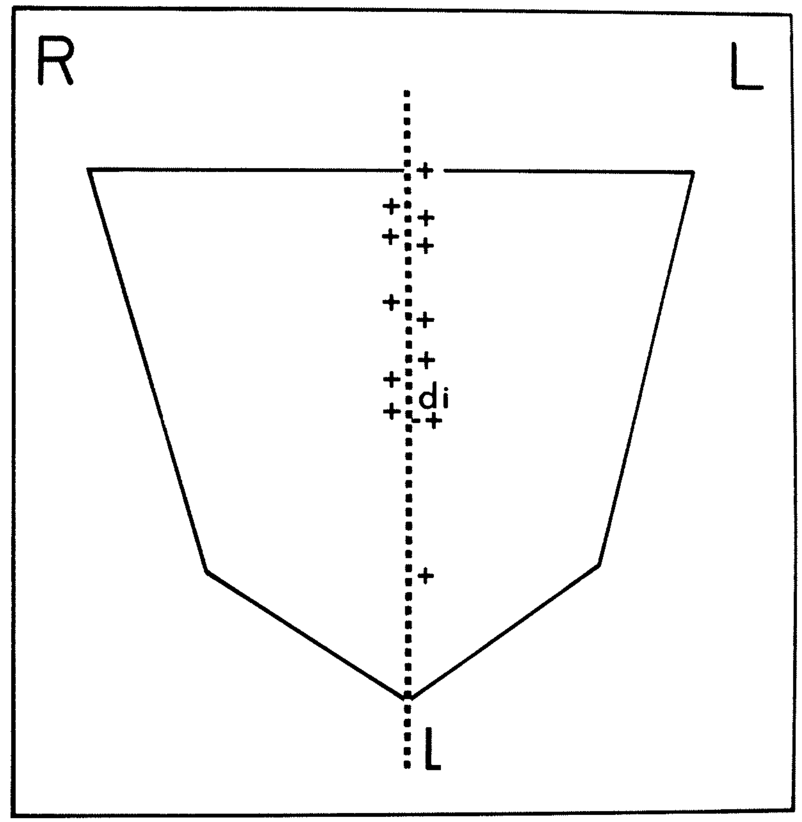
This index represents, quantitatively, the average degree of deviation of the mid-sagittal points from a straight line. A zig-zag arrangement of the midline structures, for example, will result in a high value for this index.

Figure 22. Mid-sagittal distortion

Figure 23. Bilateral distortion



o Mid-Sagittal Points



+ Midpoints of Paired Bilateral Points

6. Index of Bilateral Distortion (BD)

Similar to the previous index, this index is calculated from the following formula:

$$BD = 2\sqrt{\frac{\Sigma\, d_i^{\,2}}{n}}$$

where d_i represents the perpendicular distances of the mid-points of the lateral structures to the best fit line (L axis) (figure 23) and n is the number of pairs of the bilateral structures. This index provides a measure of the degree of bilateral horizontal distortion resulting from transverse deviation of some structures to one side and other structures to the other side. Its value represents the average deviation of the bilateral landmarks involved.

To obtain a better comprehension of the meaning and significance of each of these indices, a set of coordinates were mathematically generated depicting the various possible types of craniofacial asymmetry, and the values of the indices were computed for each set of coordinates. The results of the generated set of coordinates is found in Table III.

From this table, it is apparent, that in perfect symmetry of the face (case number 1), the values of the six indices were zero. In the situation where the lateral structures on one side were moved 5 mm. horizontally at the

Table III

Results of analysis for thirteen generated sets of coordinates.

Case	Type of Test	Lateral Expansion	Oblique Motion	Vertical Disharmony	Vertical Distortion	Mid-sagittal Distortion	Lateral Distortion
1	Perfect symmetry	0	0	0	0	0	0
2	Left side expansion (5 mm.)	+ 5.00	0	0	0	0	0
3	Right side expansion (5 mm.)	- 5.00	0	0	0	0	0
4	Clockwise diagonal expansion (5 mm.)	- 2.57	3.933	0	0	0	0
5	Counter clockwise diagonal expansion (5 mm.)	+ 2.57	- 3.933	0	0	0	0
6	Vertical disharmony of the left side (5 mm.)	0	0	+ 5.00	0	0	0
7	Vertical disharmony of the right side (5 mm.)	0	0	- 5.00	0	0	0
8	Vertical distortion of the left side (5 mm.)	0	0	0	4.80	0	0
9	Vertical distortion of the right side (5 mm.)	0	0	0	4.80	0	0

Continued -

Table III - Continued

Case	Type of Test	Lateral Expansion	Oblique Motion	Vertical Disharmony	Vertical Distortion	Mid-sagittal Distortion	Lateral Distortion
10	Mid-sagittal distortion (5 mm.)	+ 2.29	+ 2.439	- 3.77	1.55	4.80	0
11	Mid-sagittal distortion (10 mm.)	+ 4.92	+ 5.189	- 8.02	3.29	9.56	0
12	Lateral distortion of the left side (5 mm.)	0	0	0	0	0	4.80
13	Lateral distortion of the right side (5 mm.)	0	0	0	0	0	4.80

same plane (cases numbered 2 and 3) only the index of lateral expansion was affected. In cases numbered 4 and 5, clockwise and counter clockwise oblique motion of the bilateral structures was simulated by moving both the upper left side of the face and the lower right side of the face horizontally outward 5 mm., for clockwise (see figure 18) and the reverse for counter clockwise (see figure 19). In these two situations, only the indices of lateral expansion and oblique motion were affected. Vertical disharmony was generated by moving the right or the left side structures upward by 5 mm. (cases numbered 6 and 7) and as a result, the index of vertical disharmony was affected. Cases numbered 8 and 9 (which described one aspect of vertical distortion), were obtained by moving the upper right or left face structures downward 5 mm. and the remaining structures upward 5 mm. The resultant effect was reflected appreciably on the index of vertical distortion. Altering the alignment of the mid-sagittal structures (cases numbered 10 and 11) was achieved by moving the points alternatively to opposite side (right, left, right, left...etc.) by 5 mm. or 10 mm. respectively. This arrangement affected appreciably all the indices. With the exception of bilateral distortion, all the indices relate to the M line. Because the mid-sagittal distortion index approximates the standard error of the regression for this line this index may, therefore, be considered as the error of this method, i.e. a large index of mid-sagittal distortion causes less confidence in the other indices. This is noted in the somewhat large indices observed for these two cases (number 10 and number 11). Thus, the resultant effect was reflected on all the indices except the bilateral distortion index. In the last two cases, moving some of the lateral structures outward 5 mm., and the others inward 5 mm. altered only the index of bilateral distortion.

The major six indices of assessing craniofacial asymmetry were calculated for each subject from the digitized coordinates of his or her P-A radiograph by the use of the P-A coordinate analysis computer program. The values for each sex were summarized and the mean of each index for each sex tested for significance from zero. In addition, the significance of the difference between the mean of the two sexes was assessed. It was noted, in the case of three indices, vertical distortion, mid-sagittal distortion and bilateral distortion, that each index reflects absolute deviation from perfect symmetry and thus, its expected mean values will always be greater than zero. Their observed means, therefore, were not tested for significance.

Specific Indices of Measuring Craniofacial Asymmetry

In addition to the above six indices, asymmetry of specific structures was measured using the distance of the specific structures to the line of best fit.

For each of the mid-sagittal structures the deviation from the M axis (horizontally) was calculated and the means for each structure for each sex were calculated and compared.

The asymmetry of specific lateral structures was measured as the difference of the distances of each pair of bilateral structures from the M axis (horizontal and vertical distances). Similarly, the means of these distances was calculated for each sex and compared.

Other Measures of Assessing Craniofacial Asymmetry

In addition to the above, selected angular and linear measurements were calculated on both sides of the face and the differences were computed and summarized for each sex group using the paired t-test. Specification of these linear and angular measurements can be seen in Table IV and figures 24, 25, 26 and 27.

Table IV

Angular and linear measurements used to measure craniofacial asymmetry.

Linear measurements (right and left)	Angular measurements (right and left)
1. Orbital height: 4R-6R vs. 4L-6L	1. Upper maxillary region: 1M-10R-3M vs. 1M-10L-3M
2. Orbital width: 3R-5R vs. 3L-5L	2. Lateral maxillary region: 1M-10R-11R vs. 1M-10L-11L
3. Ramus height: 8R-12R vs. 8L-12L	3. Gonial region: 8M-12R-8R vs. 8M-12L-8L
4. Cranio-condylar region: 1M-8R vs. 1M-8L	4. Cranial base region: 1M-7R-8R vs. 1M-7L-8L
5. Cranio-maxillary region: 1M-10R vs. 1M-10L	5. Cranio-orbital region: 2R-6R-1M vs. 2L-6L-1M
6. Cranio-gonial region: 1M-12R vs. 1M-10L	6. Cranio-nasal region: 1M-9R-9L vs. 1M-9L-9R
7. Cranio-infra orbital region: 1M-6R vs. 1M-6L	7. Cranio-gonial region: 1M-12R-12L vs. 1M-12L-12R
8. Cranio-supra orbital region: 1M-4R vs. 1M-4L	8. Cranio-condylar region: 1M-11R-11L vs. 1M-11L-11R
9. Cranio-zygomatic region: 1M-7R vs. 1M-7L	9. Cranio-mastoidal region: 1M-11R-11L vs. 1M-11L-11R
10. Cranio-mastoidal region: 1M-11R vs. 1M-11L	10. Cranio-maxillary region: 1M-10R-10L vs. 1M-10L-10R

Figure 24. Linear measurements 1 to 5 used to study the facial asymmetry

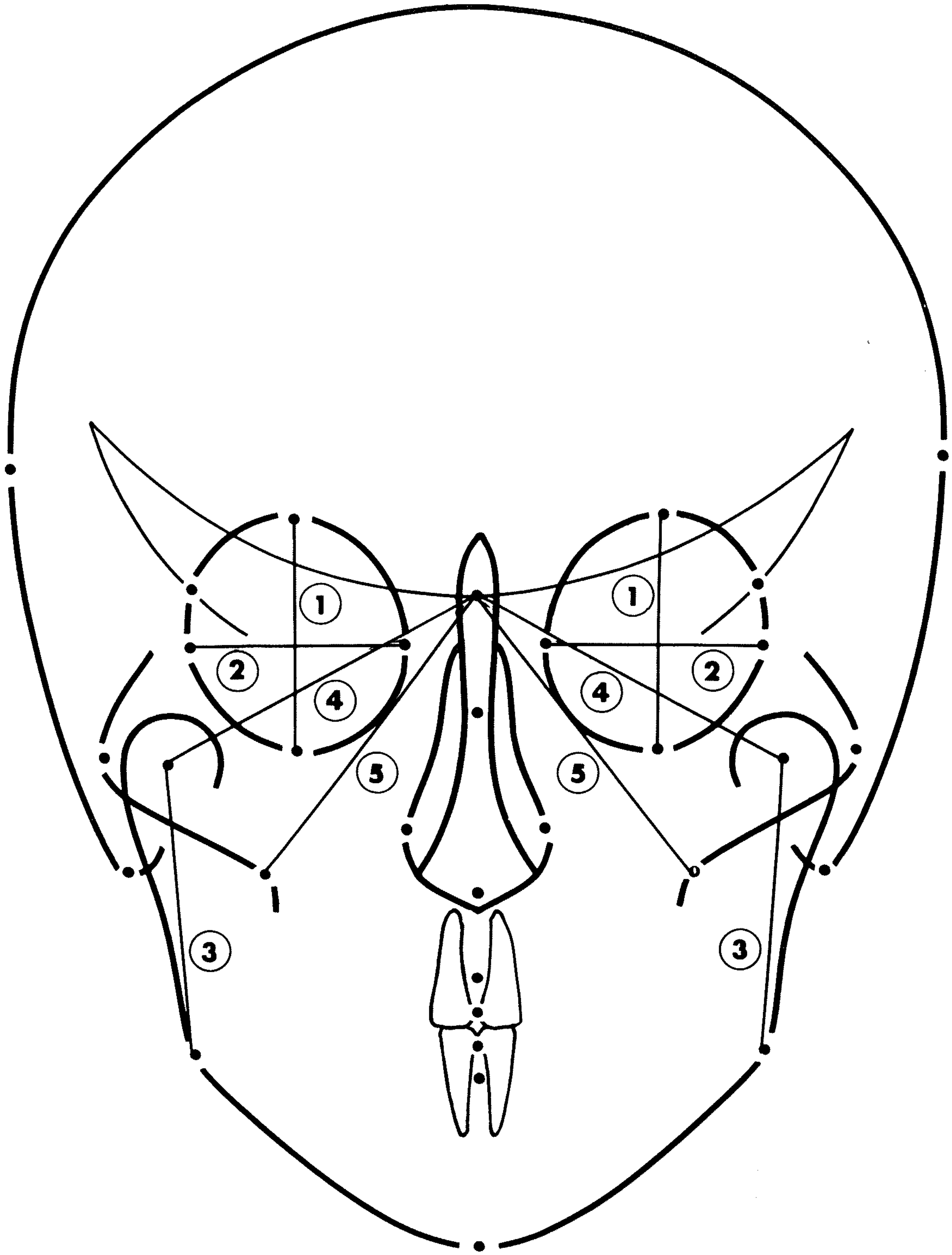

1
1
2
2
4
4
5
5
3
3

Figure 25. Linear measurements 6 to 10 used to study the facial asymmetry

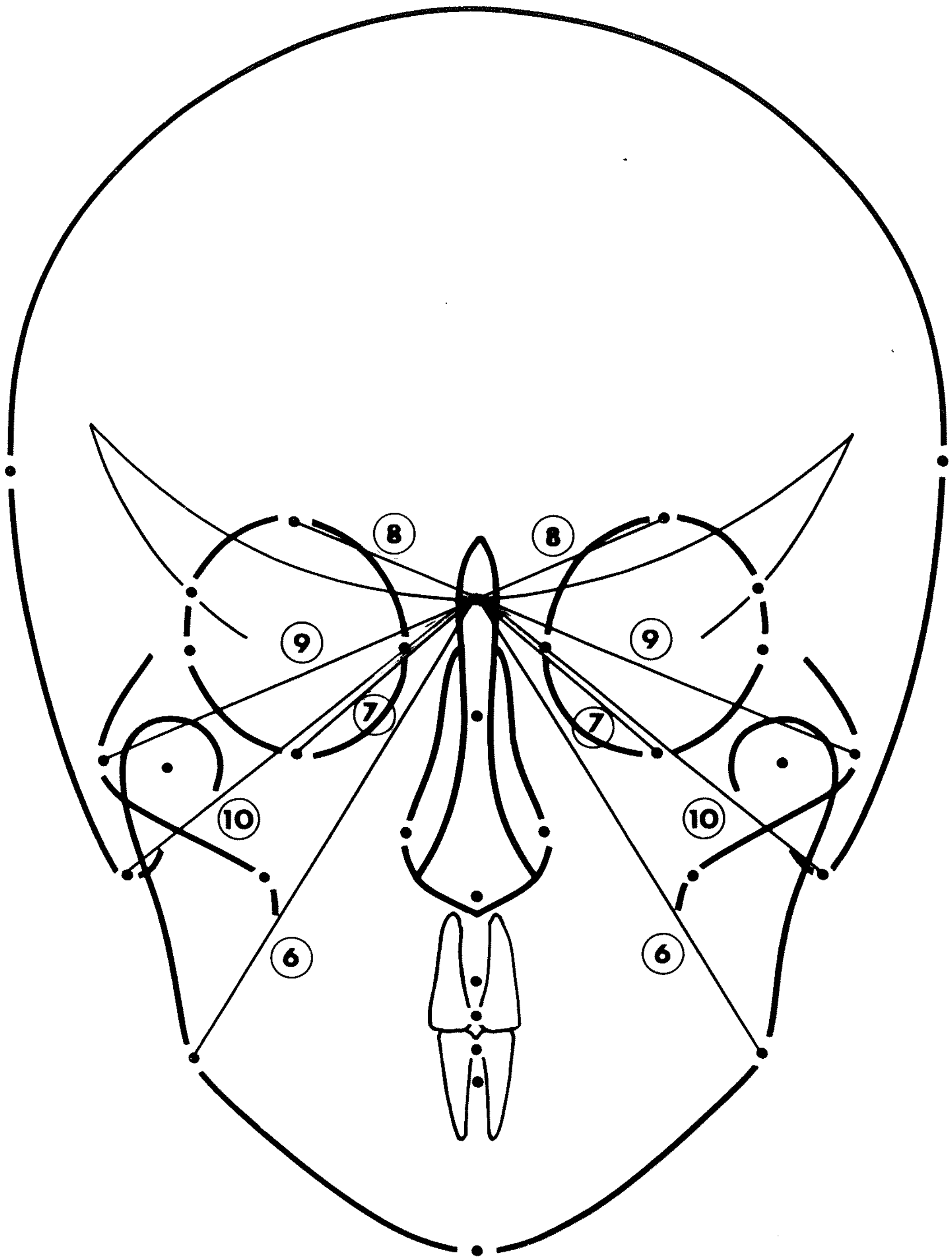

8
8
9
9
7
7
10
10
6
6

Figure 26. Angular measurements 1 to 4, 8 and 10 used to study the facial asymmetry

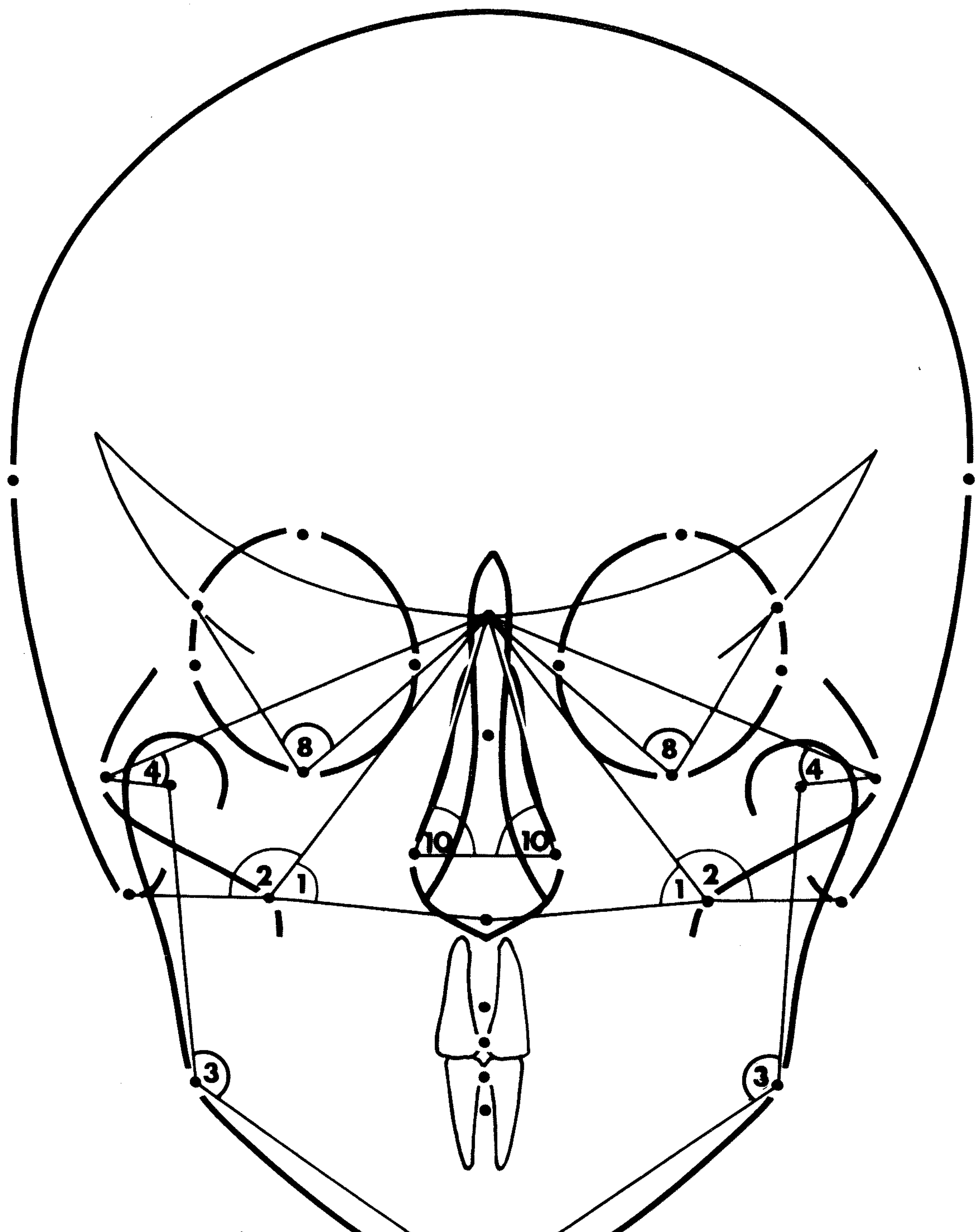
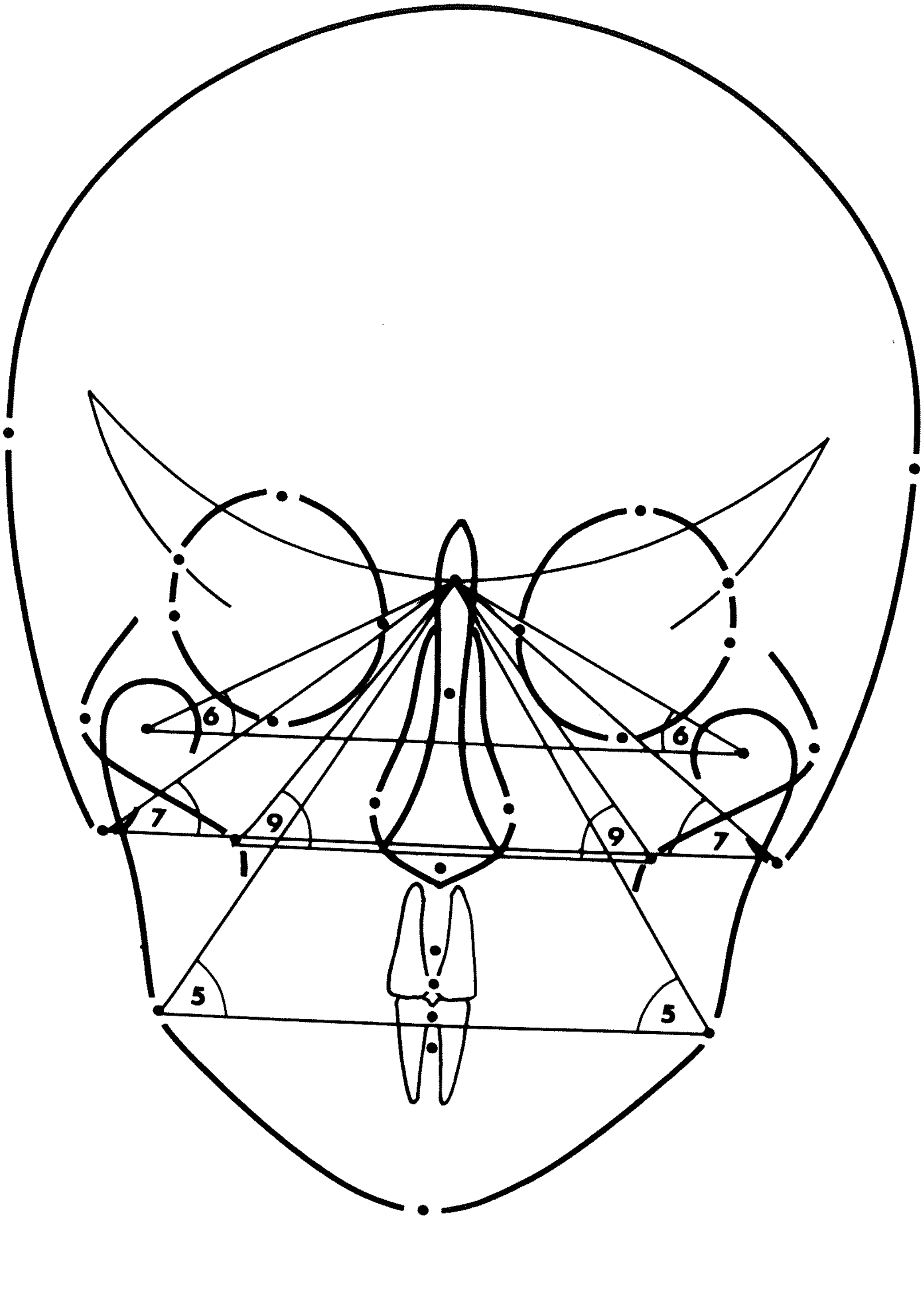

8
8
4
4
10
10
2
1
1
2
3
3

Figure 27. Angular measurements 5 to 7 and 9 used to study the facial asymmetry



6
6
7
9
9
7
5
5

RESULTS

CHAPTER IV

RESULTS

A) Indices of Craniofacial Asymmetry

Table V shows the means and standard deviations for each of the six major indices of craniofacial asymmetry for the males and females, as well as the statistical significance of each mean and the difference between the two sexes. The frequency distribution for each of the six indices are also presented as histograms in figures 28 to 33. The results of the analyses for each of the six indices of craniofacial asymmetry are presented below.

1) Index of Lateral Expansion

The index of lateral expansion (D) ranged from -2 mm. to +7 mm., with the exception of one male subject (D = -4.36 mm.). These results indicate a trend for the left side of the face to be larger than the right. The mean values were significantly larger than zero at the 0.1 percent level of significance for each of the two sexes. Ten females and fifteen males showed an absolute lateral expansion index of more than 2 mm. (see figure 28). The difference between the means of the two sexes was not statistically significant.

2) Index of Oblique Motion (OM)

The values of this index (OM) ranged from -5

Table V

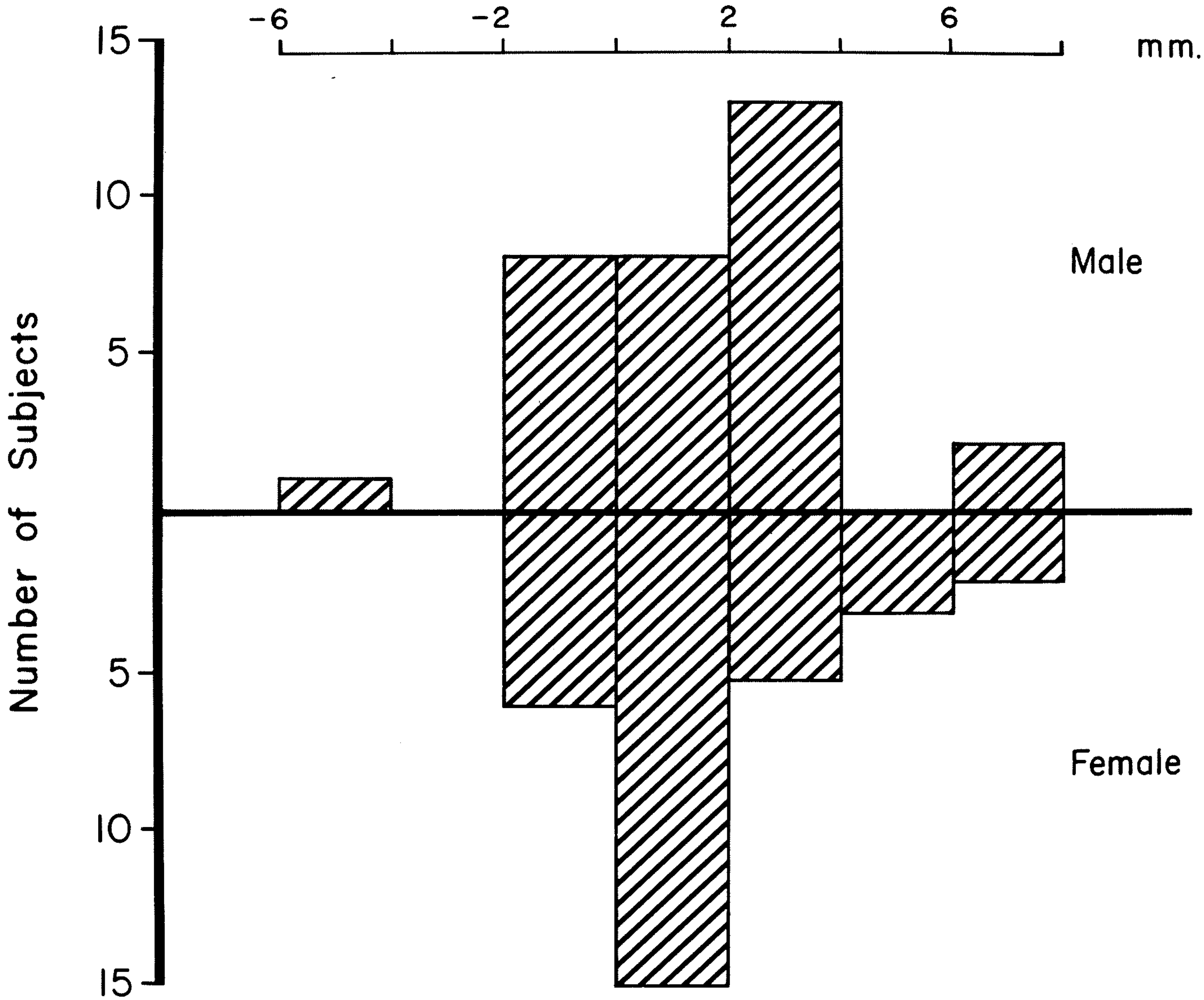
Means and Standard Deviations for the Major Indices of Craniofacial Asymmetry for the 2 Sexes and the Significance of the Difference Between the Means.

Index	Males (n = 32) $\bar{x}$	Males (n = 32) S.D.	Females (n = 31) $\bar{x}$	Females (n = 31) S.D.	t - test Values Between the Means of the Males and Females
Lateral (mm.) Expansion	1.65***	± 2.33	1.61***	± 2.11	.071
Oblique (degrees) Motion	- .446*	± 1.207	- .538*	± 1.335	-.286
Vertical (mm.) Disharmony	.26	± 1.66	.40	± 2.09	-.293
Vertical (mm.) Distortion	2.07†	± .54	1.94†	± .60	.904
Mid-Sagittal (mm.) Distortion	.69†	± .33	.69†	± .42	.000
Bilateral (mm.) Distortion	2.34†	± 1.02	2.18†	± 1.26	.553

*** $p < .001$
* $p < .05$

†- not tested for statistical significance

Figure 28. Histogram for frequency distribution of the lateral expansion index for the two sexes


-6
-2
2
6
mm.
15
10
5
5
10
15
Number of Subjects
Male
Female

degrees to +2 degrees, with similar frequency distributions for the two sexes (figure 29). However, only 7 out of the 63 subjects showed an absolute oblique motion index greater than 2 degrees. The mean oblique motion index (Table V) was negative but did not exceed 1 degree for either sex, indicating a very slight trend toward a counter-clockwise oblique motion of the bilateral craniofacial region. Testing the mean for significance from zero displayed significance at the 5 percent level of significance for each sex. The difference between the means of the two sexes did not show any statistical significance (Table V).

3) Index of Vertical Disharmony (V)

The range of this index (V) was from -6 mm. to +6 mm. indicating no trend for one side of the face to be cephalically higher than the other. The frequency distribution (figure 30) was similar for both the males and females. The total number of subjects which showed an absolute value greater than 2 mm. did not exceed 18 out of the 63 subjects. Neither of the mean values for the two sexes showed any statistically significant deviation from zero. The difference between the sexes was also not statistically significant (Table V).

4) Index of Vertical Distortion (VD)

The index of vertical distortion (VD) which describes the vertical distortion of the craniofacial complex

Figure 29. Histogram for frequency distribution of the oblique motion index for the two sexes

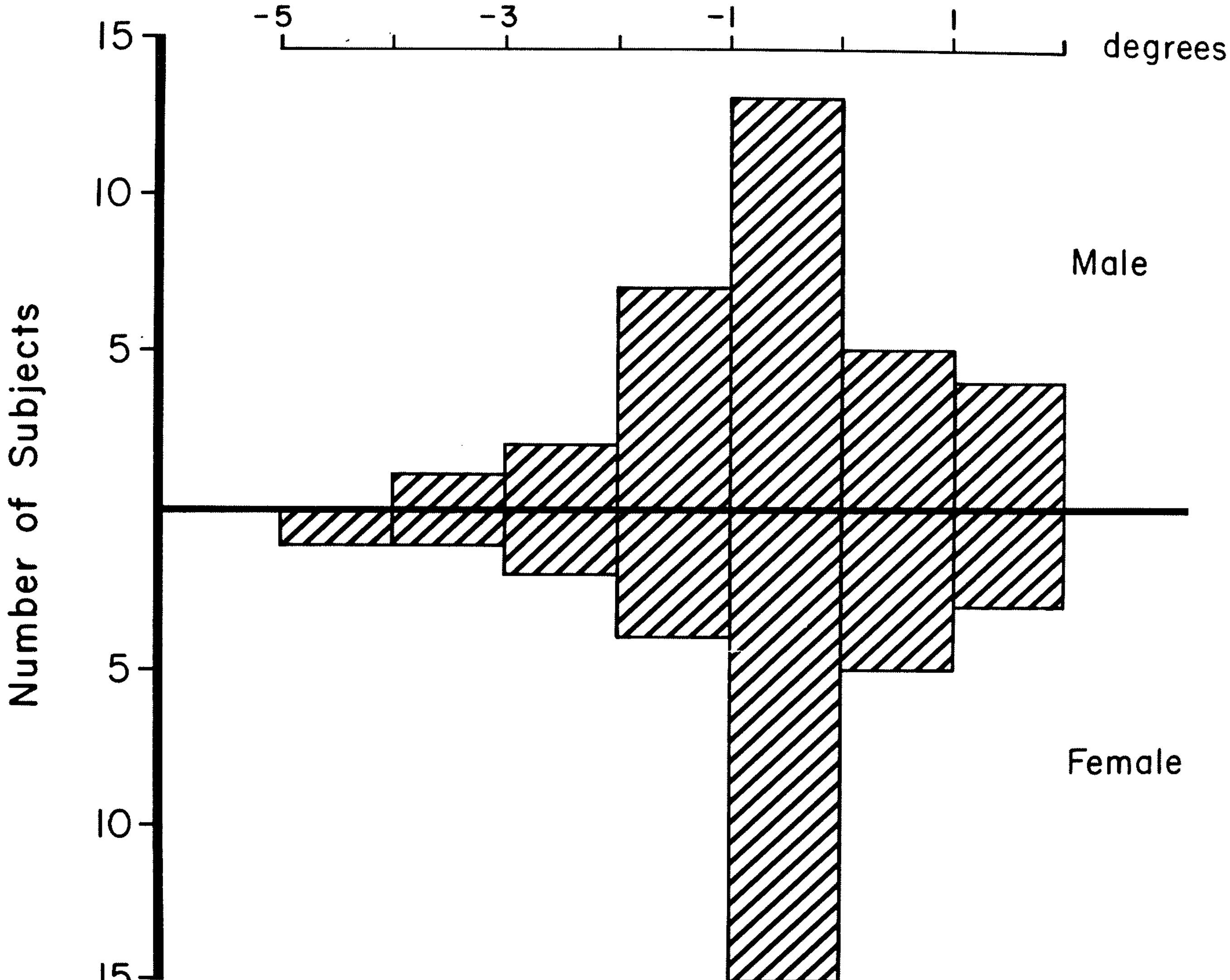
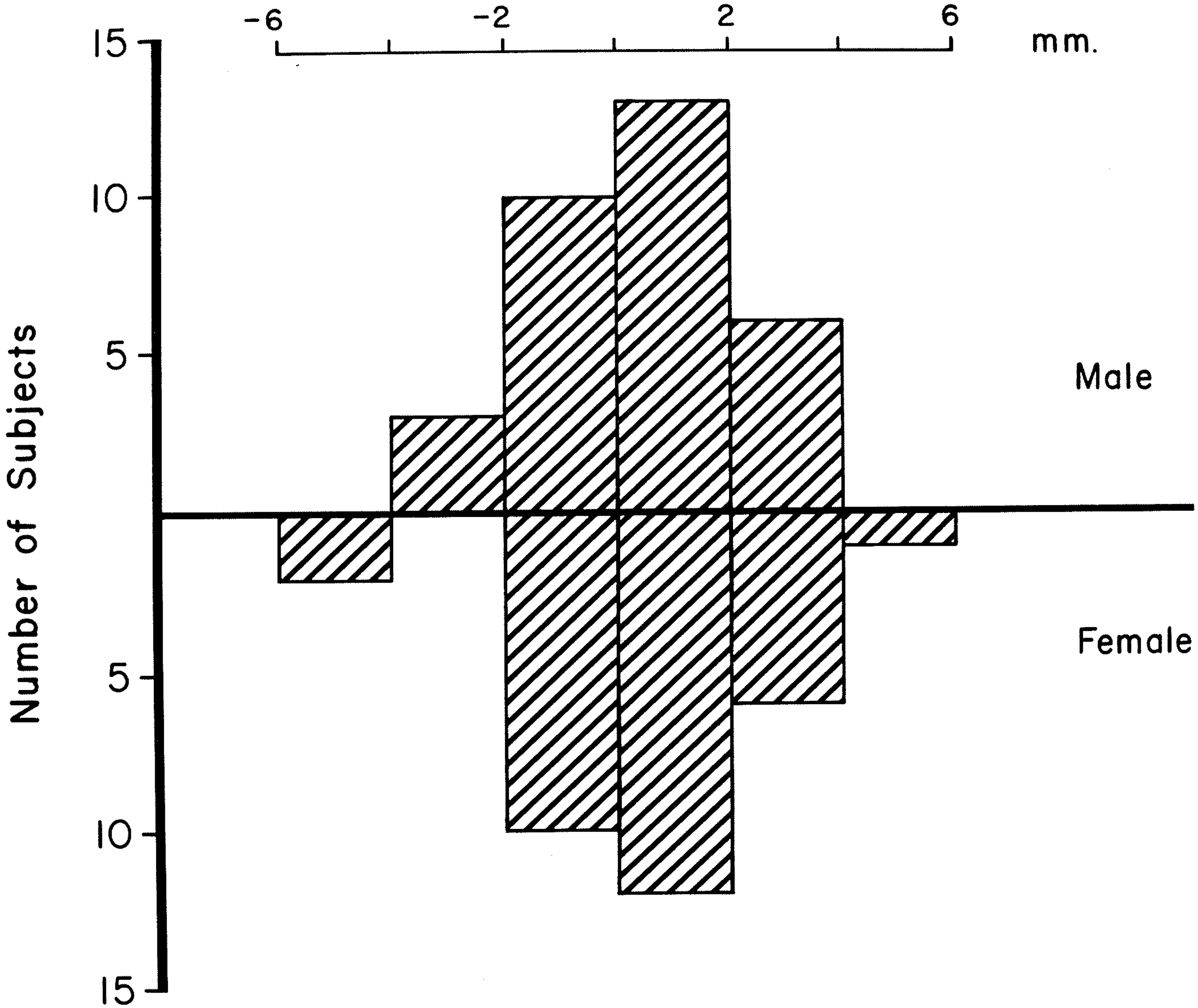

-5
-3
-1
1
degrees
15
10
5
5
10
15
Number of Subjects
Male
Female

Figure 30. Histogram for frequency distribution of the vertical disharmony index for the two sexes


-6
-2
2
6
mm.
15
10
5
5
10
15
Male
Female
Number of Subjects

ranged from 1 mm. to 3 mm. with the exception of one male subject (VD = 3.88 mm.). Eleven females and seventeen males had vertical distortion index values of 2 mm. and more (figure 31). This index measures the deviation in absolute values. As a result, its mean values were not tested for significant deviations from zero. The means of this index for both sexes indicate that the average vertical deviation of any landmark is 2 mm. (Table V). The difference between the means for the two sexes was not statistically significant.

5) Index of Mid-sagittal Distortion (MD)

This index (MD) measures the average deviations of the mid-sagittal structures from their best fit line. The values of this index ranged from 0.1 mm. to 1.90 mm. with similar frequency distributions for the two sexes (figure 32). Twelve out of the 63 subjects had an average mid-sagittal distortion greater than 1.00 mm. The means for both the males and females were also similar with no statistically significant difference between the two means (Table V). As with the Index of Vertical Distortion, this index measures the deviation in absolute values and thus, was not tested for significant deviation from zero.

6) Index of Bilateral Distortion (BD)

This index (BD) ranged from .50 mm. to 6.50 mm. with 4 females and 2 males having an index of bilateral

Figure 31. Histogram for frequency distribution of the vertical distortion index for the two sexes

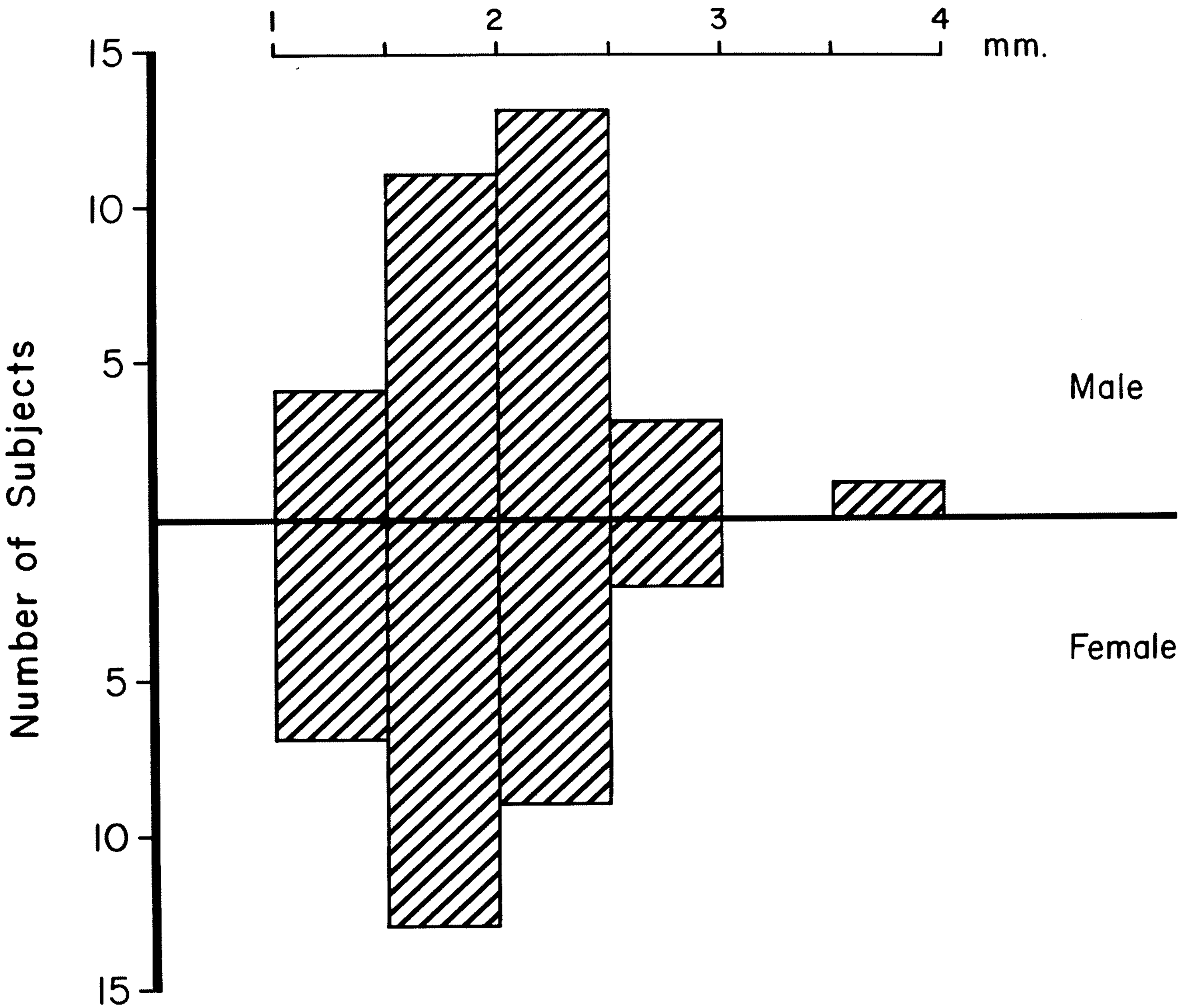
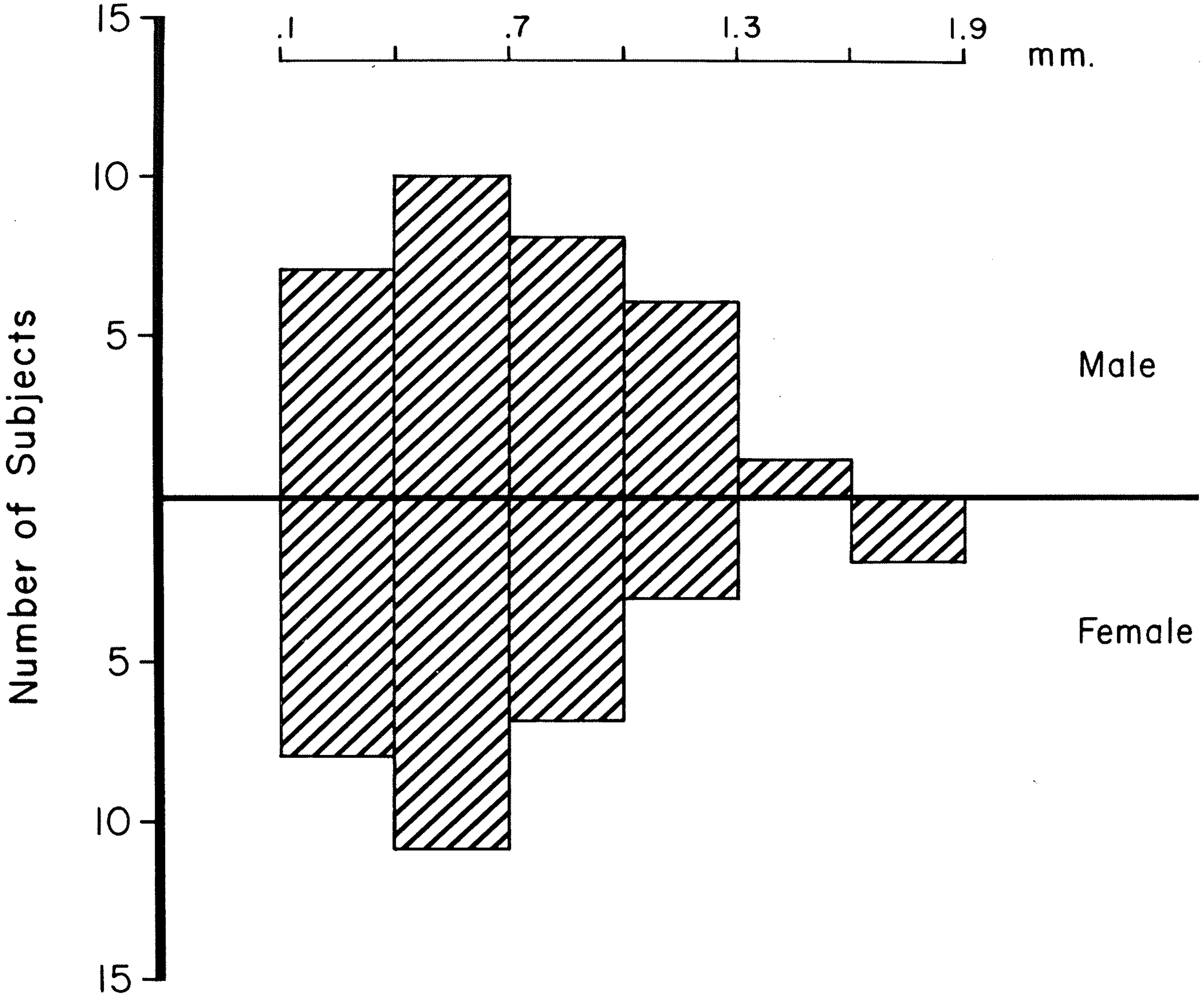

1
2
3
4
mm.
15
10
5
Number of Subjects
Male
Female
5
10
15

Figure 32. Histogram for frequency distribution of the mid-sagittal distortion index for the two sexes



15
10
5
5
10
15
.1
.7
1.3
1.9
mm.
Male
Female
Number of Subjects

distortion greater than 3.5 mm. (figure 33). The average horizontal distortion between points of bilateral points was approximately 2 mm. (Table V). The difference between the means of the two sexes did not show statistical significance.

In summary, the six major indices of craniofacial asymmetry indicated a significantly larger left side of the face but with no significant diagonal expansion or vertical disproportion. The degree of asymmetry was less evident along the mid-sagittal structures as compared to the bilateral structures. In addition, there were no significant differences due to sex for any of the six major indices studied.

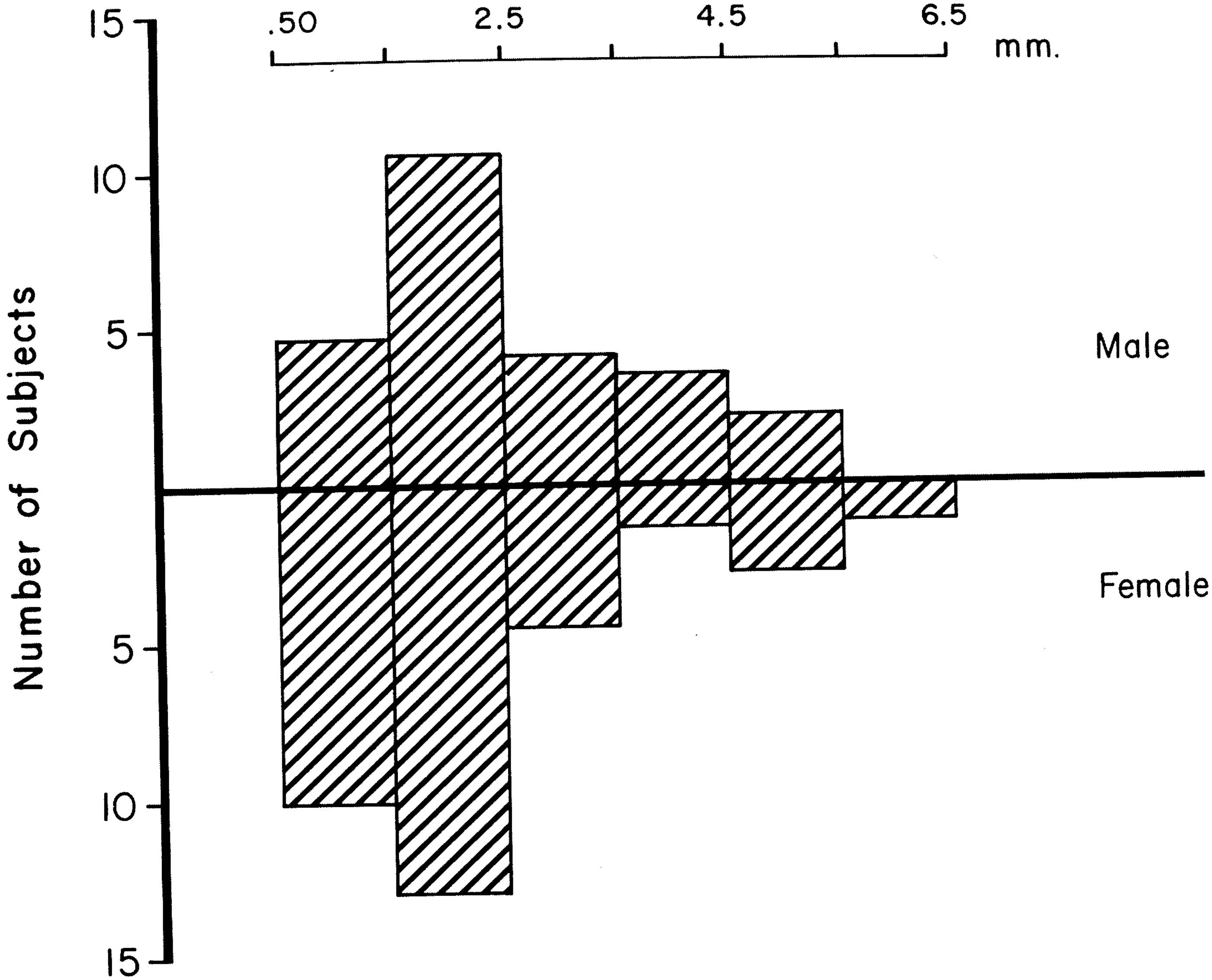
B) Specific Indices of Craniofacial Asymmetry

The results of the analyses for the specific indices are presented for each landmark separately. The specific indices for each of the mid-sagittal structures are presented as deviations from the best fit line in the horizontal direction. Those for the bilateral craniofacial structures are presented as differences between the right and left sides in both horizontal and the vertical directions.

1) Specific Indices of the Mid-sagittal Structures

The mean and standard deviations of the specific mid-sagittal indices for both males and females, as well as

Figure 33. Histogram for frequency distribution of the bilateral distortion index for the two sexes


15
10
5
5
10
15
Number of Subjects
.50
2.5
4.5
6.5
mm.
Male
Female

the statistical significance of the differences between the means of the two sexes are shown in Table VI. In addition, Table VII shows the number of subjects exhibiting absolute deviations of more than 1 mm. (chosen arbitrarily) for each of the mid-sagittal structures. This value was chosen in such a way as to allow meaningful comparison of the various specific indices as presented in Table VII. The following are the results of the analysis of the specific indices for each of the 8 mid-sagittal structures.

a) <u>Crista Galli:</u>

The specific index for crista galli shows a left side deviation for both the males and females. The mean was significantly different from zero for the females only ($p < 0.01$). However, only 7 of the 63 males and females exhibited absolute deviation of 1 mm. or more. The difference between the means of the two sexes was not statistically significant (Table VI).

b) <u>Nasal Septum:</u>

The average value of the nasal septum for the males showed a statistically significant left deviation ($p < .05$), while the average deviation of this point for the females was zero mm. (i.e., the nasal septum point for the females on the average falls on the M line). However, the difference between the means of the males and females was

Table VI

Means, Standard Deviations and the Significance of each of the Specific Indices of the Mid-Sagittal Landmarks for Both Sexes.

Mid-Sagittal Structure	Males (n = 32) $\bar{x}$ (mm.)	Males (n = 32) S.D. (mm.)	Females (n = 31) $\bar{x}$ (mm.)	Females (n = 31) S.D. (mm.)	Difference Between the Two Means (mm.)
Crista galli	.12	± .53	.30**	± .51	- .18
Nasal Septum	.21*	± .53	.00	± .54	.21
Anterior Nasal Spine	- .10	± .74	- .07	± .70	- .03
Maxillary Alveolar Crest	- .32**	± .65	- .24*	± .71	- .12
Maxillary Dental Point	- .33**	± .63	- .32*	± .74	- .01
Mandibular Alveolar Crest	.07	± .85	- .24	± .68	.17
Mandibular Dental Point	- .07	± .92	- .10	± .66	.13
Menton	.43*	± .91	.74***	±1.16	.31

*** $p < .001$
** $p < .01$
* $p < .05$

Table VII

Number of Subjects Showing Absolute Deviations of 1 mm. or more for each of the Mid-Sagittal Structures

Structure	Males (32)	Females (31)	Total (63)
Crista galli	4	3	7
Nasal Septum	2	2	4
Anterio-Nasal Spine	5	6	11
Mx Alveolar Crest	4	6	10
Mx Dental Point	6	4	10
Md Alveolar Crest	9	4	13
Md Dental Point	9	4	13
Menton	10	12	22

not statistically significant. Only 4 subjects (2 males and 2 females) showed absolute deviations of 1 mm. or more (Table VII).

c) Anterior Nasal Spine:

Both the males and females exhibited an average deviation for this point of approximately .1 mm. to the left side of the face (Table VI). This deviation was not statistically significant from zero for either sex. The difference between the two means was not statistically significant (Table VI). Five males and 6 females showed absolute deviations of 1 mm. or more (Table VII).

d) The Maxillary Alveolar Crest:

The specific index for the maxillary alveolar crest showed that both males and females displayed a significant deviation to the right side of the face (Table VI). The average deviation was statistically significant at the 5 percent level for the females and significant for the males at the 1 percent level. However, there was no statistical significance of difference between the means of the two sexes (Table VI). Ten of the 63 subjects examined demonstrated an absolute deviation of the maxillary alveolar crest greater than 1 mm. (Table VII).

e) The Upper Incisor Point:

Both the males and females exhibited right-sided statistically significant mean deviations of the upper incisor point (Table VI). The difference between the two means was not statistically significant (Table VI). Only 10 of the 63 males and females demonstrated an absolute deviation of the upper incisor point greater than 1 mm. (Table VII).

f) The Mandibular Alveolar Crest:

Although the mean value of this specific index showed a left-sided trend for the males and right-sided trend for the females, none displayed statistical significance (Table VI). Furthermore, the difference between the two means was not statistically significant (Table VI). Only 9 males and 4 females had a mandibular alveolar crest deviation on either side of the face of greater than 1 mm. (Table VII).

g) The Lower Incisor Point:

Both the males and females showed a right-sided (but not significant) deviation of the lower incisor point. The difference between the means for the two sexes was not statistically significant. Only 9 males and 4 females showed an absolute deviation of 1 mm. or more (Table VII).

h) Menton:

Both the males and females exhibited a somewhat larger and statistically significant deviation of menton point to the left side of the face as compared to the rest of the mid-sagittal points (Table VI). The average deviation of menton for the males was statistically significant at the 5 percent level, while for the females it was statistically significant at the 0.1 percent level. The difference between the means of the two sexes, however, was not statistically significant (Table VI). Ten males and 12 females exhibited absolute deviations of 1 mm. or more (Table VII).

In summary, the results of the specific indices of the mid-sagittal structures exhibited no sex differences for all the values involved. The maxillary dento-alveolar mid-sagittal structures and the chin point (menton) displayed greater statistical and biological deviations among the remaining mid-sagittal landmarks studied.

2) Specific Indices of the Bilateral Craniofacial Structures

The means and standard deviations of the specific indices for the bilateral craniofacial structures for both males and females as well as their statistical significance and the statistical significance of the differences between the means are shown in Table VIII. In addition, Table IX shows the number of subjects exhibiting an absolute deviation of 4 mm. or more for each of the bilateral structures.

The results of the analysis of the specific indices for each of the 12 bilateral points are presented as follows:

a) Temporal Point:

The horizontal specific index for this point shows

Table VIII

Means, Standard Deviations and the Significance of each of the Specific Indices for the Bilateral Structures for the Male and Female Groups.

The Bilateral Craniofacial Landmarks	Sex	Horizontal Deviation Index (mm.)		Diff.	Vertical Deviation Index (mm.)		Diff.
		$\bar{x}$	S.D.		$\bar{x}$	S.D.	
Temporal	M	2.63*	± 6.63	-.85	.37	± 4.13	-1.32
	F	3.48**	± 5.42		1.69*	± 4.50	
Orbital Sphenoidal	M	1.19***	± 1.90	.80	- .23	± 2.17	.09
	F	1.11**	± 1.86		- .14	± 2.69	
Lateral Orbital Margin	M	- .30	± 2.61	.32	2.87***	± 2.69	.88
	F	- .62	± 2.30		1.99**	± 3.43	
Superior Orbital Margin	M	.11	± 2.18	.01	.11	± 1.61	.07
	F	.10	± 2.46		- .04	± 1.76	
Medial Orbital Margin	M	.03	± 2.29	.14	- 1.55***	± 1.66	- .81
	F	- .17	± 1.78		- .74	± 1.73	
Inferior Orbital Margin	M	1.68***	± 2.15	.25	.05	± 1.79	- .01
	F	1.43***	± 2.02		.06	± 2.53	
Zygomatic	M	1.67**	± 3.08	-.7	- .86	± 2.91	- .79
	F	2.37***	± 2.94		- .07	± 3.44	
Condylar	M	3.59***	± 4.07	.81	.65	± 2.55	.04
	F	2.78***	± 3.88		.61	± 2.64	
Latero-Nasal	M	.74	± 1.98	.53	.31	± 1.86	.16
	F	.61	± 2.21		.15	± 1.11	
Maxillary	M	1.98***	± 1.79	.66	1.15***	± 1.77	.49
	F	1.32*	± 2.78		.66	± 2.20	
Mastoidal	M	2.68*	± 5.68	-.69	- .89	± 3.01	- .33
	F	3.37***	± 4.93		- .56	± 2.95	
Gonial	M	1.62*	± 3.59	-.25	.30	± 2.76	.28
	F	1.87**	± 3.13		.02	± 2.98	

*** $p < .001$
** $p < .01$
* $p < .05$

Table IX

Number of Subjects Showing Absolute Deviation of 4 mm. and More for Each of the Bilateral Structures.

Structure	Horizontal Male (32)	Horizontal Female (31)	Horizontal Total (63)	Vertical Male (32)	Vertical Female (31)	Vertical Total (63)
Temporal	14	13	27	11	11	22
Orbital Sphenoidal	3	2	5	1	5	6
Lateral Orbital Margin	4	4	8	10	10	20
Superior Orbital Margin	3	3	6	0	2	2
Medial Orbital Margin	3	1	4	2	2	4
Inferior Orbital Margin	4	3	7	2	4	6
Zygomatic	8	6	14	5	4	9
Condylar	13	8	21	5	3	8
Latero-Nasal	1	3	4	1	0	1
Maxillary	4	4	8	3	3	6
Mastoidal	13	14	27	5	4	9
Gonial	10	8	18	6	5	11

that both males and females exhibited a significant lateral expansion of the temporal point to the left ($p < .01$ and $p < .05$ respectively). The difference between the two means was not statistically significant. Twenty-seven of the 63 subjects showed absolute horizontal deviation index of 4 mm. or more.

The specific index for the vertical deviation also demonstrated that the temporal point is higher cephalically on the left side of the face than on the right. This was only significant, however, for the females ($p < .05$). The difference between the means was not statistically significant. Twenty-two of the 63 subjects showed an absolute vertical deviation of 4 mm. and more.

b) Orbital Sphenoidal Point:

The horizontal specific index of the orbital sphenoidal point showed that both sexes have a significant left horizontal deviation (Table VIII). The average horizontal deviation of this point was slightly greater than 1 mm. for both the males and females with no significant difference between the two means (Table VIII). Only a total of 5 subjects of 63 males and females showed an absolute horizontal deviation greater than 4 mm. (Table IX). The vertical deviation index displayed no significant values for both sexes. The difference between the two means was also not significant. Only 1 male and 5 females exhibited an absolute vertical deviation of 4 mm. or more (Table IX).

c) The Lateral Orbital Margin Point:

The index of the horizontal discrepancy for this point showed no statistical significant horizontal deviation for either sex and no significant difference between the means (Table VIII). Five of the 63 subjects displayed absolute horizontal deviation of 4 mm. and more (Table IX). Both males and females exhibited significant average left vertical deviations ($p < .001$ and $p < .01$ respectively). The difference between the two means was not statistically significant. Ten males and 10 females displayed an absolute vertical deviation greater than 4 mm. (Table IX).

d) The Superior Orbital Margin Point:

Both males and females exhibited, on the average, negligible specific indices in both the horizontal and vertical directions (Table VIII). The differences between the means of the two sexes were also not statistically significant. Of the 63 males and females examined, only 6 subjects, equally divided by sex, showed an absolute horizontal deviation of 4 mm. or more, while only 2 females of the sample exhibited an absolute vertical deviation greater than 4 mm. (Table IX).

e) The Medial Orbital Margin Point:

Only females exhibited a significant average right vertical deviation ($p < .01$). The differences between the means were not statistically significant (Table VIII). A total of 4 of the 63 subjects, for both the vertical and horizontal direction showed an absolute deviation of 4 mm. or more (Table IX).

f) The Inferior Orbital Margin Point:

The horizontal specific index for this point demonstrated a significant horizontal deviation to the left for both males and females ($p < .001$). No statistical significance was found between the means of the two groups (Table VIII). Four males and 3 females showed an absolute horizontal deviation of 4 mm. and more (Table IX). Both sexes showed no average significant vertical deviation for the inferior orbital margin point, nor any difference between the two means (Table VIII). Only 2 males and 4 females displayed an absolute vertical deviation greater than 4 mm. (Table IX).

g) The Zygomatic Point:

The horizontal specific index of this point demonstrated that both the males and females have their zygomatic point, on the average, deviated to the left ($p < 0.01$ and $p < 0.001$ respectively). The difference between the two means was not statistically significant. Fourteen of the 63 subjects showed absolute horizontal deviations of 4 mm. or more (Table IX).

There was no statistical significance of the average vertical deviation index for either sex as well as for the difference between the two means (Table VIII). Four females and 5 males exhibited an absolute vertical discrepancy index greater than 4 mm.

h) <u>The Condylar Point:</u>

Both males and females exhibited an appreciable horizontal deviation index for the condylar point (Table VIII). The horizontal deviation index was statistically significant ($p < .001$) and displayed a left deviation of the condylar point. No statistical significance was found between the means of two groups. Twenty-one of the 63 subjects showed an absolute horizontal deviation of 4 mm. and more (Table IX).

The vertical discrepancy index showed no significant values. The difference between the means was also not statistically significant. Only 8 of the 63 subjects displayed vertical deviation index greater than 4 mm. (Table IX).

i) <u>Latero-Nasal Point:</u>

Neither of the two sexes revealed a significant horizontal or vertical deviation for the latero-nasal point.

The difference between the means was not statistically significant. Four of the total sample showed an absolute horizontal deviation of 4 mm. and more, while for the vertical deviation index only 1 male displayed a value greater than 4 mm. (Table IX).

j) <u>Maxillary Point:</u>

The horizontal specific index of the maxillary point showed that both the males and females means have significant left deviation of maxillary point ($p < .001$ and $p < .05$ respectively). The difference between the two means was not statistically significant. Eight subjects (4 males and 4 females) displayed a horizontal deviation index greater than 4 mm.

Only the males displayed a significant left side vertical elevation ($p < .001$). The difference between the means was not significant and 6 out of the total sample showed an absolute vertical deviation of 4 mm. or more (Table IX).

k) <u>The Mastoidal Point:</u>

Both males and females exhibited a significant left horizontal deviation ($p < .05$ and $p < .001$ respectively). The difference between the two values was not statistically significant. As many as 27 of the 63 subjects revealed an absolute horizontal discrepancy index of 4 mm. or more (Table IX).

The vertical deviation index values were not significant, neither was the difference between the two means (Table VIII). Five males and four females produced an absolute vertical deviation index of 4 mm. and more (Table IX).

1) <u>The Gonial Point:</u>

The average horizontal deviation index for this point was less than 2 mm. for both sexes but revealed a significant left side deviation. The difference between the two means was negligible for both the horizontal and vertical deviations (Table VIII). Eighteen of the 63 subjects presented an absolute horizontal deviation greater than 4 mm. The number of subjects which showed an absolute vertical deviation of 4 mm. or more did not exceed eleven of the total 63 subjects examined.

Summarizing the results of the specific indices for the bilateral structures, the following was found:

a) No significant asymmetry in the orbital region.

b) The lower nasal region exhibited a greater degree of symmetry than the rest of the bilateral craniofacial structures.

c) Significant horizontal left side facial asymmetry was present for the temporal region and the middle and lower facial structures, i.e., condyle, maxilla, zygoma, mastoid and gonial region.

d) No sex differences were present.

C) Other Measures of Assessing Craniofacial Asymmetry

To provide further information of the site and magnitude of craniofacial asymmetry, 10 selected pairs of linear measurements and 10 selected pairs of angular measurements were calculated. The values for each of these variables was computed for each subject and the difference between right and left sides was examined using a paired t-test. The results are presented in Table X and Table XI.

1) Linear Measurements:

Table X shows the means and standard deviations for each of the ten paired linear measurements used to additionally assess the craniofacial asymmetry for the males and females as well as the significance of the difference between each of the paired measurements.

Of the ten paired measurements, 5 measurements displayed statistically significant differences between the right and left side of the face (Table X) with the linear measurements on the left side of the face being larger than on the right. The largest difference between the right and left side of the face was 2.77 mm. for the male group for the cranio-condylar region, followed by the linear

Table X

Means (in mm.), Standard Deviation and the Significance of the Difference Between the Paired Linear Measurements for Males and Females.

Measurements	Sex	Right $\bar{x}$ (mm.)	Right S.D. (mm.)	Left $\bar{x}$ (mm.)	Left S.D. (mm.)	Difference (mm.)
Orbital Height	M	36.64	± 3.14	36.72	± 2.73	- .08
	F	36.59	± 1.82	36.51	± 2.02	.08
Orbital Width	M	36.70	± 2.01	36.30	± 2.30	.40
	F	36.50	± 2.37	36.04	± 2.05	.46
Ramus Height	M	54.04	± 2.76	54.47	± 3.05	- .43
	F	49.53	± 4.76	50.18	± 5.19	- .65
Cranio-Condylar Region	M	55.22	± 3.75	57.99	± 3.69	- 2.77***
	F	54.06	± 3.82	55.56	± 3.85	- 1.5 **
Cranio-Maxillary Region	M	55.73	± 3.45	55.84	± 2.94	- .11
	F	54.44	± 3.26	53.24	± 3.20	.2
Cranio-Gonial Region	M	91.62	± 6.07	92.10	± 6.64	- .48*
	F	87.46	± 4.52	88.02	± 4.66	- .56*
Cranio-Infra Orbital Region	M	36.75	± 3.04	37.88	± 3.24	- 1.13**
	F	36.48	± 2.37	36.96	± 1.89	- .48*
Cranio-Supra Orbital Region	M	33.22	± 1.86	33.15	± 2.01	.07
	F	32.10	± 2.27	31.48	± 1.98	.62
Cranio-Zygomatic Region	M	64.10	± 2.71	65.69	± 3.30	- 1.59*
	F	61.45	± 2.91	63.00	± 2.99	- 1.55*
Cranio-Mastoidal Region	M	68.33	± 6.71	70.80	± 7.17	- 2.47**
	F	66.07	± 6.34	68.43	± 6.55	- 2.36**

*** $p < .001$
** $p < .01$
* $p < .05$

Table XI

Means (in degrees), Standard Deviation and the Significance of the Difference Between the Paired Angular Measurements for the Males and the Females

Measurement	Sex	Right Side $\bar{x}$ (degrees)	S.D.	Left Side $\bar{x}$ (degrees)	S.D.	Difference (degrees)
Upper Maxillary Region	M	55.74 ±	5.12	55.43 ±	5.29	.31
	F	56.10 ±	3.98	56.24 ±	3.83	- .14
Lateral Maxillary Region	M	116.67 ±	21.53	124.28 ±	21.35	- 7.61***
	F	124.69 ±	24.53	129.11 ±	22.34	- 4.42**
Gonial Region	M	122.35 ±	9.13	124.27 ±	8.83	- 1.92
	F	121.22 ±	6.65	122.04 ±	5.40	- .82
Cranial Base Region	M	49.06 ±	11.93	49.03 ±	12.80	.03
	F	52.13 ±	15.38	50.42 ±	12.39	1.71
Cranio-Orbital Region	M	78.38 ±	6.22	79.17 ±	6.05	- .79
	F	77.22 ±	5.00	77.55 ±	5.10	- .33
Cranio-Nasal Region	M	70.36 ±	4.55	70.32 ±	6.66	.04
	F	69.49 ±	2.81	70.27 ±	3.09	- .78
Cranio-Gonial Region	M	57.84 ±	3.37	57.37 ±	3.07	.47
	F	58.70 ±	2.71	58.11 ±	2.86	.59
Cranio-Condylar Region	M	25.05 ±	6.68	23.78 ±	5.90	1.27***
	F	27.50 ±	4.43	26.70 ±	4.64	.80**
Cranio-Mastoidal Region	M	38.32 ±	7.87	36.76 ±	7.17	1.55**
	F	40.11 ±	6.05	38.47 ±	5.63	1.64**
Cranio-Maxillary Region	M	53.41 ±	2.20	53.25 ±	2.60	.16
	F	52.83 ±	2.61	53.12 ±	2.83	- .29

*** $p < .001$
** $p < .05$

measurement of the cranio-mastoidal region of 2.47 mm. For the females the largest difference between right and left linear measurements was 2.36 mm. for the cranio-mastoidal region. Right vs. left differences for all the other significant measurements ranged between .5 mm. and 1.5 mm. (Table X) and were statistically significant at the 5 percent level of significance.

2) Angular Measurements:

When the ten selected paired angular measurements were compared between the right and left sides of the face, only 3 measurements viz; lateral maxillary region, cranio-condylar region and cranio-mastoidal region, indicated significant differences (Table XI). In the case of the lateral maxillary region, the angle was larger on the left side of the face than on the right side for both the males (difference = -7.61°) and females (difference = -4.42°). The reverse was true for the other two angular measurements (i.e., the angles were larger on the right side of the face) (Table XI).

DISCUSSION

CHAPTER V

DISCUSSION

With the increasing recognition of the importance of a thorough knowledge of normal growth and development of the face for the prevention and treatment of malocclusion, orthodontists have devoted much attention to the dimensions of the various facial components and the relationship between them.

The growth of the craniofacial structures is a complex process which occurs over a long period of time. The changes of the normal face from infancy to adulthood is far more complex than a mere increase in the size of each component. During growth, the individual's own pattern and the facial proportions change considerably and at the same time, functional relationships within and between different areas must be maintained to permit the performance of the many functions associated with facial structures (Enlow, 1975). The craniofacial structures are composed of many interrelated bones with their spatial arrangement responsible for the form and size of the total facial pattern.

Moyers (1972) stated that:

> "The structural arrangement and the progressive growth of the different craniofacial bones,

conform to a system of region-to-region "equivalence". Equivalence is an architectural principle based on the counterpart nature of construction among the separate bones. Any bone, or some part of that bone, is a structural counterpart of some other bone positioned more or less parallel to it. The feature of bilateral symmetry throughout the body as a whole is a simple example of the equivalent balance principle. The right side of the mandible is a structural complement of the left, the sizes of both are in approximate balance, ordinarily, remain so during continued growth. However, the mandible has other equivalent counterparts in the skull."

The present study was concerned with quantitative assessment of the sites and magnitude of craniofacial asymmetry observed in the postero-anterior (P-A) cephalograms of subjects exhibiting no pathological dysplasia or gross asymmetries. In addition, the effect of sex (males vs females) upon the craniofacial asymmetry was also examined. These objectives were tested by using a series of specially developed indices of craniofacial asymmetry based on the method of "best fit line".

The Use of Reference Axes for Assessing Craniofacial Asymmetry

The establishment of a method of assessing the degree of the craniofacial asymmetry, depends on the definition of a reference plane relative to which the sites and magnitude of horizontal and vertical asymmetry can be measured. The reliability of previously employed methods for assessment of craniofacial asymmetry may be questioned as they have ignored some mathematical principles in the construction of reference axes and/or planes.

The establishment of a reference asymmetry axis used by previous investigators (Cheney, 1961; Harvold, 1954; Sassouni, 1958 and 1960 and Fisher, 1964) was based on simple connection of two points which might be regarded as unscientific, in that those points themselves could be deviated to either side of the face which, in turn, would destroy the quantitative assessment of craniofacial asymmetry.

A more complicated method of establishing a reference axis for assessing craniofacial asymmetry was used by Vig and Hewitt, 1973 and later by Hewitt, 1975. This method is known as the method of least squares or the "best fit line". However, the method of determining the "best fit line" must have been based on calculating the equation of the line which minimizes the error measured parallel to one of the two reference axes (x or y). This method is exact only when one of the two reference axes, used to measure the cephalometric coordinates, is exactly parallel to the required "best fit line". This, however, is not always the case.

In contrast, the method used to determine the "best fit line" in this study was based on the concept of minimizing the errors measured perpendicular to the "best fit line". This method, therefore, yields an exact measurement regardless of the orientation of the original reference axes used for specifying the cephalometric coordinates. The method established in the present study would account, therefore, for correcting the rotation of the head relative to the x-ray. Ross', 1978 statement that "any rotation of the head relative to the x-ray film will cause a severe distortion in measurements" for which he has no supportive evidence to substantiate, can be regarded as invalid.

Construction of the "best fit line" used in this study provides an accurate determination of a reference axis for measuring the degree of facial asymmetry, based on the arrangement of the total mid-sagittal and/or bilateral points, which in turn account for the individual variations.

<u>Indices of Craniofacial Asymmetry</u>

The method of the "best fit line" used in this investigation was designed on the basis of constructing two "best fit lines". The first "best fit" line was calculated for the total mid-sagittal structures (see figure 11 and Appendix II), while the other "best fit line" was calculated for the total bilateral structures (see figure 11 and Appendix II). This, in turn, permitted the establishment of a series of indices (major and specific) which provided for a method of accurately assessing the site and magnitude of the vertical and horizontal craniofacial asymmetry.

a) Major Indices of Craniofacial Asymmetry

The six major indices (Table V) provide a rapid method of assessment of asymmetry for the total craniofacial complex. To further quantitatively assess asymmetry, the specific indices are used for either the mid-sagittal structures or for the bilateral craniofacial regions.

The index of lateral expansion (Table V) reveals that on the average, the left side of the face is larger than the right side in both males and females. The degree of left side asymmetry was 1.65 mm. ± 2.33 mm. for the males and 1.61 mm. ± 2.11 mm. for the females. Examination of the histogram (figure 28) reveals that only 6 females and 9 males showed a negative index of lateral expansion indicating a larger right side of the face.

Although the values of the oblique motion index were statistically significant for both the males and the females at the 5 percent level, with no significant difference between the two means, it would appear that these values of -0.446 degrees ± 1.207 degree for the males and -0.538 degrees ± 1.385 degrees for the females may be considered not biologically significant. This may indicate that the diagonal expansion of the face in the bilateral structures is relatively minor in the course of growth and development of the craniofacial structures (i.e., one part of the craniofacial region to depart independently of its growth unless there is some pathological phenomenon as in case of trauma to the condyle, for instance, and subsequent ankylosis of one condyle of the mandible to the glenoid fossa). With regard to the vertical direction, the index of vertical disharmony, both sexes exhibited an insignificant degree of vertical asymmetry (Table V). The left side of the face was higher vertically by less than 0.50 mm. Both sexes displayed a similar value of vertical distortion of 2.07 mm. ± 0.54 for the males and 1.94 mm. ± 0.60 mm. for the females. However, since this index does not locate the site of vertical deviation of the bilateral structures, the use of the specific vertical indices would give more information as to the site and magnitude of the asymmetry along the vertical axis.

The indices of mid-sagittal and bilateral distortions showed on the average, that there was no sex difference and that the degree of asymmetry was approximately 4 times larger along the bilateral structures as compared to the mid-sagittal structures (Table V). The craniofacial asymmetry tended to increase from the middle part of the face toward the lateral structures. Again, the specific horizontal and vertical indices would locate the area of asymmetry.

The findings of the six major indices, therefore, would support the hypothesis that an appreciable difference does exist between the right and left sides of the craniofacial structures. Examination of the means of variables (Table V) suggest that, regardless of sex, there was an overall horizontal left side expansion. By comparison, 6 females and 9 males showed a negative index of lateral expansion (figure 28) indicating the right side of the face was larger relative to the left. Several investigators (Woo, 1938; Burke, 1971; Alimchandani, 1973; Vig and Hewitt, 1973 and Hewitt, 1975) have also reported that the left side of the face was larger than the right side in all or some of the craniofacial structures (i.e., malar bone, temporal bone and maxillary region). The present study has demonstrated an overall horizontal, and to a lesser extent an overall vertical facial asymmetry of the left side for both sexes, not surprising, but defying explanation.

The Craniofacial structures are composed of many interrelated bones and they are all potentially affected by genetic make-up, function, habits, occlusion, musculature and other external environmental factors. The interactions between the various factors which govern the growth of the craniofacial complex has an appreciable effect on the morph-ogenetic process (size and form). This, in turn, can possibly lead to the right-left differences or asymmetries. Complete symmetry would be anticipated if the genetic penetrance and environmental influence were identical for both sides of the craniofacial region as most structures are bilateral sometime during their development. It would be apparent, of course, that bilateral symmetry can only exist if the genetic forces that guide the growth of the individual are concerned with developing two identical mirror-image halves of the body. Since mathematically identical similarity between the two mirror-image forms cannot be expected in living things, bilateral symmetry is but a theoretical concept, a principle which is rarely applicable in biology (Lundstrom, 1961). Landauer (1939), Gruneberg (1942) and Lundstrom (1961) have pointed out that cranio-facial asymmetry in non-pathological cases is a normal phenomenon and that the right-left differences can be due to genetic and non-genetic influences or combinations of both during the morphological mechanism which creates symmetry during early development. It seems also that the genotype, which can be modified to a greater or lesser degree by non-genetic influence, can be asymmetrical not only in non-pathological cases but also in craniofacial malformations. Fogh-Anderson (1942) and Longacre (1966) note that the incidence of hypoplasia of the first branchial arch is more frequent on the right side while the incidence of cleft lip is more frequent on the left side. These observations may be a reflection of their data base, i.e., sample examination and/or the limited size of the sample being evaluated. However, it has been suggested that this phenomenon (right-left difference) may be associated with some genetic predisposition (Longacre, 1966 and Lundstrom, 1961).

The large left sided asymmetry found in the present study, for the two sexes, can imply the possibility of genetic predisposition, in regard to the potential differential growth rate between the right and left sides of the face, in that greater growth potential was dominant on the left side. Lundstrom, 1961, has discussed briefly the so-called somatic mutation, in which there is a sudden change of a single gene in a somatic cell. If the mutation occurs during the intrauterine development, and if the changed gene is dominant, the cells that develop from the original cell can present phenotypic traits, leading for instance, to marked right-left differences. In order to further examine the presence of the larger left side (due possibly to genetic control), familial studies, animal studies and twin studies (identical and fraternal twins), may be investigated. There are some important limitations to be acknowledged in the study of human genetics, however. These limitations as identified by Scott (1967) are:

1) man possesses a relatively large number of chromosomes which cause a great amount of genetic diversity.
2) the human life span is relatively long and there is a considerable interval between birth and reproduction, affecting the number of generations available for study.
3) the number of offspring per mating is low and,
4) because there is little or no control possible over environmental factors, the importance of such forces on the phenotypic expression of a trait must be inferred rather than measured directly.

b) Specific Indices of Craniofacial Asymmetry

The purpose of the specific indices was to identify the site and magnitude of the horizontal and vertical deviation of the selected craniofacial structures. The specific indices for mid-sagittal structure can locate the degree of the horizontal deviation for each of the eight midline points employed in this study (see figure 11 and Appendix II), while on the other hand, the indices for the bilateral craniofacial structures permitted the isolation of the horizontal as well as the vertical deviation for each of the bilateral points used in the present investigation (see figure 11 and Appendix II).

1) Specific Indices of the Mid-sagittal Structures:

Examination of Table VI reveals that there were no significant differences between the values for both the males and females for horizontal deviation of the midline points. This would indicate that mid-sagittal asymmetries were not affected by sex and furthermore, that the site of asymmetry (i.e., left or right deviation) was similar for both sexes.

The mean value for horizontal deviation for crista galli point in the males was 0.12 mm. ± 0.53 mm. but not significant to the left side of the face, while for the females, the mean value was 0.30 mm. ± 0.51 mm. to the left, which was considered to be statistically significant ($p < 0.01$), but not, however, biologically significant. The fact that 9 females showed left side horizontal deviation of crista galli point greater than 1 mm. as compared to 5 males. This may account for their relatively higher mean value. This relative lack of asymmetry for both sexes would tend to support the Scott hypothesis which stated that the ethmoidal bone and its superior perpendicular plate (cribriform plate) is well protected from environmental factors, since it develops early in life inside the anterior cranial fossa (Scott, 1967). For the nasal septum point the index of horizontal deviation revealed that this point tended to deviate slightly to the left side in the males (0.21 mm. ± .53 mm.), while for the females there was on the average no deviation (0.00 mm. ± .54 mm.). The symmetry, or lack of symmetry for the nasal septum point may be dependent upon the functional stimulus (maintenance of airway) and environmental factors (i.e., nasal obstruction, trauma to the nose, etc.). The index of the anterior nasal spine (Table VI) shows somewhat negligible horizontal deviation or asymmetry for both sexes. The average values did not exceed 0.1 mm. This lack of asymmetry could be possibly due to the growth rate difference between the two sides of the face (whether due to genetic and/or environmental factors) of the anterior nasal spine adapting at the sutural area between the two developing maxillae.

For the horizontal deviations of the maxillary and mandibular dento-alveolar midlines, the indices indicated statistically significant horizontal deviation (Table VI), to the right for the maxillary dento-alveolar structures only. This observation was valid for both the males and the females. There may be a number of environmental factors which may contribute to such deviation. The premature loss of primary dentition in one of the arches, to one side of the face is an important factor in causing midline deviation. It has been observed by Clinch (1958) that early loss of upper deciduous molars is followed by a greater degree of mesial movement of the upper permanent molars than that of the lower permanent molars which occurs following a similar loss from the lower arch. This, in turn, as Moyers (1975) stated, will have first chance at the available space in the maxillary arch and would likely cause dental midline deviation. The possibility that the mandibular midline is less affected by environmental factors than the maxillary dento-alveolar midline, may be due to the later eruption of maxillary canines, tongue and lip habits which would tend to create spaces in the anterior segment of the upper arch and thus maxillary mid-line deviations.

The chin point, menton, showed the largest horizontal deviation of all the mid-sagittal structures. The deviation was to the left and of statistical significance for the males and females ($p < 0.01$ and $p < 0.001$ respectively). However, the difference between the two means was not statistically significant. The mandibular deviation to either side of the face due to occlusal interferences, as during the development of dentition (mixed dentition stage), might contribute to the lack of symmetry of the chin point. The spatial maxillary-mandibular archs relationship should be assessed in the rest position, or in the habitual postural position, about the sagittal plane. If the relationship (of the maxillary and mandibular archs) is not coincident about the sagittal plane, then an asymmetrical functional activity must compensate during both mastication and the approximation of the dental arches. To obtain bilateral symmetrical function (during mastication and in maximum intercuspation), compensatory changes might be operating in the course of growth and development of the craniofacial structures, which can possibly be reflected in the asymmetrical position of the chin (Hewitt, 1975).

Although the mean values of horizontal deviation of the midline points for both sexes revealed that anterior nasal spine, mandibular dento-alveolar points and to a lesser degree, crista galli and nasal septum points, have relatively minimum horizontal deviations, do not suggest that these points alone could be used in future studies as appropriate reference points for construction of a symmetry plane or axis. The values of these points are only an average and do not reflect the individual variation pattern for the individual. The "best fit line" provides a more accurate assessment for each of the individuals in that the mid-sagittal "best fit line" takes into account the arrangement of all the midline points for a particular individual. Thus, a better reference axis for assessing facial asymmetry can be obtained. It should be considered, however, that all the speculations which have been given to explain the cause for the deviation along the horizontal axis for the mid-sagittal structures have to be investigated further by applying the same method of assessment to a larger sample size of both males and females.

2) <u>Specific Indices of Bilateral Craniofacial Structures:</u>

The specific indices measuring asymmetry of the bilateral craniofacial structures yields a more accurate assessment of the site and magnitude of asymmetry in horizontal and vertical directions.

The differences between the means of the males and females for the horizontal and vertical deviations for all 12 bilateral paired points were not statistically significant (Table VIII). This would indicate that the asymmetries of the bilateral craniofacial structures were not affected by sex. In addition, the site of the vertical and horizontal asymmetries were similar for both males and females. The site and magnitude of the bilateral craniofacial indices supported the observation of the major indices of craniofacial asymmetry (Table V). The left side of the face is larger along the horizontal axis and to a lesser degree along the vertical axis. In fact, the horizontal indices of the craniofacial bilateral structures (Table VIII) revealed that for both sexes, the left side was larger for 10 of 12 horizontal measurements used in this study (the exception were external medio-orbital and internal medio-orbital points). The vertical deviation indicated that the left side was vertically higher for both sexes for 7 of the 12 vertical measurements investigated (Table VIII).

In regard to the horizontal and vertical specific indices for the orbital regions, the study of symmetry or lack of symmetry is difficult to assess. Enlow (1975) has pointed out that "the remodelling changes of the orbit throughout the growth are complex. This is because many separate bones comprise the orbit including the maxilla, ethmoid, lacrimal, frontal and zygomatic and the greater and lesser wings of the sphenoid. In addition, because of the many different rates and amounts of remodelling growth and displacement occur among these different bones and their parts".

The degree of roundness and the obliquity of the superior orbital margin is different between the two orbits (Enlow, 1975). This anatomical shape difference between the right and left orbits would account for the presence of asymmetry in the left orbital region. However, the asymmetry of the left orbital region was reflected on only two measurements along the horizontal axis (i.e., the orbital sphenoidal and inferior orbital point). While, along the vertical axis the asymmetry was present for the external and internal orbital margin.

The shape and/or form of the right and left orbits should be further studied to determine if there is greater asymmetry in this region. A method for this determination could be possibly performed by plotting more points along the outline of the orbits. Angular and linear measurements can also be somewhat beneficial in determining the right-left asymmetry of the orbital region.

With the exception of the nasal cavity region, all the horizontal craniofacial indices for the bilateral craniofacial structures (Table VIII) showed that both sexes have a statistically significant left side expansion. Furthermore, the site of asymmetry was determined to be those areas where there was muscle attachments. Those bilateral landmarks with their muscle attachments were the temporal point (temporalis), zygomatic (zygomatic muscles), condyle (lateral pterygoid), maxillary (buccinator), mastoidal (sternocleidomastoid) and gonial point (masseter and medial pterygoid).

It appears, therefore, that asymmetry of the bilateral craniofacial region in some parts of the face is related to the location of muscle attachments. The vertical muscle pull seems to be more powerful on the left side resulting in an increased outward bony apposition on one side of the face more than the other.

Washburn (1947), Sicher (1970) and Ryll (1972) have demonstrated that the removal of certain muscles (temporalis, masseters) will affect the size and shape of the skeletal unit which they are attached. While it is generally accepted that genetic factors play an important role in determining the form and size of various parts of the craniofacial complex, there is, at present, considerable controversy regarding the role of functional activity in determining the form and size of the adult face. Scott (1967) has stated that in any individual the exact balance between the genetic and functional factors in determining skull morphogenesis is impossible to determine with any accuracy. Some individuals appear to have greater "genetical drive" than others and some appear to have a greater ability to respond to functional stimuli than others.

Lundstrom (1961) has well documented the distribution of asymmetry on the normal body. As an example, the asymmetry of the heart and of the blood and lymph vessel system will have developed as a result of the different functional requirements on the left and right sides of the heart and the asymmetric positions of many of the organs that the vessels supply.

In addition to the regular and highly consistent forms of asymmetry, there are other genuine types of asymmetry. Among these might be mentioned right and left handedness and associated functional and morphological asymmetry. The preference for one side over the other is not restricted to man. An example of such differences in the animal world as Lundstrom (1961) described is found in certain types of animals. In the case of the buck reindeer and some deer, the left side is reported to be the fighting side; this is reflected in the fact that the left horn is more strongly developed and more often broken than the right one. In these animals, injuries to the forehead from fighting are reported to occur more often on the right than on the left side.

Related to right and left handedness, there is also the preference for using the corresponding leg (for instance, for pushing off the ground in the long jump or for kicking a ball). Moreover, there is even a preference for using one eye more than the other as, for instance, when using a monocular microscope. These relationships suggest that the preference for one side is deeply rooted and is associated with asymmetry in the central nervous system. Further proof of this is found in the well-known fact that the speech center is situated in the left cerebral hemisphere in left-handed persons (Ruch and Zimbardo, 1971). In fact, studies of split-brain monkeys and human beings have demonstrated that the left cerebral hemisphere is considered to be dominant over the right hemisphere in naturally right-handed individuals; the right hemisphere is dominant in naturally left-handed individuals. There is recent evidence (Gardner, 1975) that the left hemisphere tends to be dominant even in left handed persons, but often to a lesser degree, that is, the right hemisphere tends to participate to a greater extent in the usual functions of the left hemisphere. Dominance may reflect an asymmetry of morphological and physiological organization and it may be an expression of unilateral engram formation. As reported by Kimura (1973) the tactual and motor systems of the brain are almost completely crossed; sensation from the left half of the body and movement of the left half of the body are served primarily by the right cerebral hemisphere and vice versa. Visual pathways, for example, are completely crossed, so that when the eyes are fixated on a point, all of the field to the left of the fixation point excites the visual cortex in the right hemisphere and vice versa. The visual cortexes, however, can communicate via the corpus callosum, which connects the two hemisphere (Kimura, 1973).

Whether there is a close correlation between craniofacial asymmetry and brain dominance is beyond the scope of this study. It is interesting to find that the present study demonstrated an overall left side larger face for the majority of cases examined. In most individuals, the left cerebral hemisphere is specialized for hand control, language, and certain aspects of memory, and more still to be learned about functions which are related to neural performance in other parts of the body (Gardner, 1975). Most of the nerves which control the performance of the left side face musculature is uncrossed, that is, controlled by neural processes in the left dominant brain (citation). Further studies are needed to assess and analyze these functional activities.

These examples may suffice to show that systemic asymmetry is by no means uncommon, even with respect to parts of the body that are essentially similar in structure on each side.

Research, however, is lacking on the functional biological asymmetry of neuromusculature activity from one side of the face to the other. An example of this muscular activity can be explained in relation to the use of the right or left arm. It is well known that the increase in the amount of the cortical bone substance is related to the greater muscular development. Hrdlicka (1932) found that the dimensions of the left and right hand humerus can differ among various racial groups in America who perform different manual work. Irish males, who were mostly manual labourers showed greater value for their right hand mid-shaft diameter as compared to American Indians who do little manual work and also as compared to their left hand.

The habit of chewing pattern (i.e., whether left side, right side, or both sides) can also be related in principle to the above mentioned phenomenon (the habit of functional stimuli). In order to assess the chewing patterns, 58 subjects were subjectively questioned as to their preference of their chewing side. The result of this subjective evaluation is shown in Table XII and its relation to the craniofacial asymmetry. Thirty-two of the 58 subjects preferred chewing on their left side more commonly than the right side. However, of the 48 subjects who showed left side skeletal asymmetry, only 30 subjects stated that they have the habit of chewing predominantly on the left side. Of the subjects who showed right side face skeletal asymmetry, (2 females and 8 males) only 5 subjects stated that they preferred to chew on their right side.

Table XII

Number of subjects indicating chewing pattern as it related to the craniofacial asymmetry.

	Males (29)		Females (29)		
Chewing Pattern	Right face Skeletal Asymmetry	Left face Skeletal Asymmetry	Right face Skeletal Asymmetry	Left face Skeletal Asymmetry	
Left Side	2	14	0	16	
Right Side	4	2	1	4	
Both Sides	2	5	1	7	
Total	8	21	2	27	58

The implication of an association between chewing habits and craniofacial asymmetry in the region where there is muscles are attached, is suggested. In those subjects with unilateral chewing pattern there is possibly some correlation between overworking on one side of the face (i.e., the left side) and more bone apposition where the muscles insert.

However, speculation as to the effects of muscle pull as it relates to the sites of craniofacial asymmetry along with the chewing pattern should be investigated further using a sample selected according to specific criteria as to the chewing pattern.

The area of the lower nasal cavity for both sexes suggested a greater degree of symmetry than the rest of the bilateral structures. This observation would tend to support Scott's hypothesis (1967) that this region of the craniofacial complex showed a great response to function demand (maintenance of airway) on both sides of the face.

<u>Case Presentations:</u>

<u>Case I:</u>

In order to demonstrate the application of the craniofacial asymmetry indices, with regard to overdeveloped musculature on one side of the face, the following subject is presented.

A young male (age 18 years) with apparent over-development of soft tissue on the left side of the face was studied (see figure 34). The chief complaint of this patient was that the left side of the face was larger than the right. Medical history revealed a diagnosis of lymphosarcoma at age 12 years, in the region of the right maxilla. The treatment of choice at that time was exposure of the area of the tumor on the right side of the face to radiation therapy. This procedure in turn had an affect on the development of his right soft tissue including the muscles. In fact, palpation of the muscles on both sides of the face exhibited more powerful muscle on the left side as compared to the right. Examination of the dental pattern revealed that the patient exhibited an acceptable occlusion with Angle Class I molar relationship and slight tendency toward Angle Class II cuspid relationship but with relatively acceptable overjet and overbite. The patient was also subjectively questioned as to his preference of his chewing pattern and his answer was that of the left side.

Coordinates of the patient's P-A radiograph were analyzed and then compared to the mean value of the males indices as shown in Tables XIII, XIV and XV. The tracing of his P-A radiographs (figure 35) revealed on visual inspection, no significant gross skeletal asymmetries as his frontal

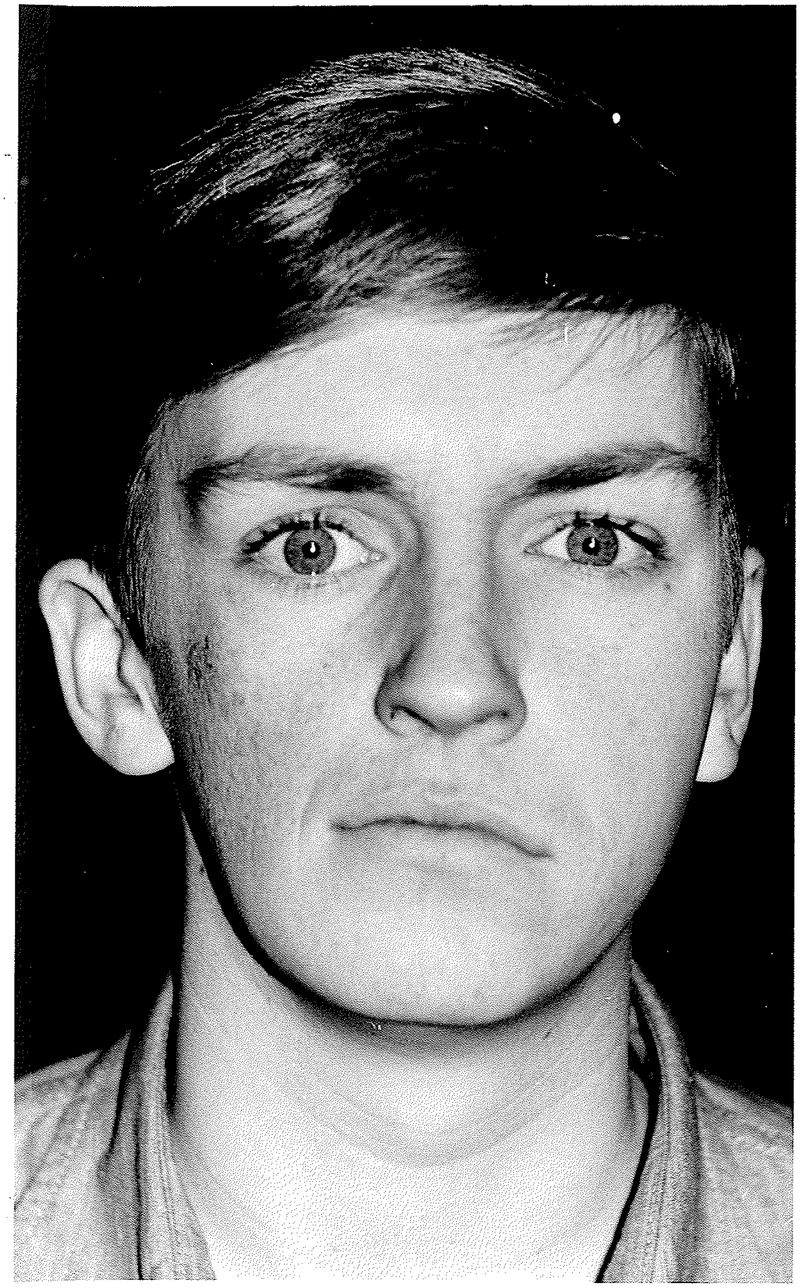


Figure 34. Frontal photographic view of the patient (Case I).

Table XIII

Comparison of the males' mean value and the patient in regard to the six major indices of craniofacial asymmetry.

		Males (32)		
Index	Patient Value (mm.)	$\bar{x}$ (mm.)		S - D (mm.)
Lateral expansion	4.73	1.65	±	2.33
Oblique motion	- 1.52	- 0.446	±	1.207
Vertical disharmony	1.20	0.26	±	1.66
Vertical distortion	1.91	2.07	±	.54
Mid-sagittal distortion	1.04	0.69	±	.33
Bilateral distortion	4.72	2.34	±	1.02

Table XIV

Comparison of the patient and males' mean group values for all the specific mid-sagittal structures.

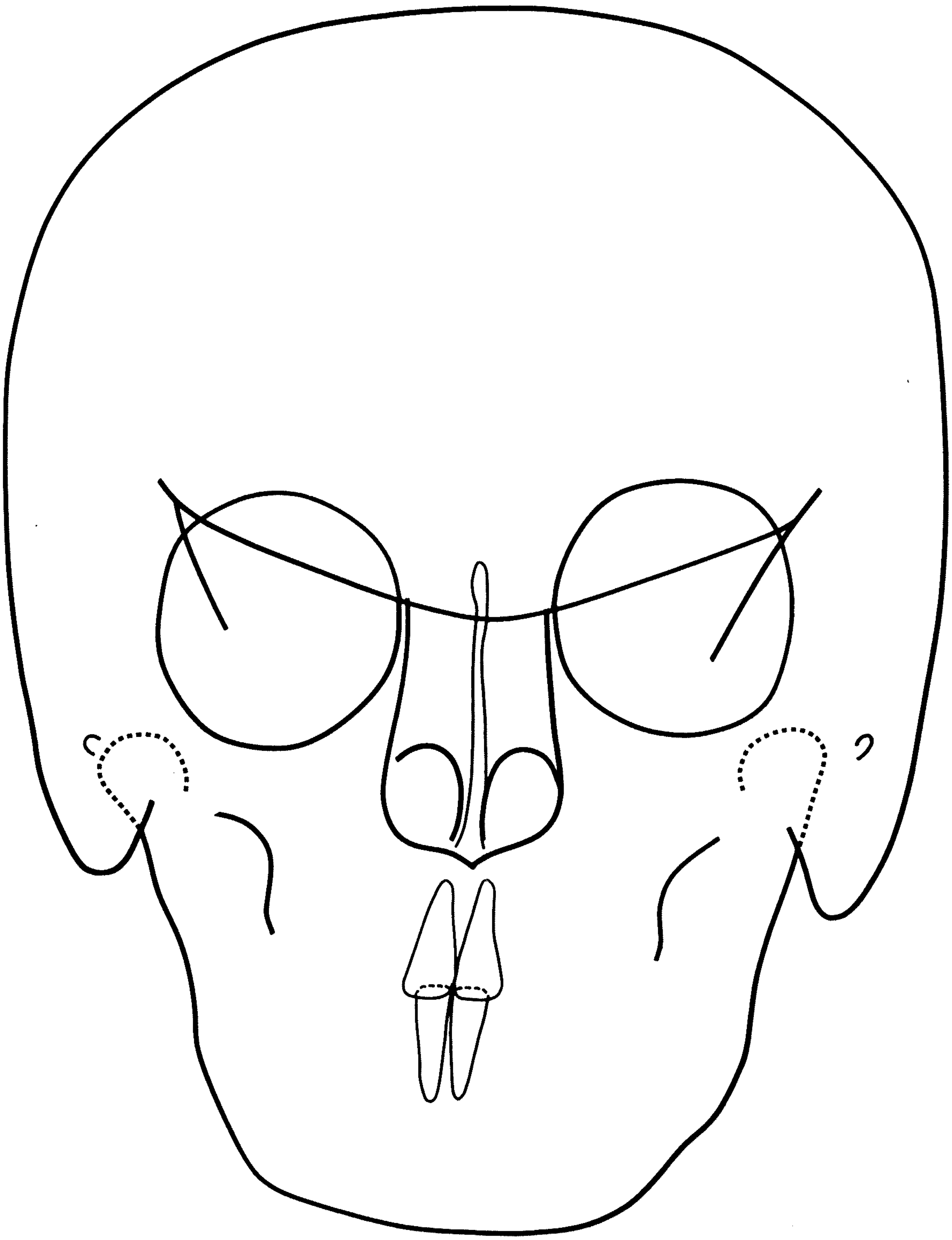
Structures (mid-line)	Patient Value	Males (32)		
		$\bar{x}$		S - D
Crista galli	0.33	.12	±	.53
Nasal septum	1.35	.21	±	.53
A.N.S.	0.23	- .10	±	.74
Mx Alveolar Point	- 0.93	- .32	±	.65
Mx Dental Point	- 0.87	- .33	±	.63
Md Alveolar Point	- 0.94	.07	±	.85
Md Dental Point	- 0.90	- .07	±	.92
Menton	2.03	0.43	±	.91

Table XV

Comparison of the patient and males' mean group values for all the specific bilateral craniofacial indices.

	Test		Mean Male	
Bilateral Structures	Horiz.	Vertic.	Horizontal	Vertical
Temporal	5.32	3.99	2.63 ± 6.63	.37 ± 4.13
Orbital Sphenoidal	- .03	1.80	1.19 ± 1.90	- .23 ± 2.17
Lateral Orbital Margin	- 1.12	3.95	- .30 ± 2.61	2.87 ± 2.69
Superior Orbital Margin	.82	1.90	.11 ± 2.18	.11 ± 1.61
Medial Orbital Margin	.58	- 1.43	.03 ± 2.29	- 1.55 ± 1.66
Inferior Orbital Margin	1.11	3.27	1.68 ± 2.15	.05 ± 1.79
Zygomatic	4.95	3.88	1.67 ± 3.08	- .86 ± 2.91
Condylar	6.32	3.29	3.59 ± 4.07	.65 ± 2.55
Latero-Nasal	- .41	- .82	1.14 ± 1.98	.31 ± 1.86
Maxillary	1.17	- 1.81	1.98 ± 1.79	1.15 ± 1.77
Mastoidal	3.25	- 4.00	2.68 ± 5.68	- .89 ± 3.01
Gonial	3.98	3.25	1.62 ± 3.59	.30 ± 2.76

Figure 35. Tracing of the patient's P-A radiograph (Case I).



photograph shows (figure 34). The indices, however, provide information as to the site and magnitude of his craniofacial asymmetry.

The major six indices (Table XIII) revealed that the patient has a larger left side of the face (index of lateral expansion), along the horizontal direction, as compared to the right side of the face of 4.73 mm. The average males lateral expansion asymmetry index value was 1.65 mm. ± 2.33 mm. This might suggest that there was possible cessation of growth of the soft tissue on the right side of the face and overworking muscles on the left side, along with the left side chewing pattern which presumably caused more apposition of bone on this side. All the remaining indices were comparable to the average values of the males except the index of lateral distortion which indicated that there is a greater horizontal asymmetry for the craniofacial bilateral structures. In fact, the specific indices for both the mid-sagittal structures and the bilateral structures, revealed a more accurate indication as to the site and magnitude of the asymmetry.

Of the mid-sagittal structures, no severe horizontal deviations were found. All the horizontal deviations (Table XIV) with the exception of nasal septum point, and menton point were comparable to the mean values of the males mid-sagittal specific indices.

For the nasal septum point, the index of horizontal deviation for this patient indicates 1.35 mm. of left side deviation as it compared to 0.21 mm. ± 0.53 mm. of the average horizontal deviation for the males. The medical history revealed that the patient had a broken nose in early childhood in addition to the fact that the lymphosarcoma was fairly large on the right side which presumably caused pressure on the nasal area which in turn possibly can be attributed to the degree of nasal septum deviation.

The chin point, menton, demonstrated that this patient has appreciable left side horizontal deviation of 2.03 mm. as compared to 0.43 mm. ± 0.91 mm. for the mean values for the males. This would possibly reflect the growth adaptation at the chin area to the relative lack of muscle pull on one side as compared to the other. The different position of the condyles in the glenoid fossa on either side of the mandible may have altered the adaptive growth at the chin region. It is also possible, that there has been an alteration in growth potential due to irradiation of the condyle as a growth site. This alteration may be contributed to the lack of symmetry at the chin region.

The specific indices of the bilateral craniofacial structure for this patient as compared to the mean value of the males specific horizontal and vertical deviations are presented in Table XV. Comparison of the values for the patient with the mean values of the males revealed that the site of the asymmetry is located in the area of muscle attachment (temporal, zygoma, condyle, maxilla, mastoidal and gonial). Although the patient's values at the site of muscles attachment are appreciably higher than the mean of the values of the males, it seems that they fit within the range of deviation (i.e., mean ± standard deviation). This observation is consistent for both the horizontal and the vertical indices. This observation therefore, would probably indicate that the age of the patient at the time of radiotherapy (age 12) was not a factor in causing severe craniofacial asymmetry since the patient at age 12 has already passed a critical part of his growth activities. The patient was forced to chew on the left, presumably due to muscle atrophy. Examination of Table XV reveals that the left orbit was more superiorly positioned relative to the right. In fact, this oberservation can also be seen in examining the frontal photograph shown in figure 34. The index of the lower nasal cavity showed more symmetry.

A case involving asymmetry of the face (particularly the facial soft tissue) has been presented to allow the reader to visualize the use of the indices provided. In future, however, a larger sample of cases who possess gross facial asymmetry, of soft tissue origin, should be assessed in an attempt to evaluate the relationship of the soft tissues and underlying asymmetry of the skeletal morphology. The assessment of such cases should be analyzed using the indices method of assessing craniofacial asymmetry, electromyographic study and assessment of soft tissue facial asymmetry, using a standardized frontal view with selected points on the face which may then be plotted and subjected to the method of steriophotogrammetric assessment such as that described by Burke (1971). The sample also should be studied longitudinally, starting at an early age, in order to identify the influence of environmental factors play on the growth of craniofacial complex.

Case II:

The following is another case exhibiting gross craniofacial asymmetry and could be considered more severe than the previous case. The patient is 21 years old, presented to the Oral Surgery Department with the complaint of facial asymmetry. The frontal photograph in Figure 36 reveals the asymmetry, particularly in the patient's lower of the face. The medical history and the clinical examination of this patient revealed no previous trauma to the neck or head region, no familial history of craniofacial deformity and no neuromuscular abnormalities (i.e., injuries and/or mandibular displacement of neuro-muscular origins).

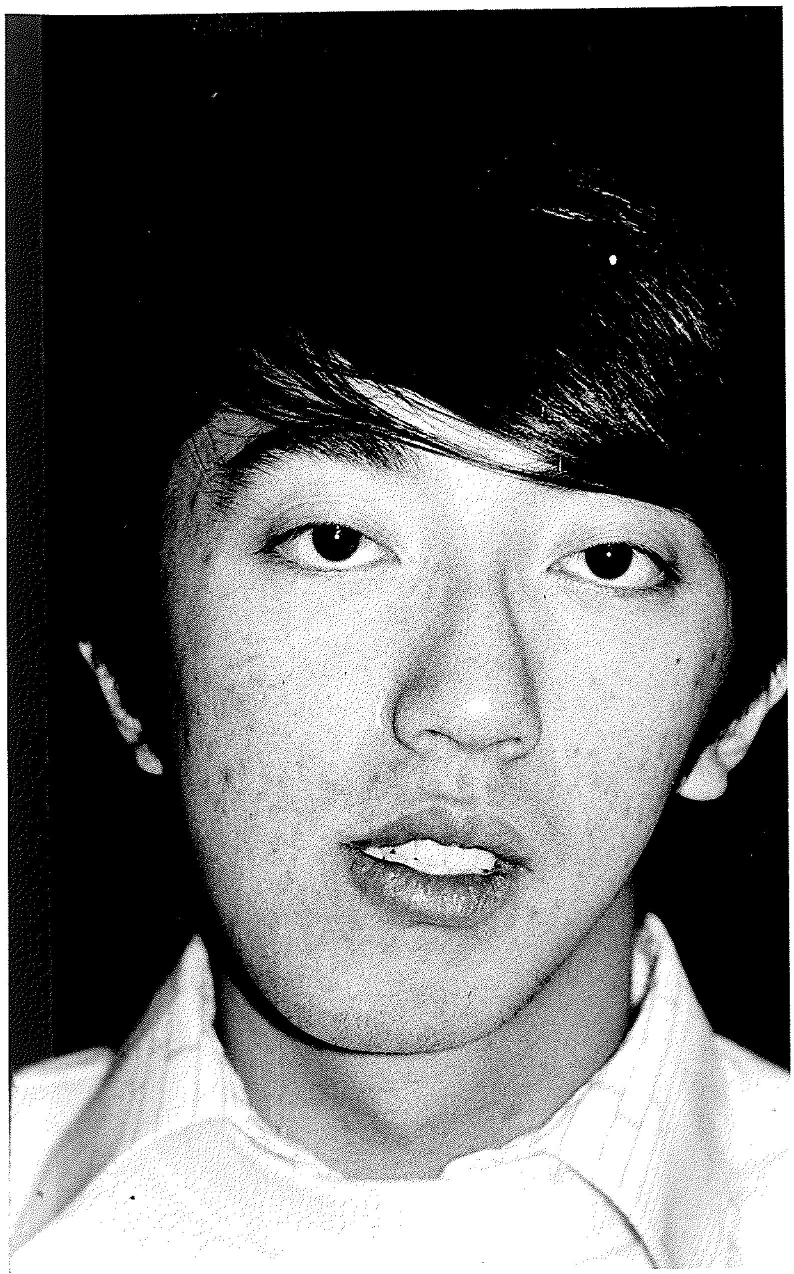


Figure 36. Frontal photographic view of the patient (Case II).

Examination of the patient's dental pattern displayed the following:

1) buccal crossbite on the right side (figure 37)
2) reasonable Angle Class I malocclusion (figures 37 and 38)
3) acceptable overbite and overjet (figures 37 and 38)
4) dento-alveolar midline discrepancy (figure 39)

The P-A film's tracing (figure 40) was digitized and the values of the major and specific craniofacial asymmetry indices was recorded and compared to the mean values of the male subjects (Tables XVI, XVII and XVIII). The major six indices (Table XVI) revealed that the patient has gross skeletal asymmetry in that the right side of the face was larger than the left by 5.46 mm., with counter clock-wise oblique diagonal expansion of the facial component of 2.16 degrees. The vertical disharmony index exhibited greater magnitude of asymmetry with the left side being vertically higher than the right of 9.48 mm. The vertical distortion index suggested 3.44 mm. of vertical distortion which would be specifically defined by using the vertical specific indices of bilateral craniofacial structures. Greater magnitude of asymmetry along the mid-sagittal structures and bilateral structures was also present and the values were 2.09 mm. and 4.36 mm. respectively.

Figure 37. Right lateral view of the patient's occlusion (Case II)

Figure 38. Left lateral view of the patient's occlusion (Case II)

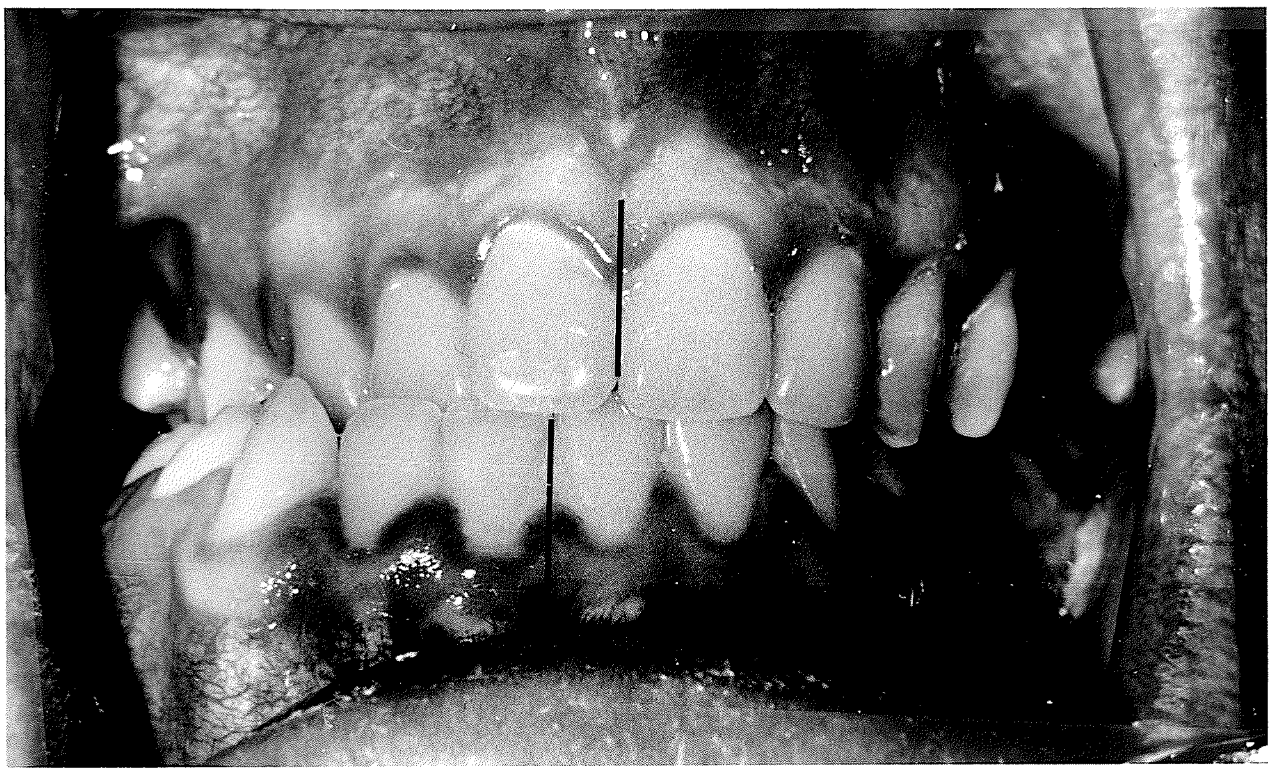


Figure 39. Frontal view of the patient's dental arches (Case II)

Figure 40. Tracing of the patient's P-A radiograph (Case II)

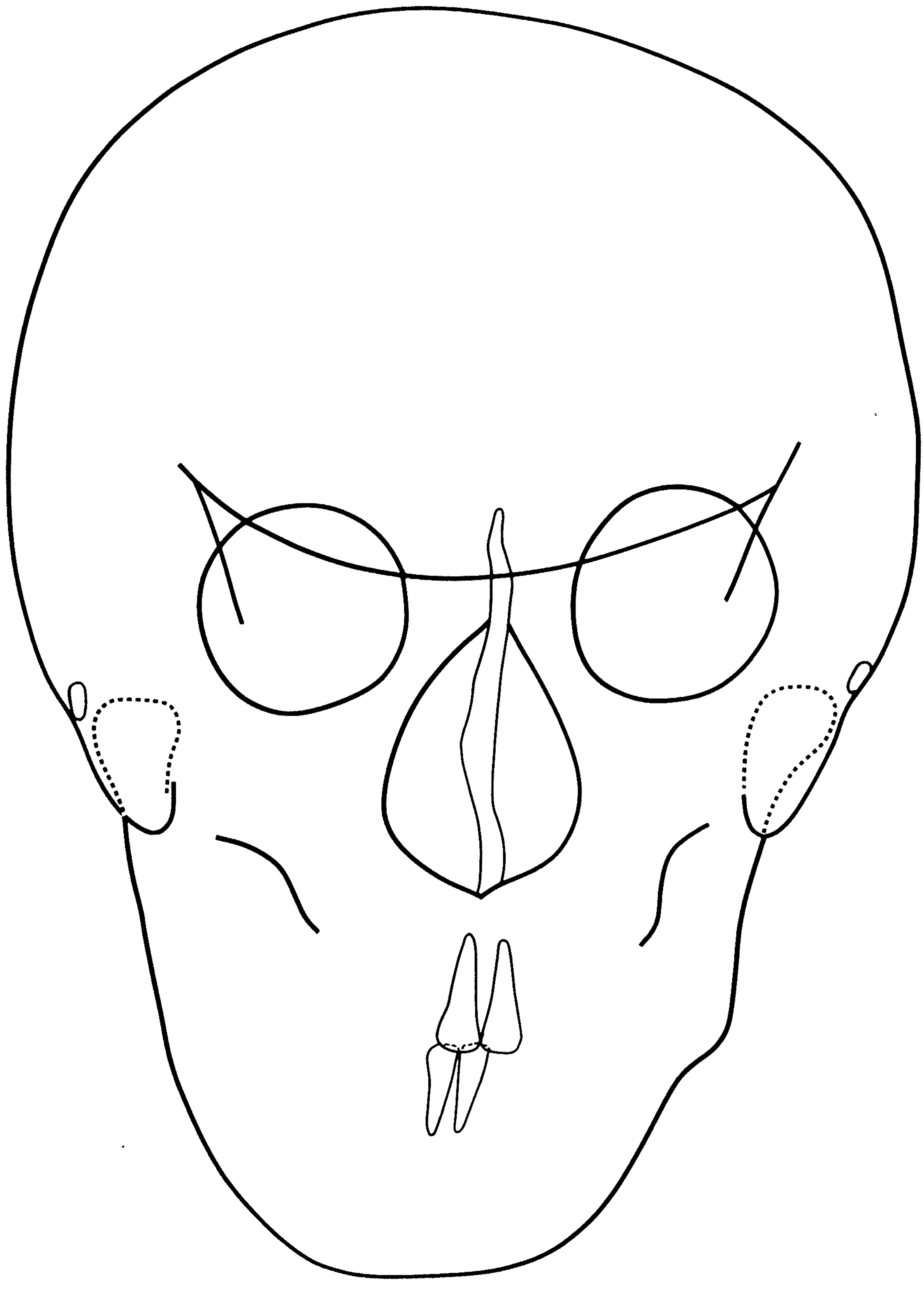


Table XVI

Comparison of the males'mean values and the patient's in regard to the six major indices of craniofacial asymmetry.

Index	Patient's Value	Males (32) $\bar{x}$	S.D.
Lateral expansion	- 5.46	1.65	± 2.33
Oblique motion	- 2.160	- .446	± 1.207
Vertical disharmony	9.48	.26	± 1.66
Vertical distortion	3.44	2.07	± .54
Mid-sagittal distortion	2.09	.69	± .33
Bilateral distortion	4.36	2.34	± 1.22

Table XVII

Comparison of the patient's and males' group mean values for all the specific mid-sagittal structures.

Index	Patient's Value	Males (32) $\bar{x}$	Males (32) S.D.
Crista galli	- 1.25	.12	± .53
Nasal septum	- 1.38	.21	± .53
Anterior nasal spine	.95	- .10	± .74
Maxillary alveolar crest	- .61	- .32	± .65
Maxillary dental point	- .43	- .33	± .63
Mandibular alveolar crest	- 3.08	.07	± .85
Mandibular dental point	- 3.01	- .07	± .92
Menton	- 3.36	.43	± .91

Table XVIII

Comparison of the patient's and males' group mean values for all the specific bilateral craniofacial indices.

	Patient's Value		Male (32)			
	Horizontal	Vertical	Horizontal		Vertical	
Bilateral Structures			$\bar{x}$	S.D.	$\bar{x}$	S.D.
Temporal	- 7.70	4.35	2.63 ±	6.63	.37 ±	4.13
Orbital sphenoidal	- 3.58	3.99	1.19 ±	1.90	- .23 ±	2.17
Lateral orbital margin	- 6.18	5.09	- .30 ±	2.61	2.87 ±	2.69
Superior orbital margin	- 3.03	6.53	.11 ±	2.18	.11 ±	1.61
Medial orbital margin	- 4.03	2.42	.03 ±	2.29	- 1.55 ±	1.66
Inferior orbital margin	- 2.24	5.74	1.68 ±	2.15	.05 ±	1.79
Zygomatic	- 7.67	9.82	1.67 ±	3.08	- .86 ±	2.91
Condylar	- 8.88	8.64	3.59 ±	4.07	.65 ±	2.55
Latero-nasal	- 0.00	2.25	.74 ±	1.98	.31 ±	1.86
Maxillary	- 1.11	8.88	1.98 ±	1.79	1.15 ±	1.77
Mastoidal	- 7.71	10.01	2.68 ±	5.68	- .89 ±	3.01
Gonial	- 7.85	7.46	1.62 ±	3.59	.30 ±	2.76

Examination of the specific mid-sagittal indices revealed that the larger degree of asymmetry was present at the mandibular dento-alveolar structures, in that the lower dental midline deviated to the right by about 3 mm. In addition, the chin point, menton, was also deviated to the right by 3.36 mm.

Relative to the specific bilateral craniofacial structures, the degree of vertical and horizontal asymmetry was greater for all the structures or landmarks with the exception of the lower nasal cavity area (latero-nasal) (Table XVIII). Although the cause of asymmetry is unknown the factors which contributed to asymmetry were effective in altering the spatial positioning of the craniofacial components. However, the soft tissue components have somewhat masked the skeletal asymmetry in the upper region of the face (see figure 36) but not the lower part including the mandible. There is the possibility of hypertrophy on the left side of the mandible, which, in turn, caused the chin point as well as the mandibular dento-alveolar structure to deviate to the right. In addition, postero-anterior position of the condyle in the glenoid fossa would also be different from the left as compared to the right, in that the right condyle would be more posteriorly positioned than the left. The specific index of the condyle provided information that the right condyle was positioned further toward the right by 8.88 mm. and also the left condyle was vertically higher than the right by a similar magnitude. There was also horizontal and vertical asymmetry at the gonial region similar to that of the condyle but of lesser magnitude. The maxilla, as the specific index of maxillary point suggested, was positioned vertically higher on the left than on the right.

The treatment of choice in this case would be a combined surgical-orthodontic approach. The oral surgeon and orthodontist have to combine their efforts to establish good and stable results. The use of the indices for this patient would help the oral surgeon locate the area of dysplasia in order to decide on the type and magnitude of surgical procedure to be employed. In this case the following procedures as a goal for establishing harmonized skeletal and dental pattern have been suggested:

1) Alignment of the upper and lower dental arches with correction of rotation and axial inclination of teeth by means of pre-surgical orthodontic therapy.
2) Ostectomy and set-back on both sides of the mandible with greater magnitude of set-back on the left than on the right (i.e., rotation of the mandible toward the left side in order to correct the position of the lower dentoalveolar structures and the chin point).

3) Sagittal-split ostectomy in the right ramus region and superiorly repositioning the mandible on the right side to correct the vertical asymmetry.
4) Sagittal-split ostectomy in the left region of the maxilla to correct the vertical asymmetry.
5) Expansion of the buccal segment orthodontically would be necessary in order to compensate for the above surgical procedures.

It would be apparent from this surgical case that the method of indices for assessing facial asymmetry is very beneficial in locating the site and magnitude of asymmetry, thus, minimizing the difficulty a surgeon would have in planning the correction of these abnormalities.

Other Measures of Assessing Craniofacial Asymmetry:

A series of linear and angular selected measurements were also used to supplement the craniofacial indices for asymmetry. All of the sites of linear measurements of craniofacial structures were similar for both sexes (Table X).

All the paired linear measurements which showed statistically significant values were related to the site of major muscle attachments (i.e., condylar region, gonial region, zygomatic region and mastoidal region) (Table X). These statistically significant linear measurements were measured from crista galli, since this region can be considered relatively unaffected by environmental factor as Scott (1967) suggested and as supported by the data of this investigation. The infra-orbital region as related to the anterior cranial base (crista galli) demonstrated statistically significant left side asymmetry, indicating that this area is more influenced by the factors which can cause asymmetry. The difficulty in locating the infra-orbital point on the P-A film may have contributed to this appreciable asymmetry value. The other linear measurements which are related to the orbital region (i.e., orbital width, orbital height and cranio-supra-orbital region) demonstrated no statistical significance between the right and left side of the face in both sexes (Table X).

It, thus, seems evident that the area of the orbital cavities on both sides of the face have been least affected by the environmental factors and thus, displayed a greater degree of symmetry than other regions of the cranio-facial structures. It is acknowledged that the growth of the orbital cavities is highly affected by underlying soft tissue forces (i.e., growth of the eyeball and its extrinsic musculature and by the growth of the soft tissue brain) (Enlow, 1975 and Scott, 1967). Therefore, the bones of the orbital cavity have maintained their growth harmoniously along with the functional activities of the underlying soft tissue.

It should be noted, however, that the linear measurements have less accuracy in defining the location and magnitude of craniofacial asymmetry since the linear measurement is related to connection of two points. Thus, movement of one of these two points in any direction would appreciably affect the measurement.

The angular measurements revealed that there were similar site distributions of craniofacial asymmetry for both the males and females (Table XI). However, only the lateral maxillary region, cranio-condylar region and cranio-mastoidal region showed statistically significant values indicating appreciable asymmetries in these regions.

The area of the lateral maxillary region showed a great deal of individual variation in the position of the points related to this angular measurement (figure 26). This was reflected by the high standard deviations for the measurements (Table XI). The cranial base angle region measurement showed lack of asymmetry indicating relative stability of this region throughout the growth and possibly as Scott (1967) pointed out, relative protection from environmental factors as it is positioned inside the cranial fossa. The region of the orbital (cranio-orbital region) and nasal region (cranio-nasal region) as illustrated in Table XI revealed a greater degree of symmetry which are consistent and supportive of the specific indices of the craniofacial measurements and the linear measurements.

The other angular measurements were also related to muscle attachment locations. However, it is only the condylar, mastoidal region as related to the anterior cranial base (crista galli) which showed a statistically significant value of asymmetry.

The angular measurements provide the least accuracy in locating the site of the craniofacial asymmetry. This is because each angular measurement is related to three points. Thus, if one of the three points is displaced in any direction, the value of the angular measurement would be appreciably affected. Therefore, it can be suggested that the method of using the linear and in particular, the angular, measurements for assessment of craniofacial asymmetry, should be considered questionable as far as the accuracy of the meaningful values are concerned.

The diagnostic value of the P-A film and this method of assessing craniofacial asymmetry (i.e., the method of indices) is not advocated for most types of routine orthodontic cases. This method of assessment can identify the site and magnitude of craniofacial asymmetry and it is likely that this method would be beneficial for those cases exhibiting "gross" facial asymmetry. The author feels this method is applicable to those patients of surgical or combined surgical/orthodontic therapy in order to establish more "harmonious" facial relationships.

However, it is important to emphasize that craniofacial asymmetry is not limited to one dimension of the face but also to other dimensions. Therefore, the other views of the craniofacial structures should be assessed, coordinated and studied quantitatively. These additional views include a basilar view, 45 degrees right and left oblique views and also lateral cephalometric view. It is also important to recognize that the sample in the present study is a small one and that means and standard deviations should not be considered population norms. Therefore, a larger sample should be assessed using the same method employed in the present study in order to provide more accurate and meaningful values for the site and magnitude of craniofacial asymmetry.

Relative to conventional orthodontics alone, the author would suggest the use of asymmetry assessment in further investigations along the following objectives:

1) assessment of asymmetry of cases exhibiting different types of malocclusion (i.e., skeletal, dental and those of soft tissue origin)
2) the assessment should be a three dimensional one using specific criteria (such as Ackerman and Proffit, 1969

and Biggerstaff et al, 1977)

3) evaluation of the activity of the masticatory system and the performance of the jaw reflexes in rest and/or habitual postural position (electromyographic studies)

4) all the above mentioned objectives should be applied on a larger sample of:

   (1) non-growing males and females sample and/or

   (2) longitudinal assessment of at least a five year period to quantitatively assess the influence of age on the magnitude of craniofacial asymmetry.

SUMMARY AND CONCLUSIONS

CHAPTER VI

SUMMARY AND CONCLUSIONS

This study was undertaken with the following objectives: 1) to establish a method of assessment of craniofacial asymmetry, 2) to quantitatively assess the degree of asymmetry, and 3) to examine the effect of sex on the degree of craniofacial asymmetry.

The sample consisted of 31 female and 32 male adult Caucasians who exhibited no craniofacial abnormalities, mandibular displacement, missing teeth or previous orthodontic therapy. Postero-anterior cephalometric radiographs (P-A films) were obtained for both sexes using a conventional technique but with slight modification.

For the measurement of the relative asymmetry of any given P-A radiograph, 32 landmarks (8 mid-sagittal and 12 paired bilateral landmarks) were used. Six major indices measuring various aspects of craniofacial asymmetry were mathematically designed via a specially developed P-A coordinate computer program. The indices were termed lateral expansion, oblique motion, vertical disharmony, vertical distortion, mid-sagittal distortion and bilateral distortion. In addition, assessment of asymmetry for any given landmarks was also studied. Furthermore, selected angular and linear measurements were also used to evaluate the degree of asymmetry. All the measurements were statistically analyzed to assess the significant difference between the right and left side of the face and between the two sexes.

The significant conclusions of this study were as follows:

1) The craniofacial structures should be considered as a unit built up of a number of semi-independent regions, each with its own pattern of growth and development.

2) Facial asymmetry in non-pathological cases is a natural phenomenon.

3) The growth pattern and development of the craniofacial structures is more harmonized along the vertical axis than the horizontal axis.

4) The degree of asymmetry tended to increase from the midline structures toward the bilateral structures. Thus, the factors responsible for the presence of craniofacial asymmetry is greater along the bilateral structures.

5) Angular and linear measurements gave less confidence in assessment of craniofacial asymmetry.

6) Sex was not a factor in influencing the degree of craniofacial asymmetry.

7) The method of assessing craniofacial asymmetry in this study could be applied for planning the

treatment for cases exhibiting craniofacial abnormalities and requiring surgical intervention.

BIBLIOGRAPHY

BIBLIOGRAPHY

Ackerman, J. L. and Profitt, W. R.: The characteristics of malocclusion; A modern approach to classification and diagnosis. Amer. J. Orthod., 56:443-454, 1969.

Alimchandani, S.: Craniofacial morphology in trisomy 21 (Down's Syndrome) individuals. A cephalometric cross section study. Master's Thesis, University of Manitoba, 1973.

Archer, W. H.: Oral Surgery. 4th Ed., W. B. Saunders Company, Philadelphia, Pennsylvania, 1966.

Balyeat, R. M. and Bower, R.: Facial and dental deformities due to perennial nasal allergy in childhood. Int. J. Orthodontics, 20:445-460, 1934.

Baker, C. G.: Personal communication, 1977.

Barnett, J. W.: Problems of facial asymmetry as diagnosed by the laminagraph; In: Mulick, J. F., Grossman, R. C. and Zaytoun, H. Z. Eds: Proceedings of the Foundation for Orthodontic Research, 4th meeting, 1971.

Berger, H.: Problems and promises of basilar view cephalograms. Angle Orthod., 31:237-245, 1961.

Biggerstaff, R. H., Allen, R. C., Tuncay, O.C. and Berkowitz, J.: A vertical cephalometric analysis of the human craniofacial complex. Amer. J. Orthod., 72:397-405, 1977.

Bjork, A. and Skieller, V.: Growth in width of the maxilla studied by the implant method. Scand. J. Plast. Reconst. Surg., 8:26-33, 1974.

Brodie, A. G.: On the growth pattern of the human head from the third month to the eighth year of life. Amer. J. Anat., 68:209-262, 1941.

Broadbent, B. H.: A new x-ray technique and its application to orthodontia. Angle Orthod., 1:45-66, 1931.

Burke, P. H.: Stereophotogrammetric measurement of normal facial asymmetry in children. Human Biol., 43: 536-548, 1971.

Buxton, L. H. and Morant, G. M.: The essential craniological techniques, Part I. Definition of points and planes. J. Roy. Anthrop. Inst., 63:19-47, 1933.

Chalk, W. N.: The effect of unilateral nasal blockage on the growth of the rat craniofacial complex. A quantified cross and histological microscopic assessment. Master's Thesis, University of Manitoba, 1975.

Chebib, F. S. and Burdick, J. H.: Estimation of measurement error. J. Gen. Psychology, 89:47-58, 1973.

Chebib, F. S. and Chamma, A. M.: Indices of measuring craniofacial asymmetry. In preparation, 1978.

Cheney, E. A.: Dentofacial asymmetries and their clinical significance. Amer. J. Orthod., 47:814-829, 1961.

Clinch, L.: A longitudinal study of the results of premature extraction of deciduous teeth between 3-4 and 13-14 years of age. Dent. Pract., 9:109-128, 1958.

Duncker, G.: Symmetrien and asymmetrien bei bilateral Thieren, Arch. Entweklngsmechn. Organ, 17:533-549, 1904.

Enlow, D. H.: <u>Handbook of Facial Growth</u>. Philadelphia, W. B. Saunders Company, 1975.

Fell, H. B. and Robison, R.: The growth, development and phosphatase activity of embryonic avian femora and limb buds cultured in vitro. Biochem. J., 23:767-774, 1929.

Fisher, B.: Asymmetries of the dento-facial complex. Angle Orthod., 24:179-192, 1954.

Fisher, W. T.: A study of methods of establishing a mid-sagittal plane in posterior-anterior cephalograms. Master's Thesis, Western Reserve University, 1964.

Fogh-Anderson, P.: <u>The Inheritance of Hare Lip and Cleft Palate</u>. Copenhagen, Nyt Nordisk Forlag, 1942.

Frostad, W. A.: Cephalometric analysis of the craniofacial area in Trisomy 21 syndrome (Down's Syndrome). Master's Thesis, Univeristy of Manitoba, 1969.

Gardner, E.: Fundamentals of Neurology. 6th Ed., Philadelphia, W. B. Saunders Company, 1975.

Gorlin, R. J., Pindborg, J. J. and Cohen, M. M.: Syndromes of the Head and Neck. 2nd Ed., New York, McGraw-Hill Book Company, 1976.

Graber, T. M.: Orthodontics Principles and Practice. 3rd Ed., Philadelphia, W. B. Saunders Company, 1972.

Greene, D.: Asymmetry of the head and face in infants and children. Amer. J. Dis. Child., 41:1317-1326, 1931.

Gruneberg, H.: The causes of asymmetry in animals. Amer. Naturalist., 59:325-332, 1942.

Hasse, C.: Uber Gesichtasymmetrien. Arch. Anat. U. Physiol. Anat., 11:119-123, 1887.

Harvold, E. P.: Asymmetries of the upper facial skeleton and their morphological significance. European. Orthod. Soc. Tr., 25:63-78, 1951.

Harvold, E. P.: Cleft lip and palate; morphological studies of the facial skeleton. Amer. J. Orthod., 40:493-506, 1954.

Harvold, E. P., Truque, M. and Viloria, J. O.: Establishing the median plane in postero anterior cephalograms. In: J. A. Salzmann, Ed., Roentgenographic Cephalometrics. 2nd Ed., Philadelphia, J. B. Lippincott Co., 1959.

Hewitt, A. B.: A radiographic study of facial asymmetry. British J. Orthod., 2:37-40, 1975.

Hilton, J.: Muscle and tendon growth. Human Biol., 32:177-189, 1963.

Horowitz, S. L. and Shapiro, H. H.: Modifications of mandibular architecture following removal of temporalies muscle. J. Dent. Res., 30:276-280, 1951.

Hrdlicka, A.: The principle of the humerus in the white races. Amer. J. Phys. Anthrop, 16:431-450, 1932.

Huxley, J.: *Problems of Relative Growth.* London, Methuen and Co. Ltd., 1932.

Jackson, A. F.: Facts fictions and fallacies in orthodontia. Amer. J. Orthod., 23:1073-1095, 1937.

Kimura, D.: The asymmetry of the human brain. Sci. Amer., 228:70-78, 1973.

Koch, J.: Laws of bone architecture. Amer. J. Anat., 21: 177-298, 1917.

Kondo, H.: Postero-anterior cephalometric study of cranio-facial and arch width. Jap. Ortho. Soc. J., 31: 117-136, 1972.

Koptsik, V. A.: *Symmetry in Science and Art.* New York, Plenum Press, 1974.

Krogman, W. M. and Sassouni, V.: *Syllabus in Roentgenographic Cephalometry.* Philadelphia, Philadelphia Center for Research in Child Growth, 1957.

Landauer, W.: Supernumerary nipples, congenital hemihyper-trophy and congenital meiatrophy. Human Biol., 11: 447-462, 1939.

Langerstrom, L. T. and Brodie, A.: A quantitative method for measuring changes in the maxilla due to growth and orthodontic procedures. Angle Orthod., 37:241-250, 1967.

Letzer, G. M. and Kronman, J. H.: A postero-anterior cephalometric evaluation of craniofacial asymmetry. Angle Ortho., 37:205-211, 1967.

Longaere, J. J.: *Craniofacial Anomalies: Pathogenesis and Repair.* Philadelphia, J. B. Lippincott Company, 1966.

Ludwig, W. and Wette, R.: Uber Klassifizierung der asymmetrien und prufung des rechts-links Verhaltnisses insbesondere beim Menschen. Ztschr. Arch. Entweklngsmechn. Organ, 71:400-409, 1958.

Lundstrom, A.: Some asymmetries of the dental arches, jaws and skull and their etiological signficance. Amer. J. Orthod., 47:81-106, 1961.

Marshall, D.: Interpretation of the postero-anterior skull radiograph. Assembly of disarticulated bones. Dent. Radiog. Photogr., 42:27-35, 1969.

Moir, R. W.: A cephalometric analysis of a North American Indian tribe: A cross sectional study. Master's Thesis, University of Manitoba, 1978.

Moloy, H. C.: Studies on head moulding. Amer. J. Obst. and Gynec., 44:762-782, 1942.

Moore, C. V. and Dennis, H. G.: Craniotabes - Its prevalence and significance. Amer. J. Dis. Child., 30:683-689, 1925.

Moore, G. R.: Heredity as a guide in dento-facial orthopedics. Amer. J. Orthod., 30:549-554, 1944.

Moss, M. L.: The functional matrix. In: Kraus, B. S. and Riedel, R. (Eds.), Vistas in Orthodontics. Philadelphia, Lea and Febiger, 1962.

Moyers, R. E.: Handbook of Orthodontics. Chicago, Yearbook, 3rd Ed., 1972.

Mulick, J. F.: An investigation of craniofacial asymmetry using the serial twin study method. Amer. J. Orthod., 51:112-129, 1965.

Parmelee, A. H.: Management of the New Born. Chicago, Yearbook, 1952.

Plint, D. A. and Ellisdon, P. S.: Facial asymmetries and mandibular displacement. Brit. J. Orthod., 1:227-235, 1974.

Pottof, J. L.: An experimental study of bone growth in the dog. Anat. Rec., 10:234-236, 1916.

Pratt, L. W.: Experimental masseterectomy in the laboratory rat. J. Mammology, 24:204-219, 1943.

Ray, L. J.: Cranial contours in the Australian aboriginal. Amer. J. Phys. Anthrop., 18:313-320, 1960.

Reiss, O. and Broder, E.: Congenital cranial osteoporosis: Its etiology and significance. Amer. J. Dis. Child., 59:931-1001, 1940.

Robison, T. G.: Craniofacial asymmetry as studied by postero-anterior cephalometrics. Master's Thesis, University of Michigan, 1966.

Ross, R. B.: Developmental anomalies and dysfunctions of the temporomandibular joint; In: Carlsson, G. E. and Zarb, G. A., Eds.,: Tempromandibular Joint Function and Dysfunction. (In press), 1978.

Ruch, F. L. and Zimbardo, P. G.: Psychology and Life. 8th Ed., Illinois, Scott, Foresman and Company, 1971.

Ryll, U. J.: Bone growth alterations after unilateral masseterectomy or molar extraction: a quantitative microscopic assessment. Master's Thesis, University of Manitoba, 1972.

Sarnat, B. G. and Engel, M. B.: A serial study of mandibular growth after removal of the condyle in the macaca rhesus monkey. Plast. Reconst. Surg., 7:364-379, 1951.

Sassouni, V.: Position of the maxillary permanent first molar in the cephalofacial complex: A study in three dimensions. Amer. J. Orthod., 43:447-510, 1957.

Sassouni, V.: Diagnosis and treatment planning via roentgenographic cephalometry. Amer. J. Orthod., 44: 433-463, 1958.

Sassouni, V.: The Face in Five Dimensions. West Virginia University, Morgantown, 1960.

Sassouni, V. and Forrest, E. J.: Orthodontics in Dental Practice. Saint Louis, C. V. Mosby Company, 1971.

Shubnikov, P. S.: Symmetry. New York, Plenum Press, 1974.

Sicher, H. and DuBrul, L. E.: Oral Anatomy. 6th Ed., Saint Louis, C. V. Mosby Company, 1970.

Scott, J. H.: The growth and function of the muscles of mastication in relation to the development of the facial skeleton and dentition. Amer. J. Orthod., 40:429-449, 1954.

Scott, J. H.: Basal and alveolar bone. Dent. Pract., 5:381-393, 1955.

Scott, J. H.: Muscle growth and function. Amer. J. Phys. Anthropol., 15:197-211, 1957.

Scott, J. H.: The analysis of facial growth: I. The anteroposterior and vertical dimension. Amer. J. Orthod., 44:585-589, 1958.

Scott, J. H.: The analysis of facial growth: II. The horizontal and vertical dimension. Amer. J. Orthod., 44:507-512, 1958.

Scott, J. H.: Dento-facial Development and Growth. New York, Pergamon Press, 1967.

Sollas, W. J.: The sagittal section of the human skull. J. Roy. Anthrop. Inst., 63:389-431, 1933.

Stewart, I.: Concepts of Modern Mathematics. London, Penguin Book, 1975.

Sumner, F. B. and Huestis, R. R.: Bilateral asymmetry in its Relation to certain problems of genetics. Genetics, 6:445-461, 1921.

Thompson, J. R.: Asymmetry of the Face. J. Amer. Dent. Assoc., 30:1859-1871, 1943.

Thompson, D. W.: Growth and Form. Cambridge, Cambridge University Press, 1952.

Tildesley, M. L.: A first study of the Burmese skull. Biometrika, 13:176-262, 1921.

Todd, T. W.: The role of allergy in the etiology of orthodontic deformity. J. Allergy, 10:246 (abst.), 1939.

Truque, M.: A study of the asymmetry of the maxillary dental arch in relation to Raphe Palatinus and the mid-sagittal plane of the upper facial skeleton. Thesis, University of Michigan, 1956.

Vig, P. S. and Hewitt, A. B.: Radiographic study of facial asymmetry. J. Dent. Res., 52:931 (abst.), 1973.

Viloria, J.: A study of the relationship of Raphe Palatinus to the cranio-facial facial skeleton. Term report, University of Michigan, Ann Arbor, 1955.

Ward, J. and Lerner, H. H.: A review of the subject of congenital hemihypertrophy and a complete case report. J. Pediatrics. 31:403-414, 1947.

Washburn, S. L.: The relation of the temporalis muscle to the form of the skull. Anat. Rec., 99:239-256, 1947.

Weyle, H.: Symmetry. Princeton, Princeton University Press, 1972.

Woo, T. L.: On the asymmetry of the human skull. Biometrika, 22:324-352, 1931.

Woo, T. L.: A biometric study of the human malar bone. Biometrika, 29:113-123, 1938.

Woodger, J. H.: The Axiomatic Theory in Biology. London, Cambridge University Press, 1937.

Woods, G. A., Jr.: Changes in width dimensions between certain teeth and facial points during human growth. Amer. J. Orthod., 36:676-699, 1950.

Yates, A. L.: The role of nose and throat disease in production of deformities of the jaw. Dent. Rec., 48:609-617, 1928.

Yen, J. K.: Identification of landmarks in cephalometric radiographs. Angle Orthod., 30:35-41, 1960.

APPENDICES

APPENDIX I

CONSENT FORM

AND DENTAL AND MEDICAL HISTORY

I, ____________________________, do consent to the following dental examinations: models, radiographs (4) and clinical examination.

Signature ________________________ Date _________________________

GENERAL INFORMATION

Name _______________________ Sex ______ Date of Birth __________

Address ________________________________ Tel. No. ________________

Dentist _________________________ Physician ________________________

A. Medical and Dental History

Date of last visit to physician ____________________________

Purpose ____

Childhood diseases ____

Major illness ____

Are you being treated by a physician now (if yes, please state nature of present illness and medication) ________

____

Were there congenital anomalies present? (Cleft Palate, Lip or other head anomalies) ______________________________

Were there any major falls, accidents or operations in the head region? ______________________________

Is there any history of chronic illness or infection? (Asthma, Hayfever or other allergies, ear, nose or throat infection) ______________________________

____

Is there any difficulty in breathing through the nose?

____

Have the tonsils and adenoids been removed? __________

Is there any difficulty swallowing or chewing food? ____

____

Is there any clicking or pain when you open or close your mouth? ______________________________

Is there any history of clenching or grinding of teeth?

____

Is there any history of abnormal habits (finger-sucking, lip-sucking, thumb-sucking, pencil-biting,...etc.)?

____

Have you had orthodontic treatment before? __________

B. Clinical Examination

Muscular tonicity: ( ) normal ( ) hypertonic ( ) hypotonic

Soft tissue facial type: ( ) convex ( ) straight ( ) concave

Soft tissue facial type: ( ) retrognathic ( ) mesognathic ( ) prognathic

Facial structures: ( ) symmetrical ( ) asymmetrical

Dental midline: a) Centric occlusion - ( ) coincident

( ) not coincident

b) Rest position - ( ) coincident

( ) not coincident

Dentoalveolar classification:

Overjet mm Overbite %

Crossbite anterior posterior

Record any abnormality of size, shape and position of teeth.

Tongue size.

C. Functional Analysis

i) Mandibular closure path from rest position to occlusion

____

ii) Inter-occlusal clearance. ( ) Normal

( ) Excessive

( ) Inadequate

iii) Occlusal interferences (premature contacts, initial contacts, etc.) ____________________

____

____

iv) Mandibular movement during opening (limitation, eccentric, symmetrical) ______________________

____

v) Clicking, crepitus of the temporomandibular joints during function. ______________________

____

APPENDIX II

List of landmarks used in the PA analysis.

A. Midline Structure

M1) Neck of Crista-galli:

Intersection point of the perpendicular lamina of the ethmoid with the projection of the floor of the anterior cranial fossa.

M2) Nasal Septum:

Midpoint of the middle third of the osseous nasal septum.

M3) Anterior Nasal Spine:

The most inferior and central point of the nasal septum on the palatal shelf.

M4) Maxillary Alveolar Crest:

The most inferior midpoint on the alveolar crest between the maxillary right and left central incisors.

M5) Upper Incisor:

Midpoint between the permanent maxillary central incisor crowns.

M6) Lower Incisor:

Midpoint between the permanent mandibular central incisor crowns.

M7) Mandibular Alveolar Crest:

The most superior midpoint on the alveolar crest between the mandibular right and left central incisors.

M8) Menton:

The lower most point of the contour of the chin.

B. Lateral Structures (right and left side)

R1,L1) Temporal Point:

The most lateral point on the outline of the cranial vault usually located on the temporal bone.

R2,L2) Orbital-Sphenoidal Point:

Intersection point between the external orbital contour laterally and the oblique line (this is a roentgenographic landmark, not anatomical). Oblique orbital line: projection of the greater wing of sphenoid (Sassouni 1971).

R3,L3) Lateral Orbital Margin:

The mid-orbital point on the external (lateral) bony outline of the orbit of the eye.

R4,L4) Superior Orbital Margin:

The most superior point on the bony outline of the orbital roof.

R5,L5) Medial Orbital Margin:

The midpoint on the internal (medial) bony outline of the orbit of the eye.

R6,L6) Inferior Orbital Margin:

The most inferior point on the bony outline of the orbit.

R7,L7) Zygomatic Process:

The most lateral point on the bony outline of the zygomatic arch.

R8,L8) Condylar Point:

The midpoint on the condylar head.

R9,L9) Latero-nasal:

Point on the outline of the nasal cavity at the widest area in the frontal prospective.

R10,L10) Maxillare:

Upper most point on the maximum concavity of the lateral contour of the maxilla.

R11,L11) Mastoidale:

Lowest point on the contour of the mastoid process.

R12,L12) Gonion:

The lowest posterior and most outward point of the angle of the mandible.

APPENDIX III

The Concept of Best Fit Line

The best fit line is defined in this study as that line which minimizes the sum of squares of the perpendicular distances from the points to the line. The methodology for the calculation of the equation for such a line has not been established in the literature and was therefore worked out in the Biostatistic Section of the Department of Preventive Dental Science. The appropriate computer program was developed within the P-A Coordinate Analysis Program*.

The formula for any straight line between two points is: (see figure A)

$$Y = a + bX$$

where a is the intercept of the line with the Y axis b is the slope of the line ($b = \tan \alpha$) α is the angle the line forms with the positive direction of the X axis.

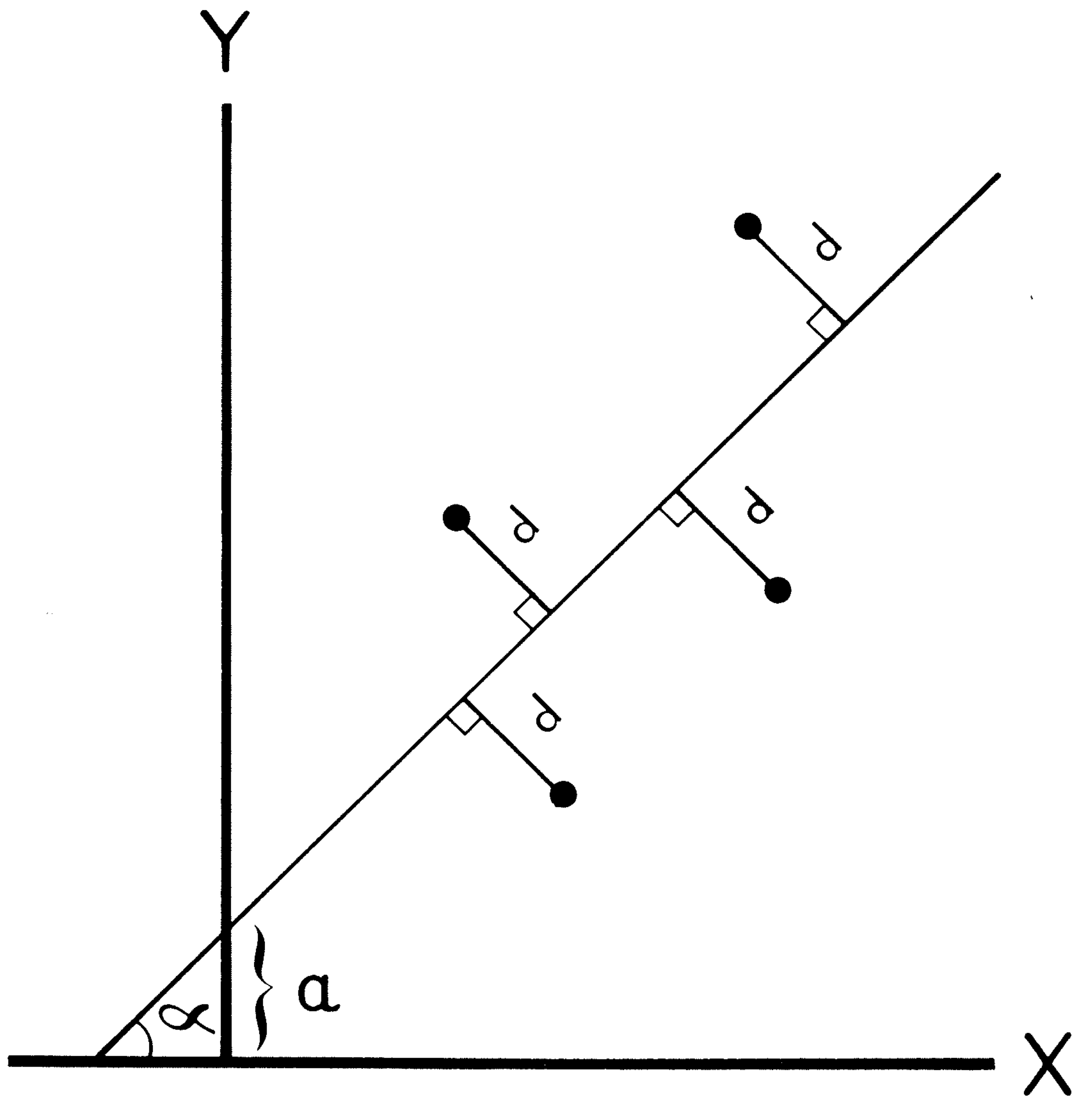
The "best fit line" which minimizes the sum of squares of the perpendicular distances (Σd^2) (see figure A) may be calculated from the two formulas:

$$b = \frac{-1 \pm \sqrt{R^2 + 1}}{R}$$

---

* Chebib, F. S. (1977) Personal communication

Figure A. Line of best fit


Y
d
d
d
d
α
a
X

$$a = \bar{Y} - b\,\bar{X}$$

where $R = 2\Sigma x_i y_i / (\Sigma x_i^{\,2} - \Sigma y_i^{\,2})$

$$x_i = Xi - \bar{X}$$

$$y_i = Yi - \bar{Y}$$

$\bar{X}$ and $\bar{Y}$ are the mean for the X_i and Y_i coordinates and Xi and Yi are the observed coordinates.

APPENDIX IV

Description of Angular and Linear Measurements used in Determining the Error of Measurement:

A. Angular measurements:

1) orbital region: (3R - 5R - 6R)
2) mandibular region: (8R - 8M - 12R)
3) external nasal region: (1M - 9L - 8L)
4) internal nasal region: (1M - 9R - 9L)
5) maxillary region (left side): (1M - 10L - 10R)
6) maxillary region (right side): (1M - 10R - 10L)
7) menton zygomatic region: (1M - 8M - 7R)
8) mental region: (8M - 8L - 12L)
9) gonial region: (8R - 12R - 8M)

B. Linear measurements:

1) spheno-orbital width: (2R - 2L)
2) medio-lateral orbital width: (3R - 3L)
3) infra-orbital width: (6R - 6L)
4) bi-zyogomatic width: (7R - 7L)
5) bi-condylar width: (8R - 8L)
6) bi-mastoidal width: (11R - 11L)
7) bi-gonial width: (12R - 12L)
8) nasal cavity height: (2M - 3M)
9) facial height: (1M - 8M)