GROWTH CHANGES IN THE FACE

A semi-longitudinal cephalometric
study of the Australian Aboriginal
by means of a coordinate analysis

by

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PREFACE

A long-term growth study of Central Australian Aboriginals, living under settlement conditions at Yuendumu, 185 miles north-west of Alice Springs, was begun in 1951 by the Department of Dental Science, University of Adelaide. The first stage of the investigation examined the oral health status of the Wailbri Tribe and serial dental casts were obtained with attention being directed towards the analysis of tooth morphology, occlusal relations and the patterns of mastication (CAMPBELL and BARRETT 1953).

In 1961 the objectives of the study were re-evaluated and its scope was extended with emphasis being placed on dental development and its relation to the patterns of craniofacial and general skeletal growth. On the annual field trips to Yuendumu, the subjects enrolled were examined and various records obtained. The serial material now available for analysis comprises dental casts, standardized roentgenograms of the head in both lateral and P-A positions, roentgenograms of the hand and wrist, observations of selected anthropometric measurements, genealogies and standardized photographic records. BARRETT, BROWN and FANNING (1965) have outlined the objectives of the study, the methodology developed and the progress to date.

BROWN (1965) published an extensive report on prognathism in the adult subjects enrolled in this study, supplementing an earlier cephalometric study on living Aboriginals by CRAVEN (1958). In cross-sectional studies, CRAVEN (1958) and GRESHAM, BROWN and BARRETT (1965) have provided the only comparisons between two Aboriginal age groups.

Maturation of the University of Adelaide cephalometric roentgenogram collection has provided sufficient data for a semi-longitudinal investigation of the Wailbri to be undertaken. The present study has been designed to investigate growth changes occurring in the craniofacial complex of this group of Central Australian Aboriginal children during the period of development from mid-childhood to young adulthood.

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During the field work in Central Australia, assistance was given by the Commonwealth Minister of Shipping and Transport, the Chief Secretary of the South Australian Government, the Director of Welfare of the Northern Territory Administration and his officers, and Mr. and Mrs. T.J. Fleming of Yuendumu Settlement.

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Mrs. I. Zaleski photographed the original illustrations and Mrs. S. Kuusk provided technical and secretarial assistance. Mrs. G. Berry undertook preparation of the manuscript and Miss D. Cella, Mrs. C. Eames and Miss T. A. Gourgas typed the final manuscript. Their efficient cooperation is greatly appreciated.

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SUMMARY

A semi-longitudinal roentgenographic cephalometric investigation was undertaken to provide information on changes occurring in the craniofacial structures of a group of Central Australian Aboriginal children during their period of growth and development. The material consisted of 390 standardized lateral head roentgenograms obtained from males and females whose maturity status ranged from childhood to young adulthood.

For most subjects, born at the settlement in recent years, birth dates were available. However, for many older subjects ages were assessed on general dental and developmental criteria. To avoid inconsistencies all subjects included for study were grouped according to physiologic maturity levels based on eruption status of the teeth. The method of classification and assessment of dental ages was described.

The roentgenographic methods followed those established by BROWN (1965) who, working under similar conditions experienced in this investigation, showed that experimental errors were small and unlikely to influence the results to any appreciable extent.

A coordinate analysis based on the mesh diagram method of analysis of MOORREES (1953) was adopted. However, due to limitations imposed during the collection of data in the field, nasion-sella line was chosen as the line of orientation instead of the vertical extracranial reference line recommended by MOORREES and KEAN (1958). Double determinations of all observations

were undertaken to minimize systematic errors. The roentgenograms were traced and landmarks were located with the use of a simple record reader. Computer facilities were employed to insure that the data had been correctly transcribed to punched cards. The statistical analysis and graphical presentation of results were also performed with the aid of the computing facilities of the University of Adelaide.

The results of the investigation were presented in tabular form and graphically illustrated to show the changes in craniofacial morphology which occurred during growth. Roentgenographic cephalometric standards for males and females, placed within seven groups determined by dental maturity, were presented. Six of these standards were previously unreported. The seventh compares favourably with the findings derived by BROWN (1965) who used a different analysis to investigate most of the present young adults.

Variability of the coordinates of the reference points was indicated in the illustrations by covariance ellipses surrounding the landmarks. These ellipses were constructed as described by McNULTY, BROWN and BARRETT (1968) to show the relative magnitudes of ordinate and abscissa variances and the covariance between them.

Variability of the reference points increased with advancing age suggesting biologic variation between individuals in the study. However, it was noted that variability of the coordinates also tended to increase with the distance between a landmark and the line of orientation. This fact, coupled with the observation of a uniformly negative inclination of the major axes of the covariances for points situated on the facial profile, indicated that a systematic error had been introduced by the orientation method tending to mask the biological variation in the location of landmarks.

Growth in both males and females proceeded downward and forward in a wave-like pattern. The revelation of this pattern of growth was attributed to the use of dental eruption criteria for grouping the subjects in this study instead of grouping them according to their chronologic ages. It was suggested that employment of physiologic maturity levels provided a truer picture of the wave-like variations in the growth pattern.

Growth increments of the lower face were observed to be larger than those of the upper face; the lower facial landmarks tending to have a strong vertical vector of growth, while the upper facial points grew in a more horizontal direction. The greatest increment of growth was between the adolescent and adult standards.

It was observed that a horizontal translation of landmarks occurred during the growth period that coincided with the exfoliation of the deciduous buccal dentition and replacement by their permanent successors. While the more mesial teeth of the buccal segment were being replaced there was an observed decrease in arch length, particularly in the mandible. It was hypothesized that an occlusal readjustment occurred as the mandible shifted bodily downwards and forwards.

Specific differences in the growth pattern of males and females were discernible. These divergent patterns resulted in the sexual dimorphism of size evident in the adult craniofacial complex. The male exhibited a greater increase in overall dimensions than revealed in the opposite sex. The female was found to have a proportionately greater increase in posterior facial height than in anterior facial height, while in the male, anterior and posterior facial height proportions remained almost the same. This is reflected in a greater flattening of the mandibular and occlusal lines in the female. Concomitant with these trends, interincisal relationships also changed; in males the incisor procumbency decreased with age, whereas in females the reverse was found. During the growth period under observation, facial prognathism in the females increased at a greater rate than it did in males.

SIGNED STATEMENT

This thesis is submitted in final fulfillment for the requirements of the Degree of Master of Dental Surgery in the University of Adelaide. Entry to candidature for the Degree was gained by passing a Qualifying Examination of a standard equivalent to the Honours Degree of Bachelor of Dental Surgery. The field of study for this examination was in Dental Anthropology, Roentgenographic Cephalometry and Computer Science.

The thesis contains no material which has been accepted for the award of any other degree or diploma in any University. To the best of my knowledge and belief, it contains no material previously published or written by another person, except when due reference is made in the text of the thesis.

SIGNED:

EDWARD CONROY MCNULTY.

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CHAPTER 1 - CRANIOFACIAL STUDIES OF THE ABORIGINAL

INTRODUCTION

Anthropologists have employed classical craniometric methods since the early 18th century to study variations in human head form. Much of this research was carried out on museum material, but with the introduction of roentgenographic techniques and the pursuant development of cephalometric analysis in the 1930's craniofacial variations could be more readily studied in living subjects. Dental researchers, realizing direct application to understanding the complex factors concerned with malocclusions of the teeth, have carried out extensive cephalometric research in recent years, investigating the normal and abnormal morphology and growth of the dentofacial region.

The craniofacial characteristics of the Australian Aboriginal have been copiously reported over the last century, providing valuable material for comparison with findings from similar studies of other ethnic groups. However, little attention has been given to the growth changes in the dentofacial complex of these people. The present investigation reports on facial changes that occur in a group of Aboriginal children from Central Australia during their period of growth and development.

HISTORICAL BACKGROUND

The Australian Aboriginal has interested the anthropologist ever since DAMPIER (1729) recorded his original observations on the inhabitants of North-west Australia. Reports have ranged from incidental observations of early settlers and explorers to the organized systematic research programs of today. Excellent publications on the general anthropology of the Aboriginal provide a more general description of the Aboriginal than the scope of this investigation allows (SPENCER and GILLEN 1899, ELKIN 1938, and SHEILS 1963).

ANTHROPOMETRY

Craniology, the study of head form and its variation, has long held a prominent position in the field of physical anthropology. For decades, skulls have been described, craniometric data has been analysed, and comparisons have been made between various ethnic groups. With the introduction of roentgenographic techniques living subjects could be included in these investigations and longitudinal growth research could be organized more systematically. Many publications have reviewed the history and techniques of craniometry and cephalometry in physical anthropology (PRITCHARD 1843, TOPINARD 1878, DUCKWORTH 1904, WILDER 1920, KROGMAN 1951a, MARTIN-SALLER 1957, ASHLEY MONTAGU 1960, COMAS 1960, COON 1963, and BROWN 1965). A brief review of craniometric studies concerned with the Australian Aboriginal follows.

Early studies were usually of a descriptive nature and, in the main, dealt with museum material or private collections. DUCKWORTH (1904) described the 38 skulls in the Cambridge University Museum collection, and by providing a summary of previous investigations, with collation of mean values of cranial capacity and craniofacial indices for the total group, he increased his sample size to 214 skulls. Included in the tabulations were the findings of TURNER (1884). His study deserves special mention with our presentday emphasis on cephalometry because he published measurements obtained from rubbings of three skulls which had been sectioned sagittally. Turner also presented a review of the existing literature and credited Blumenbach's description of two Australian skulls, given to him in 1795 by Sir Joseph Banks, for having created interest in this ethnic group.

MORANT (1927) working with a pooled sample of 300 Australian and Tasmanian specimens, which has been carefully sexed, concluded that the skulls from various regions were sufficiently alike to be classified into two types; an Australian Type A and those from the Northern Coast. He gathered his material from 18 reports, dating from Pruner-Bey in 1865 to Schultz in 1918. In a comprehensive survey of almost 1,000 sexed skulls from museums in Adelaide, Melbourne, Sydney and London, HRDLIČKA (1928) found regional variations in his sample but he preferred not to subdivide the skulls into specific morphologic groups.

WAGNER (1937) analysed data from 114 Australian skulls located in museums in Oslo and London as part of a craniologic survey of Oceania. Drawing attention to the fact that this series was distinct from that of Hrdlička, Wagner supported Morant's specific grouping of Northern Australian skulls. However, being unable to confirm that all other regions were sufficiently alike to be classified together, he proposed a graduated sequence of morphogenic types from the Northern Coasts to South Australia.

Significant data collected on field studies during this period include CAMPBELL and HACKETT'S (1927) recording of head dimensions from 57 Arunta tribesmen, with mean values being compared with previously published material. A decade later CAMPBELL, GRAY and HACKETT (1936a, 1936b) reported findings from a study of 48 Central Australian natives grouped according to sex and dental age. The authors concluded that there was no evidence to support the concept of distinct morphologic types among Central Australian Aboriginals.

Contour tracings prepared in three normae from 90 unsexed crania were presented by JONES (1929). However, of much greater significance to the science of anthropology was the scheme of standardization for non-metric characters of the Australian skull put forward by him two years later (JONES 1931). Since then several large studies have been published, including those of KROGMAN (1932) who examined 113 male and 70 female crania from the Royal College of Surgeons Museum, London, and FENNER (1939) presenting observations on over 1,000 sexed specimens classified according to their state of origin.

In a recent series of papers from the Anatomy Department, University of Sydney, LARNACH and FREEDMAN (1964) and LARNACH and MACINTOCH (1966) reported on the non-metric characters in a group of 118 skulls from coastal New South Wales, while FREEDMAN (1964) described metric observations on the same material. MILICEROW (1955), following traditional methods, measured and analysed 94 variables on 80 skulls from the Wrocław collection in Poland. These specimens were said to be a part of a larger series presented by KLAATSCH (1908). Although series numbers published by Klaatsch agreed with the Polish collection, some of the measurements and sexing did not, thus the exact relationship between the two studies is uncertain.

A major stimulus to Aboriginal research over the last forty years has been provided by the Board for Anthropological Research, an institution founded by the University of Adelaide in 1926. Acting in conjunction with the South Australian Museum, the Board has sponsored many investigations on the Aboriginal, of which only those dealing with craniology will be discussed. Contributions previously mentioned are the works of CAMPBELL and HACKETT (1927), JONES (1929, 1931) and CAMPBELL, GRAY and HACKETT (1936a, 1936b). Most research came to a standstill during World War II, but the Adelaide School has been active ever since. A short summary of their writings follow.

Abbie (1947) measured 50 male and 50 female crania in a study of head morphology related to evolution, racial characteristics, heredity and environment. He since has discussed the closure of the cranial sutures in the Aboriginal skull (ABBIE 1950). More recent publications dealt with the selection of reference points and lines for use in comparative craniometry (ABBIE 1936a, 1936b).

Over the last decade, Murphy has investigated several aspects of the Australian skull (MURPHY 1955, 1956, 1957a, and 1957b) and has described the patterns of Aboriginal tooth attrition and temporomandibular joint function (MURPHY 1965). BROWN (1967), studying 100 male specimens from the South Australian Museum has used both craniometry and cephalometry in a multivariate analysis of the Aboriginal skull.

In addition, Abbie has published many reports on the Aboriginal using data derived from a series of field expeditions to various parts of the Australian continent (ABBIE 1963c, 1966). Craniofacial data was presented as part of reports describing the metric and non-metric characters of the Wailbri (ABBIE and ADEY 1955, and ABBIE 1957). Physical changes in Aboriginals following contact with European environments (ABBIE 1960) and the patterns of physical growth in three tribal groups (ABBIE 1961a) have been studied. Craniometric observations were reported in these publications. ABBIE (1961b) has also listed mean values for craniometric variables measured on Aboriginals in the southern coastal regions, the central desert, and the northern coastal area.

CEPHALOMETRICS

Prior to the 20th century, craniology was almost exclusively in the domain of the anthropologists. In the early 1900's, however, orthodontists began relating malocclusions to the face as a whole. Since the work of VAN LOON (1915) and SIMON (1922), orthodontic research has been bound closely to the study of the face.

Following the discovery of X-radiation and the development of techniques for its use, intracranial relationships could be studied in living subjects. Two independent investigators, BROADBENT (1931) and HOFRATH (1931), simultaneously published improved techniques which permitted the practical use of X-rays for such investigations. Since its intorduction, roentgenographic cephalometry has remained almost entirely in the realm of the orthodontist where it has a most direct application in the diagnosis of malocclusions and in facial growth research.

Several excellent publications and reviews of cephalometric roentgenography have adequately documented the history and techniques of this field, including those by DOWNS (1952), BJÖRK (1954), GRABER (1954), SVED (1954), KROGMAN and SASSOUNI (1957), SALZMANN (1961), SCOTT (1963a) and ALLEN (1963). Remarks in this paper shall be restricted to cephalometric research performed on the Australian Aboriginal.

The first application of roentgenographic cephalometry in Aboriginal studies was by CRAVEN (1958). Analysing lateral head roentgenograms obtained from a group of 56 natives from Haast Bluff, Northern Territory, by HEATH (1947), he determined mean values, sex differences and age changes for many craniofacial variables. The investigation was limited by the mixed tribal origin of the subjects and the wide distribution of ages included in each group. However, some interesting comparisons were made with the Swedes and Bantus using Björk's and Down's Analyses. It was quite obvious that the Aboriginal possessed a greater alveolar prognathism than either of the other groups. Furthermore, in contrast to the other ethnic groups, the alveolar prognathism of the Aboriginal appeared to increase with age.

A long-term field study of a group of Australian Aboriginals belonging to the Wailbri tribe has provided cephalometric data from standardized lateral head roentgenograms since 1961 (BARRETT, BROWN and FANNING 1965). Craniofacial variations in young adult members of the tribe were reported in several investigations. Utilizing Björk's analysis, BARRETT, BROWN and MACDONALD (1963a) restricted their observations to the analysis of facial prognathism and outlined the experimental errors involved in the use of roentgenograms to derive indirect skull measurements. Comparisons were made with other ethnic groups. The most striking characteristic of the Wailbri material was the marked alveolar prominence, a finding similar to that reported by CRAVEN (1958).

More general aspects of craniofacial morphology were investigated by BROWN and BARRETT (1964) who reported sex differences in mean values and variances. Correlation coefficients showed a low to moderate relationship between some facial variables. However, very few of the coefficients were high. BROWN (1965) employing correlation and regression analysis gave a more detailed account of variations in facial prognathism in relation to cranial base morphology and the size and shape of other dentofacial structures.

Cephalometric investigations of the Wailbri were initially concerned with craniofacial morphology in adults, but with maturation of this field study sufficient numbers of records have accumulated to permit preliminary study of younger age groups. GRESHAM, BROWN and BARRETT (1965) have compared the facial characters in Australian Aboriginal children with those of children from Melbourne, New Zealand and North America.

The advent of modern computer technology has permitted more sophisticated analyses to be undertaken. Multivariate techniques have been applied to cephalometric data to illustrate the use of factor analysis (BROWN, BARRETT and DARROCH 1965a) and to make factorial comparisons between ethnic groups (BROWN, BARRETT and DARROCH 1965b). Both craniometry and roentgenographic cephalometry were employed in a multivariate analysis of the craniofacial morphology of Aboriginal skulls dating from the period prior to European settlement of Australia (BROWN 1967). As a part of the present investigation, techniques were developed to utilize a method of coordinate analysis (BARRETT, BROWN and MCNULTY 1968a, and MCNULTY, BROWN and BARRETT 1968).

GENERAL GROWTH STUDIES OF THE FACE

Craniologic research on the Australian Aboriginal has been quite extensive as evidenced by the preceding references. However, longitudinal data concerning the growth and development of the face in this ethnic group has yet to be reported. In their cross-sectional studies, CRAVEN (1958) and GRESHAM, BROWN and BARRETT (1965) have provided the only comparisons available between two Aboriginal age groups.

Craven separated his material into young and adolescent age groups and drew comparisons between them. The younger group had a mean age of 7.5, with a range from 4 to 11 years, while the adolescents mean age was approximately 15 years ranging from 12 years to young adults (about 20 years). He showed that growth changes in the Australian Aboriginal facial profile were, in the main, similar to those of other ethnic groups. In particular, both alveolar and basal prognathism increased with age, more so in the mandible than in the maxilla. Gresham and co-workers compared mean values obtained from a group of 7 to 9 year old Aboriginal children with those reported for adult members of the same tribe (BROWN 1965). The results were similar to those of Craven's but there was no attempt to correlate the two studies because the subjects were from different tribal origins and the age and sex distributions did not correspond.

While there has been a paucity of investigations on growth of the Australian Aboriginal face, the literature abounds with studies on the growth of the craniofacial region in other ethnic groups. Excellent reviews on this subject are readily available (KROGMAN 1951a, TANNER 1955, BAUME 1961, SCOTT 1963a, HAATAJA 1963, MOSS 1964, and HAUTVAST 1967).

An active field of modernday research has been the study of mechanisms of growth of the skull. Concepts in this area are still in flux and the literature contains many contradictions. However, a brief outline of the subject would seem appropriate.

The growth of the cranium has long been considered to represent a neural growth pattern while the face exhibits a viseral pattern of growth (WATERY 1933, NANDA 1955, and TANNER 1955). BRODIE (1941), however, regarded both growth of the face and cranium as neural in pattern.

The cranium can increase in size by three methods: growth by superficial bone deposition; growth at the sutures; and transformation of cartilage into bone. HUNTER (1771) and BRASH (1924) believed that the cranium undergoes appositional growth on the outer bony surfaces and resorption on the inner surface of the cranium. The majority of growth providing enlargement of the cranium as a whole has been held, however, to be caused by sutural growth(SCOTT 1948, SICHER 1949, MASSLER and SCHOUR 1951 and BAER 1954). The cranial base increases in size mainly by cartilagenous growth (SICHER 1947, 1949 and SCOTT 1953a, 1958a) and ceases with closure of the spheno-occipital syncondrosis.

Upper facial growth is a combination of sutural and appositional elements (SCOTT 1953b, 1956) while the mandible begins with cartilagenous growth, with later increments being shared by appositional and resorptive vectors along with specific growth centers of cartilagenous activity (SICHER 1947, 1949).

Insight into the complex processes regulating the growth of the skull did not penetrate very far beyond what HUNTER (1771) had pointed out until KEITH and CAMPION (1922) and BRASH (1934) attempted to determine what they called "mechanisms of growth". WEINMANN and SICHER (1955, 1964) believed the proliferating intersutural connective tissue was of essential importance for growth of the skull allowing that cartilagenous growth in the syncondroses and condylar cartilage of the mandible had a similar importance. SCOTT (1948, 1953a, 1953b, 1954, 1955, 1956, 1957, 1958b, 1962 and 1963b) placed a much greater emphasis on cartilagenous growth with sutural growth relegated to a secondary, more adaptive significance. Moss and co-workers, developing the theory of functional cranial components originally put forth by VAN DER KLAAUW (1946), hold to the concept that it is the growth of the soft tissues, or "functional matrices", which makes the cranial bones spread with both sutural and cartilagenous growth being adaptive in nature (MOSS 1960, 1962, 1964, MOSS and YOUNG 1960).

While there may be debates concerning the impetus to, and mechanisms of, growth in localized areas of the skull, it is generally held that over the entire period of growth the cranial bones undergo local modifications as a result of differential deposition and resorptive processes. Recently, Enlow and co-workers have made a detailed study of the patterns by which this happens in the facial skeleton (ENLOW 1962, 1963, 1966, ENLOW and HARRIS 1964, ENLOW and BANG 1965, ENLOW and HUNTER 1966).

It would be impractical to completely review the extensive literature on dimensional growth of the craniofacial complex, and therefore, comment is restricted to cephalometric investigations.

BROADBENT'S (1937) classic work "The Face of the Normal Child" followed his introductory investigation into the development of cephalometric techniques by six years (BROADBENT 1931). His material consisted of 50 girls between the ages of 3 and 18 and 50 boys between the ages of 3 and 12 years. He concluded that the face continues to grow downward and forward until adulthood is reached except for porion and the condyle of the mandible which grow downward and distally.

BRODIE (1941) carried out the first longitudinal roetenographic study on 21 boys between 3 months and 8 years, observing that the growth of the cranium is extremely steady. He expressed the view that the morphogenetic pattern of the skull was determined in the third month of life, or even before this time. In a later publication (BRODIE 1953) he presented data covering the period between 8 and 17 years; again confirming that the individual pattern was fairly constant.

In 1947 BJÖRK published his celebrated work "The Face in Profile" in which he investigated prognathism in 12 year old boys and 20 to 21 year old military conscripts. Comparing data from the two groups he observed a straightening of the facial profile with increased age which he attributed to a proportionally greater increase of mandibular prognathism over that of maxillary prognathism.

GANS and SARNAT (1951) investigated facial growth in monkeys by means of inserting amalgam implants on each side of five craniofacial sutures. LEVINE (1940) had previously used this technique, on three cranial sutures, combined with vital staining in an effort to study cranial growth of the rabbit. Introducing a variation of the method to human facial growth research by implanting vitallium pellets as fixed reference points in the facial bones of subjects, BJÖRK (1955) observed changes in position of the bony outline of the mandible and the erupting dentition in relation to these fixed reference points over a two year period. He presented tracings of lateral cephalograms revealing the path of eruption of the dentition and the direction and amount of bony growth. Using the same method, additional data has been published (BJÖRK 1963) on a preliminary investigation of the growth of the mandible in 45 Danish boys.

In a semi-longitudinal study on boys between 3 and 18 years of age, LANDE (1952) concurred with Björk's 1947 findings, noting that the convexity of the face nearly always decreased and that after age 7 mandibular prognathism tended to increase.

NANDA (1955, 1956) published the results of a longitudinal investigation on a group of 10 boys and 5 girls ranging between 4 and 20 years of age, and observed that growth of the facial dimensions tended to parallel that of the skeletal system in general except for the sella-nasion dimension which followed a neural growth pattern. He also noted that facial growth tended to reach its maximum slightly later than the circumpuberal spurt in stature.

Meredith, in conjunction with a number of co-workers, has been very prolific in this field. POTTER and MEREDITH (1948) investigated the reliability of anthropometric and roentgenographic studies, observing that both gave similar results with the source of error varying from faulty projection in obtaining roentgenograms to mobility and thickness of soft tissues when taking anthropometric measurements. MEREDITH, KNOX, and HIXON (1958) carried out a longitudinal investigation on 27 boys and 28 girls between 4 and 12 years of age, and concluded that the index between nasal height and subnasal height increased with age in both sexes. MEREDITH (1960) investigated changes in the facial proportions with different indices and the correlation between growth increments of the different facial dimensions (MEREDITH 1962). MEREDITH and CHADHA (1962) studies changes in hecd height during childhood and adolescence.

Koski has added to knowledge in the field, carrying out studies of the growth of the upper face and the base of the skull (KOSKI 1960), and growth changes in the relation between the base of the skull and the palate (KOSKI 1961).

BAMBHA (1961), during a semi-longitudinal research project, investigated 25 males and 25 females from 1 month to 30 years. His findings confirmed those of Nanda (1955, 1956), but in addition to the circumpuberal growth spurt, Bambha also observed in most individuals a distinct childhood growth spurt between 6 and 7 years. In 1963 BAMBHA and VAN NATTA published a longitudinal study on 22 boys and 28 girls between 9 years 9 months and 17 years 9 months. Correlating skeletal maturation with facial growth in the sella-gnathion dimension during adolescence, they showed that early skeletal maturers tended to have an early adolescent facial growth spurt while late maturers had a late facial growth spurt. The large middle group however showed a great amount of variation.

HUNTER (1966) studied the correlation between body height and facial growth in 25 males and 34 females from 7 years thru adolescence. He observed a relatively high correlation between increase in body height and mandibular lengthening during the circumpuberal growth period. However, contrary to previous investigations, Hunter's findings showed only 29 per cent of his subjects with maximal facial growth after reaching their maximal increase in body height. Maximal facial growth coincided with the circumpuberal spurt in body height in 57 per cent of his subjects whereas as in 14 per cent of the group studied it occurred before.

BERGERSEN (1966), using the intersection point method of analysis described by him five years earlier (BERGERSEN 1961), studied the growth movements of seven facial landmarks in a semi-longitudinal study on 30 male subjects, aged 1 to 30 years, and 30 female subjects, aged 1 to 23 years. While upper facial landmarks migrated generally in a straight line pattern, the mandible proceeded in a wave-like manner. This deviation from the straight line pattern occurred during exfoliation of deciduous and eruption of permanent incisors when the direction of growth at menton became more horizontal. Once the permanent incisors had erupted the growth trend again reverted to its original direction, maintaining it until adulthood.

Over the last decade several investigations were undertaken to study the relationship between the soft tissue contour and the underlying skeletal profile (BURSTONE 1958, NEGER 1959, SUBTELNY 1959, 1961, and SUBTELNY and SAKUDA 1966). Observations were made that some parts of the soft tissue profile do not necessarily follow the underlying facial skeleton closely and that there is considerable variation between individuals.

In 1967 POSEN presented a longitudinal study of growth of the nose using a sample of 15 boys and 15 girls for whom records were available from 3 months to 18 years of age. He found that boys showed larger nasal component dimensions that did girls, whereas girls appeared to mature more rapidly than did boys. A straightening or humping of the nasal dorsum usually occurred after 14 years since the nose tip did not grow forward to the same extent as did the nasal bones after this age.

LEVIHN (1967) has provided data in a heretofore unavailable area in his cross-sectional study of the craniofacial complex in fetuses from 12 weeks to birth. He found that the rates and proportions of growth in utero are different from postnatal growth. Also, that the maximum rate of growth during fetal life, and for that matter of any time during life, was in the fourth and fifth lunar months.

SUMMARY

The literature review traced the development of cephalometric techniques and outlined selected studies made on skulls and living subjects of different ethnic groups. Great impetus for this type of investigation was provided by the development of improved techniques in roentgenographic cephalometry. Metric and non-metric characters of the Australian Aboriginal skull have been reported extensively. However, only in recent years has it become feasible to study the living Aboriginal in the field with cephalometric equipment. In cross-sectional studies, CRAVEN (1958) and GRESHAM, BROWN and BARRETT (1965) have published the only comparisons between two Aboriginal age groups. Maturation of a long-term cephalometric investigation of the Wailbri tribe in Central Australia (BARRETT, BROWN and FANNING 1965) provided sufficient data for a longitidinal investigation of this group of Aboriginals to be undertaken. The present investigation has been designed to present an extensive report on growth changes occurring in the dentofacial complex of a group of Central Australian Aboriginal children during their period of growth and development.

CHAPTER 2 - MATERIAL AND METHODS

MATERIAL

Recordings were obtained from tracings of 390 standardized lateral head roentgenographs of Central Australian Aboriginals ranging in age from childhood to young adulthood. Both females and males were of pure Aboriginal ancestry so far as could be ascertained.

The Aboriginals studied, though sometimes referred to as the Ngalia, belong to the Wailbri tribe. Several other alternative names for this particular group have been listed by TINDALE (1940). Prior to 1946 they lived under primitive tribal conditions having only rare contact with European-orientated society. Since that time however, the tribe has congregated at Yuendumu Settlement situated 185 miles north-west of Alice Springs in the Northern Territory of Australia.

Culturally the Wailbri are traditionally orienated, and economically at an early stage of transition from a simple food gathering and hunting type of society to the adoption of a European way of life. In their methods of food preparation and eating habits, the group is at a stage intermediate between bush natives and the completely detribalized natives of the cities and towns. The population at the settlement, being geographically isolated, provides a unique opportunity of studying a group of Aboriginals which has not yet been influenced to any great extent by European culture.

TINDALE (1953) attested to the relatively homogeneous makeup of this group when compared with other populations, reporting that of a total of 166 marriages, only 13 (8 per cent) of them were with members of other tribes. Although several Pintubi tribesmen live at the settlement, only records from known members of the Wailbri tribe were accepted for this investigation in order to preserve the homogeneity of the sample.

PREVIOUS STUDIES ON THE WAILBRI

Aspects of the general anthropology of the Wailbri have been published by CAPELL (1952), ABBIE and ADEY (1953a, 1953b, 1955), SIMMONS, GRAYDON and SEMPLE (1954), CLELAND and TINDALE (1953), POIDEVIN (1957), SCHULTZ (1958), ABBIE (1957, 1961a, 1961b, 1963c and 1966), and MEGGITT (1962). Investigations by members of the Department of Dental Science, University of Adelaide dealing more specifically with the dental and craniofacial characteristics of the tribe have been undertaken since 1951 and have recently been comprehensively reviewed (BARRETT, BROWN and FANNING 1965).

The environmental conditions of the Wailbri, particularly their food and water supplies, tooth customs and beliefs have been reported by CAMPBELL and BARRETT (1953), CAMPBELL, SIMPSON, CORNELL and BARRETT (1954), CRAN (1955) and BARRETT (1956a, 1964). The masticatory function of the natives of Yuendumu has been described in a film (BARRETT 1959b) and discussed in relation to dental occlusion (BEYRON 1967). Oral conditions in the tribe have been investigated, particular attention being given to the gingiva (CRAN 1955, 1957), diet and dental caries (CRAN 1959, 1960a), histology of the teeth (CRAN 1960b), oral microbiology (CRAN 1964), oral pigmentation and oral disease (READE 1962, 1964).

In addition, tooth morphology and dental occlusion have been studied, with emphasis on the metric characters of the permanent and deciduous dentitions (BARRETT, BROWN and MACDONALD 1963b, BARRETT, BROWN and LUKE 1963 and BARRETT, BROWN, ARATO and OZOLS 1964), non-metric characters of the permanent dentition (CUUSK, BARRETT and BROWN 1968), the size and shape of the dental arches (BARRETT, BROWN and MACDONALD 1965), the patterns of tooth attrition (BARRETT 1953a, 1960), functional tooth occlusion (BARRETT 1953b, 1957b, 1958) and sequence of tooth eruption (BARRETT 1957a, BARRETT, BROWN and CELLIER 1964, and BARRETT, BROWN and MCNULTY 1968b). Also, the genetic basis of deciduous crown variation is now under investigation (KUUSK 1968).

The introduction of cephalometric roentgenography of the Wailbri in 1961 has permitted investigation of their craniofacial morphology and growth and development. Initial investigations have been cross-sectional in nature, being limited to the young adult population. Particular attention has been devoted to prognathism (BARRETT, BROWN and MACDONALD 1963a, BROWN and BARRETT 1964, and BROWN 1965), the use of factor analysis (BROWN, BARRETT and DARROCH

1965a, 1965b), and the utilization of coordinate analysis (BARRETT, BROWN and MCNULTY 1968a, and MCNULTY, BARRETT and BROWN 1968). Accumulation of material in the younger age groups has permitted craniofacial comparisons with white Australians and North American children (GRESHAM, BROWN and BARRETT 1965).

ASSESSMENT OF DENTAL AGE

Nearly all physical growth standards have been derived from averages taken from large numbers of children examined at different chronologic ages. During recent years however, it has been suggested that growth standards derived from children of similar physical maturity would provide more exacting norms than those based on chronologic age. (KROGMAN 1951b, TANNER 1955, 1961, BAYLEY 1956, GRANT and WADSWORTH 1959, HORDIJK 1961, MOORREES 1966, and HAUTVAST 1967).

Developmental age or physiological maturity is not a new concept. CHAMPTON (1908) first introduced the idea under the name of physiological age. Taking the appearance of pubic hair on the onset of male pubescence, he calculated physiological age as the number of years past or before this event. At present, there are four different systems which can be employed in assessing a developmental rather than a chronologic age for a growing child. They are skeletal age, secondary sex character age, morphological or shape age (size, height, weight, etc.), and dental age. The latter system was the methd of choice in this investigation.

Dental age, based on the eruption time of the teeth, requires only a brief visual examination to assess the subject's dental maturity. Growth of the dentition is intimately associated with the overall growth and development of the craniofacial complex. Assessment of dental maturity is probably a more useful measure of the progress of growth in the craniofacial area than any of the other methods of measuring physiological age. The use of stages of eruption in the permanent dentition offers a further advantage in that these landmarks of maturation appear during the critical growth periods of pre-adolescence and early adolescence. Skeletal development becomes rather quiescent in the 8 to 9 year range in girls and the 10 to 12 year range in boys (TANNER 1964) and thus is less sensitive as a measure of maturity at this critical stage of facial development. In conjunction with the long-term objectives of the overall investigation (BARRETT, BROWN and FANNING 1965), yearly measurements of height and weight have been obtained along with roentgenograms. Future reports will assess the correlation between morphological, skeletal and dental age.

HELLMAN (1923) commented that, "the process of dentition is a physiologic manifestation of growth and is subservient to its variations in rate, acceleration and retardation." Dental maturity standards serve to classify individuals according to their developmental maturity, and consequently eliminate some of the variation in results observed when early and late maturers are grouped together according to chronologic age criteria.

Dental age has been estimated by various methods, generally based on the eruption time of the teeth. MATIEGKA (1921) established average times of eruption on the basis of the appearance in the mouth of one to four teeth of any type of tooth. He then calculated the dental age of a child by counting all the permanent teeth of each type that had not yet reached the full number of four and determined from his tables the age at which each of these conditions should be reached. He did the same for the tooth class that had most recently achieved its full complement of four. The dental age of the individual was determined by calculating the average of these ages.

CATTELL (1928) noted that an abnormal eruption sequence could result in a lowering of a child's previous dental age if Matiegka's method was employed. Thus she counted the number of erupted teeth and determined from tables of mean values the mean age corresponding to this number. STEGGARDA (1945) calculated the arithmetic mean from the average times of eruption of those teeth that emerged between annual examinations. According to him, the dental age, estimated solely on the number of erupted teeth, provides an assessment of the stage of dental development as accurate as more laborious methods.

Means and standard deviations of the time of eruption of each tooth have been derived from data by inspectional methods (HURME 1948, 1949); by fitting a normal curve to the cumulative incidence curve (KLEIN, PALMER and KRAMER 1937); and by probit transformation (CLEMENTS, DAVIES-THOMAS and PICKETT 1953 and DAHLBERG and MENEGAZ-BOCK 1958). KIHLBERG and KOSKI (1954) found a normal distribution present when using the logarithms of the ages of eruption, with conception as the zero point of age. HAYES and MANTEL (1958) employing CORNFIELD and MANTEL'S (1950) adaptation of Karber's method found that this simpler technique yielded similar results to the maximum likelihood methods (i.e.: probit analysis) and recommended its use whenever eruption data adequately covered the range from zero to 100 per cent erupted. They also examined logarithmic and arithmetic normality in distribution of the ages of eruption finding both assumptions apparently reasonable and that neither method was more appropriate.

One should note that the aforementioned works have used eruption of the tooth into the oral cavity as their criteria for dental age. In recent years, observation of the calcification of the developing tooth has provided a new and exciting approach in estimation of dental age. Fanning, Moorrees, Garn and others have taken lateral jaw roentgenograms and ascertained the stage of development of both unerupted teeth and those which have erupted but have not fully completed their root structure. GLEISER and HUNT (1955) showed a high correlation between body height and the calcification of the third molars. GARN, LEWIS and POLACHECK (1958, 1959) studied the variability of tooth formation and LEWIS and GARN (1960) reported on the relationship between tooth formation and other maturational factors. FANNING (1961) published a longitudinal study of tooth formation and root resorption and MOORREES (1959) analysed the dentition of the growing child from 3 to 18 years of age.

One of the characteristics of using eruption status as a criterion of physiologic maturity is that it permits the investigator to divide his material into several phases of levels of development. MOORREES (1966) related the change in dimension of dental arches to the eruption of the permanent teeth. He noted that the increase in arch dimension had a definite spurt-quiescent rhythm which coincided with the eruption of the incisors in the first incidence of rapid increase in dimension and the canines and premolars in the latter rapid dimensional increase.

Birth records have only been kept at the settlement since 1951, thus chronologic age could not be used as a criterion for grouping the subjects of this study. The older Aboriginals, that is those over 15 years of age, and any newcomers who were born in the bush could only have their age estimated. HELLMAN (1927), faced with a similar lack of chronologic age data while studying a collection of North American Indian skulls, derived a classification formulated on the major stages of dental development. These categories, slightly modified and used by BARRETT (1953a) are seen in Table 1.

Subsequent investigations by BARRETT (1957a) and BARRETT,

TABLE 1

Criteria adopted for age-grouping subjects

Age Group	Dental Criteria	Description	Approximate Age in Years
A	Deciduous dentition	Infant	0-5
B	Mixed Dentition	Juvenile	6-12
C	Permanent second molars erupted	Adolescent	13-18
D	Third Molars erupted	Adult	19-29
E		Mature Adult	30-49
F		Aged	50 and over

BROWN and CELLIER (1964) on the timing and sequence of tooth eruption in Aboriginal deciduous and permanent dentitions provided information permitting further subdivision of the dental age group categories. As a point of departure, Barrett's adaptation of Hellman's criteria of dental age was assessed and enlarged upon in order to provide as comprehensive a division of eruption sequence as possible, especially during the period of mixed dentition with its associated rapid growth of the dental arches. Care was also taken to prevent any possibility of an individual being classified in more than one of the groups deliniated; a situation which could occur if using previously reported detailed classifications (HELLMAN 1935 and BJÖRK, KREBS and SOLOW 1964).

During development and testing of the classification, observations were made on the entire collection of 1206 casts obtained from 411 subjects who have been examined during the sixteen years that these field surveys have been undertaken. Actual ages were unknown except for children born at the settlement in recent years.

The estimation of age in children was accomplished chiefly by examination of the teeth erupted into the mouth. Observation of the differential attrition of the molars of young adults and adults provided an estimation of their physiologic maturity. Hospital records, familial history and general physical development were also employed as a guide in determining the age of these subjects.

Gingival emergence was used as the criterion of "eruption".

Therefore, a tooth was considered "erupted" when any portion of the crown, however small, had penetrated the gingivae. In order to prevent any errors in classification, a simple yes/no criterion was evolved to provide as complete coverage of the developmental phases of the dentition as possible without any overlapping of the groups deliniated. Casts of all the subjects were examined independently by two investigators on separate occasions. Any observations which did not coincide were re-examined by both investigators before final classification.

Classification

Dental development may be divided into fourteen stages* as defined by tooth eruption status.

Deciduous Dentition

This period of dental development commences prior to the gingival emergence of the deciduous dentition and is completed with the attainment of the full complement of 20 deciduous teeth. A quiescent period then follows after attainment of occlusal contact by the deciduous dentition.

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* The classification originally evolved contained several stages which were dependent on attainment of occlusal contact by different sets of teeth. However, during examination of the casts it was often found most difficult to make a positive judgement as to whether or not occlusal contact was present in a percentage of the cases. The problem was most notable on making a decision on the arrival at occlusal contact by the permanent maxillary incisors and/or canines. Therefore, categories demanding attainment of occlusal contact were deleted from the classification.

Infant Stage 1 – The period prior to the emergence of the first deciduous tooth.

Stage 2 – Commences with the emergence of the first deciduous tooth

Stage 3 – Commences with the emergence of the deciduous second molars

Stage 4 – Commences with the emergence of the last deciduous tooth.

Mixed Dentition

This period of dental development commences with the emergence of the first permanent tooth and is completed with the first loss by exfoliation of a deciduous canine or molar.

During the first phase of the mixed dentition, the permanent first molars are emerging or have reached occlusal contact and the deciduous incisors are being replaced or have been replaced by their permanent successors. Two stages can be distinguished within this first phase of the mixed dentition; an early active stage when teeth are emerging, and a quiescent stage after the attainment of occlusal contact by the permanent first molars and the incisors.

Early Juvenile Stage 1 – Commences with the emergence of the first permanent tooth.

Stage 2 – Commences with the emergence of the permanent maxillary central incisors.

Stage 3 - Commences with the emergence of the permanent maxillary lateral incisors.

The second phase of the mixed dentition commences with the first loss by exfoliation of a deciduous canine or molar and is completed when the last deciduous tooth has been exfoliated. During this period of dental development, the deciduous canines and deciduous first and second molars are being replaced by their permanent successors and the permanent second molars are emerging. Owing to the wise variation in eruption sequence only two stages can be distinguished within this second phase of the mixed dentition.

Late Juvenile Stage 1 - Commences with the exfoliation of a deciduous canine or molar.

Stage 2 - Commences with the emergence of the maxillary second premolars.

Adolescent Dentition

This period of dental development commences with the loss by exfoliation of the last deciduous tooth and is completed with the emergence of the third molars. There is a brief period of quiescence during this stage when all the teeth of the adolescent dentition have attained occlusal contact.

Adolescent Stage - Commences with the exfoliation of the last deciduous tooth.

Adult Dentition

This period of dental development commences with the emergence of the third molars and is completed with the attainment of occlusal contact of the complete permanent dentition.

Adult Stage 1 - Commences with the emergence of the third molars.

Stage 2 - Commences with the attainment of occlusal contact by all the teeth of the permanent dentition.

SELECTION OF SUBJECTS

At the commencement of this investigation there was available for study a total of 502 sets of cephalometric records on 224 subjects. In order to make full use of the material at hand, a semi-longitudinal technique of selection of the subjects was employed. In this case any individual with multiple cephalometric records could be represented in successive dental age groups but not repeated within the same age group. There were 103 individuals with multiple records capable of being represented in two or more dental age groups. As a result, the final sample size to be analysed was increased from 224 to 390 cephalograms. The sex distribution of the subjects included in the investigation are shown in Table 2.

The distribution of ages of the subjects within each group is presented in Table 3. As most previous growth studies have been based

TABLE 2

Sex distribution of subjects studied

Dental Age Group	Male	Female	Total
Early Juvenile Stage 1	11	9	20
Early Juvenile Stage 2	25	14	39
Early Juvenile Stage 3	33	22	55
Late Juvenile Stage 1	49	40	89
Late Juvenile Stage 2	19	11	30
Adolescent Stage	49	43	92
Adult Stage	34	31	65
TOTAL	220	170	390

TABLE 3

Age distribution of subjects studied (Age in years)

Dental Age Group	n	Minimum	Mean	Maximum	Median
Early Juvenile Stage 1	♂ 11	5.42	6.27	7.08	6.25
	♀ 9	5.50	6.22	7.08	6.08
Early Juvenile Stage 2	♂ 25	6.00	7.79	9.83	7.92
	♀ 14	6.17	7.10	7.92	7.17
Early Juvenile Stage 3	♂ 33	7.00	8.88	11.50	8.83
	♀ 22	7.33	8.40	9.58	8.38
Late Juvenile Stage 1	♂ 49	7.92	10.56	13.25	10.75
	♀ 40	7.42	9.79	12.33	9.67
Late Juvenile Stage 2	♂ 19	8.92	11.68	13.33	12.00
	♀ 11	9.83	10.87	11.83	10.75
Adolescent Stage	♂ 49	9.75	13.02	16.25	13.33
	♀ 43	10.33	12.45	15.17	12.17
Adult Stage	♂ 34	14.58	21.77	30.00	20.50
	♀ 31	14.42	20.91	30.00	20.00

on chronologic age with data generally presented in yearly increments, Table 4 is given to show the incremental increase between dental age groups for males and females and the age difference between the male and female mean ages for each group. While the age difference was negligible in Early Juvenile Stage 1, the male was slightly older and this difference in chronological age increased in the ensuing dental age groups, thus supporting the contention that females develop at an earlier age than males.

In addition to these individuals with longitudinal records which could be represented in several age groups, the occasion often arose where subjects had from two to four longitudinal roentgenograms congregated in the same age group. In order to make an unbiased selection for inclusion in the investigation, a method of random sampling was devised as follows and numbers were read from "Random Sampling Numbers" arranged by TIPPETT (1937).

Random Sampling

If Two Sets of Cephalograms - Assigned odd numbers 1,3,5,7,9 to the early cephalograms and even numbers 2,4,6,8,0 to the later cephalograms. Read numbers from random table to select the cephalogram to be used in the investigation.

If Three sets of Cephalograms - Assigned odd numbers to Set No. 1 add even numbers to Set No. 2. Read random tables. Repeated from Set No. 1 vs. Set No. 3. Repeated for Set No. 2 vs Set No. 3. If one

TABLE 4

Age comparisons of the dental groups studied

Dental Age Group		Increment in Mean Ages Between Dental Age Groups	Mean Ages	Sex Differences (♂ - ♀) in Mean Ages
Early Juvenile Stage 1	♂	-	6.27	0.05
	♀	-	6.22	
Early Juvenile Stage 2	♂	1.52	7.79	0.69
	♀	0.88	7.10	
Early Juvenile Stage 3	♂	1.09	8.88	0.48
	♀	1.30	8.40	
Late Juvenile Stage 1	♂	1.68	10.56	0.77
	♀	1.39	9.79	
Late Juvenile Stage 2	♂	1.12	11.68	0.81
	♀	1.08	10.87	
Adolescent Stage	♂	1.34	13.02	0.57
	♀	1.58	12.45	
Adult Stage	♂	8.75	21.77	0.86
	♀	8.46	20.91	

set was picked more than once, selected this set of cephalograms to be used in the investigation; if not then repeated the whole procedure.

1 2 1 3 3 2

odd vs even   odd vs odd   odd vs even

Only possible combinations - 11112222
11333131
23233223

Thus 1, 2, and 3 dominate twice and the combination 1, 2, 3 appears twice.

If Four sets of Cephalograms - Assigned odd numbers 1, 3, 5, 7, 9 to the earliest two sets of cephalograms and even numbers 2, 4, 6, 8, 0 to the later two sets of cephalograms. Read numbers from random table. After having reduced the sample in half, proceeded to select final set of cephalograms by assigning odd numbers to earlier cephalograms and even numbers to the later cephalograms. Once again read numbers from the random table to select the cephalograms to be used in the investigation.

DENTAL STATE

During the yearly expeditions throughout the course of this long-term investigation each subject has had his dental state assessed and recorded. The mouth has been examined and dental casts were obtained for each subject. In addition, dental roentgenographs have been taken on selected expeditions. Publications with observations dealing specifically with the dental state of the Wailbri at Yuendumu have been published by BARRETT (1953a), CRAN (1955, 1957) and BARRETT, BROWN and MACDONALD (1963a).

These studies all reveal an incidence of dental disease lower than would be seen in European communities, but possibly higher than with typical nomadic native groups. It is believed that the introduction of civilized food habits may be a factor in the deterioration of native dental health.

BROWN (1965) reporting on the dental state of 58 young adult Wailbri noted that tooth loss from dental caries, as apart from accidents, occurred in only 6 of the subjects. This, in contrast to the finding that 8 teeth, all among males, had been lost by ceremonial evulsion alone. He also stated that the group had a total of 29 amalgam restorations placed in 14 subjects by visiting Government dentists, which once again illustrates the low incidence of dental decay in this group.

CEPHALOMETRY - FIELD METHODS

The roentgenographic methods employed were essentially the same as those described by BROWN (1965). These followed closely accepted methods previously published (KROGMAN and SASSOUNI 1957, SALZMANN 1961) except for certain modifications required by the nature of the investigations.

X-ray Unit and Power Supply

A Watson Victor Model Konrad 3T X-ray machine was modified for use in the field. In order to simplify transportation, the X-ray head and control unit were dismantled and shipped to Yuendumu.

Upon arrival, the X-ray head was reassembled on a prefabricated steel stand and connected up with the power supply through the control unit. The head was fitted with a lead cone to reduce scatter radiation to a minimum.

The power supply at the settlement was generated by a 20 Kv A alternating current generator powered by a diesel motor. It provided a current of 240 volts A.C. which was found to remain reasonably stable during operation of the X-ray machine.

Cephalostat

The head-holder, designed by M.J. Barrett, was similar to that suggested by BJÖRK (1950). The main structure was cast in aluminium and contained a simple lever mechanism which moved the right and left ear-rods simultaneously so that the median sagittal plane remained constant for all subjects regardless of age or head breadth. The ear-rods were made of two hollow steel tubes embedded in perspex to facilitate checking of superimposition of the right and left sides. These rods in turn were fitted into wooden supports which fastened to the lever system above.

When used in conjunction with the ear-rods, a median nasion rest, which could be adjusted vertically and horizontally, permitted fixation of the subject's head. An orbitale indicator was provided to facilitate checking of head orientation after rotation of the subject for A-P films. The head-holder was capable of being rotated "en masse" on its support through 90 degrees with locking pins located at both 45 degrees and 90 degrees. Figure 1 illustrates the cephalostat as it was used on location.

As with the X-ray head, the cephalostat was shipped to the settlement then reassembled to a prefabricated Dexion stand and securely bolted to the floor. A built-in spirit level on the head holder facilitated the alignment procedure.

Method of Alignment of Apparatus

Once the X-ray head and cephalostat were preliminarily bolted to the floor, final alignment of the anode of the X-ray unit with the ear-rods were undertaken. The ear-rods were first sighted along the path of the central X-ray beam with a string. When considered aligned, a dental film was taped to the cassette holder and exposed. If the center of the right and left ear-rods and the anode were perfectly aligned, the images of the right and left ear-rods appeared as concentric circles without distortion in any direction. Once this test was satisfied, the stands were fixed and maintained in their positions for the remainder of the expedition. Two or three daily test exposures insured correct alignment of the apparatus throughout the period in the field.

Specifications of X-ray Beam

The anode to film distance was set at 195 cm. with the anode to median sagittal plane distance being a constant 180 cm. Due to a relatively

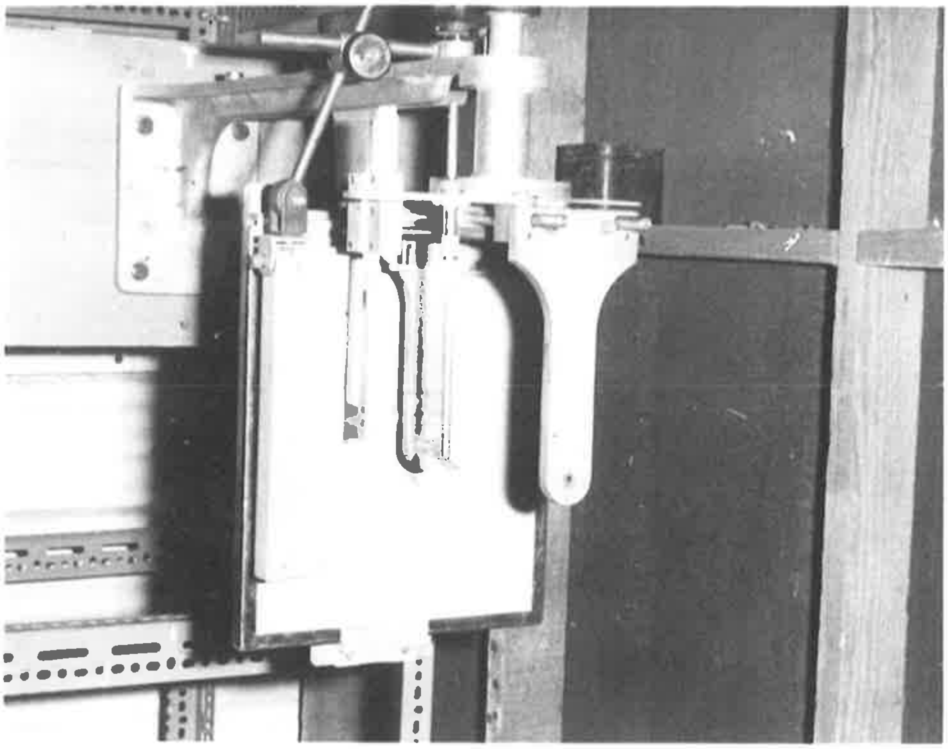

Fig. 1 - Three-quarter view of cephalostat used during field expeditions at Yuendumu Settlement.

short cervical spine which is a characteristic of the Australian Aboriginal (JONES1938) it was difficult for many of the older aboriginals to adjust to the median sagittal plane - film distance of 10 cm. as used by BJÖRK (1950) without severe distortion of the shoulders. As a result, the median sagittal plane to film distance was set for all subjects at 15 cm. The porionic plane to film distance was also a constant 15 cm. when P-A films were taken.

Enlargement Factor

The above distances produced a calculated enlargement of 8.3 per cent for linear structures situated in the median sagittal plane. A leaded millimeter rule was suspended in the median sagittal plane to produce an image of known length on the roentgenographs (ADAMS 1940) and measurement of this image confirmed that all films were subject to a constant 8.3 per cent magnification.

Soft Tissue Contrast

In order to obtain a good soft tissue profile the cephalostat was equipped with an alumimium wedge 250 mm X 65 mm X 20 mm tapering to 1 mm which was placed between the facial profile and the cassette at the time of exposure of the lateral films. This technique provided a well defined soft tissue profile shadow without detracting from the clarity of the underlying bony structures.

Positioning of Subjects

Subjects were positioned in the cephalostat in the following manner. Asked to sit in an adjustable chair fitted with castors, the subject's sitting height was adjusted so that the external auditory meati were level with the ear-rods of the head-holder. The chair was then rolled into place and natural head position was obtained by asking the subject to focus his eyes on a spot at eye level on the far wall. The ear-rods and then the nasion support were moved into position; the orbitale indicator was adjusted. After three lateral exposures had been made, the cephalostat and subject were rotated 90 degrees and a film was obtained in the P-A position. Although this investigation deals only with results obtained from lateral films taken in the tooth position, other exposures were made during the expeditions for future research.

Some difficulty was encountered in taking the tooth position roentgenograms because a significant number of the subjects, especially in the older groups, possessed occlusal relationships that varied from the classic concept of centric occlusion. These Aboriginals possessed a dentition which was incapable of maximum interdigitation of the left and right sides simultaneously due to a disparity in the widths of the upper and lower dental arches. BARRETT (1958) first described this condition in the Wailbri; it has subsequently been found present in a different group of Aboriginals (HEITHERSAY 1961). In order to minimize any discrepancy, the tooth position was visually checked in most instances before the roentgenogram was exposed.

Precautions Against Excessive Radiation Exposure

Monitoring the X-ray unit in Adelaide showed that the anode delivered a skin dose of 0.1 roentgen per second at a distance of 180 cm. from the anode. Scatter radiation amounted to 6 milliroentgens per 250 seconds. Since most subjects received four exposures, each of 0.5 seconds, their total skin dose to the head region amounted to 0.2 roentgen. All subjects were required to wear a lead apron during exposure to radiation to decrease body abosrption of scatter radiation. During field work, members of the expedition were given monitor badges which were also strategically placed around the work area. These films were later developed and attested to be within accepted safe limits by South Australian Health officials.

Film Information

All cephalometric exposures were made on Kodax 25 cm x 30 cm. (10" x 12") Blue Brand Safety Film with alignment tests being taken with standards dental films. Each head film was loaded into a Watson Victor Kotak cassette fitted with two Dupont Stainless Fast Speed intensifying screens.

Six cassettes were used which permitted the cephalostat operator to take the multiple exposures required in rapid succession and yet have extra cassettes available should movement of a subject have necessitated a repeat exposure. The cassettes were loaded and unloaded in a portable "dark room" tent which was designed especially for field work. All film,except for each day's supply, was kept in the living quarters where it was stored in light-proof containers in a cool location. A lead-lined box was used to store the day's supply of film with unexposed film being taken as needed and then being replaced immediately after exposure.

All films exposed were labelled for ease in identification. This was accomplished by clipping lead numbers, which corresponded to the subject's expedition number, onto the lower left corner of the cassettes prior to exposure. After exposure, the cassettes were unloaded, and with the exception of test films, the roentgenograms were placed back in their original paper folders to be packed and shipped to Adelaide for processing. After developing, the films were identified by the subject's expedition number and details of name, age group, expedition number, and master code or delta number were printed on the film.

Exposure Date

During preparation for the field expeditions, trial exposures were taken of several European subjects in Adelaide in order to determine the most suitable length of exposure for field use of the equipment available. Roentgenograms of satisfactory quality with sufficient contrast for ease in landmark identification were obtained on both children and adults when the following settings were used:

Film	Power	Current	Time
Lateral Head Roentgenograms	78 Kvp	15mA	0.5 sec.
P-A Roentgenogram	78 Kvp	15mA	0.5 - 0.75 sec.

FILM PROCESSING

The roentgenograms were developed in Kodax liquid X-ray developer Type 2, and fixed in Kodax liquid X-ray fixer according to the recommended time - temperature specifications of the manufacturer. A final wash of about one hour was given in clear running water, after which the films were allowed to dry at room temperature. The corners of the roentgenograms were then trimmed and each film was placed in a paper folder to prevent scratching. Each subject's films were placed in a manilla folder and filed in delta number order for future reference. When filed in this manner the longitudinal record of each subject was available for immediate perusal.

TRACING METHOD

Lateral head cephalograms for this investigation,selected as previously described, were traced with a 6H pencil on to permatrace films of 0.05 mm. thickness. All tracing was performed on a standard adjustable drawing board modified by inclusion of a back-illuminated translucent viewing screen. Separate switches for three fluorescent bulbs permitted controlled illumination. The drawing board was adjustable to provide the investigator with the maximum of support for the forearms at a comfortable position to retard the onset of fatigue.

REFERENCE POINTS

The reference points located on each roentgenogram and transferred to film tracings are illustrated in Figure 2 and defined below. All reference

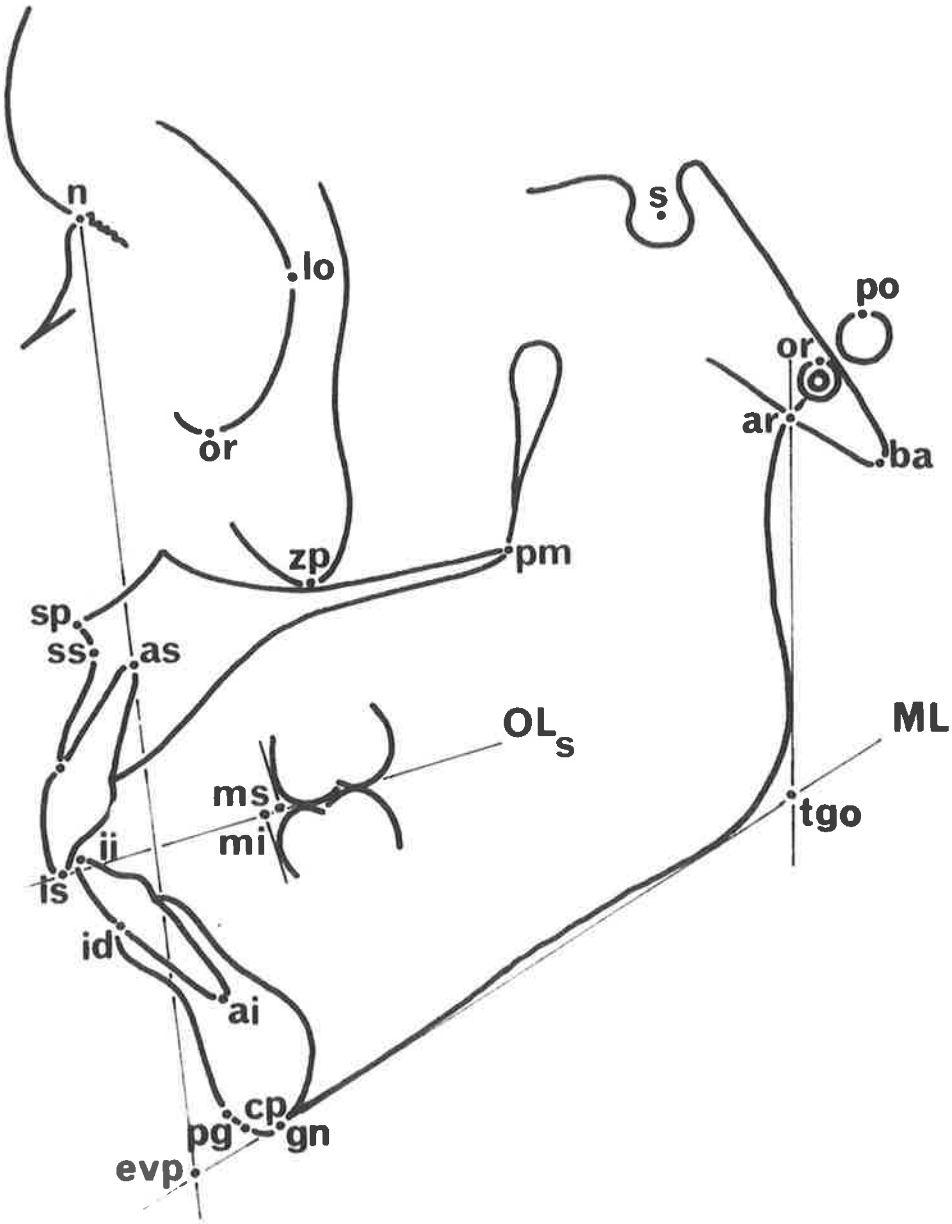

Fig. 2 - Reference Points and Lines.

points were situated in the median sagittal plane or were projected on to that plane. When double projection occurred mid-points of the two images were used.

Apart from the reference points ear-rod, porion and EVER line point, all landmarks were located according to the definitions of MOORREES (1953) or BJÖRK (1960) as indicated.

Anterior Cranial Base Region

Nasion (n)* :Most anterior point of the fronto-nasal suture.

Sella (s) * :Center of the bony crypt known as the sella turcica. The upper limit of the sella turcica is defined as the line joining the tuberculum sellae and the dorsum sellae.

Lateral orbit (lo)°:Most posterior point on the curved lateral border of the orbit.

Orbitale (or)* :The deepest point of the infraorbital margin.

Zygomatic process (zp)°:Lowest point of the projection of the zygomatic processes.

Maxilla

Spinal point (sp)* :Apex of the anterior nasal spine. This point is also referred to as acanthion.

Pterygomaxillare (pm)* :Point representing the dorsal surface of the

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* Landmark defined according to BJÖRK (1960)
° Landmark defined according to MOORREES (1953)

maxilla at the level of the nasal floor. The point is located on the dorsal contour of the maxilla, which, above, forms the anterior limit of the pterygo-palatine fossa, where this contour intersects that of the hard and soft palates.

Subspinale (ss)*: Deepest point on the anterior contour of the upper alveolar arch. This point is also referred to as point A.

Prosthion(pr)*: Lowest and most prominent point on the upper alveolar arch.

Apex superius (as)°: Apex of the root of the most prominent maxillary central incisor.

Incision superius (is)*: Mid-point of the incisal edge of the most prominent upper central incisor.

Molare superius (ms)*: Mesial contact point of the upper first molar projected normal to the superior occlusal line.

Mandible

Molar inferius (mi)*: Mesial contact point of the lower first molar projected normal to the superior occlusal line.

Incision inferius (ii)*: Mid-point of the incisal edge of the most prominent lower central incisor.

Apex inferius (ai)°: Apex of the root of the most prominent central incisor.

Infradentale (id)*: Highest and most prominent point on the lower alveolar arch.

Pogonion (pg)*: Most prominent point of the chin.

Chin point (cp)°:Lowest and most anterior point on the curvature of the body of the bony chin between pogonion and gnathion. This point is similar in location to prognathion.

Gnathion (gn)*:Lowest point of the mandibular symphsis.

Gonial tangent point (tgo)*:Intersection between the mandibular line (ML) and the ramus line (ar-tgo).

Posterior Cranial Base Region

Basion (ba)*:Normal projection of the anterior border of the occipital foramen (endobasion) on the occipital foramen line.

Articulare (ar)*:Intersection between the contour of the external cranial base and the dorsal contour of the condylar head.

Porion (po):Highest point of the usually ovoid shadow of the external auditory canal.

Ear-rod (er):Mid-point on the upper border of the ear-rod shadows. This point is the same as that defined as porion by Björk.

Extracranial Reference Point

EVER line point (evp): Point where the extimate of the true vertical extracranial reference line passing through nasion intersects a horizontal line passing through gnathion.

True vertical extracranial reference line has been defined as a line perpendicular to the horizontal when the subject's head is in natural position. BROCA (1862) defined this position of the head as follows:

"when a man is standing and when his visual axis is horizontal, he (his head) is in the natural position".

In this study the vertical extracranial reference line was estimated on the roentgenogram tracings after inspection of orthogonal profile photographs obtained with the subjects seated comfortably with their heads in an unstrained position.

Reference lines used for the determination of some of the reference points are defined as follows:

Mandibular line (ML)*: Tangent to the lower border of the body of the mandible through gnathion.

Occlusal line, superior (OL_s)*: Line through the incision superius and the distobuccal cusp of the upper first molar. (If this tooth is absent the mesiobuccal cusp of the upper second molar).

Ramus line (ar-tgo)*: Tangent to the posterior border of the mandibular ramus and through articulare.

STATISTICAL METHODS

Estimates of the descriptive parameters were calculated for each male and female dental age group. Mean, standard deviation, standard error of the mean, and maximum and minimum were computed for both abscissa and ordinate of each of the reference points recorded according to the following formulae:

$\bar{x}$	Mean	$\frac{\Sigma x}{N}$
s	Standard deviation	$\sqrt{\frac{\Sigma (x - \bar{x})^2}{N - 1}}$
$\bar{x}$	Standard error of the mean	$\frac{s}{\sqrt{N}}$

Besides the absolute values listed, proportionate values were calculated and recorded for each dental age group. Proportionate values of both abscissa and ordinate for each of the reference points were based on a coordinate's position in relation to the total mesh area and expressed in per cent of the total grid size.

Due to the emphasis in the present investigation on the use of coordinate analysis, the requirements of this technique demanded particular attention. Accordingly, they were dealt with in the following chapter devoted solely to coordinate analysis. Special statistical procedures required for determination of the covariance between abscissa and ordinate of each variable were also computed and likewise are discussed in subsequent sections.

In addition, estimates of several other parameters were computed but are not listed in the tables. They include the range, the coefficient of variation and measures of skewness and kurtosis. The latter two parameters were calculated using the method of PEARSON (1931) and RAO (1952) as described by SOLOW (1966). Normally they require sample sizes in excess of 100 for significance limits to be considered reliable. Due to the small sample sizes of each separate group in this investigation, the parameters, while calculated for general interest by the investigator, are not presented in this report.

RELIABILITY OF ROENTGENOGRAPHIC DATA

Cephalometric roentgenography has been adopted as a tool by physical anthropologists and orthodontists because it is the only method for examining the craniofacial structures of living subjects with any degree of thoroughness and accuracy. However, when using this technique certain errors of observation invariably arise through biologic and technical limitations. Nevertheless, the use of any method is justified if it can be shown that the various sources of error in the technique do not seriously affect true values.

The sources of systematic and accidental errors that occur in cephalometric roentgenography have been investigated extensively by many workers including BJÖRK (1947), POTTER and MEREDITH (1948), FRANKLYN (1952), WERNER (1955), HIXON (1956), HATTON and GRAINGER (1958), HALLETT (1959), GRØN (1960), BJÖRK and SOLOW (1962), BROWN (1965), RICHARDSON (1966), SAVARA, TRACY and MILLER (1966) and HOLLENDER, KAASILA and SARNÄS (1968). Although the shortcomings of the technique were recognised, their conclusions emphasised the usefulness of cephalometric roentgenography as a clinical and research tool as long as these deficiences were taken into consideration.

In 1965, BROWN examined the extent of errors in field investigations using roentgenographic cephalometry. During statistical analysis of the data he followed the method of DAHLBERG (1940). Brown showed that the systematic and accidental errors inherent in the study did not seriously affect the results. The linear and angular measurements recorded were therefore reasonably close to their true values. Roentgenograms of the subjects analysed during his study form a part of the cephalometric material under investigation at the present time. As the method for taking lateral head cephalograms on field trips to Yuendumu has undergone few changes, it would be assumed that experimental errors would remain similar in magnitude and it would be superfluous to perform new estimations of the errors involved.

POTTER and MEREDITH (1948), while comparing cephalometric and anthropometric methods of measurement, found that the roentgenographic technique was superior to, or at least as good as, the latter method depending on the measurement being taken. SAVARA, TRACY and MILLER (1966) remarked that landmark location variability was about five times that due to measurement. RICHARDSON (1966) noted that certain points were more reproducible vertically than horizontally, while the reverse may hold true for other landmarks. Attempts to reduce reading and measurement errors to a minimum were carried out in this investigation. They are discussed separately in a subsequent section.

CHAPTER 3 - COORDINATE ANALYSIS

INTRODUCTION

Most investigations of craniofacial morphology have utilized various linear, angular or proportionate measurement to express the size, shape and relations of components of the skull. These variables are defined by craniometric reference points and once measured on a sample of skulls can be subjected to statistical analysis. The present study, however, departs from conventional methods by using coordinates of selected reference points in place of linear and angular measurements. The coordinates of a reference point define precisely the location of that point within the skull and are treated like conventional variables in statistical analysis. Thus the morphological characters under examination are described in terms of Cartesian coordinates of selected reference points. The present chapter first presents an historical account of coordinate systems in measurement and analysis, and goes on to describe the system used for the present investigation.

HISTORICAL BACKGROUND

Centuries before orthodontics became a recognised speciality of dentistry and the orthodontist turned his attention to facial form and its interrelation with malocclusion, artists had expressed and described the laws of facial proportion. ALBRECHT DÜRER (1532) has often been credited with having introduced the proportional or mesh technique (DE COSTER 1939, MOORREES and LEBRET 1962). Undeniably, his graphic illustrations and versatile adaptation of the coordinates to demonstrate variations in facial features (Figures 3 and 4) served to propagate and popularize the technique.

However, GARDNER (1959) stated that Dürer gained this knowledge of art theory while in Italy.

> "On his trips to Italy he was much impressed by the painters and by the 'secrets' of their art which he endeavoured to learn. He studied perspective and the theory of proportions in order to capture the logic and order which characterized the High Renaissance in Italy."

PANOFSKY (1955) confirmed this, stating that Dürer made two trips to Italy: one to Venice in 1494, and another from 1505 to January 1507 during which he wrote a letter stating he was looking forward to his visit to "....Bologna where he expected to receive instruction in the 'secret art of perspective'."

The originator of the theory of art perspective in all probability shall remain an enigma. Nevertheless, O'MALLEY and SAUNDERS (1952) have shed some light on the subject. Referring to figures drawn by daVinci (Figure 5) in their publication "Leonardo da Vinci on the Human Body", they made the following statement:

> ".....However, these diagrams are important for another reason since they demonstrate the technique of 'transformation' or parallel projection whereby any required diagram can be developed from any two others provided that the latter occupy planes perpendicular to one another.... This method of construzione legittima had already been employed by mediaeval architects but was restricted to buildings and architectural details. Its application to the human figure developed into a special branch of renaissance art-theory and according to Giovanni Paolo Lomazzo (1584) it became almost a speciality of the Milanese such as Vincenzo Foppa and

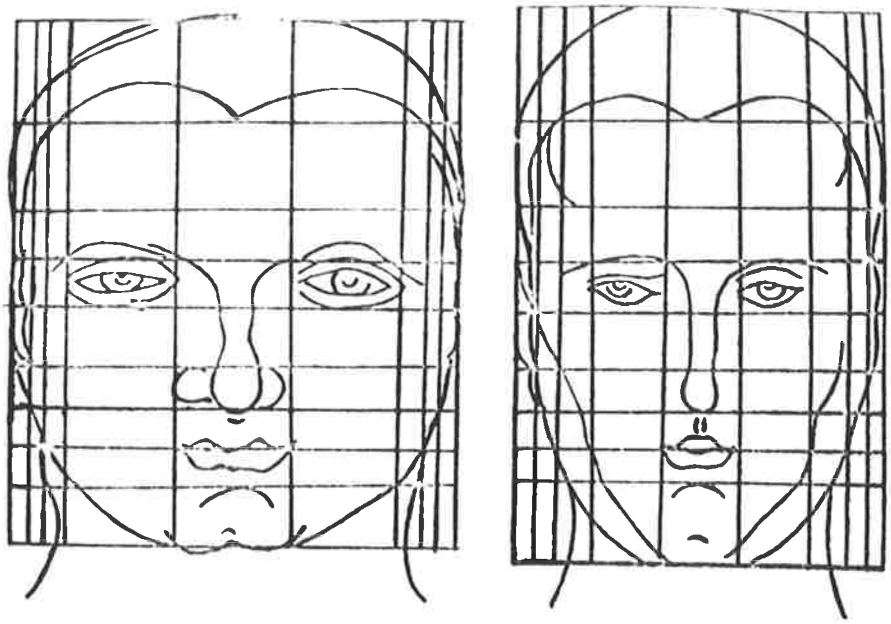


Fig. 3 - Drawing by Albrecht Dürer demonstrating how a difference in facial type means only a difference in scale when the artist employs the network or mesh technique.

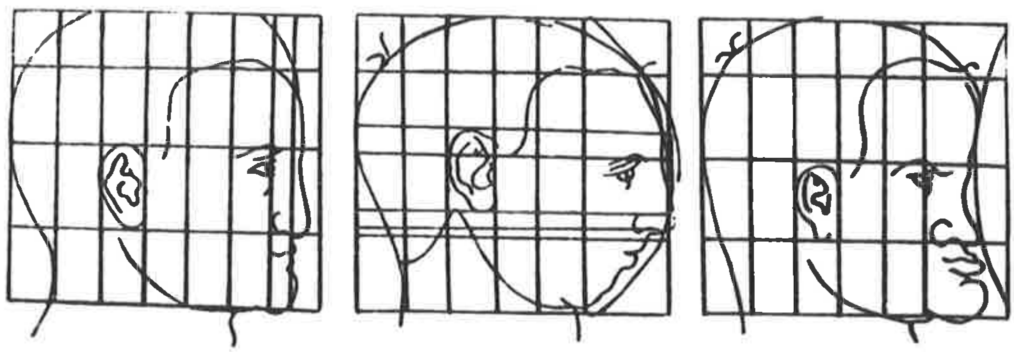


Fig. 4 - Drawing by Albrecht Dürer demonstrating three types of facial profile; straight, convex and concave.

Fig. 5 - Drawings by Leonardo da Vinci including diagrams on technique of cross-sectional representations of the head - Quad. Anat. V,fol.6r.

> Bramantino. Panofsky (1940) points out that the first known parallel projection of an inclined head is found in a drawing by Leonardo (Windsor, 12605r) belonging to his Milanese period and that it is probable that Albrecht Dürer, although he greatly advanced and extended the technique, derived if from his North Italian colleagues...."

That Leonardo was a master in the art of perspective is unquestionable, and he must be credited with having anticipated Dürer in the use of the grid or net method of analysis. ARGENTIERI (1956) quotes a description of the method in paragraph 94 of Leonardo's own "Treatise on Painting" (Cod. Ashb., 1, fol. 24r):

> "Set a frame with a network of thread in it between your eye and the nude model you are drawing, and draw these same squares on the paper...Then place a pellet of wax on a spot of the net which will serve as a fixed point...Afterward, remember when drawing figures to use the rule of the corresponding proportions of the limbs as you have learned it from the frame and net..."

In another section of the same publication, BIAGGI (1956) remarks that while material on the subject of ratios and proportions is surely copious, both in drawings and annotations, they cannot be used as a basis for setting up a Leonardian canon of proportions.

Leonardo's use of proportions was not limited to study of the human figure but carried over into his studies of comparative anatomy. Figures 6 and 7 illustrate this characteristic of da Vinci to attempt to provide the art of drawing with a scientific basis. It has been argued that Leonardo often used himself as a model in his studies of proportions. NICODEMI (1956) presented the following two illustrations (Figures 8 and 9) to support his contention that this was true in the case of facial proportions.

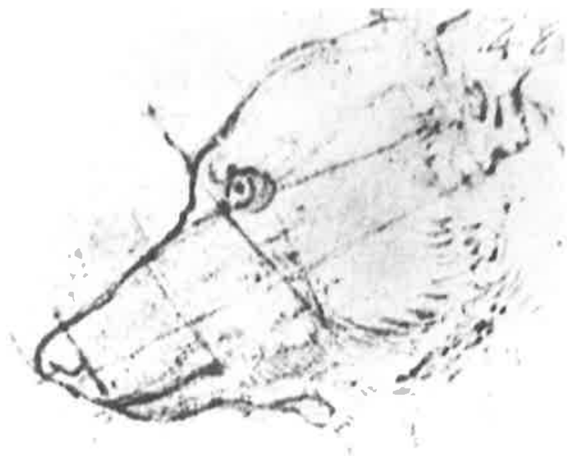


Fig. 6 - Head of a bear by Leonardo da Vinci - Ms.I,fol.96r.

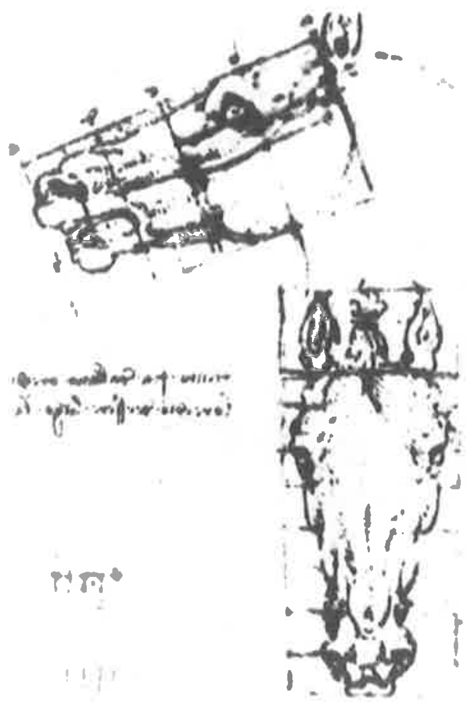
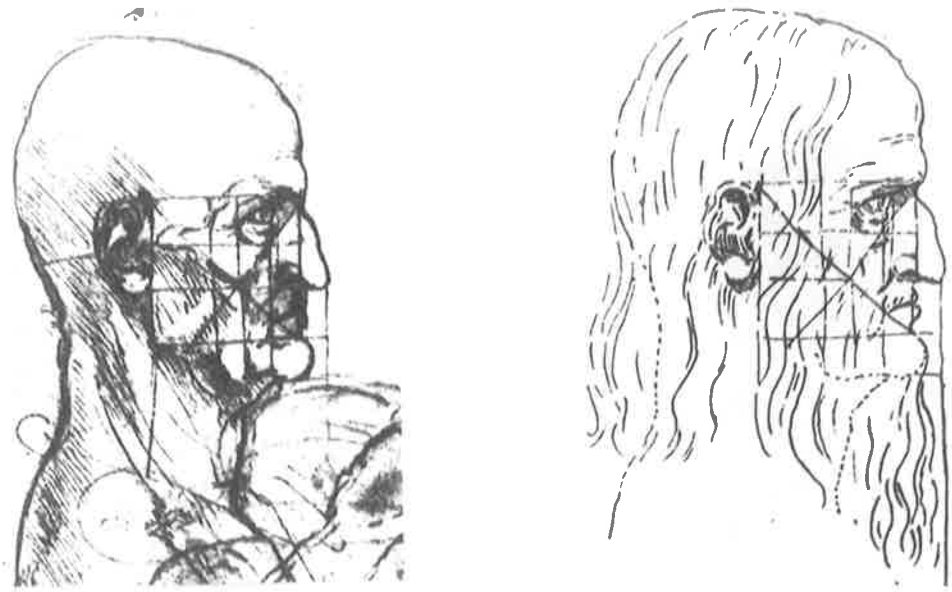


Fig. 7 - Proportions of the head of a horse by Leonardo da Vinci - Ms.F,fol.62v.



A B

Fig. 8 - A: Drawing by Leonardo da Vinci demonstrating facial proportions. Venice, Academy.

B: Profile of Leonardo taken from Venice drawing.

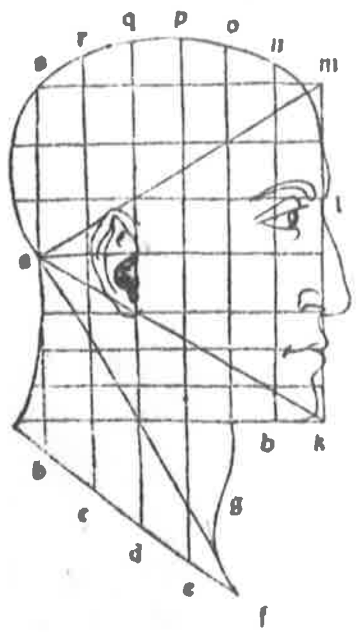


Fig. 9 - Presumed portrait of Leonardo da Vinci. Venice, 1509.

Albrecht Dürer's propagation of the mesh diagram was so successful that even today it constitutes the classic approach for studying facial proportions in art. The anthropologic study of facial growth and form, however, developed along several different lines. PIETER CAMPER (1791) determined the profile contour by measuring the angle formed between the facial line and a horizontal (Figure 10). This technique of using two coordinates and measuring the angle between them is the basis of many contemporary cephalometric analyses, including those of DOWNS (1948), STEINER (1953) and SCHWARZ (1961).

The triangle being a convenient shape that is easily defined mathematically was introduced to craniometric studies by KOSTER (1860) and first applied to orthodontic diagnosis by MARGOLIS (1947). The polygon was advocated for analyzing facial form by WELCKER (1862) and has since been employed by HELLMAN (1930), BJÖRK (1947) and KORKHAUS (1960).

A system of two perpendicular coordinates was used by LUCAE (1864) to study facial configuration and is found again in COBEN's (1955) study of facial growth. HOLL (1898) employing a proportionate method of analysis, graphically demonstrated the relative changes in craniofacial height and width between birth and adulthood (Figures 11 and 12).

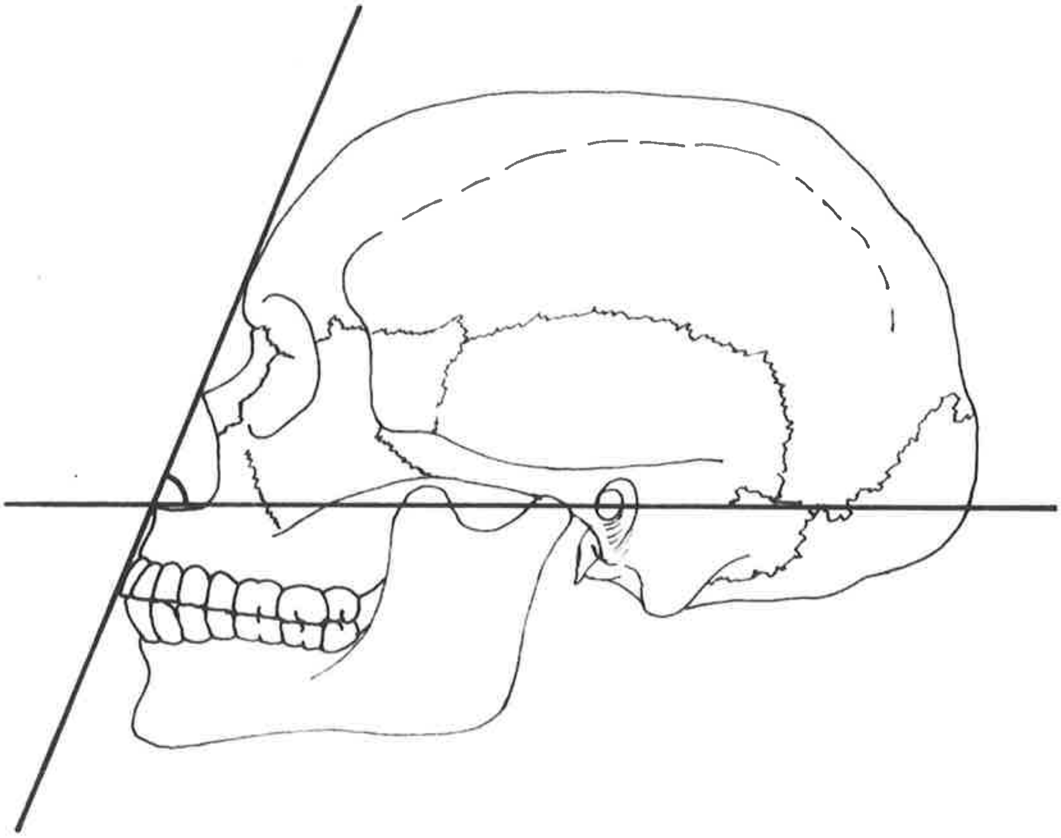


Fig. 10 - Pieter Camper's facial angle (1791).

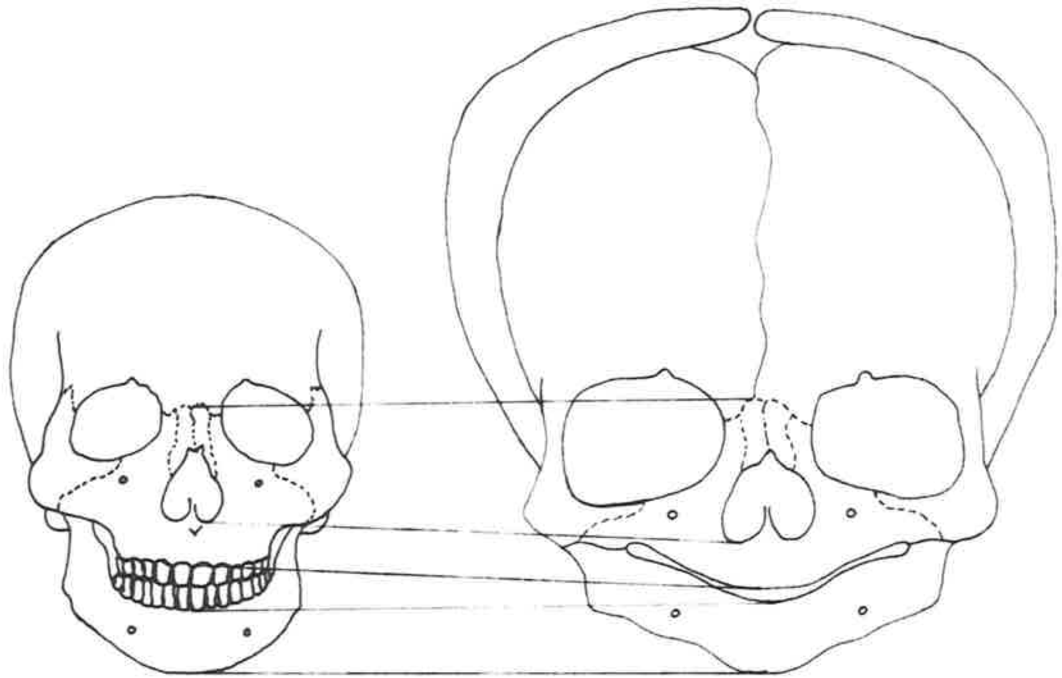


Fig. 11 - Demonstration of relative changes in craniofacial height between birth and adulthood. Nasion - pogonion distance has been kept constant (after HOLL, 1898).

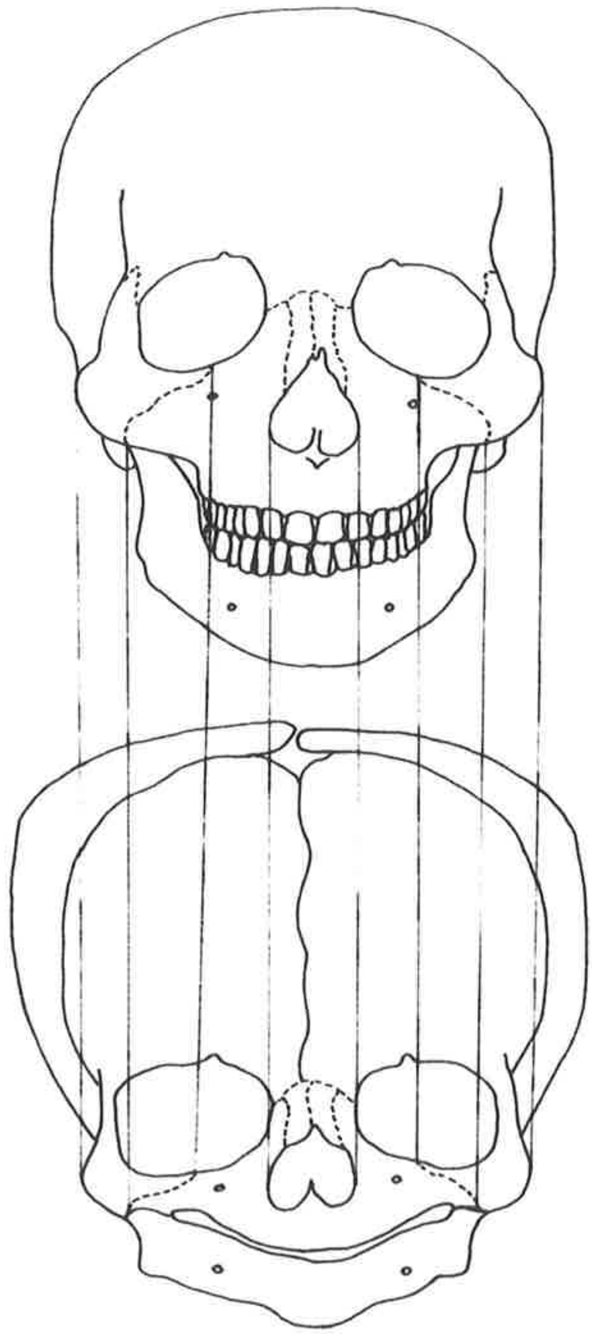


Fig. 12 - Demonstration of relative changes in craniofacial width between birth and adulthood. Bizygomatic width has been kept constant (after HOLL, 1898).

ADAPTATION OF THE MESH TECHNIQUE FOR BIOLOGIC PURPOSES

D'ARCY THOMPSON (1917) was the first to utilize a coordinate system of analysis for biologic purposes. His classic monograph "On Growth and Form" applied the principles of coordinates and Cartesian transformations to afford comparisons of related forms and studies of growth. Under the stimulus provided by Thompson many significant investigations have been undertaken to yield some understanding of biologic metamorphosis and growth (HUXLEY 1932, MEDAWAR 1944, 1945, and RICHARDS and KAVANAGH 1945).

DeCoster's publication, "The Network Method of Orthodontic Diagnosis", introduced coordinate analysis to orthodontics (DECOSTER 1939) (Figure 13).

> "The method consists in the application of a normal network upon a deformed face and then in deforming the lines of the net in the same degree to coincide with the features of the face, thus displacing the lines till they are in normal concurrence with chosen points....When we deform the normal network by adapting it to the position of the anatomical points, the deformation of the meshes of the net will be the graphical expression of the divergence from the normal average".

Moorrees and co-workers have since continued to refine the technique and demonstrate various applications of this method of analysis. MOORREES (1953) in his study of normal variation and its bearing on the use of cephalometric roentgenograms in orthodontic diagnosis, advocated the mesh diagram technique for its ability to furnish the most useful means for evaluation of proportionate differences.(Figure 14). MOORREES and YEN (1955) demonstrated the ability

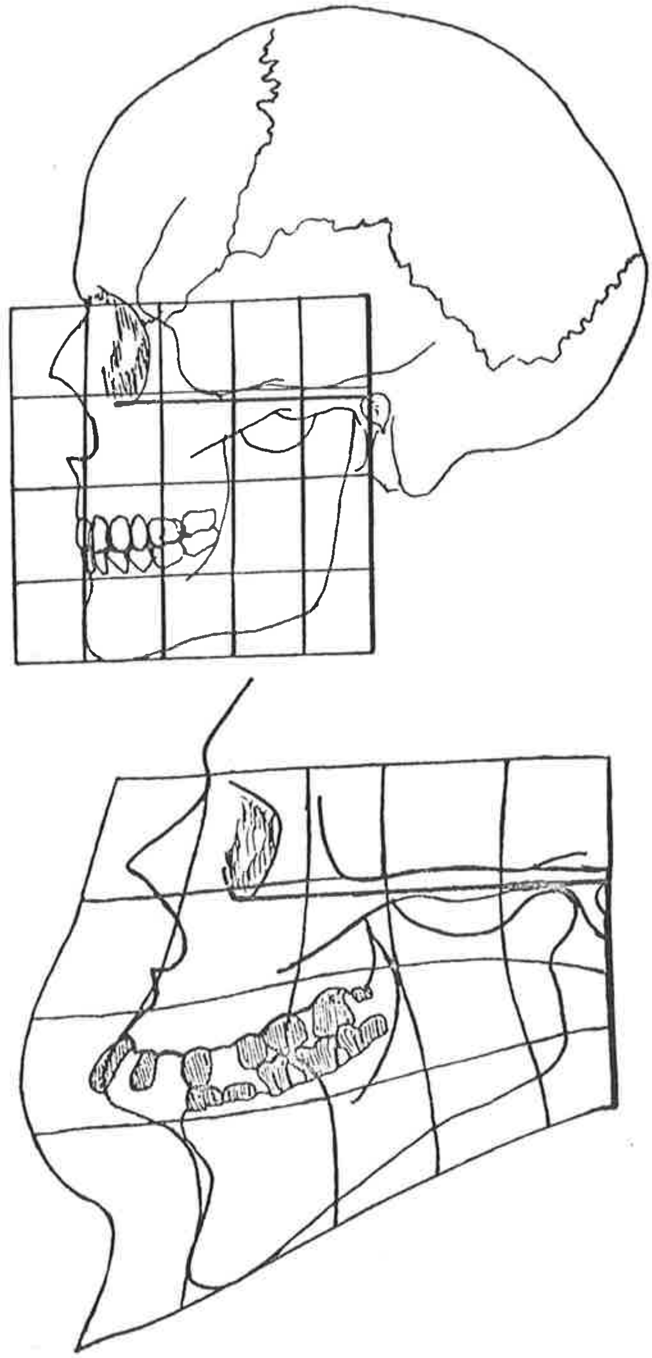


Fig. 13 - The De Coster Network Analysis. Coordinate lines on the malformed skull have the same relationship to the anatomical points of the normal skull (after DE COSTER 1939).

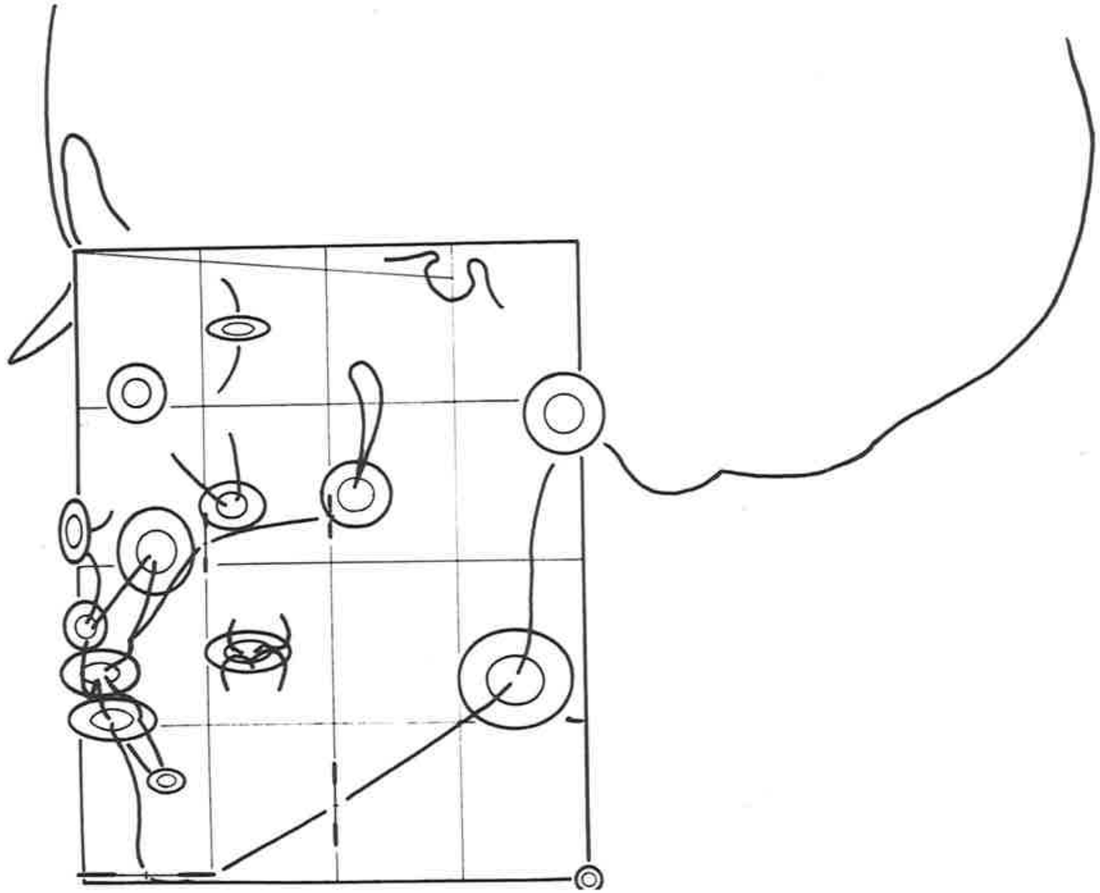


Fig. 14 - The Moorrees Mesh Analysis. Standard drawn for North American young adult females. Concentric ovals demonstrate the range of variation for the location of landmarks at one and two standard deviation limits (after MOORREES 1953).

of the mesh technique to provide a graphic analysis of changes in the dentofacial skeleton following orthodontic treatment. Using the mesh technique as a basis of analysis, MOORREES and KEAN (1958) promulgated the importance of using the natural head position as a basic consideration in the interpretation of cephalometric roentgenograms. MOORREES and LEBRET (1962) published the most comprehensive demonstration of the uses to which the mesh diagram could be adapted. The method was applied in studying facial pattern, growth changes both in the dentofacial region and the cranium, results of orthodontic treatment and familial resemblences. The mesh diagram method has since been cited as another approach for genetic studies of facial form (MOORREES 1962). The marked variations in facial development among young adult females with normal occlusion noted by Moorrees in 1953 has been taken as an indication of partial independence between facial and dental development (MOORREES 1966).

COORDINATE SYSTEM ADOPTED FOR PRESENT STUDY*

Measurements relating the set of reference points to rectangular coordinate axes were obtained. The observations were checked, double determinations averaged, and basic descriptive statistics calculated by computer.

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*The remaining sections of Chapter 3 have been taken from the papers dealing with coordinate analysis by McNULTY, BARRETT and BROWN (1968) and BARRETT, BROWN and MCNULTY (1968). Changes have been limited to a slight modification and rearrangement of the descriptive passages of these publications to provide a more logical sequence of presentation in keeping with the previous and subsequent text of the present thesis.

The statistical analysis provided group findings for male subjects and for female subjects in terms of mean values and standard deviations of the coordinates of each reference point. The results were used to construct diagrams illustrating the average facial patterns as indicated by the locations of reference points in relation to a rectilinear mesh system by a method similar to that used by MOORREES (1953) and MOORREES and LEBRET (1962).

MOORREES and KEAN (1958) recommended the use of a vertical extracranial reference line derived from registration of natural head position for cephalometric studies rather than the nasion-sella line or other intracranial reference lines. However, this procedure has not been followed because of the doubtful validity of the extracranial reference point as it was determined in the present study. The mesh diagrams were orientated on the nasion-sella line.

The mesh was constructed by first drawing the abscissa axis, a line from the origin at point nasion through sella and equal in length to four-thirds of the nasion-sella distance. The ordinate axis was then drawn from nasion and equal in length to the ordinate value of point gnathion. These two lines determined the overall dimensions of the mesh which was then completed by drawing the two remaining sides of the rectangle and subdividing the area into sixteen rectangular patches with depths and heights equal to one-quarter of the dimensions of the abscissa and ordinate axes. As point nasion was made the origin of the coordinate system and point sella to lie on the abscissa axis, almost all of the points were located within the fourth quadrant. Consequently, most of the abscissae were postive and, apart from those of nasion and sella, all of the ordinates were negative. The relationship of the mesh to points nasion, sella and gnathion is shown in Figure 15.

MOORREES (1953) presented his findings from a study of fifty North American females in a table giving proportionate distances of the anatomical landmarks from the axes of the individual mesh patches within which they were located. Locations of reference points in the present study were calculated as abscissa and ordinate values in relation to the main axes of the system. The measurements, corrected to compensate for roentgenographic enlargement, are expressed in millimetres.

PROPERTIES PECULIAR TO THE MESH SYSTEM

For many landmarks there was a significant correlation between abscissa and ordinate. Assuming the coordinates of each point to follow a bivariate normal distribution, the relationship between abscissa and ordinate was illustrated by constructing an ellipse determined in shape by the variances of each coordinate and the covariance between them. The lengths of the semi-major and semi-minor axes of such an ellipse are determined by:

$$l_{1,2} = \frac{v_1 + v_2}{2} \pm \sqrt{\left(\frac{v_1 + v_2}{2}\right)^2 - (v_1 v_2 - v_{12}^2)}$$

where $\sqrt{l_{1,2}}$ are the lengths of the semi-axes,

v_1 is the variance of the abscissa,

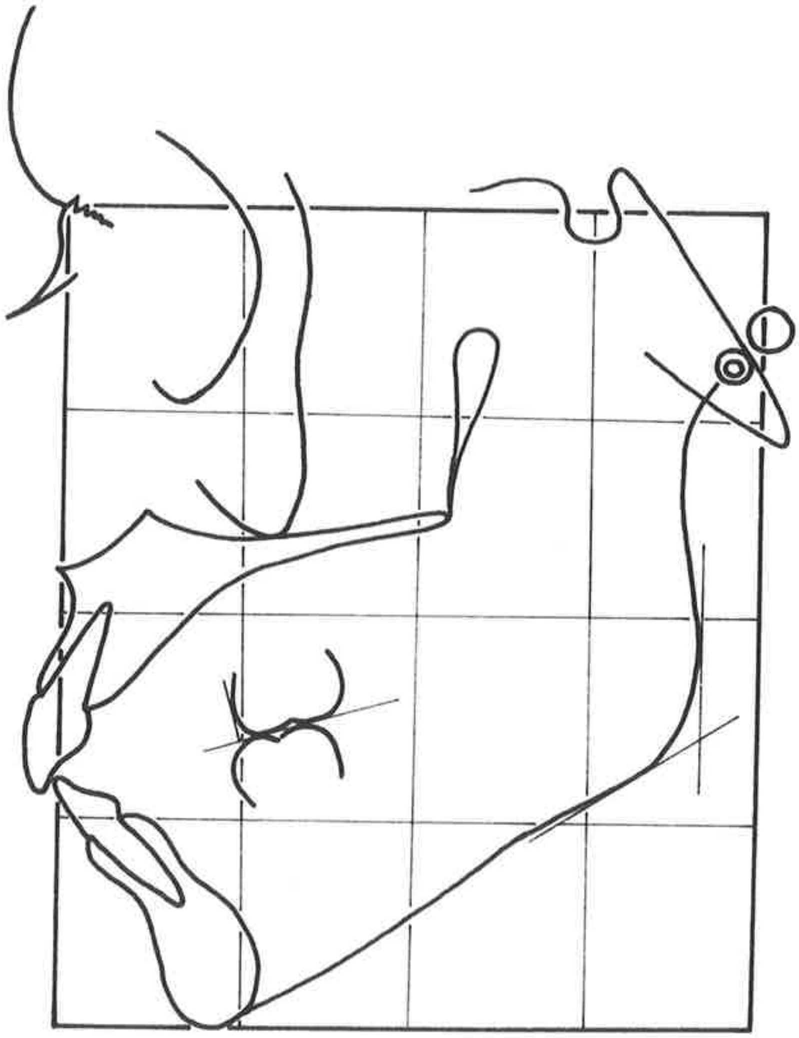


Fig. 15 - Mesh Diagram as used in this investigation.

v_2 is the variance of the ordinate,

v_{12} is the covariance between abscissa and ordinate.

The above equation is the expanded notation for determining the eigenvalues of the variance/covariance matrix for abscissa and ordinate. The term $(v_1 + v_2)$ is the trace of the matrix and the term $(v_1 v_2 - v_{12}^2)$ is its determinant. The angle through which the major axis of the ellipse is rotated in the case of correlated coordinates is given by:

$$\tan\ 2a = \frac{2v_{12}}{v_1 - v_2}$$

Covariance ellipses constructed in this study are not related to the concentric ellipses based on standard deviation values used by MOORREES (1953). Standard deviation values apply to the variates singly and, when used to illustrate the range of landmark variation, only approximate a bivariate distribution, particularly when the variates are correlated. The ellipses surrounding the reference points were constructed as described to show the relative magnitudes of the coordinate variances and the covariance between abscissa and ordinate. With equal variances the ellipses become circles, and with zero correlation between coordinates, the major axes of the ellipses would be parallel with the abscissa axis.

A covariance ellipse does not indicate the range of variation of a point but illustrates graphically the relation between the variances of the coordinates of a point and the covariance between abscissa and ordinate. However, provided the number of paired observations is large, frequency distributions for a bivariate population can be represented by equiprobability or tolerance ellipses (DIEM 1962 and SEAL 1964). A tolerance ellipse constructed for, say the $p = 0.05$ level, would enclose 95 per cent of the subjects and would be concentric to the covariance ellipse described above. Because of small sample size, tolerance ellipses were not constructed in the present study. But to illustrate the relations between a tolerance ellipse, a covariance ellipse and the ellipse based on standard deviation values as used by MOORREES (1953), the three representations are shown in Figure 16 for the point prosthion using the data collected on males in the adult dentition stage. The comparison shows that subjects P_1 and P_2 lie well within the 95 per cent tolerance ellipse but are excluded from the ellipse based on standard deviations. The true frequency distribution of a bivariate normal population is only represented by a tolerance ellipse based on a large number of paired observations.

Another characteristic noted during analysis of the final results was the tendency of the variances of point coordinates to increase as the distance of the point from the registration line increased. This observation was also noted by MOORREES (1953). While this tendency of increased variance is not a property peculiar to the mesh system, it is mentioned at this point because of its effect on the size and shape of the covariance ellipses. This characteristic will be discussed more fully under Discussion and Results.

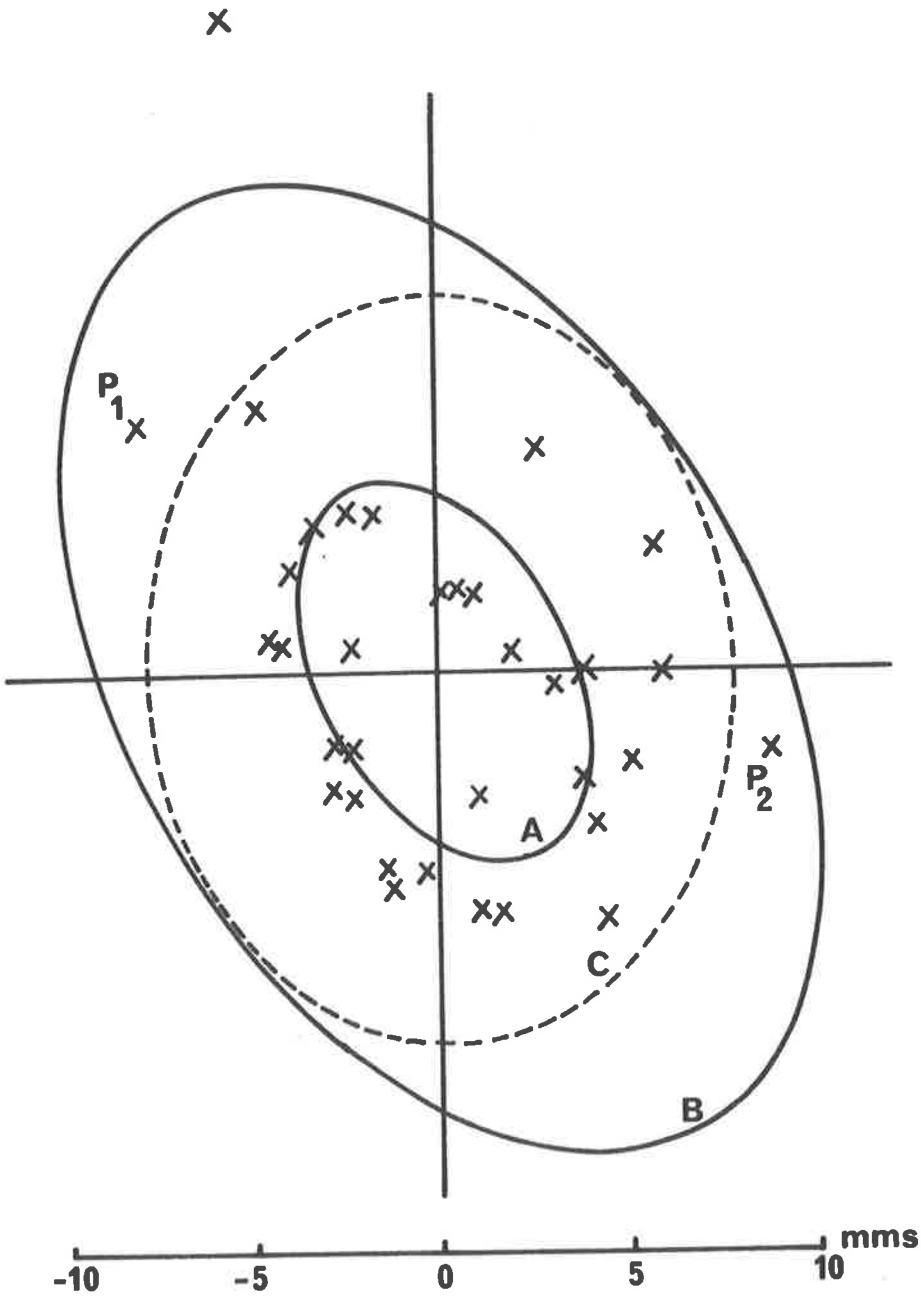


Fig.16 - Distribution of point locations about the mean for prosthion in young adult males demonstrating covariance ellipse (A), 95 per cent tolerance ellipse (B) and ellipse based on 2 standard deviation units in the horizontal and vertical directions (C). Redrawn from a computer plot.

The points raised are of more than academic interest particularly if mesh systems are used in the analysis and appraisal of facial types in research or clinical diagnosis. The common procedure of orientating head films along selected lines of reference introduces systematic errors that increase the variances of point coordinates lying at a distance from the line of reference and probably bias the covariance between coordinates, thus masking the true biological associations. The mathematical properties of mesh systems and the consequences of standard orientation require further consideration particularly in relation to the measurement and analysis of craniofacial structures.

COMPUTER ANALYSIS ADOPTED

In the coordinate system of measurement the observations were confined to determinations of coordinate values for each of the landmarks in relation to rectangular axes. Construction of the mesh, location of the reference points within the mesh, and definition of the covariance ellipses were carried out by use of the computer and its plotting facilites. Deriving measurements indirectly from observations of coordinates of the defining landmarks with the aid of a reading machine and computer facilities had many advantages over the usual methods of direct measurement with slide calipers and protractor. Coordinate values were determined accurately and speedily. Computer entry and storage of the data in coordinate form simplified subsequent processing and analysis. Measurement values for a wide range of variables were calculated. Computer plotting and visual display facilities were used more readily.

USE OF RECORD READER

Several types of record readers, used in science and technology to reduce graphical data to digital form for computer processing and analysis, would be suitable for use in the coordinate system of measurement. These semi-automatic reader digitizers accept cephalometric roentgenograms, tracings from roentgenograms, film records and paper records. One type reads out the data on punched cards ready for computer entry. Another type outputs the data directly on magnetic tape. With the use of these record readers there would be no need for the intermediate stages of recording the observations by handwriting and subsequent transcription of the data to punched cards.

If a semi-automatic reader digitizer were not available, the coordinate system of measurement could be used with the aid of graph paper overlays. This procedure would be tedious, however. In the present study a simple record reader was used, a device capable of construction in any well-equipped workshop. Basically the reader was a standard drawing table modified by the inclusion of a back-illuminated viewing screen (Figure 17). A parallelogram drafting machine, with a specially constructed cursor and scale carriage fitted to the protractor head, was attached to the table. A millimetre scale set flush into the surface of the viewing screen constituted the ordinate axis and a similar scale on the movable carriage constituted the abscissa axis of a rectangular coordinate system (Figure 18). In use, the abscissa scale

Fig. 17 - Record reader used in investigation consisting of a standard drawing table with illuminated viewing screen and drafting machine attachment.

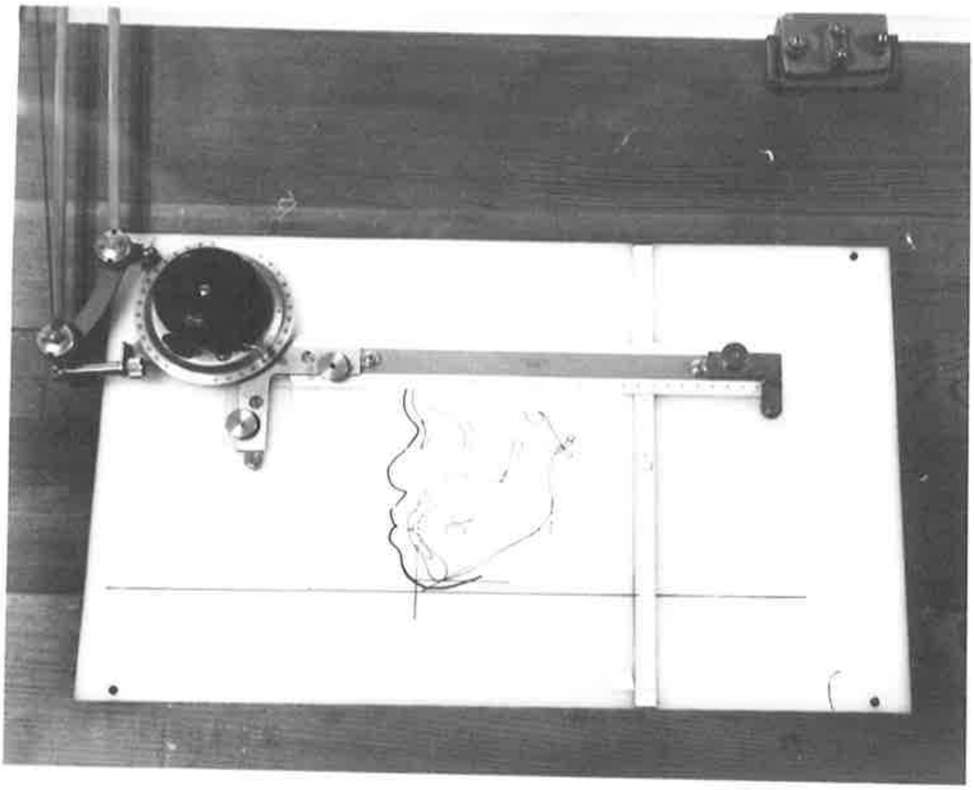


Fig. 18 - Closer view of parallelogram drafting machine showing specially constructed cursor attached to movable abscissa scale, which rides over tracing of roentgenogram and ordinate scale embedded into viewing screen. Cross-hairs were located over landmark and coordinates read from ordinate and abscissa scales.

was first aligned by means of the protractor head's coarse and fine adjustments, to coincide with a line scribed on the viewing screen at right angles to the ordinate scale. The cursor cross-hairs were then centered over the landmarks in turn and the coordinate values were read from the two scales where they intersected.

RELIABILITY OF RECORD READER

With the use of a simple record reader there was the possibility of mistakes due to mis-reading of the scales, incorrect recording of values called by the observer, and incorrect transcription of data from record sheets to punched cards. To control the reliability of measurements with the machine a strict reading procedure was followed and computer facilities were used to detect gross mistakes and to evaluate errors of observation arising from observer and the instrument.

The following procedure was carried out when reading the cephalometric roentgenograms. A tracing from the film was fixed to the viewing screen with masking tape, but no attempt was made to position the record in any particular orientation relative to the coordinate axes because the computer subsequently transformed the set of coordinates by mathematical translation and rotation to give a standard orientation. After alignment of the abscissa scale had been checked visually, the cursor was centered over the landmarks in turn and coordinate values called by the observer in a sequence corresponding to the format of the data record sheet. Appendix 1 illustrates a data sheet for the particular analysis used in the present investigation. An assistant entered the values on the data sheet as they were called and at the same time a tape recording was made.

Subsequent play-back of the tape enabled the observer to check the entries. An office adding machine was used to obtain a total of all the values on the data sheet irrespective of the variables to which they referred. This figure was entered on a separate punched card and placed ahead of the set of punched cards recording the total observations for the subject. In the example cited above there were five data cards per subject, each card recording coordinate values for five points. The computer read a deck of cards for a group of subjects and summed the values on the set of data cards for each subject in turn. An error message was printed out if a discrepancy between the adding machine total and the computer total was found, thus checking the punched card transcriptions. At the same time the computer checked that the punched cards in each set referred to the same subject and that the cards were in proper sequence.

If a manually or electrically operated punch machine was available the time taken to prepare data cards could be reduced and one source of error eliminated. As the observer called the values an assistant could immediately code the cards without recording the observations on a data sheet. Subsequently, a computer listing of the data cards could be checked against the tape recording of the observer's calls.

The relative ease of the reading procedure simplified repeat determinations of coordinate values. In the present study double determinations were made routinely, that is, a second set of readings were obtained independently of the first. The computer transformed both sets of coordinate values to the standard orientation and then calculated the differences between the two sets of values and also the linear discrepancies represented by the differences. Mistakes due to mis-reading of the scales were revealed by this means. In these instances the original record had to be re-measured.

Coordinate values were read to the nearest 0.5 mm. Due to limitations in definition of bony structures inherent in cephalometric roentgenograms (BJÖRK 1947 and POTTER and MEREDITH 1948) and errors introduced in the location of landmarks and transfer to tracings (RICHARDSON 1966 and SAVARA, TRACY and MILLER 1966), no attempt was made to obtain greater precision in the measurements.

A study of the errors of observation arising from the reading machine indicates that an acceptable order of accuracy was achieved. In a series of 192 measurements computed from coordinate values read from a graph paper grid, 48 per cent showed zero discrepancy, 72 per cent were within ± 0.2 mm., 84 per cent within ±0.4 mm., and all within ±0.6 mm. of the actual value.

CHAPTER 4 - RESULTS

BASIC DESCRIPTIVE STATISTICS

A summary of the findings for coordinates of craniofacial reference points in males and females grouped according to dental age is presented in Tables 5 to 18. The basic descriptive statistics are tabulated according to anatomical regions of the skull.

Differences between mean values of males and females were assessed by Student's "t - test". In instances of significant sex differences in variances a modified "t-test", suggested by BAILEY (1959), was used. Mean values that differed between sexes at the five or one per cent probability level are indicated in the tables relating to the female subjects (Tables 12 to 18).

TABLE 5

Coordinates of craniometric reference points in males

Age Group: Early Juvenile Stage 1

		Mean		$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
				Anterior Cranial Base Region				
n	x	0.00		0.00	0.00	0.00	0.00	11
	y		0.00	0.00	0.00	0.00	0.00	11
s	x	61.21		0.64	2.13	63.25	57.33	11
	y		-.00	0.00	0.00	0.00	-.00	11
lo	x	21.19		0.46	1.53	24.21	18.71	11
	y		-8.01	0.58	1.93	-3.41	-10.75	11
or	x	14.26		0.77	2.56	18.47	10.94	11
	y		-23.30	0.29	0.97	-22.25	-25.12	11
zp	x	25.34		0.69	2.30	28.08	21.29	11
	y		-36.91	0.67	2.23	-31.84	-39.92	11
				Posterior Cranial Base Region				
ba	x	82.56		0.98	3.26	87.17	77.48	11
	y		-27.87	0.67	2.21	-24.01	-31.50	11
ar	x	71.40		1.07	3.38	77.94	66.01	10
	y		-20.19	0.34	1.08	-19.14	-21.96	10
po	x	82.43		1.21	4.00	88.40	76.65	11
	y		-13.08	0.65	2.17	-9.31	-16.19	11
er	x	77.10		3.24	5.62	82.57	71.34	3
	y		-16.99	3.35	5.81	-12.30	-23.48	3
				Extracranial Reference Point				
evp	x	12.87		1.71	5.13	21.58	5.48	9
	y		-89.85	1.01	3.04	-85.92	-95.24	9

TABLE 5 (continued)

		Mean		$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
				Maxilla				
pm	x	45.92		0.84	2.79	50.65	41.23	11
	y		-33.84	0.52	1.71	-31.07	-37.48	11
sp	x	-1.06		0.63	2.10	1.42	-5.03	11
	y		-40.73	0.63	2.09	-38.08	-44.46	11
ss	x	2.48		0.63	2.11	5.18	-1.16	11
	y		-44.65	0.61	2.03	-40.76	-47.45	11
pr	x	1.79		0.72	2.40	5.26	-2.83	11
	y		-57.23	0.08	2.66	-52.08	-61.15	11
as	x	No Observations Recorded						
	y	No Observations Recorded						
is	x	3.04		0.87	2.88	6.65	-2.49	11
	y		-64.62	0.82	2.74	-60.26	-69.32	11
ms	x	30.21		0.87	2.90	34.46	26.61	11
	y		-54.65	0.69	2.29	-51.59	-59.71	11
				Mandible				
mi	x	28.41		1.02	3.24	32.74	23.66	10
	y		-54.73	0.54	1.71	-51.59	-57.16	10
ii	x	4.06		1.02	3.21	7.90	-2.04	10
	y		-64.00	0.93	2.94	-60.21	-69.15	10
ai	x	21.48		1.99	3.98	27.31	18.42	4
	y		-81.13	2.37	4.75	-77.60	-87.85	4
id	x	7.47		1.36	4.30	15.21	2.50	10
	y		-70.35	1.30	4.11	-65.52	-78.90	10
pg	x	17.04		1.45	4.58	24.78	10.51	10
	y		-86.10	0.93	2.93	-81.80	-91.47	10
op	x	19.91		1.33	4.21	26.71	14.28	10
	y		-88.44	0.79	2.49	-85.17	-92.71	10
gn	x	23.51		1.58	5.00	31.51	17.07	10
	y		-88.62	0.81	2.58	-85.16	-93.08	10
tgo	x	68.68		1.52	4.81	77.71	61.25	10
	y		-56.10	0.76	2.41	-52.73	-59.66	10

TABLE 6

Coordinates of craniometric reference points in males

Age Group: Early Juvenile Stage 2

		Mean	$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
		Anterior Cranial Base Region					
n	x	0.00	0.00	0.00	0.00	0.00	25
	y	0.00	0.00	0.00	0.00	0.00	25
s	x	62.23	0.45	2.24	66.02	57.72	25
	y	-.00	0.00	0.00	0.00	-.00	25
lo	x	22.40	0.39	1.97	27.56	18.90	25
	y	-10.72	0.34	1.69	-7.16	-14.29	25
or	x	13.75	0.44	2.22	17.18	8.74	25
	y	-24.65	0.27	1.37	-22.20	-27.22	25
zp	x	26.24	0.44	2.18	30.66	19.90	25
	y	-38.81	0.41	2.05	-35.22	-43.82	25
		Posterior Cranial Base Region					
ba	x	84.04	0.68	3.39	92.68	78.76	25
	y	-27.67	0.62	3.12	-18.43	-32.75	25
ar	x	73.96	0.76	3.15	78.85	67.63	17
	y	-21.44	0.36	1.49	-18.54	-23.78	17
po	x	83.39	0.62	3.10	90.71	78.03	25
	y	-12.88	0.48	2.40	-7.29	-16.73	25
er	x	77.28	1.15	5.00	87.33	67.95	19
	y	-17.78	1.19	5.20	-7.47	-25.39	19
		Extracranial Reference Point					
evp	x	11.85	0.96	3.94	18.98	5.98	17
	y	-94.62	0.85	3.49	-88.22	-100.07	17

TABLE 6 (continued)

		Mean	$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
			Maxilla				
pm	x	46.02	0.48	2.42	52.19	41.05	25
	y	-34.26	0.32	1.61	-30.38	-37.93	25
sp	x	0.34	0.38	1.88	4.79	-2.28	25
	y	-40.90	0.47	2.37	-35.96	-46.07	25
ss	x	3.22	0.38	1.89	7.15	0.38	25
	y	-44.62	0.54	2.68	-37.27	-50.41	25
pr	x	1.34	0.40	2.02	5.17	-1.49	25
	y	-53.99	0.56	2.80	-48.67	-59.50	25
as	x	7.63	0.50	2.01	11.50	4.35	16
	y	-43.23	0.65	2.59	-38.78	-47.55	16
is	x	1.56	0.54	2.72	6.27	-3.19	25
	y	-67.30	0.60	2.98	-61.26	-72.69	25
ms	x	28.86	0.47	2.37	33.58	25.20	25
	y	-56.87	0.49	2.44	-52.77	-61.60	25
			Mandible				
mi	x	27.92	0.66	2.71	31.93	22.91	17
	y	-57.26	0.52	2.14	-54.00	-60.13	17
ii	x	2.91	0.70	2.89	7.84	-2.34	17
	y	-65.80	0.66	2.74	-60.45	-70.88	17
ai	x	18.78	0.92	3.57	24.25	13.45	15
	y	-83.25	0.81	3.12	-77.47	-89.27	15
id	x	8.20	0.79	3.24	13.10	2.32	17
	y	-74.92	0.67	2.77	-69.85	-79.65	17
pg	x	17.07	0.92	3.81	24.20	10.99	17
	y	-90.43	0.76	3.15	-84.81	-96.07	17
cp	x	19.65	0.95	3.90	26.59	14.57	17
	y	-92.82	0.81	3.34	-86.86	-98.88	17
gn	x	24.14	1.00	4.12	32.34	18.24	17
	y	-93.10	0.84	3.45	-86.79	-98.48	17
tgo	x	72.12	0.79	3.26	77.94	65.54	17
	y	-58.09	0.70	2.89	-52.42	-63.85	17

TABLE 7

Coordinates of craniometric reference points in males

Age Group: Early Juvenile Stage 3

		Mean	$\pm \Sigma(\bar{x})$	s	Maximum	Minimum	N
		Anterior Cranial Base Region					
n	x	0.00	0.00	0.00	0.00	0.00	33
	y	0.00	0.00	0.00	0.00	0.00	33
s	x	62.92	0.36	2.06	68.27	58.10	33
	y	-.00	0.00	0.00	0.00	-.00	33
lo	x	22.61	0.27	1.56	25.34	19.47	33
	y	-9.98	0.37	2.11	-5.96	-14.64	33
or	x	14.13	0.40	2.27	17.69	8.10	33
	y	-25.00	0.30	1.75	-21.38	-30.12	33
zp	x	26.34	0.49	2.84	31.95	19.11	33
	y	-39.54	0.36	2.05	-34.14	-43.05	33
		Posterior Cranial Base Region					
ba	x	85.44	0.58	3.32	92.60	78.39	33
	y	-28.93	0.49	2.84	-19.42	-33.52	33
ar	x	75.13	0.57	3.17	82.85	69.68	31
	y	-22.64	0.38	2.12	-16.42	-26.62	31
po	x	84.68	0.50	2.89	91.62	80.09	33
	y	-13.63	0.45	2.60	-8.84	-19.95	33
er	x	78.11	0.90	4.94	92.84	69.72	30
	y	-18.54	1.00	5.45	-10.08	-34.94	30
		Extracranial Reference Point					
evp	x	12.14	0.74	4.13	19.71	2.88	31
	y	-96.24	0.56	3.13	-89.78	-103.49	31

TABLE 7 (continued)

		Mean	$\pm \Sigma(\bar{x})$	s	Maximum	Minimum	N
			Maxilla				
pm	x	47.14	0.45	2.57	51.59	40.98	33
	y	-35.83	0.32	1.85	-31.91	-40.00	33
sp	x	0.60	0.52	2.98	7.21	-7.12	33
	y	-42.61	0.41	2.34	-37.93	-48.18	33
ss	x	3.44	0.48	2.77	8.46	-4.49	33
	y	-45.84	0.45	2.56	-39.89	-50.76	33
pr	x	0.95	0.54	3.12	5.28	-7.49	33
	y	-55.78	0.46	2.65	-51.72	-62.06	33
as	x	8.23	0.49	2.78	12.71	2.30	32
	y	-44.64	0.39	2.20	-40.28	-50.31	32
is	x	0.05	0.73	4.18	6.74	-10.53	33
	y	-68.97	0.49	2.79	-65.18	-75.72	33
ms	x	28.73	0.51	2.91	34.58	21.76	33
	y	-58.71	0.35	2.02	-54.71	-62.62	33
			Mandible				
mi	x	27.33	0.53	2.96	33.20	21.39	31
	y	-59.29	0.38	2.10	-55.41	-64.21	31
ii	x	2.01	0.60	3.34	8.26	-5.63	31
	y	-66.98	0.51	2.86	-62.79	-75.69	31
ai	x	18.78	0.67	3.72	27.09	11.37	31
	y	-84.41	0.53	2.95	-78.49	-91.52	31
id	x	7.71	0.61	3.42	14.56	0.51	31
	y	-75.85	0.53	2.95	-70.80	-84.09	31
pg	x	16.84	0.68	3.81	25.55	9.56	31
	y	-92.28	0.57	3.18	-85.78	-99.00	31
cp	x	19.47	0.74	4.14	28.92	11.51	31
	y	-94.52	0.58	3.23	-87.50	-101.28	31
gn	x	23.78	0.77	4.30	32.36	15.56	31
	y	-94.75	0.56	3.14	-87.77	-101.40	31
tgo	x	73.10	0.64	3.55	78.68	66.35	31
	y	-59.94	0.64	3.57	-53.63	-66.69	31

TABLE 8

Coordinates of craniometric reference points in males

Age Group: Late Juvenile Stage 1

		Mean	± Σ(x̄)	s	Maximum	Minimum	N
		Anterior Cranial Base Region					
n	x	0.00	0.00	0.00	0.00	0.00	49
	y	0.00	0.00	0.00	0.00	0.00	49
s	x	64.23	0.29	2.04	68.98	58.84	49
	y	-.00	0.00	0.00	0.00	-.00	49
lo	x	22.93	0.28	1.97	27.88	18.80	49
	y	-9.78	0.32	2.26	-4.09	-14.44	49
or	x	14.12	0.35	2.42	20.76	10.02	49
	y	-24.99	0.30	2.11	-20.12	-28.75	49
zp	x	26.42	0.39	2.72	34.12	20.53	49
	y	-41.07	0.31	2.16	-36.89	-45.99	49
		Posterior Cranial Base Region					
ba	x	87.57	0.52	3.61	93.75	78.43	49
	y	-28.89	0.45	3.16	-21.16	-35.06	49
ar	x	77.09	0.47	3.18	84.96	70.52	46
	y	-22.98	0.36	2.41	-18.18	-29.57	46
po	x	86.61	0.47	3.28	94.18	78.95	49
	y	-13.59	0.40	2.78	-7.10	-18.60	49
er	x	80.97	0.62	4.33	93.12	72.34	48
	y	-19.35	0.53	3.64	-11.04	-28.03	48
		Extracranial Reference Point					
evp	x	12.44	0.77	5.21	25.60	1.63	46
	y	-99.78	0.65	4.41	-91.13	-110.18	46

TABLE 8 (continued)

		Mean		$\pm \Sigma(\bar{x})$	s	Maximum	Minimum	N
				Maxilla				
pm	x	48.50		0.39	2.72	56.21	43.55	49
	y		-37.13	0.30	2.09	-33.12	-42.13	49
sp	x	0.71		0.37	2.58	7.60	-4.40	49
	y		-43.88	0.40	2.80	-38.40	-50.46	49
ss	x	3.54		0.37	2.58	10.54	-2.33	49
	y		-47.39	0.45	3.12	-41.97	-53.38	49
pr	x	-0.10		0.46	3.24	8.59	-10.48	49
	y		-58.50	0.52	3.65	-50.21	-69.06	49
as	x	7.99		0.41	2.84	15.84	0.56	49
	y		-46.62	0.45	3.15	-39.89	-55.97	49
is	x	-1.28		0.56	3.91	6.65	-14.65	49
	y		-71.74	0.54	3.75	-63.53	-82.61	49
ms	x	28.38		0.47	3.29	36.40	19.95	49
	y		-61.43	0.43	3.02	-54.62	-69.40	49
				Mandible				
mi	x	26.60		0.54	3.65	35.73	18.62	46
	y		-61.93	0.47	3.15	-55.47	-69.83	46
ii	x	0.32		0.57	3.84	8.12	-11.54	46
	y		-69.43	0.59	3.98	-62.53	-80.82	46
ai	x	18.22		0.70	4.71	28.32	7.68	46
	y		-86.77	0.62	4.18	-78.12	-95.33	46
id	x	6.10		0.61	4.14	14.20	-5.27	46
	y		-78.19	0.58	3.95	-69.76	-88.65	46
pg	x	16.95		0.77	5.22	26.44	4.30	46
	y		-96.03	0.61	4.15	-87.21	-104.36	46
cp	x	19.79		0.79	5.39	30.27	8.37	46
	y		-98.28	0.61	4.17	-88.97	-107.78	46
gn	x	23.86		0.80	5.42	34.15	10.22	46
	y		-98.38	0.63	4.25	-89.31	-108.19	46
tgo	x	75.22		0.63	4.25	86.59	67.02	46
	y		-61.61	0.49	3.29	-54.12	-67.82	46

TABLE 9

Coordinates of craniometric reference points in males

Age Group: Late Juvenile Stage 2

		Mean	$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
		Anterior Cranial Base Region					
n	x	0.00	0.00	0.00	0.00	0.00	19
	y	0.00	0.00	0.00	0.00	0.00	19
s	x	65.02	0.64	2.77	69.91	59.02	19
	y	-.00	0.00	0.00	0.00	-.00	19
lo	x	22.76	0.38	1.64	25.74	18.92	19
	y	-10.08	0.48	2.10	-7.01	-14.50	19
or	x	13.25	0.52	2.29	15.91	7.41	19
	y	-24.86	0.38	1.64	-22.21	-27.64	19
zp	x	26.40	0.60	2.61	32.22	21.47	19
	y	-40.56	0.52	2.27	-36.10	-44.46	19
		Posterior Cranial Base Region					
ba	x	87.54	1.12	4.86	95.43	75.82	19
	y	-27.76	0.89	3.87	-21.29	-35.21	19
ar	x	78.21	0.94	4.10	84.10	68.50	19
	y	-23.03	0.53	2.33	-18.54	-28.91	19
po	x	87.77	0.90	3.92	94.24	77.46	19
	y	-13.73	0.51	2.23	-9.85	-18.01	19
er	x	81.07	1.06	4.60	90.99	70.71	19
	y	-19.76	1.23	5.36	-10.72	-28.67	19
		Extracranial Reference Point					
evp	x	10.96	1.45	6.32	23.53	0.57	19
	y	-98.10	0.95	4.15	-91.94	-106.62	19

TABLE 9 (continued)

		Mean	± Σ(x̄)	s	Maximum	Minimum	N
			Maxilla				
pm	x	48.59	0.56	2.46	52.96	45.01	19
	y	-37.26	0.53	2.29	-33.42	-41.09	19
sp	x	-0.39	0.74	3.23	4.22	-8.08	19
	y	-43.98	0.59	2.58	-37.35	-47.59	19
ss	x	2.30	0.66	2.88	6.24	-4.39	19
	y	-47.55	0.60	2.63	-41.74	-52.31	19
pr	x	-1.45	0.85	3.72	3.62	-12.47	19
	y	-57.97	0.66	2.89	-54.31	-64.62	19
as	x	6.65	0.72	3.14	10.34	-1.62	19
	y	-46.57	0.57	2.48	-42.48	-51.66	19
is	x	-2.62	1.06	4.62	4.40	16.16	19
	y	-70.94	0.72	3.16	-67.05	-77.99	19
ms	x	26.54	0.75	3.27	30.26	17.31	19
	y	-61.42	0.58	2.54	-58.09	-67.17	19
			Mandible				
mi	x	25.30	0.82	3.58	30.78	15.93	19
	y	-61.86	0.62	2.70	-58.21	-68.07	19
ii	x	-0.26	1.01	4.40	6.13	-12.70	19
	y	-67.76	0.78	3.42	-63.47	-75.84	19
ai	x	17.34	1.11	4.85	24.66	4.62	19
	y	-84.97	0.85	3.72	-78.31	-92.21	19
id	x	5.24	1.05	4.56	11.48	-7.16	19
	y	-76.37	0.79	3.45	-72.05	-84.15	19
pg	x	15.47	1.24	5.41	24.60	1.62	19
	y	-94.44	0.95	4.14	-87.91	-102.85	19
cp	x	18.34	1.27	5.52	28.84	4.62	19
	y	-96.87	0.95	4.15	-90.32	-105.00	19
gn	x	21.75	1.29	5.63	32.55	8.08	19
	y	-96.99	0.95	4.12	-89.91	-105.09	19
tgo	x	74.94	1.01	4.40	83.69	66.02	19
	y	-62.46	0.86	3.74	-56.47	-69.60	19

TABLE 10

Coordinates of craniometric reference points in males

Age Group: Adolescent

		Mean		$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
				Anterior Cranial Base Region				
n	x	0.00		0.00	0.00	0.00	0.00	49
	y		0.00	0.00	0.00	0.00	0.00	49
s	x	66.31		0.40	2.78	73.57	59.62	49
	y		-.00	0.00	0.00	0.00	-.00	49
lo	x	24.15		0.34	2.36	29.70	15.42	49
	y		-10.48	0.37	2.56	-6.52	-16.88	49
or	x	15.46		0.37	2.61	22.64	9.13	49
	y		-26.13	0.26	1.82	-22.70	-31.50	49
zp	x	28.06		0.45	3.18	36.56	21.31	49
	y		-43.47	0.37	2.56	-37.72	-52.34	49
				Posterior Cranial Base Region				
ba	x	90.91		0.61	4.29	105.69	82.54	49
	y		-30.77	0.49	3.40	-23.25	-37.25	49
ar	x	81.11		0.63	4.35	93.11	70.27	47
	y		-24.75	0.32	2.22	-20.22	-29.68	47
po	x	89.91		0.58	4.03	100.23	78.94	49
	y		-13.96	0.37	2.60	-4.59	-18.56	49
er	x	85.42		0.68	4.74	96.43	73.48	49
	y		-20.37	0.74	5.20	-4.44	-31.49	49
				Extracranial Reference Point				
evp	x	13.83		1.05	6.36	30.03	2.00	37
	y		-105.97	0.85	5.15	-97.81	-122.19	37

TABLE 10 (continued)

		Mean		$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
				Maxilla				
pm	x	50.06		0.44	3.05	58.92	43.61	49
	y		-39.79	0.34	2.37	-33.97	-45.10	49
sp	x	1.13		0.42	2.97	8.53	-5.20	49
	y		-46.23	0.39	2.71	-39.91	-54.53	49
ss	x	3.42		0.43	3.02	11.26	-2.70	49
	y		-49.77	0.38	2.67	-44.75	-59.23	49
pr	x	-0.90		0.48	3.39	7.48	-7.60	49
	y		-62.66	0.58	4.03	-56.62	-74.88	49
as	x	7.18		0.46	3.22	14.58	0.82	49
	y		-50.28	0.52	3.63	-43.41	-61.05	49
is	x	-1.67		0.59	4.14	10.12	-10.32	49
	y		-75.66	0.61	4.26	-69.27	-87.06	49
ms	x	26.64		0.51	3.59	35.52	19.41	49
	y		-66.60	0.56	3.95	-59.55	-79.11	49
				Mandible				
mi	x	24.72		0.52	3.54	33.80	16.59	47
	y		-67.41	0.59	4.03	-60.17	-79.72	47
ii	x	0.58		0.58	3.94	11.20	-8.13	47
	y		-72.97	0.64	4.37	-66.33	-86.49	47
ai	x	18.49		0.66	4.52	29.96	7.02	47
	y		-90.75	0.64	4.36	-81.71	-102.46	47
id	x	5.96		0.59	4.01	17.29	-3.08	47
	y		-81.80	0.64	4.38	-74.47	-94.82	47
pg	x	17.47		0.77	5.29	29.20	7.01	47
	y		-101.93	0.84	5.73	-89.27	-119.41	47
cp	x	20.66		0.78	5.37	31.20	9.95	47
	y		-104.58	0.80	5.51	-92.14	-120.50	47
gn	x	24.27		0.77	5.28	34.51	13.08	47
	y		-104.58	0.81	5.53	-92.10	-120.11	47
tgo	x	80.16		0.73	5.01	96.66	69.65	47
	y		-66.19	0.61	4.19	-59.53	-74.86	47

TABLE 11

Coordinates of craniometric reference points in males

Age Group: Adult

		Mean	$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
			Anterior Cranial Base Region				
n	x	0.00	0.00	0.00	0.00	0.00	34
	y	0.00	0.00	0.00	0.00	0.00	34
s	x	70.40	0.50	2.94	75.76	62.34	34
	y	-.00	0.00	0.00	0.00	-.00	34
lo	x	24.75	0.47	2.72	31.09	20.32	34
	y	-10.53	0.49	2.85	-4.00	-17.00	34
or	x	16.35	0.48	2.81	21.53	10.80	34
	y	-25.65	0.41	2.38	-19.66	-30.01	34
zp	x	29.31	0.53	3.07	34.61	21.54	34
	y	-45.24	0.64	3.71	-35.62	-54.59	34
			Posterior Cranial Base Region				
ba	x	97.27	0.72	4.18	104.16	89.88	34
	y	-33.35	0.64	3.71	-26.52	-41.11	34
ar	x	87.34	0.63	3.69	96.28	79.91	34
	y	-26.89	0.49	2.84	-20.81	-32.98	34
po	x	96.27	0.88	5.15	113.39	87.56	34
	y	-14.30	0.57	3.30	-4.94	-20.68	34
er	x	91.74	0.93	5.41	100.78	76.21	34
	y	-18.49	0.77	4.50	-10.45	-33.62	34
			Extracranial Reference Point				
evp	x	13.46	1.91	8.08	26.32	-1.97	34
	y	-117.94	1.74	7.40	-99.94	-131.90	34

TABLE 11 (continued)

		Mean		$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
				Maxilla				
pm	x	51.89		0.55	3.19	56.49	42.81	34
	y		-42.49	0.42	2.47	-34.96	-48.46	34
sp	x	0.46		0.57	3.34	7.19	-7.50	34
	y		-49.87	0.80	4.67	-31.94	-59.55	34
ss	x	2.55		0.59	3.44	9.56	-5.86	34
	y		-54.27	0.87	5.07	-34.72	-64.56	34
pr	x	-1.11		0.66	3.86	7.75	-9.15	34
	y		-68.88	0.87	5.08	-51.06	-75.71	34
as	x	5.90		0.61	3.54	13.08	-0.90	34
	y		-55.33	0.82	4.76	-39.18	-62.79	34
is	x	-0.74		0.87	5.08	10.26	-9.66	34
	y		-81.30	0.93	5.44	-61.14	-88.62	34
ms	x	24.75		0.75	4.35	33.85	15.81	34
	y		-74.28	0.75	4.35	-60.09	-82.30	34
				Mandible				
mi	x	22.21		0.81	4.74	30.89	10.12	34
	y		-75.01	0.76	4.44	-60.36	-83.82	34
ii	x	1.07		0.89	5.17	10.24	-10.22	34
	y		-79.22	0.95	5.53	-61.11	-88.32	34
ai	x	18.37		1.09	6.37	32.61	3.62	34
	y		-98.81	0.95	5.53	-83.72	-109.13	34
id	x	5.77		0.92	5.39	16.97	-6.40	34
	y		-88.23	0.93	5.42	-71.86	-98.40	34
pg	x	18.05		1.34	7.84	31.86	-3.04	34
	y		-113.30	1.16	6.76	-97.37	-129.16	34
cp	x	21.08		1.33	7.73	34.74	-1.49	34
	y		-115.86	1.13	6.57	-99.49	-130.93	34
gn	x	24.78		1.26	7.36	37.59	1.95	34
	y		-116.21	1.11	6.45	-100.06	-131.11	34
tgo	x	88.63		1.01	5.87	98.66	67.39	34
	y		-74.97	0.89	5.16	-66.24	-85.93	34

TABLE 12

Coordinates of craniometric reference points in females

Age Group: Early Juvenile Stage 1

		Mean	$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
		Anterior Cranial Base Region					
n	x	0.00	0.00	0.00	0.00	0.00	9
	y	0.00	0.00	0.00	0.00	0.00	9
s	x	60.22	0.56	1.69	62.36	57.64	9
	y	-.00	0.00	0.00	0.00	-.00	9
lo	x	21.49	0.89	2.66	24.94	16.45	9
	y	-9.62	0.62	1.85	-6.09	-12.34	9
or	x	13.95	0.73	2.19	17.32	9.88	9
	y	-23.53	0.62	1.86	-21.61	-26.71	9
zp	x	25.74	0.68	2.05	28.73	22.66	9
	y	-36.29	0.85	2.55	-32.72	-41.06	9
		Posterior Cranial Base Region					
ba	x	82.19	0.64	1.92	84.27	79.69	9
	y	-26.15	0.73	2.19	-22.56	-29.71	9
ar	x	71.31	1.26	2.51	74.23	68.68	4
	y	-18.82	0.61	1.22	-17.36	-20.34	4
po	x	81.04	0.61	1.83	83.23	77.32	9
	y	-12.00	0.74	2.21	-9.28	-16.60	9
er	x	71.38	0.54	1.09	72.97	70.57	4
	y	-19.22	3.09	6.18	-10.09	-23.68	4
		Extracranial Reference Point					
evp	x	13.59	1.99	3.98	18.29	9.45	4
	y	-91.35	2.90	5.90	-82.80	-95.68	4

* Mean difference between male and female significant at P>0.05

** Mean difference between male and female significant at P>0.01

TABLE 12 (continued)

		Mean	$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
			Maxilla				
pm	x	46.25	0.97	2.91	50.31	42.83	9
	y	-32.89	0.48	1.45	-30.29	-34.41	9
sp	x	1.44 *	0.96	2.88	5.43	-2.32	9
	y	-40.05	1.11	3.33	-34.01	-45.07	9
ss	x	4.69 *	0.73	2.20	7.85	2.57	9
	y	-43.86	1.12	3.35	-39.11	-49.57	9
pr	x	4.73 *	0.87	2.60	9.09	2.25	9
	y	-56.97	1.58	4.74	-48.52	-63.61	9
as	x	No Observations Recorded					
	y	No Observations Recorded					
is	x	6.60 **	0.80	2.41	10.55	3.70	9
	y	-64.10	1.31	3.93	-57.44	-69.74	9
ms	x	31.43	1.02	3.05	37.03	28.37	9
	y	-52.60 *	1.05	3.15	-47.20	-55.75	9
			Mandible				
mi	x	31.42	1.18	2.36	33.73	29.28	4
	y	-53.32	1.93	3.85	-47.71	-56.41	4
ii	x	8.68	1.14	2.27	10.62	6.06	4
	y	-63.87	2.77	5.54	-55.77	-68.25	4
ai	x	29.85	0.00	0.00	29.85	29.85	1
	y	-82.23	0.00	0.00	-82.23	-82.23	1
id	x	12.78	2.34	4.68	18.14	8.56	4
	y	-70.63	3.39	6.77	-61.29	-76.21	4
pg	x	21.28	2.74	5.48	28.59	16.22	4
	y	-85.20	2.74	5.47	-77.12	-89.28	4
cp	x	24.97	2.97	5.94	32.68	19.15	4
	y	-88.62	2.80	5.60	-80.27	-92.26	4
gn	x	29.73	2.72	5.44	36.89	25.49	4
	y	-88.94	2.68	5.37	-80.92	-92.18	4
tgo	x	71.83	2.14	4.29	75.67	67.18	4
	y	-53.47	1.48	2.97	-49.78	-56.41	4

* Mean difference between male and female significant at $P>0.05$

** Mean difference between male and female significant at $P>0.01$

TABLE 13

Coordinates of craniometric reference points in females

Age Group: Early Juvenile Stage 2

		Mean	$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
		Anterior Cranial Base Region					
n	x	0.00	0.00	0.00	0.00	0.00	14
	y	0.00	0.00	0.00	0.00	0.00	14
s	x	60.42 *	0.46	1.74	63.47	57.75	14
	y	-.00	0.00	0.00	0.00	-.00	14
lo	x	21.50	0.58	2.17	25.11	18.42	14
	y	-9.41*	0.55	2.06	-5.23	-12.37	14
or	x	13.69	0.83	3.10	18.50	8.45	14
	y	-23.15**	0.33	1.24	-21.11	-25.41	14
zp	x	26.69	0.52	1.95	29.05	23.36	14
	y	-36.36**	0.42	1.58	-33.96	-39.64	14
		Posterior Cranial Base Region					
ba	x	82.04	0.77	2.90	86.70	77.49	14
	y	-25.88	0.70	2.61	-19.29	-29.37	14
ar	x	72.36	0.80	2.39	74.68	68.48	9
	y	-20.45	0.45	1.35	-17.45	-21.95	9
po	x	81.35 **	0.73	2.75	85.33	76.17	14
	y	-12.21	0.60	2.24	-6.92	-15.28	14
er	x	74.25	1.60	4.53	78.80	66.42	8
	y	-17.15	1.25	3.52	-12.45	-23.63	8
		Extracranial Reference Point					
evp	x	14.26	1.42	4.26	21.93	7.92	9
	y	-91.99	1.30	3.90	-85.24	-97.92	9

* Mean difference between male and female significant at P >0.50

** Mean difference between male and female significant at P>0.01

TABLE 13 (continued)

		Mean		$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
				Maxilla				
pm	x	44.90		0.51	1.91	48.46	40.78	14
	y		-33.24	0.38	1.44	-30.77	-35.24	14
sp	x	0.74		0.60	2.23	4.18	-3.96	14
	y		-39.79	0.56	2.09	-36.97	-44.37	14
ss	x	3.39		0.64	2.41	7.99	-1.97	14
	y		-43.07	0.57	2.13	-40.17	-47.82	14
pr	x	1.80		0.66	2.48	6.31	-2.71	14
	y		-52.02*	0.66	2.47	-49.07	-58.19	14
as	x	7.88		0.76	1.86	9.83	4.58	6
	y		-41.35	0.63	1.54	-39.83	-44.28	6
is	x	2.04		0.81	3.03	6.40	-3.71	14
	y		-63.39**	0.80	3.00	-59.16	-70.60	14
ms	x	28.91		0.68	2.55	34.00	24.23	14
	y		-54.25**	0.54	2.03	-50.61	-57.11	14
				Mandible				
mi	x	28.56		0.55	1.65	32.08	26.47	9
	y		-55.11*	0.65	1.96	-52.05	-58.09	9
ii	x	5.11		0.85	2.55	8.90	0.94	9
	y		-64.47	1.12	3.37	-59.06	-68.52	9
ai	x	20.76		1.30	3.67	26.85	17.57	8
	y		-79.78*	1.16	3.29	-75.36	-85.25	8
id	x	10.63		0.76	2.29	14.42	8.39	9
	y		-73.11	1.05	3.14	-68.48	-77.26	9
pg	x	19.97		1.45	4.35	29.11	15.99	9
	y		-87.33*	1.14	3.42	-81.16	-91.84	9
cp	x	22.30		1.60	4.79	31.64	17.41	9
	y		-89.57*	1.20	3.59	-82.82	-94.83	9
gn	x	26.19		1.52	4.56	35.71	21.76	9
	y		-90.14*	1.16	3.47	-83.80	-94.67	9
tgo	x	71.42		1.13	3.38	77.85	65.41	9
	y		-54.79**	0.94	2.81	-51.52	-60.27	9

* Mean difference between male and female significant at $P>0.50$

** Mean difference between male and female significant at $P>0.01$

TABLE 14

Coordinates of craniometric reference points in females

Age Group: Early Juvenile Stage 3

		Mean	$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
		Anterior Cranial Base Region					
n	x	0.00	0.00	0.00	0.00	0.00	22
	y	0.00	0.00	0.00	0.00	0.00	22
s	x	61.01 **	0.55	2.57	66.43	56.24	22
	y	-.00	0.00	0.00	0.00	-.00	22
lo	x	21.52 *	0.43	2.02	25.05	17.76	22
	y	-9.09	0.35	1.64	-5.34	-11.92	22
or	x	13.94	0.50	2.34	18.73	8.84	22
	y	-23.88*	0.34	1.58	-20.23	-25.94	22
zp	x	26.36	0.36	1.71	29.66	22.33	22
	y	-37.93**	0.50	2.34	-34.14	-41.36	22
		Posterior Cranial Base Region					
ba	x	83.37 *	0.62	2.91	87.86	77.36	22
	y	-27.27*	0.54	2.53	-22.11	-33.33	22
ar	x	72.98 *	0.62	2.57	76.80	68.36	17
	y	-21.26*	0.50	2.06	-16.88	-25.10	17
po	x	82.69 *	0.66	3.08	88.25	76.82	22
	y	-12.25*	0.46	2.13	-7.71	-15.41	22
er	x	77.18	0.73	2.72	80.91	71.76	14
	y	-17.32	0.96	3.60	-11.03	-22.65	14
		Extracranial Reference Point					
evp	x	10.76	1.17	4.81	21.54	4.50	17
	y	-94.82	1.25	5.17	-85.89	-102.78	17

* Mean difference between male and female significant at P>0.05
** Mean difference between male and female significant at P>0.01

TABLE 14 (continued)

		Mean		$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
				Maxilla				
pm	x	46.27		0.51	2.37	50.85	42.05	22
	y		-34.98	0.44	2.05	-31.78	-38.92	22
sp	x	0.86		0.56	2.63	4.76	-4.36	22
	y		-41.42	0.56	2.64	-35.15	-45.94	22
ss	x	3.93		0.51	2.39	7.82	-0.75	22
	y		-45.14	0.59	2.76	-39.70	-50.42	22
pr	x	1.60		0.59	2.77	7.32	-3.99	22
	y		-55.34	0.67	3.14	-47.98	-61.58	22
as	x	8.43		0.53	2.49	12.50	3.18	22
	y		-44.03	0.60	2.80	-38.16	-48.15	22
is	x	1.19		0.73	3.42	8.67	-5.47	22
	y		-67.92	0.75	3.53	-59.97	-74.24	22
ms	x	28.94		0.69	3.21	36.87	21.54	22
	y		-56.88*	0.61	2.85	-51.48	-61.73	22
				Mandible				
mi	x	27.47		0.94	3.87	36.65	20.64	17
	y		-57.09*	0.73	3.03	-51.81	-62.52	17
ii	x	3.00		0.92	3.81	12.18	-3.17	17
	y		-66.12	0.94	3.88	-59.19	-71.86	17
ai	x	20.37		1.29	5.32	31.98	10.72	17
	y		-82.95	0.97	4.01	-76.33	-89.54	17
id	x	8.80		1.13	4.65	18.51	0.03	17
	y		-74.74	0.96	3.96	-67.58	-80.88	17
pg	x	18.81		1.35	5.55	29.55	9.43	17
	y		-90.82	1.16	4.77	-82.10	-98.13	17
cp	x	21.64		1.52	6.28	34.94	10.41	17
	y		-92.86	1.21	5.01	-84.41	-100.96	17
gn	x	25.65		1.44	5.93	38.20	16.08	17
	y		-93.08	1.17	4.81	-84.76	-101.03	17
tgo	x	73.34		0.91	3.76	81.83	67.92	17
	y		-56.61**	0.81	3.32	-49.87	-61.74	17

* Mean difference between male and female significant at P>0.05

** Mean difference between male and female significant at P>0.01

TABLE 15

Coordinates of craniometric reference points in females

Age Group: Late Juvenile Stage 1

		Mean		$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
				Anterior Cranial Base Region				
n	x	0.00		0.00	0.00	0.00	0.00	40
	y		0.00	0.00	0.00	0.00	0.00	40
s	x	62.20	**	0.40	2.54	67.35	53.87	40
	y		-.00	0.00	0.00	0.00	-.00	40
lo	x	22.03	*	0.30	1.93	25.31	18.10	40
	y		-9.84	0.31	1.94	-6.48	-15.80	40
or	x	14.03		0.31	1.95	18.50	9.01	40
	y		-24.47	0.28	1.77	-21.38	-28.28	40
zp	x	25.84		0.43	2.74	30.43	17.69	40
	y		-39.46**	0.35	2.22	-33.61	-44.05	40
				Posterior Cranial Base Region				
ba	x	85.42	*	0.65	4.11	92.41	74.60	40
	y		-26.64**	0.55	3.46	-17.57	-32.18	40
ar	x	75.04	**	0.59	3.50	81.25	65.22	35
	y		-21.21**	0.31	1.81	-17.85	-24.71	35
po	x	84.31	*	0.57	3.60	91.03	73.46	40
	y		-11.89**	0.37	2.36	-6.09	-16.05	40
er	x	77.66	**	0.79	4.75	86.30	67.72	36
	y		-18.27	0.75	4.52	-11.46	-29.21	36
				Extracranial Reference Point				
evp	x	11.66		0.68	4.04	21.08	3.50	35
	y		-99.14	0.82	4.88	-86.96	-107.01	35

* Mean difference between male and female significant at P>0.05

** Mean difference between male and female significant at P>0.01

TABLE 15 (continued)

		Mean	$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
			Maxilla				
pm	x	47.46	0.44	2.80	52.79	42.77	40
	y	-36.05*	0.33	2.08	-31.86	-39.88	40
sp	x	0.74	0.42	2.67	5.08	-4.19	40
	y	-43.12	0.47	2.97	-37.91	-49.00	40
ss	x	3.36	0.44	2.80	8.46	-1.81	40
	y	-46.63	0.47	2.96	-41.19	-52.84	40
pr	x	0.28	0.57	3.63	7.28	-5.97	40
	y	-57.96	0.58	3.70	-48.22	-66.20	40
as	x	7.97	0.52	3.27	14.35	1.90	40
	y	-45.86	0.50	3.15	-38.65	-52.87	40
is	x	-0.41	0.67	4.27	7.96	-8.67	40
	y	-70.58	0.60	3.81	-60.73	-78.44	40
ms	x	27.88	0.51	3.24	37.01	21.81	40
	y	-59.97*	0.48	3.06	-52.45	-65.97	40
			Mandible				
mi	x	26.35	0.62	3.64	33.01	19.57	35
	y	-60.79	0.52	3.10	-52.72	-65.97	35
ii	x	1.17	0.79	4.67	11.00	-6.44	35
	y	-69.17	0.65	3.86	-58.62	-74.38	35
ai	x	19.18	0.88	5.21	31.83	10.92	35
	y	-85.83	0.66	3.92	-77.14	-91.63	35
id	x	7.00	0.81	4.76	17.03	-0.68	35
	y	-77.66	0.64	3.79	-68.31	-83.43	35
pg	x	18.57	1.01	5.98	32.44	9.14	35
	y	-95.01	0.81	4.82	-83.35	-102.91	35
cp	x	21.12	1.00	5.90	34.39	11.57	35
	y	-97.12	0.83	4.91	-84.88	-105.68	35
gn	x	25.38	1.00	5.95	38.74	15.74	35
	y	-97.48	0.80	4.72	-86.29	-105.43	35
tgo	x	75.48	0.65	3.83	83.64	67.37	35
	y	-59.21**	0.70	4.14	-50.12	-69.81	35

*Mean difference between male and female significant at P>0.05
**Mean difference between male and female significant at P>0.01

TABLE 16

Coordinates of craniometric reference points in females

Age Group: Late Juvenile Stage 2

		Mean		$\pm\Sigma(\bar{x})$	s	Maximum	Maximum	N
				Anterior Cranial Base Region				
n	x	0.00		0.00	0.00	0.00	0.00	11
	y		0.00	0.00	0.00	0.00	0.00	11
s	x	63.24		0.95	3.15	67.46	58.17	11
	y		-.00	0.00	0.00	0.00	-.00	11
lo	x	21.88		0.59	1.96	25.94	19.62	11
	y		-8.78	0.53	1.77	-6.54	-11.73	11
or	x	12.55		0.73	2.44	15.32	9.04	11
	y		-24.34	0.55	1.81	-22.06	-27.61	11
zp	x	25.91		0.86	2.86	28.96	20.94	11
	y		-40.67	0.46	1.54	-38.42	-43.25	11
				Posterior Cranial Base Region				
ba	x	85.24		1.58	5.24	93.17	76.72	11
	y		-29.82	0.58	1.93	-26.02	-33.60	11
ar	x	74.23	*	1.54	4.87	83.33	66.77	10
	y		-22.55	0.52	1.66	-21.18	-26.47	10
po	x	83.77	*	1.36	4.52	91.87	75.42	11
	y		-12.75	0.64	2.14	-8.71	-15.52	11
er	x	77.10	*	1.62	5.39	84.52	66.69	11
	y		-21.29	1.77	5.85	-13.11	-29.32	11
				Extracranial Reference Point				
evp	x	10.14		1.42	4.50	15.17	0.60	10
	y		-100.12	1.09	3.45	-95.72	-106.86	10

* Mean difference between male and female significant at P>0.50
** Mean difference between male and female significant at P>0.01

TABLE 16 (continued)

		Mean			$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
					Maxilla				
pm	x	45.81		*	0.94	3.13	52.33	40.82	11
	y		-37.63		0.44	1.47	-35.52	-39.52	11
sp	x	-1.06			0.82	2.73	3.87	-4.18	11
	y		-43.51		0.40	1.34	-41.32	-45.14	11
ss	x	1.66			0.93	3.07	6.07	-2.73	11
	y		-47.48		0.73	2.41	-43.26	-51.66	11
pr	x	-1.52			1.26	4.20	4.92	-7.49	11
	y		-58.99		0.65	2.17	-54.61	-62.45	11
as	x	6.23			0.97	3.22	10.23	1.92	11
	y		-47.93		0.54	1.79	-44.15	-50.08	11
is	x	-2.45			1.49	4.95	5.71	-9.74	11
	y		-71.17		0.64	2.12	-67.01	-74.50	11
ms	x	25.59			1.26	4.20	32.53	19.38	11
	y		-61.42		0.66	2.18	-57.53	-64.81	11
					Mandible				
mi	x	22.36			1.48	4.69	31.24	14.18	10
	y		-62.22		0.75	2.36	-58.26	-65.98	10
ii	x	-2.11			1.40	4.44	6.93	-8.25	10
	y		-69.57		0.96	3.03	-62.46	-74.62	10
ai	x	15.34			1.62	5.13	24.80	9.89	10
	y		-86.75		0.58	1.84	-83.92	-89.34	10
id	x	2.92			1.58	4.99	12.63	-2.87	10
	y		-78.39		0.87	2.74	-72.55	-82.81	10
pg	x	14.77			1.65	5.23	22.76	7.95	10
	y		-96.41		1.18	3.72	-91.00	-103.41	10
cp	x	16.86			1.79	5.66	24.61	9.87	10
	y		-98.19		1.18	3.73	-92.50	-104.61	10
gn	x	21.75			1.70	5.38	30.71	14.45	10
	y		-98.96		1.07	3.37	-94.90	-105.47	10
tgo	x	74.12			1.55	4.91	81.61	64.51	10
	y		-61.97		0.98	3.09	-57.83	-66.89	10

* Mean difference between male and female significant at P>0.05

** Mean difference between male and female significant at P>0.01

TABLE 17

Coordinates of craniometric reference points in females

Age Group: Adolescent

		Mean	$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
			Anterior Cranial Base Region				
n	x	0.00	0.00	0.00	0.00	0.00	43
	y	0.00	0.00	0.00	0.00	0.00	43
s	x	63.79 **	0.45	2.96	70.06	54.75	43
	y	-.00	0.00	0.00	0.00	-.00	43
lo	x	22.09 **	0.37	2.40	26.95	17.37	43
	y	-10.08	0.37	2.45	-5.39	-16.02	43
or	x	13.31 **	0.37	2.41	18.78	7.29	43
	y	-25.09*	0.36	2.38	-19.62	-30.13	43
zp	x	26.33 **	0.45	2.98	34.64	19.53	43
	y	-41.74**	0.41	2.71	-33.09	-48.28	43
			Posterior Cranial Base Region				
ba	x	87.81 **	0.68	4.48	98.79	77.93	43
	y	-28.09**	0.52	3.43	-19.71	-35.24	43
ar	x	78.24 **	0.59	3.62	86.03	69.77	38
	y	-22.56**	0.37	2.30	-17.66	-27.41	38
po	x	86.28 **	0.64	4.18	93.13	75.44	43
	y	-11.86**	0.39	2.55	-6.86	-16.45	43
er	x	80.75 *	0.73	4.70	90.27	69.22	41
	y	-18.54	0.73	4.67	-9.94	-31.27	41
			Extracranial Reference Point				
evp	x	10.46 *	1.01	5.88	20.34	0.46	34
	y	-103.43	1.00	5.82	-84.94	-112.59	34

* Mean difference between male and female significant at P>0.05

** Mean difference between male and female significant at P>0.01

TABLE 17 (continued)

		Mean	$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
			Maxilla				
pm	x	47.91 **	0.51	3.34	55.00	41.05	43
	y	-38.05**	0.36	2.35	-31.16	-45.09	43
sp	x	-0.06	0.48	3.16	6.23	-9.07	43
	y	-45.22	0.42	2.74	-39.58	-49.91	43
ss	x	2.35	0.51	3.35	9.59	-4.83	43
	y	-49.01	0.48	3.15	-40.48	-54.66	43
pr	x	-1.92	0.65	4.26	7.36	-10.57	43
	y	-61.40	0.54	3.56	-51.19	-67.62	43
as	x	5.79	0.58	3.83	14.21	-1.79	43
	y	-49.39	0.43	2.82	-42.27	-54.39	43
is	x	-2.57	0.71	4.68	8.59	-12.58	43
	y	-73.68*	0.63	4.15	-59.51	-81.14	43
ms	x	24.87 *	0.62	4.05	34.00	15.96	43
	y	-64.52**	0.49	3.22	-54.89	-70.46	43
			Mandible				
mi	x	23.12	0.69	4.28	31.79	13.93	38
	y	-65.33*	0.53	3.26	-54.90	-70.46	38
ii	x	-0.06	0.71	4.37	9.18	-7.91	38
	y	-71.33	0.72	4.45	-58.52	-80.56	38
ai	x	17.24	0.89	5.50	28.63	7.55	38
	y	-88.18*	0.81	4.97	-72.66	-98.23	38
id	x	5.17	0.80	4.91	14.56	-3.24	38
	y	-79.69*	0.77	4.73	-64.87	-89.23	38
pg	x	16.31	1.03	6.34	30.43	7.28	38
	y	-98.78*	0.89	5.49	-81.97	-108.68	38
cp	x	19.45	1.06	6.53	33.95	10.15	38
	y	-101.58*	0.90	5.54	-83.78	-110.91	38
gn	x	23.66	1.07	6.60	37.40	13.91	38
	y	-101.78*	0.88	5.40	-84.59	-110.80	38
tgo	x	78.59	0.69	4.26	86.39	69.37	38
	y	-63.30**	0.77	4.75	-54.72	-74.26	38

* Mean difference between male and female significant at P>0.05
** Mean difference between male and female significant at P>0.01

TABLE 18

Coordinates of craniometric reference points in females

Age Group: Adult

		Mean	$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
		Anterior Cranial Base Region					
n	x	0.00	0.00	0.00	0.00	0.00	31
	y	0.00	0.00	0.00	0.00	0.00	31
s	x	66.71 **	0.44	2.46	72.25	61.66	31
	y	-.00	0.00	0.00	0.00	-.00	31
lo	x	22.93 *	0.58	3.22	29.48	16.26	31
	y	-9.58	0.51	2.83	-2.87	-15.65	31
or	x	14.79 *	0.54	3.02	20.69	9.86	31
	y	-25.04	0.46	2.56	-18.70	-31.05	31
zp	x	26.90 **	0.51	2.85	31.14	20.08	31
	y	-42.87**	0.59	3.28	-37.58	-50.11	31
		Posterior Cranial Base Region					
ba	x	91.29 **	0.73	4.08	100.71	83.04	31
	y	-28.42**	0.65	3.63	-21.66	-34.35	31
ar	x	82.16 **	0.61	3.40	88.92	73.12	31
	y	-23.45**	0.47	2.60	-19.56	-28.54	31
po	x	90.16 **	0.58	3.24	97.83	82.55	31
	y	-11.91**	0.57	3.17	-5.38	-19.82	31
er	x	85.25 **	0.81	4.52	99.12	78.10	31
	y	-17.30	0.82	4.55	-11.65	-28.68	31
		Extracranial Reference Point					
evp	x	12.03	1.89	7.05	22.00	-6.13	14
	y	-107.14**	0.90	3.37	-101.82	-111.92	14

* Mean difference between male and female significant at P>0.05

** Mean difference between male and female significant at P>0.01

TABLE 18 (continued)

		Mean	$\pm\Sigma(\bar{x})$	s	Maximum	Minimum	N
			Maxilla				
pm	x	49.37 **	0.64	3.57	55.32	40.29	31
	y	-39.67**	0.35	1.96	-36.16	-43.94	31
sp	x	-0.28	0.58	3.21	4.88	-7.53	31
	y	-46.99**	0.40	2.22	-41.46	-51.56	31
ss	x	1.41	0.56	3.10	7.61	-4.58	31
	y	-51.09**	0.55	3.07	-44.35	-60.59	31
pr	x	-2.77	0.68	3.77	5.22	-11.21	31
	y	-64.49**	0.70	3.88	-58.05	-74.73	31
as	x	5.23	0.65	3.63	13.27	-1.24	31
	y	-52.23**	0.66	3.68	-46.72	-63.06	31
is	x	-3.31 *	0.84	4.70	4.86	-12.77	31
	y	-76.11**	-.74	4.14	-69.78	-88.34	31
ms	x	22.62 *	0.69	3.85	28.79	14.03	31
	y	-69.24**	0.55	3.08	-64.38	-80.34	31
			Mandible				
mi	x	20.73	0.69	3.84	26.98	11.75	31
	y	-69.83**	0.58	3.25	-65.31	-81.69	31
ii	x	-1.09	0.87	4.82	6.92	-11.59	31
	y	-74.61**	0.75	4.15	-65.14	-84.73	31
ai	x	15.92	1.08	6.04	27.48	3.75	31
	y	-90.78**	0.77	4.29	-83.05	-101.75	31
id	x	4.10	0.92	5.10	12.66	-6.70	31
	y	-82.56**	0.74	4.10	-73.80	-92.84	31
pg	x	14.31 *	1.21	6.74	22.88	1.03	31
	y	-102.86**	0.94	5.26	-92.60	-119.73	31
cp	x	17.72	1.23	6.84	25.72	4.21	31
	y	-105.88**	0.90	5.00	-98.50	-122.62	31
gn	x	21.41	1.24	6.88	30.19	7.19	31
	y	-106.30**	0.87	4.86	-98.85	-123.12	31
tgo	x	81.52 **	0.90	4.99	92.20	70.24	31
	y	-68.73**	0.93	5.19	-58.78	-80.25	31

* Mean difference between male and female significant at P>0.05

** Mean difference between male and female significant at P>0.01

PROPORTIONATE STATISTICS

To eliminate size differences absolute values of the reference point coordinates were converted to proportionate values, thereby permitting both within sex and between sex comparisons of the age group norms.

Tables 19 and 20 show the proportionate values of the coordinates expressed in per cent of the total grid size for all seven dental age groups for both males and females. The abscissa value is recorded as a percentage of the grid depth and the ordinate as a percentage of the grid height.

TABLE 19 MALE PROPORTIONATE VALUES (Expressed in per cent of total grid size)

		Early Juvenile Stage 1		Early Juvenile Stage 2		Early Juvenile Stage 3		Late Juvenile Stage 1		Late Juvenile Stage 2		Adolescent		Adult	
		Anterior Cranial Base Region													
n	x	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
	y		0.00		0.00		0.00		0.00		0.00		0.00		0.00
s	x	75.00		75.00		75.00		75.00		75.00		75.00		75.00	
	y		-.00		-.00		-.00		-.00		-.00		-.00		-.00
lo	x	25.97		27.00		26.95		26.78		26.25		27.31		26.37	
	y		-9.04		-11.51		-10.53		-9.94		-10.39		-10.02		-9.06
or	x	17.47		16.57		16.85		16.49		15.28		17.49		17.42	
	y		-26.29		-26.48		-26.39		-25.40		-25.63		-24.99		-22.07
zp	x	31.05		31.63		31.39		30.85		30.45		31.73		31.22	
	y		-41.65		-41.69		-41.73		-41.75		-41.82		-41.56		-38.92
		Posterior Cranial Base Region													
ba	x	101.16		101.29		101.84		102.26		100.98		102.82		103.62	
	y		-31.44		-29.72		-30.54		-29.37		-28.62		-29.42		-28.70
ar	x	87.49		89.13		89.55		90.02		90.22		91.74		93.04	
	y		-22.78		-23.04		-23.89		-23.36		-23.75		-23.67		-23.14
po	x	101.00		100.50		100.94		101.14		101.24		101.69		102.56	
	y		-14.75		-13.83		-14.38		-13.81		-14.15		-13.35		-12.31
er	x	94.47		93.14		93.11		94.56		93.52		96.62		97.73	
	y		-19.17		-19.10		-19.57		-19.67		-20.38		-19.48		-15.91
		Extracranial Reference Point													
evp	x	15.76		14.28		14.47		14.53		12.64		15.64		14.34	
	y		-101.39		-101.63		-101.57		-101.43		-101.14		-101.33		-101.49

TABLE 19 (continued)

		E Juv. 1	E Juv. 2	E Juv. 3	L Juv. 1	L Juv. 2	Adolescent	Adult
Maxilla								
pm	x	56.26	55.47	56.19	56.63	56.04	56.62	55.28
	y	-38.18	-36.80	-37.81	-37.74	-38.42	-38.05	-36.56
sp	x	-1.30	0.42	0.71	0.83	-0.45	1.28	0.49
	y	-45.96	-43.94	-44.97	-44.60	-45.34	-44.20	-42.92
ss	x	3.04	3.88	4.10	4.14	2.65	3.87	2.72
	y	-50.39	-47.92	-48.38	-48.17	-49.02	-47.59	-46.70
pr	x	2.20	1.61	1.14	-0.11	-1.67	-1.02	-1.18
	y	-64.58	-57.99	-58.87	-59.46	-59.77	-59.92	-59.27
as	x	-----	9.19	9.81	9.33	7.68	8.12	6.29
	y	-----	-46.43	-47.12	-47.38	-48.02	-48.07	-47.61
is	x	3.72	1.88	0.06	-1.50	-3.02	-1.88	-0.79
	y	-72.92	-72.29	-72.79	-72.92	-73.14	-72.34	-69.95
ms	x	37.02	34.78	34.24	33.15	30.62	30.13	26.36
	y	-61.67	-61.08	-61.97	-62.44	-63.33	-63.68	-63.92
Mandible								
mi	x	34.81	33.64	32.58	31.06	29.19	27.96	23.66
	y	-61.75	-61.51	-62.57	-62.95	-63.78	-64.46	-64.54
ii	x	4.98	3.50	2.39	0.37	-0.30	0.66	1.14
	y	-72.22	-70.68	-70.69	-70.57	-69.86	-69.77	-68.17
ai	x	26.32	22.63	22.39	21.27	20.01	20.91	19.57
	y	-91.55	-89.43	-89.09	-88.19	-87.61	-86.78	-85.03
id	x	9.15	9.88	9.19	7.12	6.04	6.74	6.14
	y	-79.39	-80.48	-80.06	-79.48	-78.73	-78.22	-75.92
pg	x	20.88	20.57	20.07	19.79	17.84	19.76	19.23
	y	-97.16	-97.14	-97.40	-97.61	-97.37	-97.46	-97.49
cp	x	24.39	23.68	23.21	23.11	21.16	23.37	22.46
	y	-99.79	-99.70	-99.76	-99.90	-99.88	-100.00	-99.70
gn	x	28.81	29.10	28.34	27.87	25.08	27.45	26.39
	y	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
tgo	x	84.15	86.92	87.13	87.83	86.45	90.67	94.42
	y	-63.31	-62.40	-63.27	-62.63	-64.40	-63.30	-64.51

TABLE 20 FEMALE PROPORTIONATE VALUES (Expressed in per cent of total grid size.)

		Early Juvenile Stage 1	Early Juvenile Stage 2	Early Juvenile Stage 3	Late Juvenile Stage 1	Late Juvenile Stage 2	Adolescent	Adult
Anterior Cranial Base Region								
n	x	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	y	0.00	0.00	0.00	0.00	0.00	0.00	0.00
s	x	75.00	75.00	75.00	75.00	75.00	75.00	75.00
	y	-.00	-.00	-.00	-.00	-.00	-.00	-.00
lo	x	26.77	26.70	26.46	26.56	25.94	25.97	25.77
	y	-10.81	-10.44	-9.76	-10.10	-8.87	-9.90	-9.02
or	x	17.37	16.99	17.14	16.92	14.88	15.65	16.63
	y	-26.45	-25.68	-25.66	-25.11	-24.60	-24.65	-23.56
zp	x	32.06	33.13	32.41	31.16	30.72	30.96	30.25
	y	-40.81	-40.34	-40.76	-40.49	-41.10	-41.02	-40.33
Posterior Cranial Base Region								
ba	x	102.36	101.85	102.49	103.00	101.10	103.25	102.63
	y	-29.40	-28.71	-29.30	-27.33	-30.13	-27.60	-26.74
ar	x	88.82	89.83	89.71	90.48	88.03	91.99	92.37
	y	-21.16	-22.68	-22.85	-21.76	-22.78	-22.17	-22.06
po	x	100.93	100.99	101.65	101.65	99.35	101.45	101.36
	y	-13.49	-13.55	-13.16	-12.20	-12.89	-11.65	-11.21
er	x	88.91	92.17	94.87	93.63	91.44	94.95	95.84
	y	-21.61	-19.03	-18.61	-18.75	-21.51	-18.21	-16.28
Extracranial Reference Point								
evp	x	16.92	17.71	13.22	14.06	12.02	12.30	13.52
	y	-102.70	-102.06	-101.87	-101.71	-101.17	-101.62	-100.79

TABLE 20 (continued)

		E Juv. 1	E Juv. 2	E Juv. 3	L Juv. 1	L Juv. 2	Adolescent	Adult
				Maxilla				
pm	x	57.60	55.74	56.88	57.22	54.33	56.34	55.50
	y	-36.98	-36.88	-37.58	-36.98	-38.02	-37.39	-37.32
sp	x	1.79	0.92	1.06	0.90	-1.26	-0.07	-0.32
	y	-45.03	-44.14	-44.50	-44.24	-43.97	-44.43	-44.21
ss	x	5.84	4.21	4.83	4.05	1.96	2.76	1.59
	y	-49.31	-47.78	-48.50	-47.84	-47.98	-48.15	-48.06
pr	x	5.89	2.23	1.96	0.34	-1.81	-2.26	-3.11
	y	-64.05	-57.71	-59.46	-59.46	-59.61	-60.32	-60.67
as	x	No observ.	9.79	10.36	9.60	7.39	6.81	5.88
	y	recorded	-45.87	-47.31	-47.05	-48.44	-48.52	-49.13
is	x	8.21	2.54	1.46	-0.50	-2.90	-3.02	-3.72
	y	-72.06	-70.32	-72.97	-72.41	-71.92	-72.39	-71.61
ms	x	39.14	35.89	35.57	33.62	30.34	29.24	25.43
	y	-59.13	-60.19	-61.11	-61.52	-62.06	-63.39	-65.14
				Mandible				
mi	x	39.14	35.46	33.77	31.77	26.52	27.19	23.30
	y	-59.95	-61.14	-61.34	-62.37	-62.87	-64.19	-65.69
ii	x	10.80	6.35	3.68	1.41	-2.50	-0.07	-1.23
	y	-71.81	-71.52	-71.03	-70.96	-70.30	-70.08	-70.19
ai	x	37.17	25.78	25.04	23.13	18.20	20.27	17.90
	y	-92.45	-88.50	-89.12	-88.05	-87.66	-86.64	-85.40
id	x	15.92	13.20	10.82	8.44	3.47	6.07	4.61
	y	-79.41	-81.10	-80.30	-79.67	-79.21	-78.29	-77.67
pg	x	26.50	24.79	23.12	22.39	17.52	19.18	16.08
	y	-95.78	-96.88	-97.58	-97.47	-97.42	-97.05	-96.77
cp	x	31.11	27.69	26.60	25.46	19.99	22.87	19.92
	y	-99.64	-99.37	-99.77	-99.64	-99.22	-99.81	-99.61
gn	x	37.03	32.51	31.53	30.60	25.80	27.83	24.07
	y	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
tgo	x	89.47	88.66	90.15	91.01	87.90	92.41	91.65
	y	-60.11	-60.78	-60.82	-60.74	-62.62	-62.20	-64.66

COVARIANCE STATISTICS

In many of the reference points there was significant correlation between abscissa and ordinate. Covariance statistics were obtained to illustrate the relation between the variances of the coordinates of a landmark and the covariance between abscissa and ordinate. Covariances between the abscissa and ordinate for each reference point were computed. The covariances for both sexes in each dental age group are recorded in Table 21. Due to the small sample size in each age group the numerical values of the covariances must be interpreted with caution. The question of covariances between x and y coordinates is taken up in the next chapter.

TABLE 21 Covariance Statistics - MALE and FEMALE

		Early Juvenile Stage 1	Early Juvenile Stage 2	Early Juvenile Stage 3	Late Juvenile Stage 1	Late Juvenile Stage 2	Adolescent	Adult
					Anterior Cranial Base Region			
n	♂	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	♀	0.00	0.00	0.00	0.00	0.00	0.00	0.00
s	♂	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	♀	0.00	0.00	0.00	0.00	0.00	0.00	0.00
lo	♂	-0.84	0.91	-1.41	-0.30	0.94	-0.70	-1.27
	♀	0.13	-0.91	1.39	-0.58	0.51	-0.88	-1.33
or	♂	-0.13	1.17	-0.23	-0.83	0.22	0.04	-1.81
	♀	-0.23	-2.07	-1.24	-0.68	0.51	-1.03	-3.72
zp	♂	-2.41	1.71	1.89	-0.75	1.14	-0.30	0.80
	♀	-0.02	-0.23	-1.52	-0.12	-1.82	-1.32	-0.26
					Posterior Cranial Base Region			
ba	♂	2.00	0.89	2.53	-0.29	-2.80	3.97	-1.80
	♀	2.19	-0.06	0.66	-6.08	1.29	0.07	-4.69
ar	♂	-0.21	1.35	-1.45	-1.31	-0.79	1.36	-0.42
	♀	1.58	0.17	0.46	-1.66	-0.88	1.45	-3.45
po	♂	-2.77	2.29	-0.86	-0.58	4.18	3.59	0.41
	♀	-0.99	1.37	-2.44	0.50	1.97	1.64	-0.04
er	♂	6.65	0.58	4.52	3.61	9.05	7.29	-0.04
	♀	-0.51	-3.08	4.57	8.56	3.88	4.52	1.03
					Extracranial Reference Point			
evp	♂	-12.33	-3.36	0.85	-6.45	-6.34	-7.17	-36.99
	♀	-18.43	-11.46	-13.35	-8.76	-3.77	-13.88	-5.15

TABLE 21 (continued)

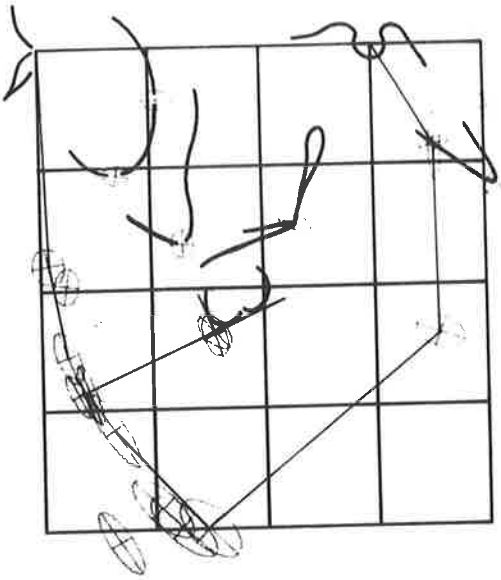
		E Juv. 1	E Juv. 2	E Juv. 3	L Juv. 1	L Juv. 2	Adolescent	Adult
Maxilla								
pm	♂	-2.69	-0.15	-0.24	-0.97	1.23	-0.24	0.98
	♀	-1.98	-0.63	-2.11	-1.49	0.74	-1.07	-1.59
sp	♂	-0.56	1.33	-1.36	-1.74	-4.63	-2.32	-1.59
	♀	-0.59	-1.30	0.13	-1.88	-1.29	-3.48	-1.74
ss	♂	-2.20	0.72	-1.02	-3.05	-2.02	-1.98	-3.37
	♀	0.84	-2.92	-1.61	-3.01	-2.60	-5.70	-1.87
pr	♂	-2.93	0.60	-1.89	-2.60	-2.95	-3.04	-8.08
	♀	-7.04	-2.84	-2.30	-2.38	-3.59	-4.75	-4.63
as	♂	No observ.	0.59	-0.20	-0.90	-1.41	0.85	-3.08
	♀	recorded	-1.11	-1.42	-0.26	-0.77	-3.29	-2.28
is	♂	-3.66	0.00	-2.67	-4.54	-2.59	-4.55	-11.12
	♀	-7.23	-2.76	-4.40	-3.47	-6.14	-6.97	-6.34
ms	♂	-3.58	0.40	-0.98	-1.61	-0.67	0.11	-5.22
	♀	-4.95	-2.14	-3.12	-1.77	-0.20	-3.07	-3.29
Mandible								
mi	♂	-1.11	2.31	0.33	-0.95	0.33	0.48	-6.67
	♀	-3.67	-1.84	-3.93	0.26	1.84	-3.20	-2.25
ii	♂	-4.31	1.26	0.27	-4.14	-1.84	-2.03	-7.90
	♀	-10.64	-1.90	-6.46	-1.90	-4.29	-6.60	-5.53
ai	♂	-18.61	0.74	0.62	-5.73	-2.31	-1.61	-10.30
	♀	0.00	-6.86	-7.09	-3.66	-0.29	-7.99	-6.84
id	♂	-13.45	-0.09	-0.08	-5.22	-2.47	-2.85	-9.30
	♀	-27.38	-2.74	-6.99	-2.48	-3.44	-8.64	-6.22
pg	♂	-9.13	-1.12	-0.24	-5.72	-5.37	-7.97	-25.65
	♀	-21.74	-11.90	-12.16	-7.68	-5.74	-12.44	-14.52
cp	♂	-6.08	-1.90	-0.85	-5.01	-4.87	-7.14	-21.54
	♀	-24.15	-14.31	-17.29	-6.70	-6.81	-13.57	-12.79
gn	♂	-8.49	-1.03	0.26	-5.91	-2.69	-6.80	-19.75
	♀	-16.47	-12.57	-13.02	-5.68	-1.99	-11.64	-12.03
tgo	♂	2.50	-1.53	0.38	0.46	-0.16	-1.76	-0.42
	♀	-3.85	-0.06	0.30	-6.25	3.25	-0.85	-4.56

MESH DIAGRAMS

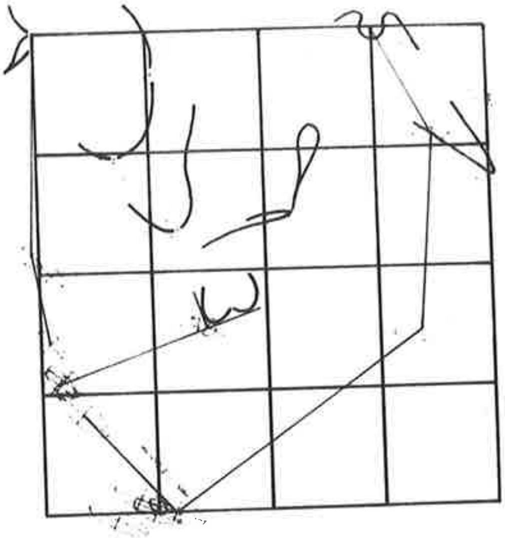
The mesh diagrams shown in Figures 19 and 25 supplement the statistical results presented in the preceding tables of this chapter. All the figures were reproduced to the same scale, and each age group is represented by a separate illustration. Figures A and B were constructed from the mean coordinate values for females and males respectively. Figure C illustrates the proportionate differences between the average facial patterns of the males and females. Lines forming the network of the mesh diagram for females have been deformed so that the relationship of the reference points to the lines is the same as in the undistorted mesh diagram of the males.

Attention is drawn to the fact that Figures A and B illustrate absolute values and therefore may be compared directly with each other in overall dimensions and also in regard to the relative position of the same reference points in each norm grid. Figure C, however, cannot be measured on absolute size with figures A and B. A standard size for all ages was selected to compare the proportionate differences between the sexes. The adult male grid dimensions were chosen for this purpose, although any grid dimension would have sufficed.

The arbitrary assignment of any standard grid dimensions has a distorting effect on the illustration of sex differences. When using the adult male grid size, this is most evident in the younger age groups. Proportionate differences, while valid in themselves, tend to be exaggerated when forced into a grid with dimensions enlarged more in one direction than the other. Figure 26 illustrates this point; when the grid was enlarged more in the horizontal direction the resulting figure was expanded horizontally. A grid enlarged in the vertical dimension would result in vertical expansion of the figure. The findings of the present investigation showed that proportionate sex differences were greatest in the horizontal direction. By selecting the adult male absolute dimensions for the standard grid size, the distortion effect was mainly in the vertical dimension. Thus the exaggeration of the sex differences, while present to some extent, was minimized as much as possible.

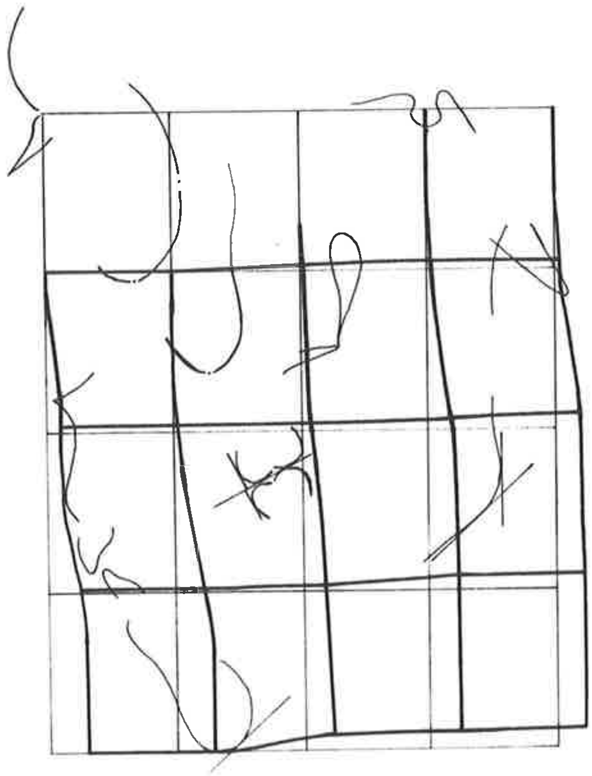


A: Females



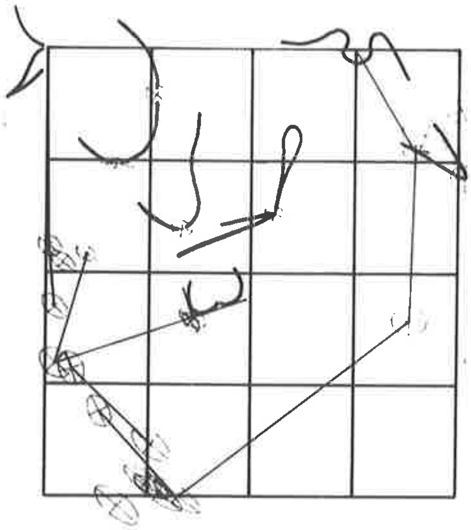
B: Males

mms.
0 20

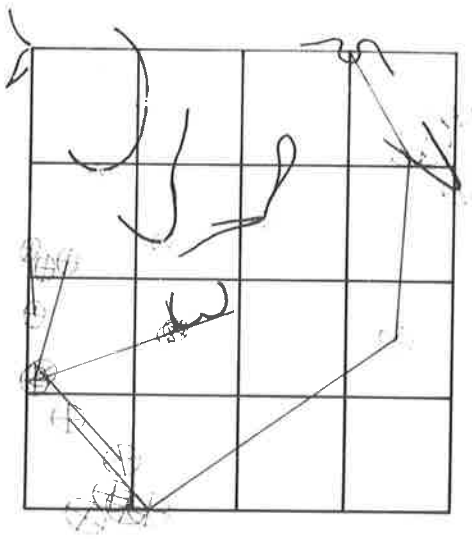


C: Proportionate Difference

Figure 19
Early Juvenile - Stage 1



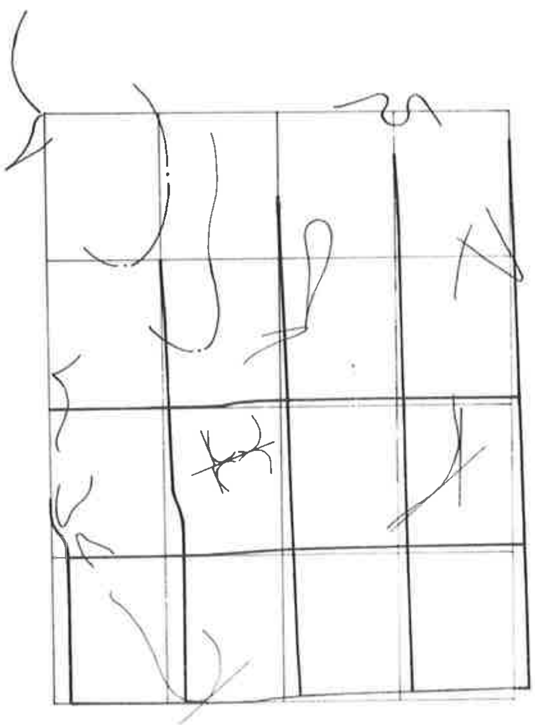
A: Females



B: Males

mms.

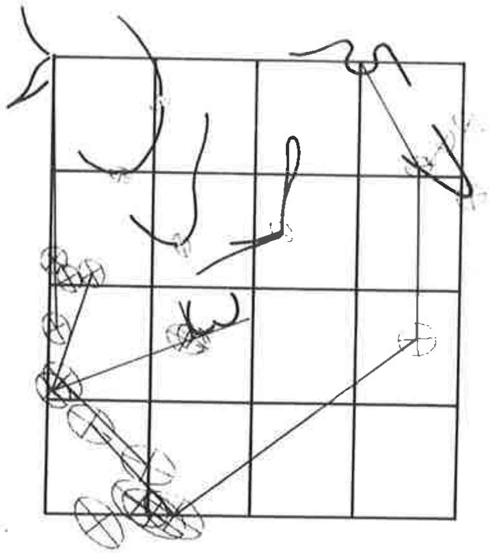
0 20

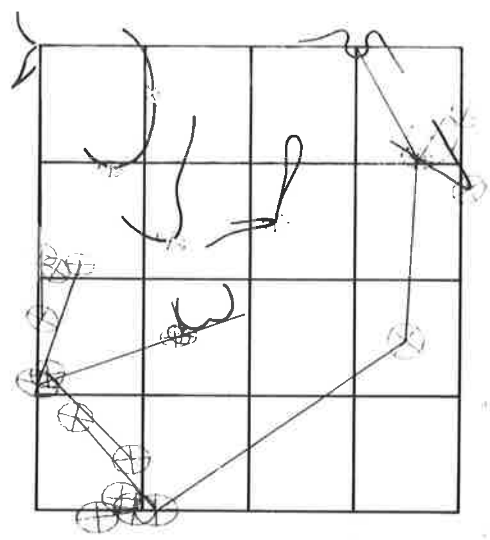


C: Proportionate Difference

Figure 20

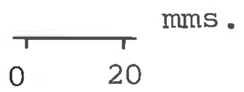
Early Juvenile - Stage 2

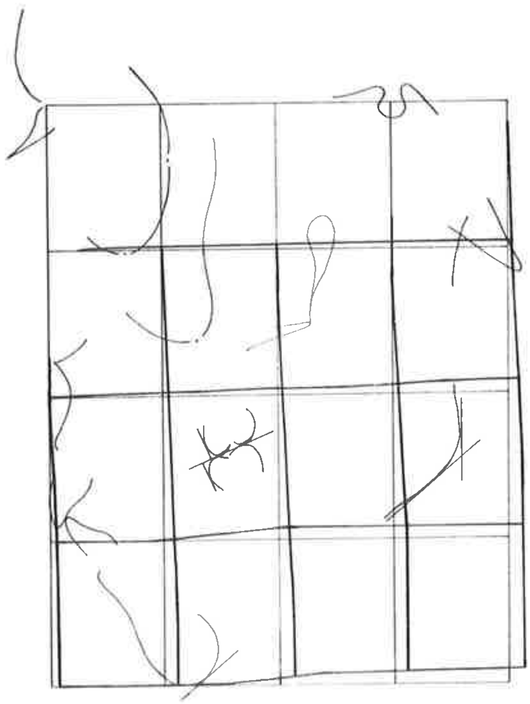




A: Females

B: Males

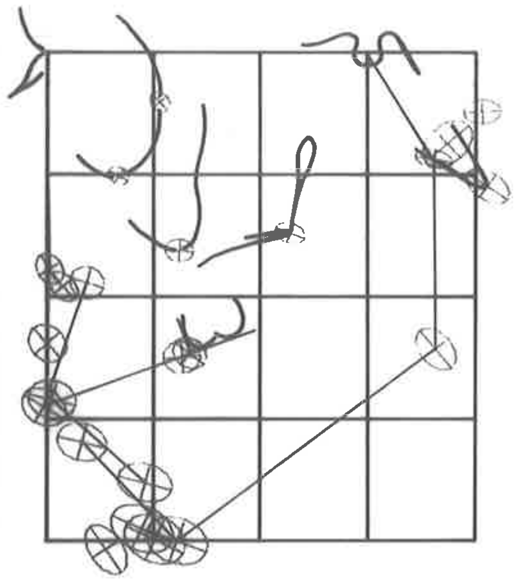




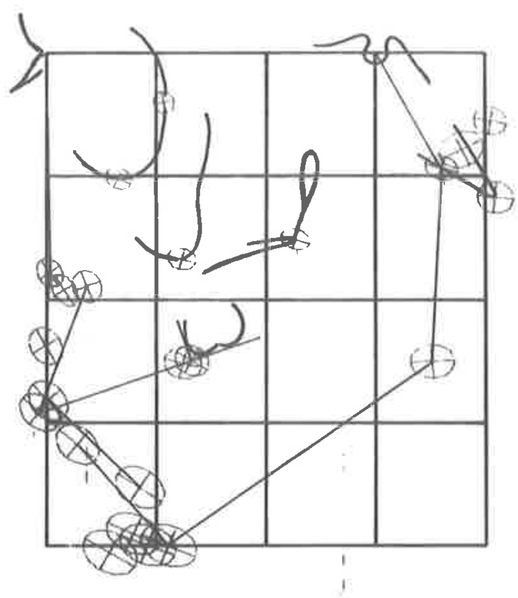
C: Proportionate Difference

Figure 21

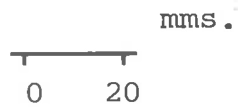
Early Juvenile - Stage 3

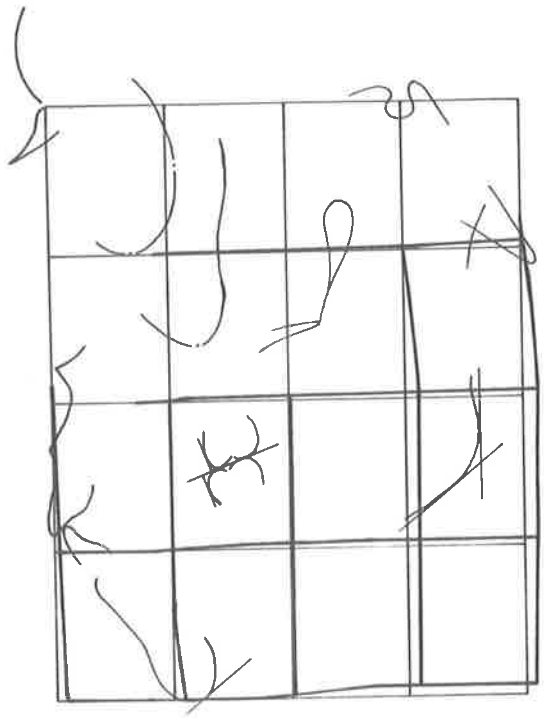


A: Females



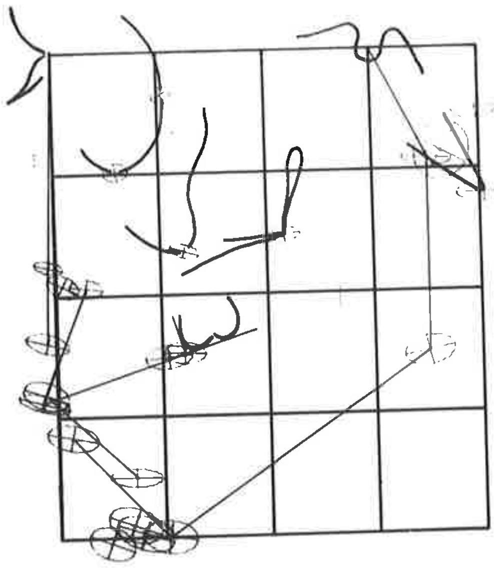
B: Males



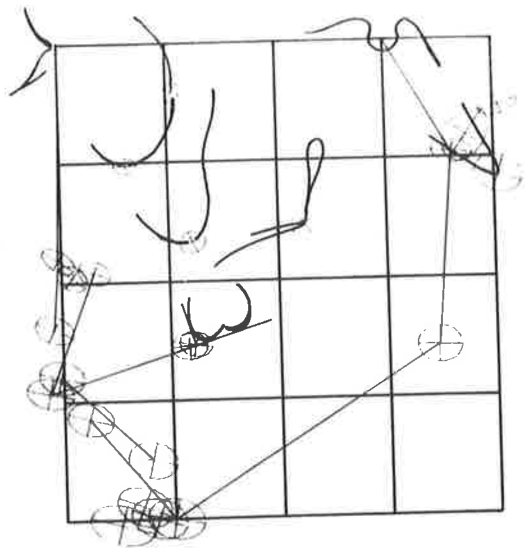


C: Proportionate Difference

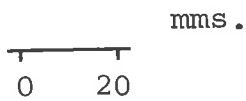
Figure 22
Late Juvenile - Stage 1

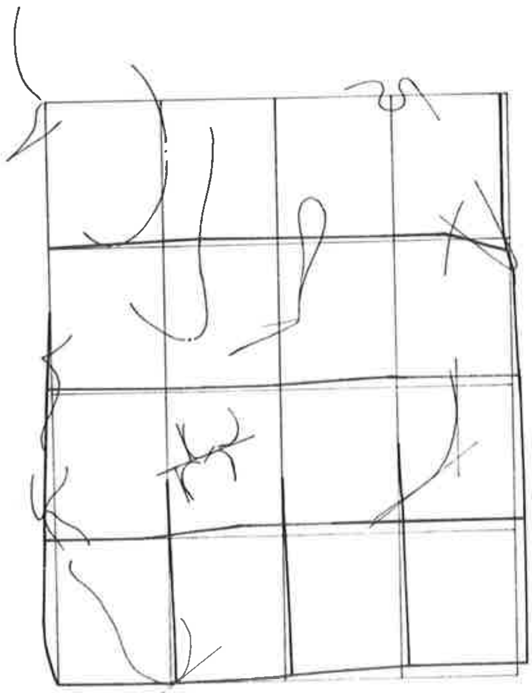


A: Females



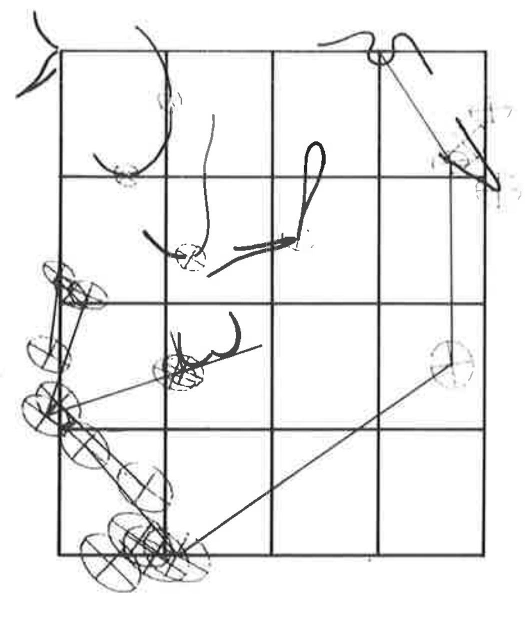
B: Males



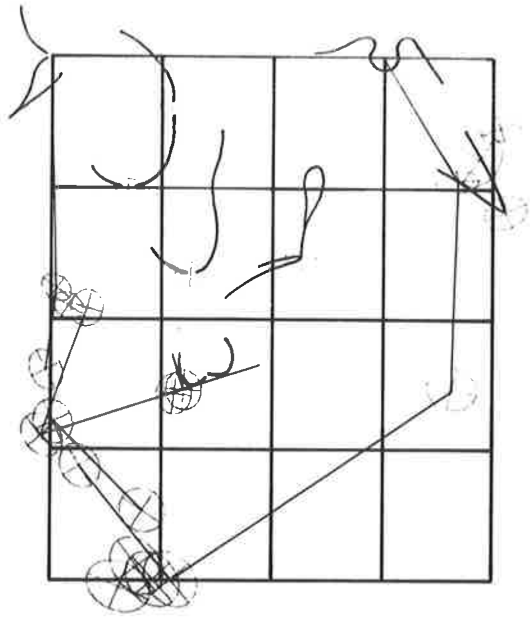


C: Proportionate Difference

Figure 23
Late Juvenile - Stage 2



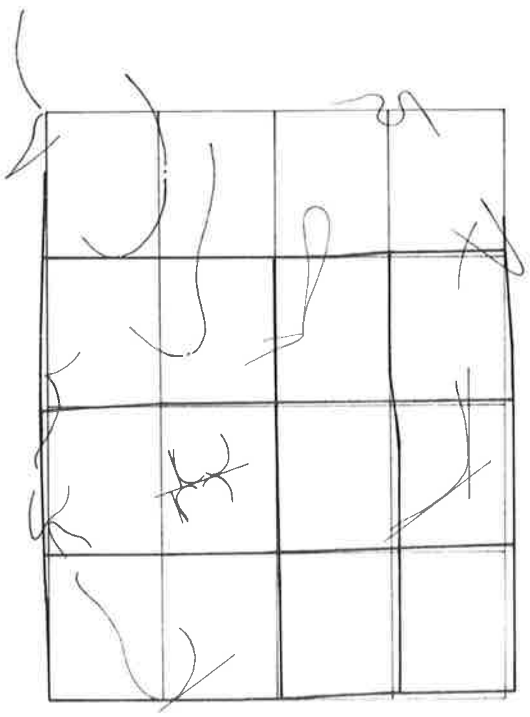
A: Females



B: Males

mms.

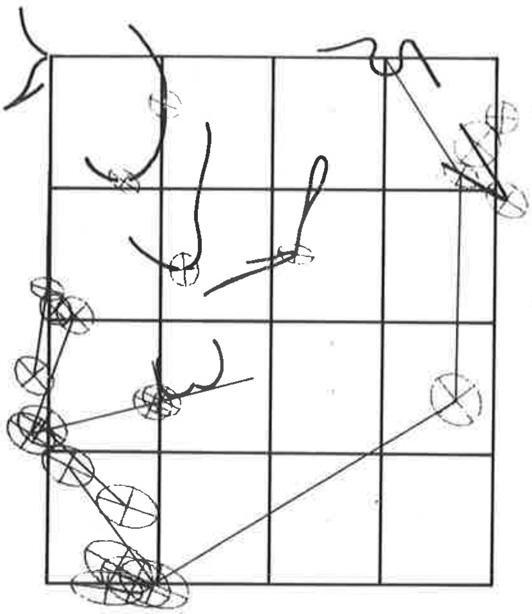
0 20



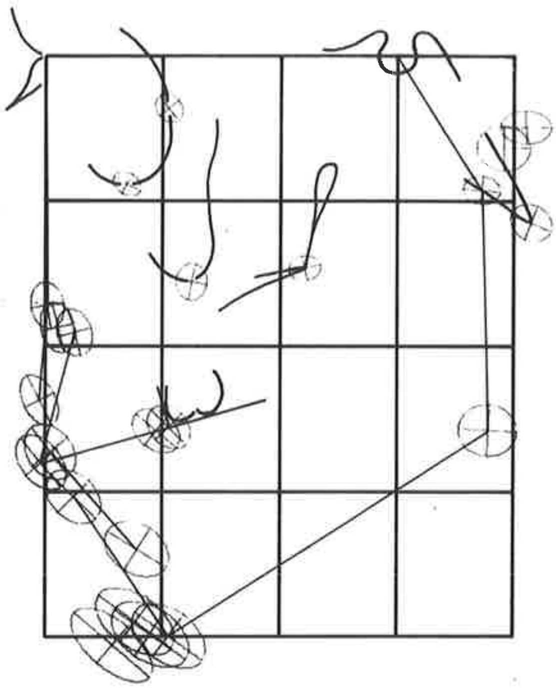
C: Proportionate Difference

Figure 24

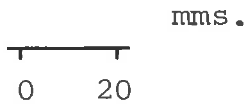
Adolescent

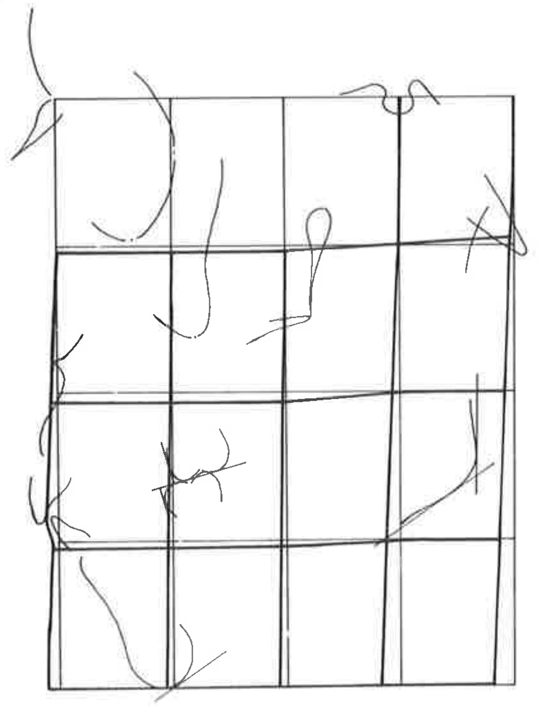


A: Females



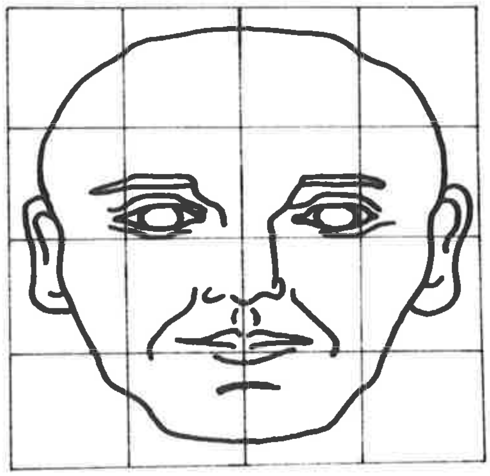
B: Males

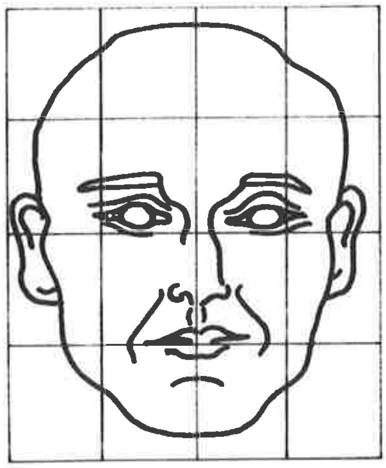




C: Proportionate Difference

Figure 25
Adult





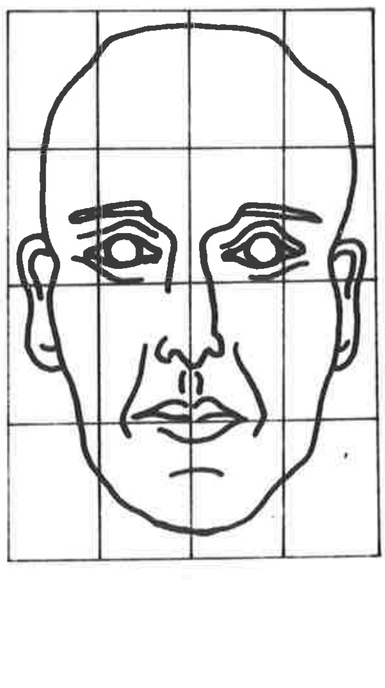


Figure 26

Distortion of proportions when grid is enlarged in one direction. (Upper - enlarged horizontally; Middle - normal; Lower - enlarged vertically).

CHAPTER 5 - DISCUSSION

GENERAL CONSIDERATIONS

For each dental age group, standard deviation values were computed for all coordinates as an indication of the within group variability of the cephalometric reference points. MOORREES (1953) followed this procedure when studying a group of 50 females with normal anatomic occlusion, and illustrated the area of variation for each point by constructing ovals determined in size by the standard deviations of ordinate and abscissa and centered on the mean values of the coordinates.

The presentation of standard deviations in this manner provides a graphic illustration of the variability of the reference points. However, by arbitrarily assigning the variation of the coordinates to the ordinate and abscissa axes, this procedure does not allow for any covariation between the coordinates of these points. Therefore, in this study, distributions of the reference points was indicated in the illustrations (Figure 19 to 25A and B) by covariance ellipses surrounding the reference points. These ellipses were constructed as described previously (McNULTY, BROWN and BARRETT 1968) to show the relative magnitudes of ordinate and abscissa variances and the covariance between them. If the variances were equal, the ellipses would become circles. If there is a zero correlation between coordinates, the major and minor axes of the ellipse would be parallel with the Cartesian axes.

Recognition of the importance of variability in biological systems is indicated by its extensive treatment in scientific textbooks (KALMUS 1967, BARNICOT 1964), and by the widespread usage of means, standard deviations, standard errors and other statistical parameters to define the variability in populations studied. BOAS (1940) commented on the divergence of development of individuals as growth progresses. He suggested that adult female forms are not quite as variable as those of the male, partly due to earlier attainment of skeletal maturity in the female. The various age group norms calculated in this study supports Boas' observations, with the size of the covariance ellipses tending to increase in both sexes with advancing age. It is further supported by comparison of the male and female adult norms (Figure 25), the reference points in males being much more variable than in females of this age group. This latter observation may be explained by the longer duration of growth in males.

All of the variation present in the reference points, however, cannot be ascribed solely to biologic variation. Examination of each of the age group norms reveals that the greater the distance of any given reference point from the abscissa axis, the greater the variability of that point. This observation is partly explainable by the arbitrary selection of nasion as the point of registration with alignment of the nasion-sella line on the abscissa axis. Observation of covariances for the points situated on the facial profile provides evidence in support of the contention that a systematic error had been introduced by the orientation method used. The covariances between coordinates of these points were all negative, resulting in similar inclination of the major axes of their elliptical representation.

The uniformly negative covariances for the profile points suggests that a rotation of the points occurred around sella during the orientation procedure. An investigation on longitudinal data by BERGERSEN (1966), using the intersection point method of orientation, provided evidence of slow but continued growth of nasion throughout the period of growth. BROWN and BARRETT (1968), using relatively stable structures in the anterior cranial fossa for orientation purposes, showed that nasion at times is displaced in a forward and downward direction during growth; sella also being displaced slightly in a distal direction. In the orientation method used for the present investigation, with nasion being selected as the registration point, the natural variability of the profile points would be biased by the within-group variability of the points nasion and sella. This is reflected in the negative inclination of the major axes of the profile points which becomes more acute with advancing age. The effect is probably due to the larger grid size of successive age groups which is based on the ever-increasing dimensions of the craniofacial complex with advancing age. The only exception to this trend is seen in the Early Juvenile Stage 1 norm, which however, was computed from a small sample. Therefore, it may be concluded that the biological variation in the location of reference points used in the study tended to be masked by the systematic error present.

GROWTH CHANGES IN THE FEMALE*

An examination of the mean values of the coordinates for the various age groups revealed a progressive increase in absolute size, with a greater increase in the vertical dimension than the horizontal.

Since nasion was designated as the origin of the coordinate system and sella was made to lie on the abscissa axis, the changes in vertical dimension could be estimated by observing the ordinate of gnathion for the anterior facial height and gonial tangent point for the posterior facial height. The findings of the investigation revealed gnathion descended from -88.94 mm to -106.30 mm and gonial tangent point from -53.47 mm to -68.73 mm, showing that on the average the anterior facial height increased by 17.36 mm and the posterior facial height increased 15.26 mm.

Changes in facial depth were indicated by movements in the abscissae of basion which increased from 82.19 mm to 91.29 mm for a total increase of 9.10mm and articulare which increased 10.85mm, from 71.31 mm to 82.16 mm during the growth period under investigation.

The increasesin facial height and depth are graphically illustrated for successive age groups in Figures 19A to 25A and are summarized in Figure 27. The latter illustration, which also provides an indication

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*In the following pages the term "growth" is used to indicate overall changes in the size and shape of the face with age. In the absence of implant markers no information can be gained on sites of growth or the direction of growth in individual bones.

Fig. 27 - Composite of seven stages of growth
in the female.

of the direction of growth away from the cranial base, was drawn to scale from the absolute values of each succeeding age norm with superimposition along the sella-nasion line and registration at sella.

GROWTH CHANGES IN THE MALE

Similar observation of the male coordinate values also revealed progressive increase in absolute size. The ordinate of gnathion changed from -88.61 mm to -116.21 mm while the gonial tangent point's ordinate descended from -56.10 mm to -74.97 mm, thus revealing an increase of 27.59 mm in anterior facial height and 18.87 mm in posterior facial height. Facial depth was estimated by measuring the abscissae of basion and articulare. The former increased from 82.56 mm to 97.27 mm for a total increment of 14.71 mm, while articulare increased from 71.40 mm to 87.34 mm, or an increase of 15.94 mm. Figures 19B to 25B illustrate the absolute values of the male age groups, and Figure 28 summarizes the growth changes which have taken place. In this latter figure, the norms have been superimposed along the sella-nasion line and registered at sella.

GROWTH CHANGES COMMON TO BOTH SEXES

In both sexes growth occurred in a vertical and horizontal direction with the greatest increment of growth in the vertical dimension. Figures 27 and 28 illustrate this general trend of growth and Table 22 is presented to show growth increments between age groups for both males and females.

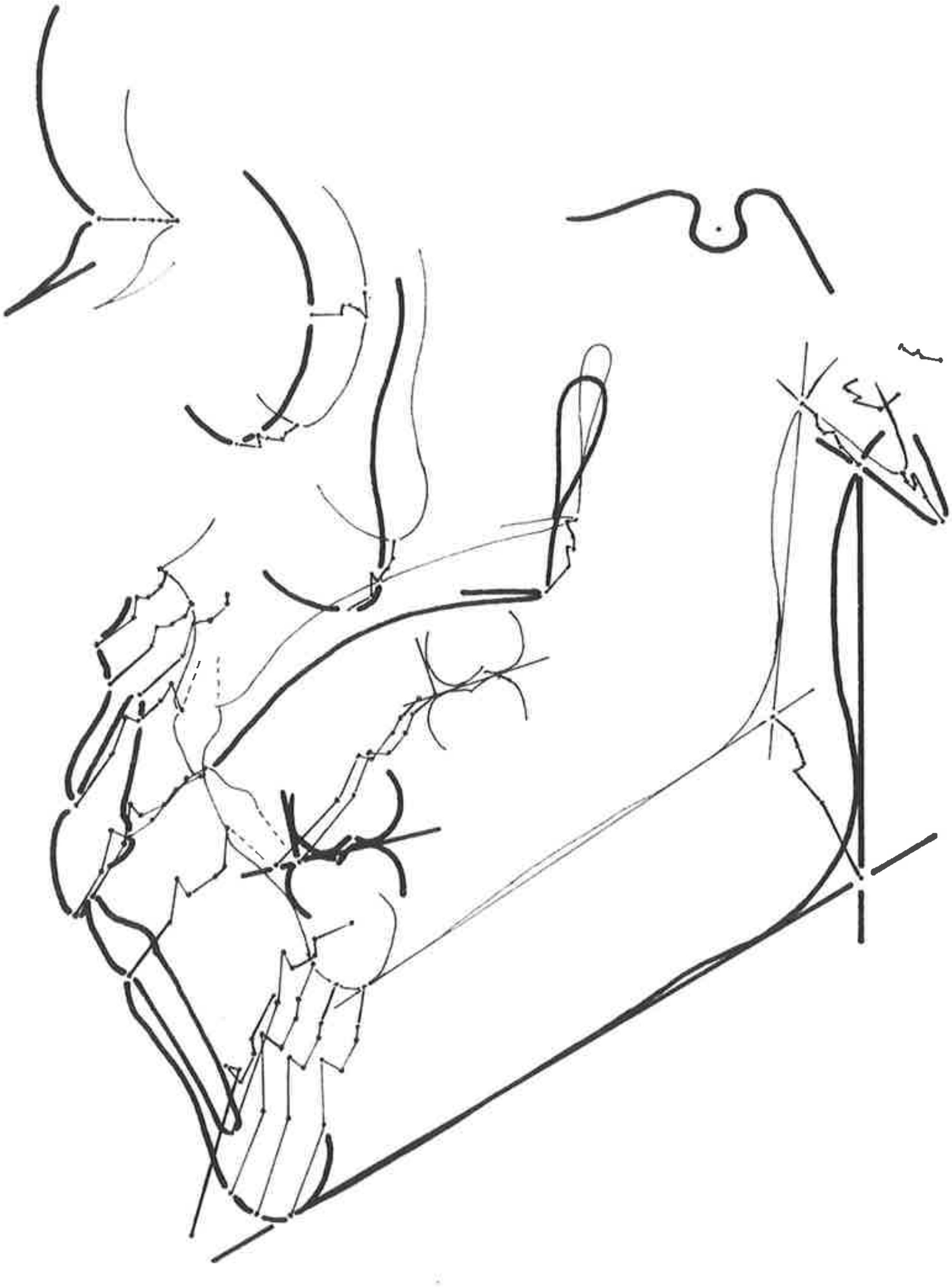


Fig. 28 - Composite of seven stages of growth in the male.

TABLE 22 GROWTH INCREMENTS (Expressed in mm's)

		Early Juvenile Stage 2	Early Juvenile Stage 3	Late Juvenile Stage 1	Late Juvenile Stage 2	Adolescent	Adult	Total Increment	Angle* of Growth
Anterior Cranial Base Region									
n	♂	1.0	0.7	1.3	0.8	1.3	4.1	9.2	180.0°
	♀	0.2	0.6	1.2	1.0	0.5	2.9	6.5	180.0°
s	♂	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0°
	♀	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0°
lo	♂	2.7	0.9	1.0	1.0	0.4	3.5	6.2	204.2°
	♀	0.3	0.7	1.0	1.6	1.3	2.1	5.1	179.6°
or	♂	2.0	0.5	1.3	1.7	1.6	3.2	7.5	198.3°
	♀	0.6	0.8	1.2	2.5	0.8	1.4	5.8	195.0°
zp	♂	1.9	0.9	2.0	1.0	2.9	3.3	9.8	237.9°
	♀	0.8	1.8	2.3	1.5	1.1	2.6	8.5	231.0°
Posterior Cranial Base Region									
ba	♂	0.5	1.5	0.8	1.4	3.7	3.4	7.8	-44.9°
	♀	0.4	1.6	1.1	3.4	2.7	0.6	3.5	-41.1°
ar	♂	2.0	1.3	0.7	0.3	2.4	3.0	9.5	-44.8°
	♀	1.8	0.8	0.9	2.3	3.5	1.3	6.4	-46.8°
po	♂	0.2	1.0	0.6	0.4	0.9	2.3	4.8	-14.8°
	♀	0.2	0.7	0.6	1.8	2.2	1.0	2.6	2.0°
er	♂	1.2	0.8	1.8	0.8	3.1	2.9	5.6	-15.4°
	♀	3.4	2.3	1.2	3.4	4.1	2.0	7.6	14.6°

* Measurement in a counter clockwise direction from the abscissa axis

TABLE 22 (cont.)

		E Juv 2	E Juv 3	L Juv 1	L Juv 2	Adolescent	Adult	Total	Angle of G
					Maxilla				
pm	♂	1.0	1.6	1.3	0.7	2.5	3.5	9.2	249.6°
	♀	1.6	1.9	1.1	3.1	1.6	2.2	7.6	243.5°
sp	♂	0.4	1.8	1.7	1.9	2.3	6.0	11.9	230.0°
	♀	0.9	1.7	2.1	2.9	1.8	3.6	10.8	220.2°
ss	♂	0.3	1.3	2.0	2.0	2.2	6.7	13.3	226.5°
	♀	1.7	2.1	2.3	2.9	1.5	4.4	12.2	216.5°
pr	♂	3.6	2.1	3.6	2.2	4.7	7.6	16.8	223.9°
	♀	5.9	3.4	3.6	3.0	2.6	4.9	15.9	208.2°
as	♂	No obser-	1.4	2.5	2.1	3.8	7.4	15.6	230.7°
	♀	vation*	2.7	2.5	3.5	1.8	4.5	14.1	230.6°
is	♂	3.7	2.8	3.8	2.3	4.7	6.5	21.1	232.1°
	♀	4.8	4.8	3.9	3.1	2.6	4.4	20.3	216.2°
ms	♂	3.2	2.0	3.2	2.6	5.3	9.7	24.5	233.3°
	♀	3.2	2.7	3.8	3.6	3.3	7.0	22.6	227.4°
					Mandible				
mi	♂	3.0	2.4	3.3	2.1	5.9	10.1	25.5	232.8°
	♀	3.5	2.6	4.4	5.2	3.1	7.0	23.8	223.8°
ii	♂	2.8	2.0	3.9	2.2	5.2	7.2	19.5	231.3°
	♀	3.8	3.2	4.3	4.3	2.3	5.1	19.5	213.5°
ai	♂	4.3	1.3	3.0	2.4	5.8	9.1	21.5	235.2°
	♀	9.6**	3.3	3.7	5.0	2.0	5.0	15.6**	224.6°**
id	♂	4.6	1.5	3.7	2.5	5.5	7.7	20.9	238.6°
	♀	3.4	2.9	4.2	5.2	2.1	4.9	19.3	218.2°
pg	♂	4.4	2.1	3.9	2.8	7.5	11.9	28.4	253.3°
	♀	2.6	3.9	4.4	5.0	2.6	6.4	22.2	232.7°
cp	♂	4.6	1.9	3.9	2.6	7.8	11.9	28.6	253.7°
	♀	3.0	3.5	4.6	5.4	4.0	6.3	22.1	231.5°
gn	♂	4.5	2.0	3.8	3.2	7.7	12.2	28.7	254.0°
	♀	3.9	3.1	4.6	4.9	3.1	6.9	22.8	229.5°
tgo	♂	3.1	1.9	1.9	1.4	5.4	9.8	21.7	-60.3°
	♀	1.5	2.2	2.8	3.7	4.1	5.4	15.6	-78.2°

* No observations in Early Juvenile Stage 1 therefore no increment in Early Juvenile Stage 2

** Increment marked is not valid because it is based on only one observation in Early Juvenile Stage 1

In obtaining these measurements, the age group norms have been superimposed along sella-nasion line and registered at sella as illustrated in the figures referred to above. All the increments are linear and expressed in millimeters, the measurement being calculated from the coordinates of the reference point in sucessive group norms. The Early Juvenile Group Stage 1 norm was accepted as the base line for the calculations of incremental data which therefore begin with Early Juvenile Stage 2.

Notice should be made that the total increment differed from the sum of all the individual increments of growth for any particular reference point, because, as is illustrated in Figures 27 and 28, growth occurred in wave-like progressions. Therefore, the total increment was taken as the direct linear measurement of a particular reference point from its location in Early Juvenile Stage 1 to its final location in the Adult norm.

The angle of growth is the angular measurement of the total increment, with sella representing the origin of the axes. This angle related to the displacement of a point during growth, and it should not be inferred that the growth takes place at the point in question. Horizontal growth of any reference point anterior to sella would therefore have an angle of growth of 180 degrees, while growth in avertical direction would have an angle of growth of 90 or 270 degrees. The fourth quadrant, which includes all reference points distal to sella, is recorded in negative degrees, and ranges from 0 degrees for a purely horizontal movement in a distal direction from sella to -90 degrees for vertical displacements.

Thus, any angle of growth approaching 180 degrees would indicate growth forward of sella mainly horizontal in direction, while those angles approaching 270 degrees delineate forward growth mainly in the vertical dimension. Any negative angle of growth indicates growth in a downward and backward direction.

As revealed in Figures 27 and 28 and Table 22, all the landmark migration, with the exception of reference points in the posterior cranial base region and gonial tangent point, proceeded in a downward and forward manner as suggested by BROADBENT (1937). It does not, however, follow the straight line pattern suggested by BRODIE (1941) to occur after the age of 1 to 1 1/2 years. While the latter author was referring to mean growth patterns, the norms produced during the present investigation conform more to the staggered wave-like pattern of growth noted by BERGERSEN (1966) in his longitudinal study of the Bolton collection. Brodie's material, as was also the case in the vast majority of other cross-sectional growth studies performed during the pioneering period of cephalometric research (BROADBENT 1937, BRODIE 1941, 1953 and DOWNS 1948), was grouped according to chronological age. The phenomenon of smoothing out of growth curves was recognized as early as 1892 by Boas. It was one of the reasons for his insistance that longitudinal growth studies were needed before we could hope for an accurate knowledge of human growth (BOAS 1892). The same point was later made by DAVENPORT (1931, 1934), SHUTTLEWORTH (1937), TANNER (1959) and MOORREES (1966). By using physiologic maturity levels, such as dental ages for grouping subjects, a truer picture was revealed of the wave-like variations in the growth pattern.

Growth in the upper face appears to be more horizontal than it is in the lower face, judging by the strong vertical direction of displacement of the lower facial reference points. While the use of the nasion-sella line as the axis of orientation with nasion as the point of registration tends to exaggerate this horizontal component of growth in the upper face, it also negates some of the vertical growth vector present in the lower face, and therefore, the overall balance between the growth vectors for the two areas remains essentially the same as would be seen if a different method of orientation were used.

Growth increments in the lower face tended to be larger than those in the upper face. Since all measurements were taken with the nasion-sella line as origin, any increase in the vertical dimension of upper facial reference points would be included in increases observed in the vertical measurements of the lower facial landmarks. However, as noted previously, most of the upper facial reference points had growth vectors with a horizontal component while the lower facial dimension increased mainly in the vertical direction. Therefore, the additive effect of the upper facial points was minimal and the larger growth increments of the lower facial landmarks may be considered to be genuine and not due to any systematic error in orientation.

The greatest increment of growth observed for both sexes was between the adolescent and adult standards. Although this increment was 2 to 3 times greater than any previous increment, the incremental increase in mean age between these norms was approximately six times greater than the incremental increase between the previous two norms. Furthermore, it also should be noted that the adult group is represented by subjects from 14.5 years to 30 years of age. TANNER (1964) stated that while most head and face measurements continue to increase steadily after adolescence, they do so very slowly with the increase at age 60 amounting to between only 2 and 4 per cent of the young adult value. Therefore, the majority of growth represented in the final increment studied in the present investigation can be considered to have occurred during the adolescent growth spurt and represents growth which took place prior to reaching the adult status recorded.

One of the most interesting features in the progressive downward and forward growth exhibited by both sexes and illustrated in Figures 27 and 28 was the sudden forward shift in the horizontal direction of the facial reference points in the increment between the Late Juvenile Stage 1 norm and the Late Juvenile Stage 2 norm. Concomitant with the horizontal increase, the vertical dimension increased slightly in females, but decreased in males.

Cursory inspection of these phenomena might suggest that the revealed displacement of reference points would depend greatly on the orientation of the cephalometric roentgenograms. However, a prelinimary independent longitudinal investigation of individual subjects included in the present study, by BROWN and BARRETT (1968), using a method of orientation based on stable areas in the anterior cranial fossa, revealed a similar pattern of sudden horizontal translation of the reference points. The following brief review of the literature is presented to develop some thoughts on why this sudden shift in position occurred.

MOORREES (1959) noted that there was considerable agreement among previous investigators that mandibular arch length decreased during growth while maxillary arch length remained about the same. He then reported a decrease in arch length in both the upper and lower arches with increasing age. BARRETT, BROWN and MACDONALD (1965) reporting on the size of the dental arches in the Wailbri, stated that maxillary and mandibular arch length was smaller in adults than adolescents; their findings being comparable with those previously published on Australian Aboriginals (CAMPBELL 1925 and HEITHERSAY 1961). Discussion on how a reduction in the depth of the dental arches could take place between adolescence and adulthood included the following possibilities:

by closing of spaces between the teeth;

by a broadening of the dental arches anteriorly;

by a reduction of the procumbency of the incisor teeth;

and by approximal tooth attrition reducing the mesiodistal crown diameters of the teeth.

While the exact mechanism of this observed arch reduction remains hidden, some data on the timing of this decrease in arch length has been reported by MOORREES (1966). Data on dental development previously obtained with reference to chronological age (MOORREES 1959) was reanalyzed on the basis of dental age. Arch lengths, instead of decreasing gradually as reported previously, were found to decrease suddenly about the time of eruption of the permanent canines and premolars (Figure 29). This was the only major change seen in arch length in the mandible. The maxilla however, was also found to have a rather abrupt increase in arch length during the eruption of the permanent incisors.

As noted in Chapter 2, the present investigation has adopted dental age criteria for the grouping of subjects. The observed horizontal shift of reference points occurred in the growth period between the Late Juvenile Stage 1 and Late Juvenile Stage 2. During this period of dental development, the deciduous canines and deciduous first and second molars are being replaced by their permanent successors and the permanent second molars are emerging.

In developing a working hypothesis, it is suggested that while the more mesial teeth of the buccal segment are being replaced, with concomitant decrease in arch length, particularly in the mandible, there is an occlusal readjustment as the mandible moves downward and forward. The coincidence in timing apparent in the findings of these separate investigations can only serve as a platform for conjecture as to the reason for the sudden horizontal translation of landmarks and much further study into the reasons for this phenomenon is required.

However, the concept is not without some support. It has been demonstrated by BJÖRK (1963) that those individuals with condylar

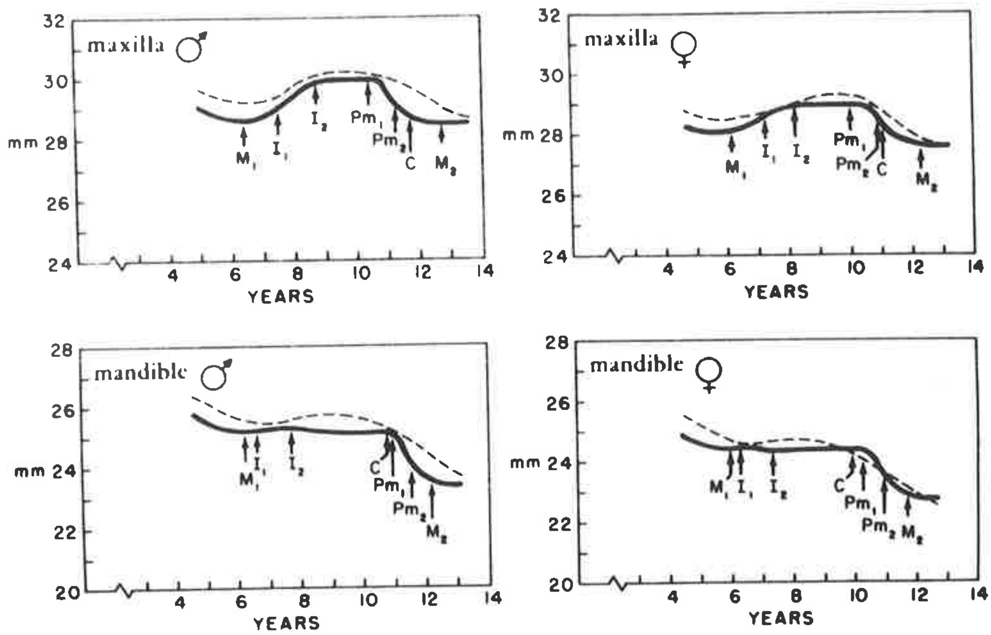


Fig. 29 - Average arch lengths scaled according to dental age (solid line) and chronologic age (dotted line). Note the sudden decrease in arch length during eruption of premolars and canines (after MOORREES 1966).

growth anterior in direction from the posterior border of the mandibular ramus typically exhibit a decrease in the gonial angle. In the present study, a decrease in gonial angle was evident in both the male and female norms during the growth period under investigation. The male gonial angle decreased from 130.5 degrees in Early Juvenile Stage 1 to 121.5 degrees in the Adult norm for a total decrease of 9.0 degrees while the female gonial angle was reduced from 129.0 degrees in Early Juvenile Stage 1 to 123.0 degrees in the Adult standard for an overall decrease of 6.0 degrees. In his 1963 publication, Björk illustrated that in subjects showing vertical condylar growth there was an accompanying forward eruption of all the teeth (Figure 30).

In a longitudinal investigation of facial growth, BERGERSEN (1966) remarked on the wave-like manner of migration of the mandible seen in the majority of individuals under study. He stated that the direction of growth movement at <u>menton</u> became flattened or more horizontal during exfoliation of deciduous and eruption of permanent incisor teeth; a period of growth noted by Moorrees to provide a sharp increase in maxillary arch length. The several figures provided by Bergersen to illustrate this characteristic also revealed a second flattening in growth direction which occurred after the completed eruption of the permanent upper incisors; Bergersen indicating this level of physiological maturity by a marker in the illustrations. However, he did not report the method used to determine when the permanent incisors had erupted.

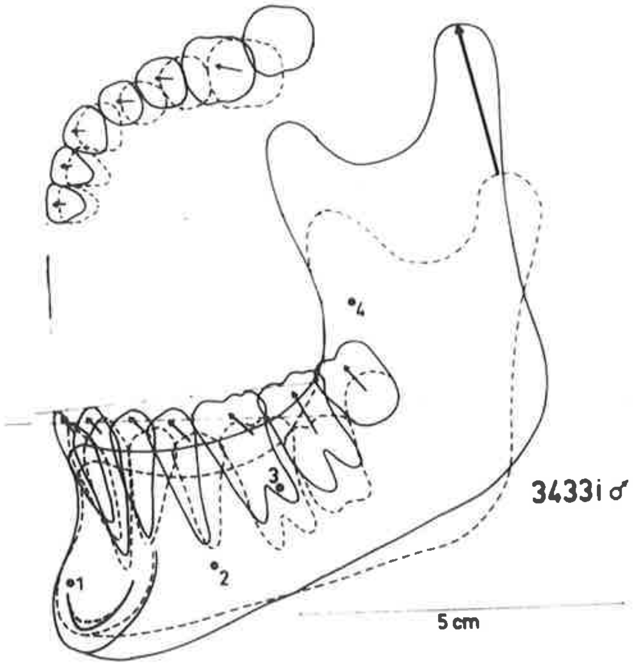


Fig. 30 - Case illustrating vertical growth at the condyles. Ages 11 years 7 months (dotted line) and 17 years 7 months (solid line). Note the forward eruption of all the teeth (after BJÖRK 1963).

SEX DIFFERENCES IN GROWTH PATTERNS

Before discussing particular aspects of the difference in growth between the sexes, it would be of benefit to examine the overall growth trends exhibited in the findings of this investigation. Inspection of parts A and B of Figures 19 to 25 permits direct comparison of the female and male norms. The basic descriptive statistics will be reviewed in a subsequent section.

The Early Juvenile Stage 1 norms were noted to be almost identical with both sexes having similar anterior facial height, but the male possessing about 1 mm greater depth (Figures 19A and B). Comparison of the facial profiles, however, revealed that the female was markedly retrognathic in appearance. This characteristic is graphically illustrated in the distorted mesh diagram (Figure 19C). It was also seen in succeeding standards, with the female observed to become more prognathic with advancing age, until the Late Juvenile Stage 2 norm when the female first exhibited a prognathism greater than the male; this profile pattern being maintained through adulthood. The small sample size of the Early Juvenile Stage 1 group, coupled with a systematic error in positioning, may have had an exaggerating effect on this retrognathic characteristic.

The Early Juvenile Stage 2 norms revealed a greater absolute increase in both facial height and depth in the male over the dimensions in the female which remained close to the Early Juvenile Stage 1 values so that the male was almost 3 mm larger in anterior facial height and approximately 2mm greater in depth (Figure 20A and B). The female facial profile, as noted previously, was less retrognathic than in the preceding age group. Early Juvenile Stage 3 presented an almost identical situation, showing the male maintaining his 2 mm advantage in facial depth although the female had reduced the male's anterior facial height to an advantage of only 2 mm (Figure 21A and B). The illustrations of the proportionate differences between the sexes (Figures 20C and 21C) for these two age groups revealed that the increasing prognathism of the female was beginning to equalize the porportionate differences between the facial profiles of the two sexes.

The anterior facial height in the female of the Late Juvenile Stage 1 had continued to increase more rapidly than the male so that the male only held a slight 0.9 mm advantage while maintaining his 2 mm advantage in facial depth over the female (Figure 22A and B). The facial profiles at this point were almost identical with only a slight retrognathism still evident in the female when compared with the male (Figure 22C).

During the growth period between the Late Juvenile Stage 1 and Late Juvenile Stage 2 norms, the female had continued to grow at an accelerated rate and the anterior facial height in the Late Juvenile Stage 2 standard was 2 mm larger than that of the male (Figure 23A and B). Facial depth during this period had been maintained at a 2mm advantage for the male. In this age group the female facial profile exhibited a prognathism when compared with the male (Figure 23C).

The male once again assumed dominance in anterior facial height in the Adolescent norm where a 3 mm advantage over the female was revealed (Figure 24A and B). Facial depth also increased slightly to a 2.5 mm advantage over the female. The difference in facial profile showed an increase in the prognathism of the female particularly in the dento-alveolar regions (Figure 24C).

In the Adult norm the male standard had become much larger than its female counterpart (Figure 25A and B). The facial depth revealed a 5 mm advantage with the anterior facial height being 10 mm greater in dimension. The female facial profile had become more prognathic than previously and for the first time the male gonial tangent point was posterior in relation to the location of this landmark in the female (Figure 25C). The posterior facial height in females, after increasing proportionately in the Adolescent standard, reached the same dimension as the male in adulthood.

The reported basic descriptive statistics confirmed the characteristic growth trends noted above (Tables 5 to 18). For many of the reference points there were statistically significant differences between males and females in the mean values of one or both coordinates. Levels of significance have been noted in the statistical tabulations for females (Tables 12 to 18). These findings express a sex difference in the height and depth of craniofacial structures.

The number of significant differences between male and female reference points increased with advancing age. Upon reaching the Adult norms there was a significant difference in one or both of the ordinate and abscissa for each landmark. The only exception to this pattern of increasing differences was in the Late Juvenile Stage 2 standards where significant sex differences at the 5 per cent level was recorded for the abscissae of articulare, porion, ear-rod and pterygomaxillare. However, it will be recalled that the Late Juvenile Stage 2 norms were the product of the sudden forward shift of reference points with a slight increase in female anterior facial height while the anterior facial height in males actually decreased (Figures 27 and 28). The resulting standards showed no significant differences in the ordinates while only four abscissae of the posterior craniofacial landmarks differed between sexes (Table 16).

The pattern of the significant differences was maintained throughout the growth period under investigation, permitting certain conclusions to be drawn. Since all the roentgenograms were orientated on nasion-sella line with registration at nasion, differences in facial height and depth would be reflected in significant sex differences in the coordinates of reference points at the extremities from the registration point nasion. Therefore, we see facial depth differences consistently and increasingly recorded by sex differences in the abscissae of the points sella, ear-rod, articulare, porion and basion. Significant differences for the last three points were also seen in their ordinate values.

Vertical height differences were revealed by an increase in the number of significant differences of the ordinates for the mandibular reference points seen to occur principally in the Adolescent and Adult norms. The Adult norms also provided significant differences in the ordinates of the reference points of the maxilla. This expression of sexual dimorphism is probably caused by the longer growth period in males manifested by the increased landmark coordinate values in the later age groups. Gonial tangent point situated at the posterior extremity of the lower jaw showed a significant difference in its ordinate throughout the growth period except for Early Juvenile Stage 1 and Late Juvenile Stage 2. A similar pattern was evident with both zygomatic process and molare superius reference points.

There were few significant sex differences in the abscissae of craniometric points located on or near the anterior border of the profile during the growth period under investigation. Close observation of these values, however, revealed that the female values steadily decreased with advancing age while the male abscissae changed only slightly. In other words, with increasing age, the profile points in females tended to become more prognathic than in males. By adulthood, landmarks pterygomaxillare, incision superius, molare superius and pogonion also showed significant sex differences in abscissae. Prognathism of the female Aboriginal profile was also observed by BARRETT, BROWN and MACDONALD (1963) and BROWN (1965).

Of particular interest in the present study was the observation of a progressive flattening of both the mandibular and occlusal lines during the growth period. This flattening towards a more horizontal position was more evident in the female than in the male and is illustrated in Figure 31. Absolute values of reference points were plotted for each sex, allowing determination of the nasal line, occlusal line, and mandibular

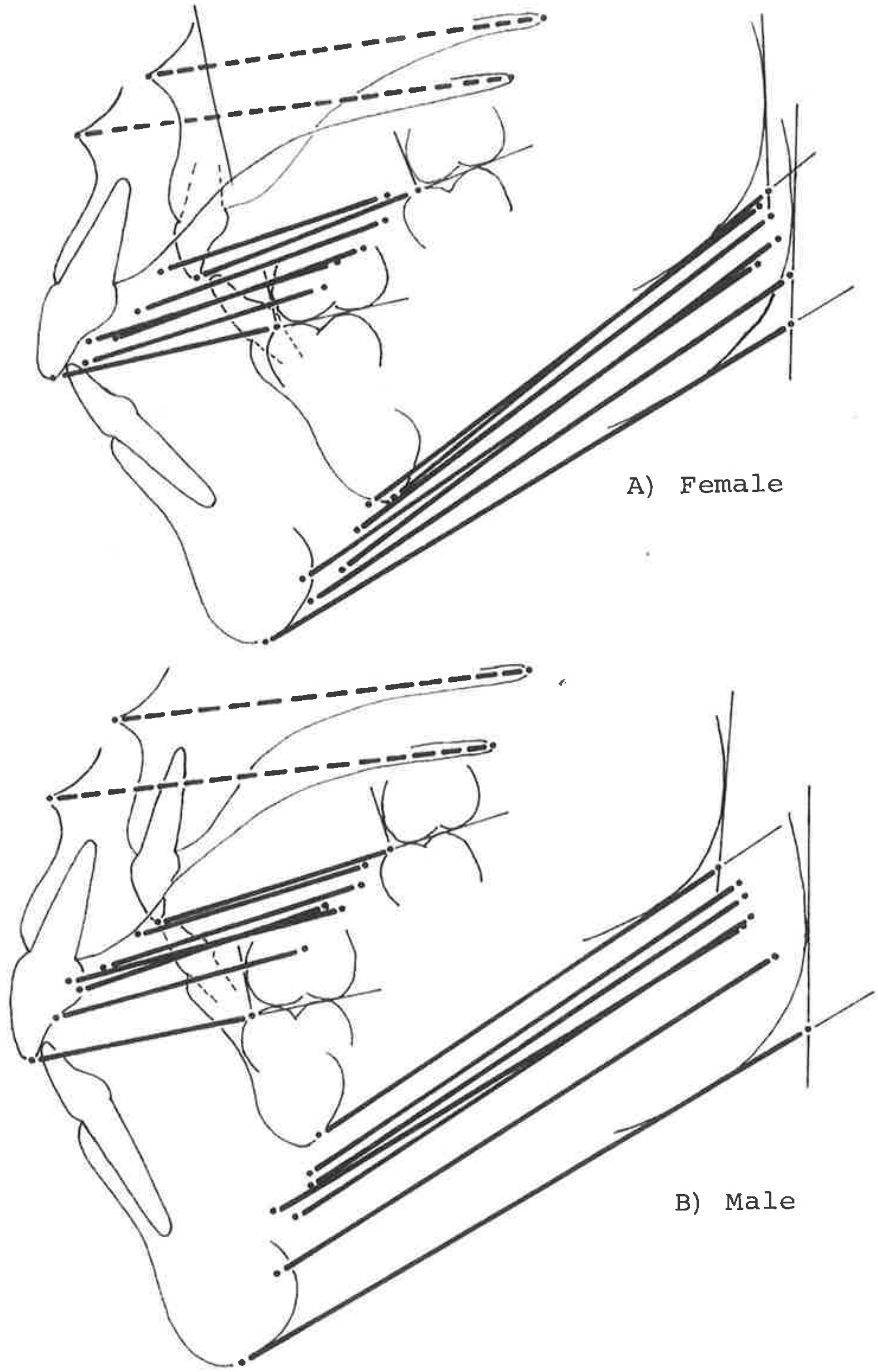


Fig. 31 - Translation of Occlusal and Mandibular lines during growth.

line. Nasion-sella was selected as the line of orientation with registration at sella and the nasion-sella line of both male and female standards were aligned parallel to each other.

Nasal line has been included in the illustration because of the parallel fashion of its descent during the growth period investigated. In the male there was no change in nasion-sella line - nasal line angle between Early Juvenile Stage 1 and Adulthood, and it only decreased 0.5 degrees in the female. In the meantime, the mandibular line - nasion-sella line angle in the male decreased from 35.5 degrees to 32.5 degrees for a total decrease of 3.0 degrees, and in the female decreased a total of 7.5 degrees from 40.0 degrees in the earliest norm to 32.5 degrees at adulthood. The flattening of the occlusal line was of even greater magnitude; in the male the occlusal line - nasion-sella line angle becoming 5.0 degrees more acute from 20.0 degrees to 15.0 degrees while in the female the angle decreased from 25.0 degrees to 14.0 degrees for a total decrease of 11.0 degrees.

The findings of this study, therefore, are in agreement with those of BJÖRK (1947) reporting on Swedes, and CRAVEN (1958), who published data on Australian Aboriginals and compared his findings with those of Björk. These authors noted that the inclination of the palatal planes of both Swedes and Aboriginals remained almost the same with advancing age, but the occlusal and mandibular planes showed a tendency to become more parallel with the nasion-sella line. Although the phenomenon was evident in both sexes, females produced a more marked horizontal vector in growth than males.

Although the gonial tangent point ordinate of the male norms was constantly significantly larger throughout growth than the corresponding female coordinate, calculation of the proportionate increase in posterior facial height as opposed to anterior facial height revealed that the female and a greater progressive increase in vertical dimension in the posterior face than anteriorly. The male had a 32.3 per cent increase in anterior face height while posterior facial height increased 33.6 per cent, producing a vertical growth vector with a slight horizontal component. The female, on the other hand, produced a 19.5 per cent increase in anterior facial height along with a 28.3 per cent increase in posterior facial height giving a much stronger horizontal component to the overall growth vector.

This observation would partly account for the progressive flattening of both the mandibular and occlusal lines while the palatal line was descending with minimal rotation. Although the characteristic flattening of these lines was progressive throughout the growth period, it is of interest that there was a sudden and most significant translation of these lines to a more horizontal position during the growth period between Late Juvenile Stage 1 and Late Juvenile Stage 2, at the time when the permanent canines and premolars were replacing their deciduous precursors.

Changes in the incisor relationship of both sexes during the growth period are shown in Table 23. The interincisal angle, the angle between incision inferius-apex inferius line and the mandibular line, and the angle between incision superius-apex superius line and the nasal line were measured

TABLE 23

Incisor Relationship in Male and Female

Dental Age Group	Sex	is-as line - nasal line Angle	Inter-incisal Angle	ii-ai line mandibular line Angle
Early Juvenile Stage 2	♂	113.5°	125.0°	96.0°
	♀	112.5°	119.5°	97.5°
Early Juvenile Stage 3	♂	118.0°	117.0°	99.0°
	♀	119.0°	117.5°	97.5°
Late Juvenile Stage 1	♂	120.5°	114.0°	100.5°
	♀	117.0°	114.0°	100.0°
Late Juvenile Stage 2	♂	119.0°	113.5°	103.0°
	♀	118.0°	114.5°	100.0°
Adolescent Stage	♂	115.0°	115.5°	100.5°
	♀	118.5°	114.5°	101.5°
Adult Stage	♂	113.5°	123.5°	98.0°
	♀	117.5°	114.0°	104.5°

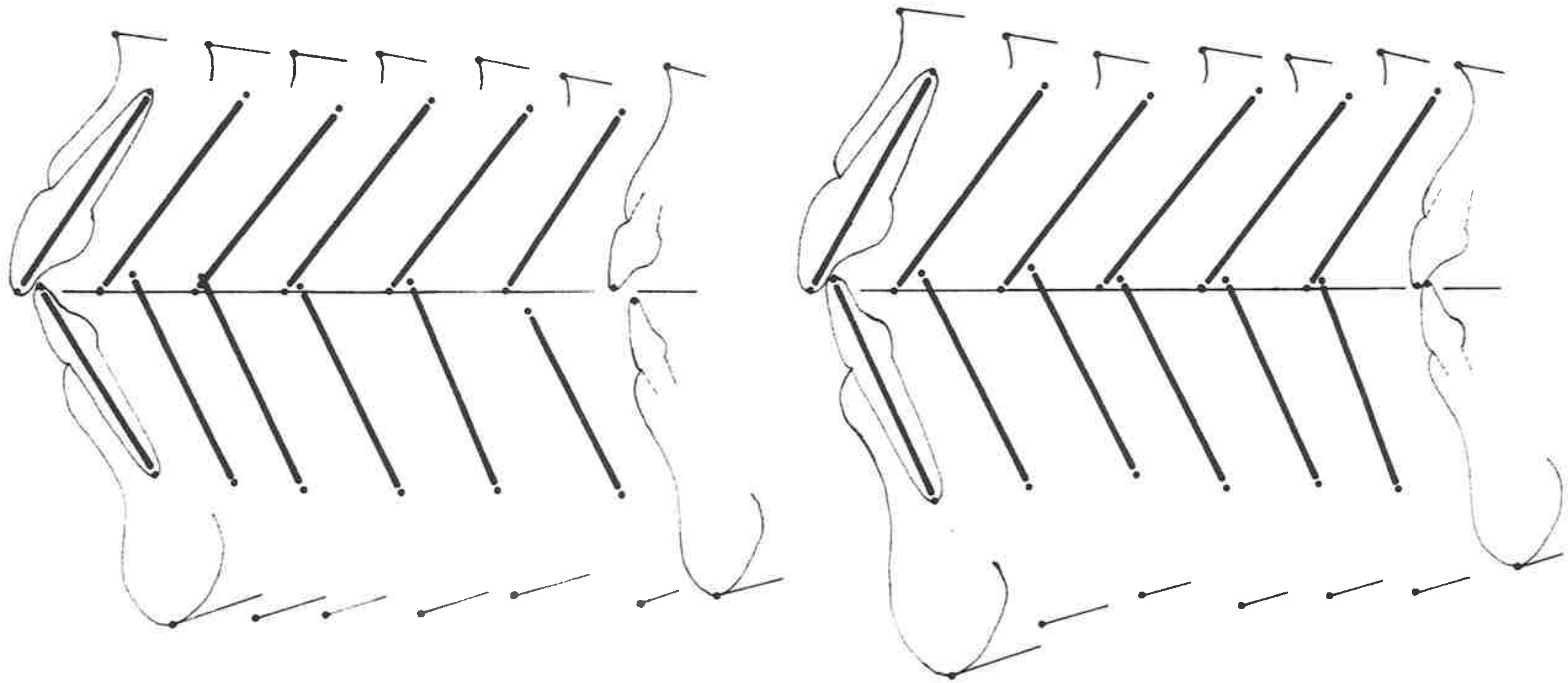
on all groups except Early Juvenile Stage 1; the young age of this group of subjects providing insufficient observations of the landmarks apex superius and apex inferius.

The incisal relationships are illustrated in Figure 32. All the groups were orientated on the occlusal line and successive ages are represented from left to right.

BROWN (1965) observed that the adult male interincisal angle was more obtuse than in the female, a finding also found in this study. However, during a major period of growth, the male interincisal angle was approximately the same as the female's, and it was only during the long growth period between the Adolescent and Adult standards where the typical opening of the interincisal angle occurred. The only exception to this trend was seen in the first age group recorded in which the male standard was initially 5.5 degrees more obtuse than its female counterpart.

Closer examination, however, revealed that the pattern during growth was completely different for the two sexes. The female interincisal angle, after initially becoming slightly more acute, remained the same throughout the growth period. Conversely, the male's interincisal angle, while initially decreasing, showed a significant increase in angulation in the Adolescent norm which became more marked in the Adult standard.

The findings of this study are in mixed agreement with those reported by GRESHAM, BROWN and BARRETT (1965). Comparing interincisal angles of Aboriginal children with those reported previously for adult members of the same tribe (BROWN 1965), they showed an increase of



A) Females B) Males

Fig. 32 - Incisal Relationships during growth.

7.9 degrees in males and 2.2 degrees in females. The male findings compare favourably with results of the present investigation, but the female data in this study shows a slight decrease in interincisal angulation as opposed to the 2.2 degree increase noted by Gresham and co-workers. This disparity between the findings of the two studies in part can be attributed to the combining of 7, 8 and 9 year olds by Gresham into his children's group for the comparison with adult standards.

The decrease in procumbency in the male appears to be achieved by an uprighting of the maxillary and mandibular incisors. The female, on the other hand, appears to compensate for the increased procumbency of the maxillary alveolar region by proclining the mandibular incisors. However, it is important to realize that too much cannot be read into the individual angles being examined, for they can be, and are, affected by changes occurring elsewhere in the dentofacial complex.

CONCLUSIONS

The investigation provided roentgenographic cephalometric standards for males and females of seven different dental age groups of Central Australian Aboriginal children. The subjects ranged in age from childhood to young adulthood. Six of these dental age groups had not previously been studied but the findings for young adults compared favourably with those published by BROWN (1965) who used a different analysis to investigate the same subjects. The material permitted observation on growth changes occurring in the craniofacial structures of this group of subjects during their period of growth and development. The conclusions may be summarized:

1. The variability of landmarks increased with advancing age. This is in agreement with BOAS (1940) who commented on the divergence of development of individuals as growth progresses.

2. Observed variability was not entirely due to biologic variation. Evidence of systematic errors in orientation of the roentgenograms was supported by the observation that variability of coordinates increased as the distance a reference point was away from the line of orientation.

3. The negative inclinations of the major axes of the covariance ellipses, plotted to illustrate the distributions of reference points situated on the facial profile provided further support of the contention that a systematic error had been introduced by the orientation method used. Therefore it may be concluded that the biological variation in the location of landmarks used in this study tended to be masked by the systematic error present.

4. In both sexes growth proceeded in a downward and forward direction as suggested by BROADBENT (1937) but it did not follow the straight line pattern advocated by BRODIE (1941) to occur after the age of 1 to 1 1/2 years. The staggered wave-like pattern of growth noted in this study may be attributed to the use of physiologic maturity levels, such as dental ages, for grouping the subjects in this investigation.

5. Growth increments of the lower face tended to be larger than those of the upper face. The lower facial landmarks also tended to have

a strong vertical direction of growth, while the upper facial points grew in a more horizontal direction. While the method of orientation had some effect on these values, the overall balance between the growth vectors for the two areas remained essentially the same as would be seen if a different method of orientation was employed.

6. The greatest increment of growth observed for both sexes was between the adolescent and adult stages. While the incremental increase in mean ages between the two norms is large, evidence published by TANNER (1964) would suggest that this growth increment can be considered to have occurred during the adolescent growth spurt and prior to reaching the adult status recorded.

7. The horizontal translation of landmarks during the growth period between the Late Juvenile Stage 1 and Late Juvenile Stage 2 has been noted and it has been observed that this period of growth coincided with the exfoliation of the deciduous buccal dentition and replacement by their permanent successors. It is suggested that while the more mesial teeth of the buccal segment were being replaced, with an observed concomitant decrease in arch length, particularly in the mandible, there was an occlusal readjustment as the mandible moved downward and forward. It should be stressed that this suggestion is only an hypothesis and further research into the causes of this phenomenon are required.

8. At the age of 6 years the craniofacial complex of the male and female were quite similar in size but the male increased in overall

dimensions at a greater pace than the female with advancing age. The female's velocity of growth exceeded that of the male during the Late Juvenile Stages 1 and 2, but then the male began his growth spurt and by adulthood the male was substantially larger in overall craniofacial dimensions than the female.

9. The female facial profile is quite retrognathic at 6 years when compared with the male, but mid-facial development continued throughout growth at a proportionately accelerated rate, so that by adulthood the female had a strong bimaxillary protrusion.

10. This protrusion was accompanied by a flattening of the mandibular and occlusal planes; a result of the proportionately greater increase in posterior facial height which the female had over the male.

11. In the male, on the other hand, the dimensions increased in a more vertical direction, and as a result the anterior facial height only lagged slightly behind the proportionate increase in posterior facial height. This produced a weaker flattening of the mandibular and occlusal lines.

12. The inter-incisal angle of the female, after initially becoming more acute, remained almost stationary throughout growth. The mandibular incisor - mandibular line angle became more obtuse in compensation for the increasing maxillary dento-alveolar prognathism and flattening of the mandibular line. The inter-incisal angle of the male initially decreased as in the female, but during Adolescence and Adulthood it became more obtuse as the male face became less prognathic in relation to the female.

The present study has examined the overall growth changes in facial morphology of a group of Aboriginal children and revealed specific differences in the pattern of growth between males and females. These divergent patterns culminated in the sexual dimorphism evident in the adult cranio-facial morphology. Similarities and differences in the growth patterns of both sexes have been discussed and reasons for the resulting sexual dimorphism have been put forward.

The coordinate system of analysis was used in this investigation becuase it was readily handled by computer techniques. The programs developed in the course of the study may be utilized to analyse many types of metric data recorded in the form of Cartesian coordinates. Once the initial data has been stored on punched cards or magnetic tape various parameters may be obtained, including basic descriptive statistics and linear and angular measurements. Furthermore comparisons of both absolute and proportionate values in males and females may be made. These results may be presented in tabular form or output by the computer's plotting facilities. The presentation of the results of this thesis may therefore be regarded as a further development in the continuing research to elucidate the determinants of facial growth in the human.

APPENDIX

DENTGRO Form 5

DATA SHEET - CEPHALOMETRIC MESH GRID ANALYSIS

Delta No. Exam No.

First Name Kinship Group

AGE

Family Date of Birth Years Months Date of Exam

POINT COORDINATES

1. N
6. PO
11. SP
16. MI
21. AI
2. S
7. ER
12. SS
17. MS
22. PG
3. LO
8. AR
13. PR
18. II
23. CP
4. OR
9. BA
14. AS
19. IS
24. GN
5. PM
10. TGO
15. ZP
20. ID
25. EVP

CONSTANT DATA

Sex Delta No. Age Group Age Series

Card Card Card Card Card

REMARKS

Symbols Code - See Over Page

SYMBOLS CODE

Point	Symbol	Description
1	N	Nasion
2	S	Sella
3	LO	Most posterior point on the lateral border of the orbit
4	OR	Orbitale
5	PM	Pterygomaxillare
6	PO	Porion
7	ER	Highest point of ear rod shadows
8	AR	Articulare
9	BA	Basion
10	TGO	Gonial tangent point
11	SP	Spinal point or anterior nasal spine (Acanthion)
12	SS	Subspinale or point A
13	PR	Prosthion
14	AS	Apex superius
15	ZP	Lowest point on the zygomatic process
16	MI	Mesial contact of $\overline{6}$ projected to occlusal line
17	MS	Mesial contact of $\underline{6}$ projected to occlusal line
18	II	Incison inferius
19	IS	Incison superius
20	ID	Infradentale
21	AI	Apex inferius
22	PG	Pogonion
23	CP	Chin point
24	GN	Gnathion
25	EVP	EVER Line Point or Estimated Vertical Extracranial Reference Line Point

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