CRANIO-FACIAL VARIATIONS IN A CENTRAL AUSTRALIAN TRIBE

An X-ray cephalometric investigation of young adult males and females

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SUMMARY

Cephalometric radiography was used to investigate cranio-facial relationships within young adult Central Australian aborigines. The sample comprised 31 males and 27 females who are all full-blood members of the Wailbri tribe, and who live under settlement conditions at Yuendumu, Central Australia. The purpose of the study was to provide cephalometric standards for this particular population group, and to obtain other data relevant to research being conducted by the University of Adelaide into the nature of tooth occlusion within Central Australian aborigines.

The radiographic technique and subsequent cephalometric analysis followed accepted methods with certain modifications necessitated by field conditions. This is the first time such techniques have been used to study a single tribal group of Australian natives, and for this reason X-ray cephalometric data, which were previously unavailable, have been obtained.

It has been shown that although the methods are subject to errors of estimation, in the present study they were of low magnitude and did not seriously affect the results.

Throughout the study emphasis was placed on the nature of prognathism within the subjects radiographed. Basal and alveolar prognathism were differentiated by selecting the angles between an anterior cranial base line joining nasion and sella, and profile lines joining nasion with subspinale, prosthion, infradentale and pogonion.

It was shown that in common with other ethnic groups, Yuendumu aboriginal females tend to be more prognathous than males particularly in the maxillary alveolar region. The sex difference was statistically significant when the gnathic index was used to measure maxillary alveolar prognathism. There were no significant differences in most angular measurements between males and females, but linear variables were usually greater in the male subjects. This indicates that male and female profiles were similar in shape but different in size. Mean prognathic angles and gnathic indices of the subjects studied were compared with those obtained from different groups of Australian aborigines and other ethnic groups.

Variations of facial prognathism within the male group were investigated by calculating coefficients of correlation between the angles of basal prognathism and other cranio-facial variables, and by the use of a regression analysis which revealed discrepancies in the sagittal jaw positions. A prognathic facial build was found to be associated with jaw bases large in relation to the cranial base length, and a protruded upper jaw base. In addition, marked prognathism existed in combination with a short anterior face height and relative parallelism between nasal, mandibular and nasion-sella lines. With the exception of the foramen magnum angle, the cranial base size and shape were not strongly correlated with the angles of prognathism.

Relative maxillary or mandibular prognathism existed when either jaw base was long or short in relation to the other, but various factors appeared to compensate for disharmony in the sagittal jaw positions so that the effect on incisor relationships was minimised. Five subjects were selected to illustrate the main points of interest in cranio-facial relationships within the male group.

The investigation will be extended by a longitudinal growth study of young members of the Wailbri tribe and by research into the associations between general body build, cranio-facial form and tooth relationships.

This thesis is submitted in fulfilment of the requirements for Part II of the degree of Master of Dental Surgery, University of Adelaide. Part I of the degree was completed in the following subjects: Anatomy (pass with distinction, 1958); Pathology (pass, 1959); Physiology (pass with credit, 1960).

I hereby certify that the text of this thesis is entirely my own composition, that the findings reported herein (except where due reference is made) are the result of my own personal investigations, and that no part of this work has been previously submitted for a degree in this or any other University.

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September, 1962

PREFACE

In January, 1961 a research team from the University of Adelaide visited Yuendumu, Central Australia, to continue dental observations of members of the Wailbri tribe. One object of the visit was to obtain standardised cephalometric radiographs for as many adult subjects as possible. It was also practical to examine some juvenile subjects, and the radiographs of this group will be used in a future longitudinal growth study.

The present thesis is limited to observations resulting from the examination of profile radiographs of the young adult subjects, but additional data relating to this group and the juvenile subjects will be presented in future reports.

INTRODUCTION

Investigations into the nature of relationships between the cranial, facial and dental components of the skull are of considerable importance in dentistry, and have wide application in the field of physical anthropology. Besides providing information about similarities and differences in the dental characteristics of population groups, such studies throw light on the problems of growth and development of the head region. In this regard a longitudinal study of a geographically isolated and relatively homogeneous group of subjects could be expected to provide useful information.

In 1951 a study was commenced among full-blood Australian aborigines living under settlement conditions at Yuendumu, Central Australia. Since that time Mr. M.J. Barrett of the Department of Dental Science, University of Adelaide, has conducted regular repeat examinations of the group, and has made available for study some 636 sets of dental casts, representative of 294 individuals. This collection, which is probably the most complete set of casts of native populations available in the world, is being used to determine the pattern of age changes in occlusal relationships of this group.

In January 1961 the longitudinal study was extended to include considerations of cranio-facial variations, and their relationship to occlusion of the teeth within the group. For this purpose, radiographs were obtained of 58 adult and 35 juvenile subjects during the four week period spent in the field. Repeat radiographic examination of the present and future juvenile subjects will provide data for a longitudinal growth study.

In addition, somatometric data were obtained from all subjects radiographed and these will be used in the future to investigate general body build and its relation to cranio-facial structures within the group.

The present thesis deals only with the profile radiographs of the adult subjects for whom photographs and dental casts were also obtained. In analysing the cranio-facial relationships within these subjects, the author has approached the problem by placing emphasis on the nature of prognathism of the jaws, and variations in length and height dimensions of the facial complex. The study of variations in prognathism within the group is only one aspect of the whole problem at hand, but such a study has provided preliminary information for use in research programmes planned for the future.

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The writer is indebted to many people for assistance and advice in the work of this thesis.

Professor A.A. Abbie, the Elder Professor of Anatomy and Histology, in his capacity of supervisor, has taken a close interest in the progress of the investigation and has been a constant source of encouragement. The writer has gained the benefit of his guidance at all times.

Professor A.M. Horsnell, Dean of the Faculty of Dental Science, kindly extended the facilities of his Department to the writer and has followed the work with great interest. I am grateful for his helpful advice on many occasions.

The project was undertaken on the suggestion of Mr. M.J. Barrett of the Department of Dental Science. His considerable help during the period of field work and the subsequent stages of the research is acknowledged with gratitude.

Special thanks are due to Mr. K. Morris of the Department of Mathematics for his assistance during the statistical treatment of the data. Acknowledgement is recorded of the help given by Mrs. X. Zaleski who photographed the illustrations, and by Miss P. Stevens who typed the tables. My teaching colleagues at the University of Adelaide have given me many helpful suggestions. To them I record my appreciation.

During the period of field work, 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.

Messrs Kodak (Australasia) Pty. Ltd. provided the radiographic film used in the project, and Messrs Watson Victor Ltd. gave considerable help with the X-ray equipment.

The project was supported financially by a research grant, U.R.G. 095, from the University of Adelaide.

CHAPTER I

THE STUDY OF CRANIO-FACIAL RELATIONSHIPS WITH SPECIAL REFERENCE TO PROGNATHISM

The study of variations in the head form of man has occupied a favourite place in physical anthropology since its recognition as a modern science in the early 18th century. Since that time anthropologists have employed methods of classical craniometry and cephalometry to increase the understanding of cranio-facial relationships in various groups of mankind. In an endeavour to further elucidate the complex nature of variations in tooth occlusion and the relationship between jaws and cranial base, dental workers have contributed valuable information in this field during recent years.

It has long been known that the facial profile of lower primates is more prominent in relationship to the braincase than it is in man. This characteristic very often distinguishes fossil hominids from modern man, and is also noticeable when the facial profiles of certain living ethnic groups are compared. The prominence of the facial skeleton, and in particular the upper jaw, is universally known as prognathism, which means literally a forward jaw (Greek - pro, forward; gnathos, a jaw). The term was introduced by PRITCHARD (1843), who described three types of skulls: oval, pyramidal and prognathous. The latter type he associated with negroid skulls which showed a forward projection of the cheek bones accompanied by a lateral compression of the skull.

Unfortunately over the years the concept of prognathism has been burdened by so many diverse meanings that today there exists a great deal of confusion and lack of understanding of what is implied by the term. Nearly seventy-five years ago TOPINARD (1890), the French disciple of Broca, reviewed 19th century concepts of prognathism and wrote:

> "Nothing is more simple, and yet we meet with the term among authors in various acceptations. Some speak of prognathism of the face, others of that of the jaws; others go so far as to exclude all that portion of the face below the nares....."

Later OPPENHEIM (1928) advised against the use of the term prognathism by "dentists in general and orthodontists in particular" in any but the true anthropological sense. FISHER (1949) expressed concern at the current usage of the term prognathism to describe both normal and pathological conditions bearing little if any relation to the original morphological concept of facial prominence. In addition he urged writers to define clearly their meaning of the term.

DELATTRE and FENART (1960), aware of persistent ambiguity wrote:

> "Le degre d'avancement des machoires par rapport au crane chez les Mammiferes donne la notion generale de Prognathisme," and they added "Mais si ce fait est universellement reconnu, il est beaucoup plus difficile a definir avec precision." - a statement which recalls the words of Topinard some three-quarters of a century previously.

Thus the concept of prognathism, although apparently well understood, has defied the precision of definition demanded by modern science for over a century. The term prognathism is used to express a highly variable morphological characteristic, the prominence of the facial skeleton in relation to the brain case, for which there is no single definitive measure. The whole enigma of variations in this relationship between species, between groups of mankind and within a single group, cannot be answered without serious consideration of the evolution of the form of the human head, evolution of the sense organs and other viscera of the head and neck, and additional research into growth patterns of the entire cranio-facial complex.

Such considerations are beyond the scope of this thesis, but a brief review of the changing methods of analysing the relationship of facial profile to brain case throws light on various concepts of prognathism which have existed over the years.

BÜCHNER (1912), WILDER (1920), BJÖRK (1947), FISHER (1949), HOYME (1953), MOORREES and KEAN (1958) and DELATTRE and FENART (1960) have reviewed the instruments and earlier methods which have been used in the study of cranio-facial relationships.

Conventional craniometric studies

Variations in the facial profile of man and animals had been recognised and investigated for many years before Pritchard's contributions. Of historical interest is the method adopted by CAMPER (1791), who measured the inclination of the facial profile by the angle between a reference line passing through the external acoustic meatus and the anterior nasal spine, and a profile line tangent to the forehead and face (Fig. 1.). Because of limitations in the application of Camper's angle and with the successive introduction of new planes of reference in craniometrics, it was inevitable that many methods would be offered in an endeavour to standardise the measurement of the facial profile by procedures which could have wider application.

TOPINARD (1890) reviewed the numerous 19th century methods of measuring prognathism and listed some 15 planes of reference which enjoyed popularity during that period. Besides Camper's method, facial angles had been suggested by Cloquet, Saint-Hilaire, Cuvier, Spix, Welcker, Vogt, Virchow, Broca and Topinard, most of which are now only of historical interest.

Until late in the 19th century, prosthion (or alveolare) which is the most anterior point on the maxillary alveolar margin, was the usual anterior reference point used for measuring facial prominence. The anterior nasal spine was sometimes employed as a profile landmark, so it would appear that the earlier anthropologists considered that the maxillary region was of prime importance in the analysis of the facial profile. However BROCA (1872) recognised prognathism of the body of the lower jaw as being indicated by the angle between the chin profile line at the symphysis and the plane of the inferior border of the mandible.

TOPINARD (1890) appears to have been first to differentiate the following types of prognathism:

Superior facial	Inferior facial
a) in its entirety	a) inferior dental
b) superior maxillary	b) inferior maxillary
c) alveolo-subnasal	
d) superior dental	

Of these Topinard considered only alveolo-subnasal prognathism to be important. This he regarded to concern both the portion of the maxilla subjacent to the nasal spine, and that next to it in which the alveoli are situated, and he suggested that:

> "It is to it that the term prognathism should be strictly reserved. It is to this subnasal region that we must look when endeavouring to find out the source whence a skull has been derived."

It is significant that Topinard differentiated types of prognathism, but even so the maxillary subnasal and alveolar regions were not clearly separated.

One important plane of reference suggested was that of VON IHERING (1872) and MERKEL (1882): - a plane passing through the centre of the external acoustic meati and the lowermost point of the infra-orbital margin. The use of this plane was discussed at Munich in 1877, and officially adopted, with a minor change, at the Frankfurt Craniometric Agreement in 1884. Point porion, the most lateral point on the roof of the external acoustic meatus vertically over the middle of the meatus, was considered more suitable than the centre point of the meatus.

With the adoption of the Frankfort horizontal as a standard plane of reference and orientation, the principal method of measuring the facial profile was by the total profile angle (MARTIN-SALLER No 72), sometimes known as the facial angle. The total profile angle (Fig. 2.) may be defined as the angle made when a straight line joining nasion and prosthion meets the ear-eye plane, and in effect

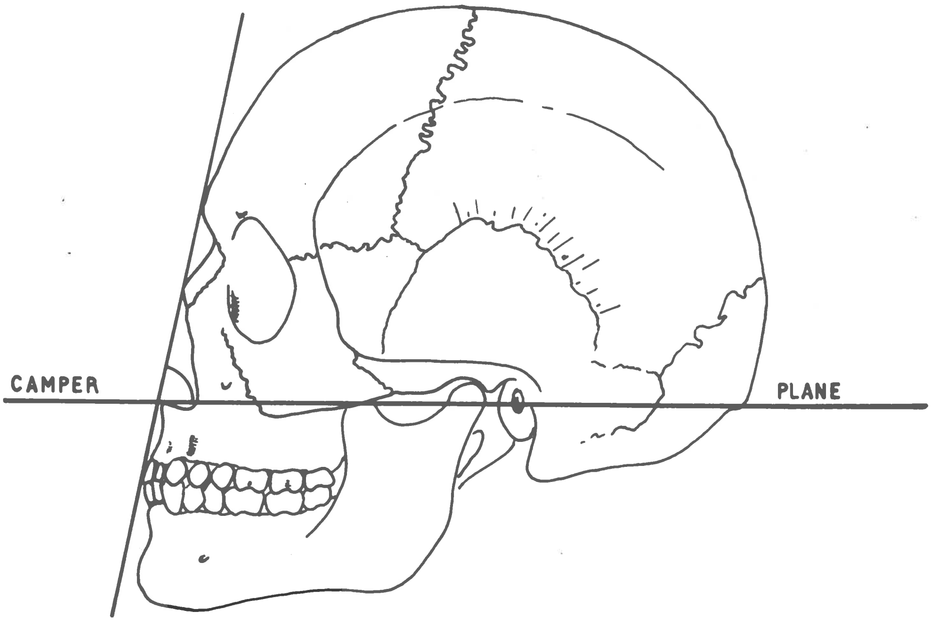


Fig. 1. Camper's facial angle (1791).

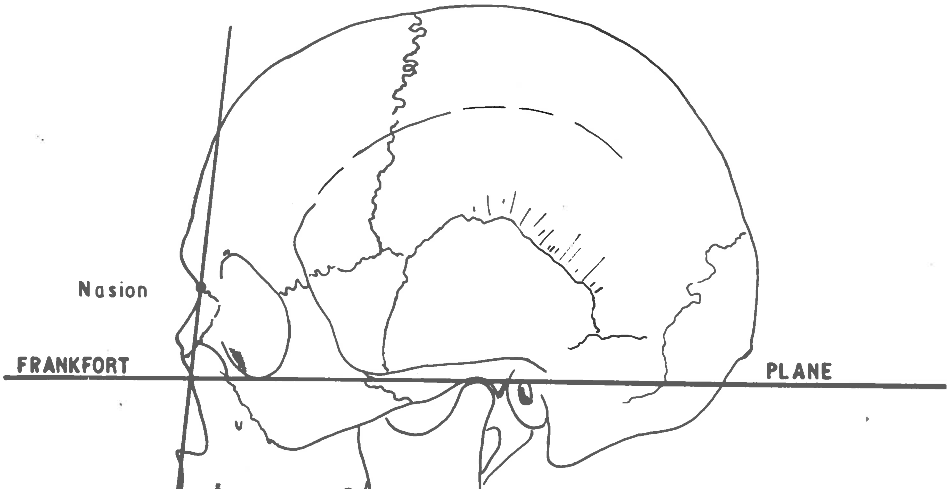


Fig. 2. Frankfort plane (1877) and total profile angle.

it indicates the prominence of the upper alveolar margin in relation to nasion, the arbitrary anterior cranial base point. The general acceptance of the total profile angle was endorsed by the work of LÜTHY (1912) who used it in his comparative studies to show that the Frankfort horizontal was subject to only small variations within population groups. Today the total profile angle has survived as the principal measure of profile shape, and therefore indirectly prognathism, in classical anthropometry. The following classification is used:

Classification	Total profile angle
Hyperprognathous	below 69.9°
Prognathous	70.0° - 79.9°
Mesognathous	80.0° - 84.9°
Orthognathous	85.0° - 92.9°
Hyperorthognathous	above 93.0°

Another measure of prognathism which has survived to be used today is the gnathic index of FLOWER (1897), also known as the jaw index or alveolar index (MARTIN-SALLER No. 160). It is calculated as follows:

$$\text{Gnathic index} = \frac{\text{basion - prosthion length}}{\text{basion - nasion length}} \times 100$$

and the following classification is used:

Classification	Gnathic index
Prognathous	above 103
Mesognathous	98 - 103
Orthognathous	below 98

Both the total profile angle and the gnathic index employ prosthion as the most anterior point of the facial skeleton. Therefore they indicate in different ways the degree of prominence of prosthion, but if unaccompanied by other data, give no information about the nature of prognathism. A fairly high correlation between the total profile angle and the gnathic index could be expected, and in fact ABBIE (1947) found a significant correlation of r = -0.62 between the two variables after analysing a group of Australian skulls. They can thus be regarded as useful alternative measures of maxillary alveolar prognathism.

An attempt to differentiate basal and alveolar prognathism in the upper jaw was made by CAMERON (1930), who divided the facial triangle (a triangle originally used by Virchow which joins points basion, prosthion and nasion) into superior and inferior gnathic triangles by the use of a constructed point subnasion, behind the anterior nasal spine (Fig. 3). By measuring certain angles of the triangles so formed, Cameron indicated variations in the whole facial structure rather than in the anterior profile only. PARSONS (1930) was also aware of limitations in the measurement of the facial profile and suggested differentiating basal and alveolar prognathism.

Thus in classical anthropometry, prognathism is usually measured by the prominence of the upper alveolar margin in relation to the brain base, but little attention is given to the lower jaw. Usually basal and alveolar prognathism are not separated, and the inclinations of the maxillary and mandibular insisors to each other and to their jaw bases are somewhat neglected. The alveolar profile angle (MARTIN-SALLER No. 74) which is the angle a line joining nasospinale and prosthion makes with the Frankfort horizontal, may be used as an indication of alveolar prominence alone. In addition MARTIN (1928) used the term "prodentie" to describe incisor inclinations.

The above methods of indicating prognathism may be adequate for general studies of differences within and between population groups, but for investigations of dental arches and the mode of tooth occlusion, many other variables assume importance and must be considered. It was not until X-rays were used to investigate cranio-facial form, that structures inaccessible to conventional methods could be examined and their influence on facial form assessed.

Radiographic cephalometric studies

As long ago as 1896 WELCKER suggested the use of profile radiographs in physical anthropology, but it was not until 1931 that this method was adopted for routine use. In that year BROADBENT (1931) and HOFRATH (1931) independently introduced improved techniques which permitted the practical use of X-rays for investigations of cranio-facial relationships in living subjects.

Several reviews of cephalometric radiography including those of DOWNS (1952), BJÖRK (1954), GRABER (1954), SVED (1954) and MOORREES (1953) are available, and recently two comprehensive manuals covering this field have been published by KROGMAN and SOUSSINI (1957) and SALZMANN (1961).

Since its introduction, cephalometric radiography has remained almost exclusively in the domain of the orthodontist where it has most direct application in growth studies and the diagnosis of malocclusions. The difficulties involved in transporting the equipment required into remote areas, as well as the special problems which arise during the use of a precise radiographic technique in the field, have presented serious obstacles to the application of this method to anthropological research. As a result only a few radiographic studies are available which deal with

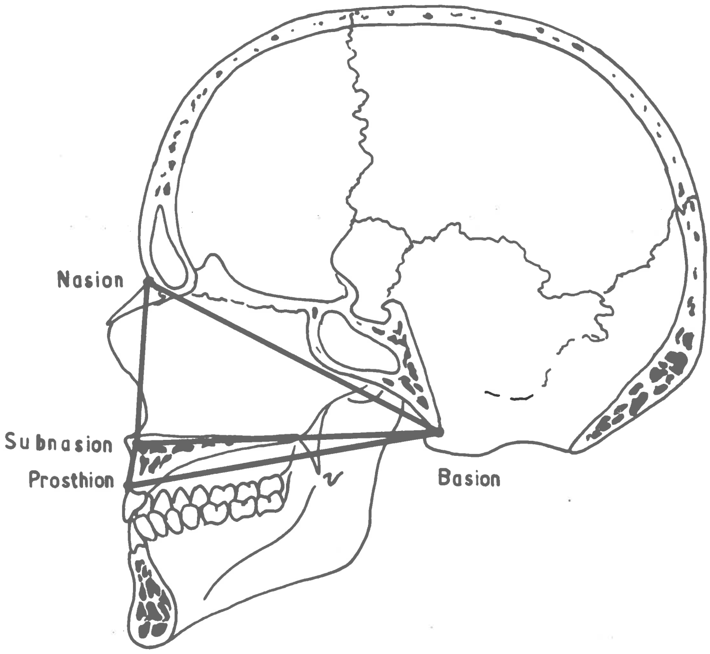


Fig. 3. The superior and inferior gnathic triangles of Cameron (1930).

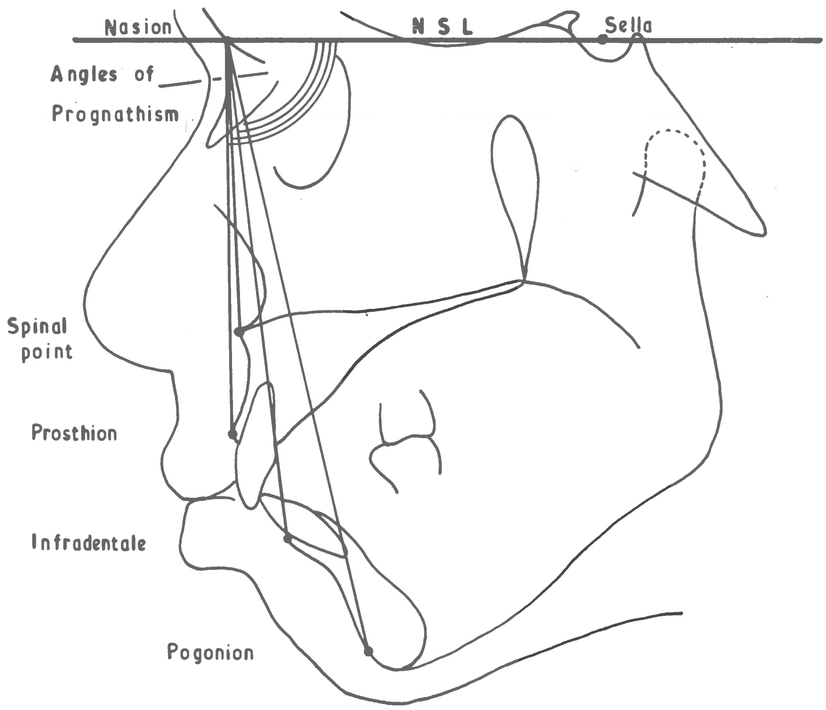


Fig. 4. The Björk angles of prognathism (1947).

variations in cranio-facial structures within geographically isolated population groups.

BJÖRK (1947, 1950) approached the study of cranio-facial variations by investigating prognathism in Swedish conscripts and in South African Bantu males. In this work he employed a reference line joining nasion and the centre of the sella-turcica to indicate the anterior cranial base, and measured maxillary and mandibular basal prognathism by the angles between the nasion-sella line and profile lines joining nasion to spinal point and pogonion respectively. In a similar way points prosthion and infradentale were used in the measurement of alveolar prognathism in both jaws (Fig. 4).

The various influences on the degree of prognathism imparted by racial variations (+), individual variations, ontogenetic changes, domestication and racial admixture (+) were discussed by Björk.

(+) The use of the terms "racial variations" and "racial admixture" by Björk may be criticised. There is as yet insufficient evidence to conclude that variations between population groups are greater than variations within a single group, even though mean values of a character may differ significantly between groups.

(UNESCO PUBLICATION, 1952)

In a later study (BJÖRK and PALLING, 1954), the profile point subspinale was substituted for spinal point in the measurement of maxillary basal prognathism, and the measurements of profile angle (n-ss-pg) and sagittal jaw relation (ss-n-pg) were included as an additional indication of facial profile.

DOWNS (1948) introduced an analysis now known as the Downs analysis, which is used primarily in orthodontic diagnosis for the assessment of facial relationships. In this method, the facial profile is measured by a facial angle, and an angle of convexity (Fig. 5); other measures are also included in the Downs analysis.

LINDEGÅRD (1953) introduced a slightly different concept of prognathism in his somatometric and radiographic investigation of Swedish adults. The protrusion of the maxillary body was measured as the distance from pterygomaxillare (the most posterior point on the maxillary base) to a line perpendicular to the nasion-sella line and passing through sella. Lindegård also found that the profile measure of maxillary basal prognathism (s-n-ss) was highly correlated ($r = +0.68$) with mandibular basal prognathism (s-n-pg), and from the linear regression function he calculated a series of residuals Fs-n-pg(s-n-ss) which then became new measures of relative basal mandibular prognathism.

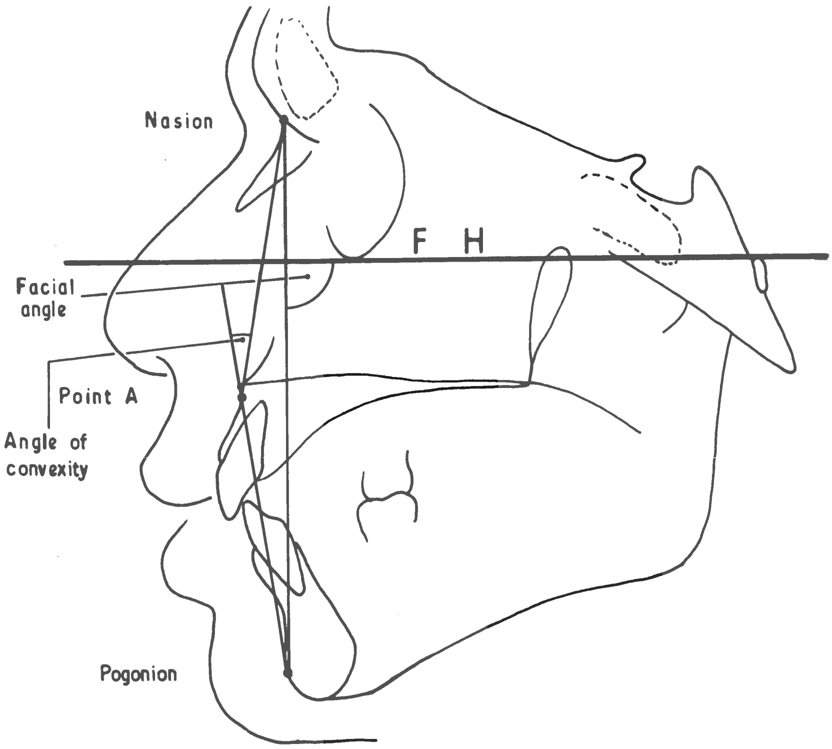


Fig. 5. The Downs analysis (1948).

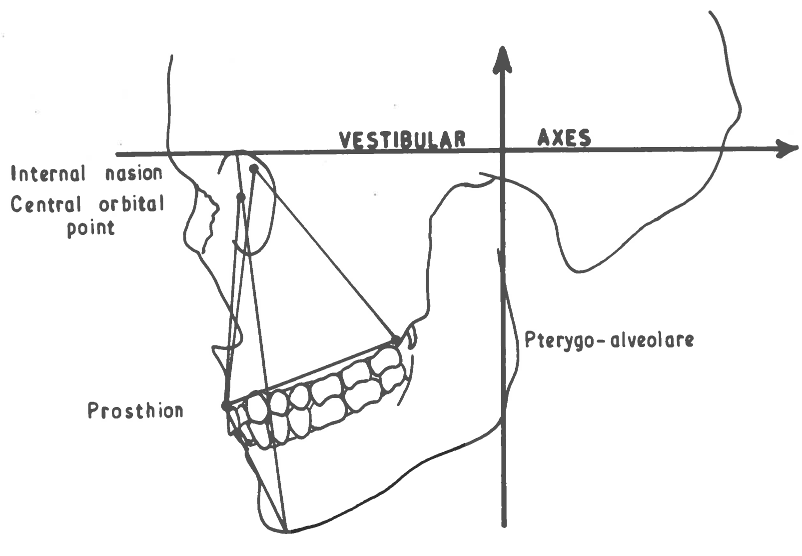


Fig. 6. The exo-face and endo-face of Delattre and Fenart (1960).

Mandibular alveolar prognathism was measured by Lindegard as the angle between the chin line and a line tangential to the lower border of the mandible, a method advocated by BROCA (1872). It is significant that in the comprehensive report of Lindegard, the cranio-facial structures were studied in association with general body build, a relationship which had been largely overlooked previously.

COTTON, TAKANO and WONG (1951) studied American Negroes, Nisei and American Chinese by applying the Downs analysis to data derived from lateral head radiographs. This study emphasised that although mean values deviated from those obtained from American whites, there was considerable overlap of ranges between different ethnic groups. HARALABAKIS (1954) also used the Downs analysis in his investigation of cranio-facial structures in Greek families. In a study of antero-posterior incisor relationships, KAYUKAWA (1957) used both the methods of Bjork and Downs to assess the profile of a group of adolescent Japanese. LYSELL and FILIPSSON (1958) applied the method of Bjork to the study of medieval Swedish skulls.

As far as the present author can ascertain, CRAVEN (1958) has provided the only available information,(obtained by radiographic cephalometry) on cranio-facial relationships in a group of Australian aborigines. Craven applied the Bjork and Downs analyses to his sample, but it is unfortunate that the radiographs made available to Craven were limited in number, and that subjects of different tribes, and with wide age variation were represented.

DELATTRE and FENART (1960) discussed a new concept of prognathism, based on the division of the facial skeleton into exo-face and endo-face (Fig. 6). The endo-face is determined by the sagittal projection of a triangle formed with its apex at an intra-cranial point, internal nasion. The base of the triangle is the maxillary alveolar line, whose anterior point is prosthion and whose posterior point (pterygo-alveolare) is formed by the intersection of the alveolar line with the anterior border of the pterygoid plates. The exo-face is limited posteriorly by the sagittal projection of a line joining the centres of the superior and inferior orbital margins with the lowermost point of the mandibular symphysis. In most primates the three latter points are situated on a common orbito-mandibular line. The anterior limit of the exo-face is prosthion, which completes a triangle. Delattre and Fenart measured exo-facial prognathism by a facial angle, which is the angle formed by the exo-facial triangle, measured at prosthion.

<u>Cranial reference lines</u>

Since prognathism is essentially a relationship between neuro-cranium and viscero-cranium, the prominence or retrusion of the facial skeleton can only be assessed by reference to some selected plane or line, preferably one which is relatively constant in different groups, and at different stages of growth of the same individual. There is yet to be found a line or plane which fulfils all requirements.

It is apparent that confusion has arisen over the years not so much in the selection of craniometric points as in the choice of planes of orientation and lines of reference on the skull. Classical craniometry has long preferred the Frankfort horizontal, since it has the obvious advantage of closely approximating the natural postural position of the head in living subjects. With the adoption of cephalometric radiography, intracranial structures were more readily accessible for analysis in both skull material and living subjects, and several lines of reference besides the Frankfort horizontal have been suggested. The more popular of these are:

KORKHAUS	(1936)-	Nasion-tragion line.
BROADBENT	(1937)-	Nasion-Bolton point line.
MARGOLIS	(1940)-	Nasion-sphenooccipital synchondrosis.

BRODIE	(1941)-	Nasion-sella turcica line.
LINDEGÅRD	(1953)-	Nasion-sella perpendicular.
MOORREES and KEAN	(1958)-	Vertical to natural head position.

The reference lines most commonly used in X-ray studies are the Frankfort horizontal, the nasion-sella line and the nasion-Bolton point line. The use of the Frankfort horizontal in radiographic studies has been criticised by BJÖRK (1950, 1954) and KOSKI (1956). In determining this reference line, two highly variable points, orbitale and porion, must be located from the sagittal projection of bilateral structures, this location being difficult even when skin markers are used. Furthermore Björk considered that since the Frankfort horizontal is related to the facial skeleton, it could not justifiably be used in the analysis of relationships between face and cranial base.

Another objection to the use of the Frankfort horizontal in radiographic studies is the wide variation in radiographic porion even within the same individual from time to time. One definition of radiographic porion widely used depends on the position of the ear rods of the head positioning device within the external acoustic meati, and KOSKI (1956) considered it impossible to replace ear rods in identical positions in the same subject. The present author has noticed the same difficulty, which would appear to be greater in a group of native subjects (see Chapter III).

However the use of Frankfort horizontal in radiographic studies may be necessary if comparative research is anticipated, because of its extensive use in classical craniometry.

MOORREES and KEAN (1958), aware of difficulties in the location of porion, substituted the superior point of the mandibular condyle when investigating variations in the Frankfort horizontal, but the mandibular condyle is often difficult to locate precisely on radiographs especially if bilateral images are not symmetric.

The Bolton point which marks the height of the curvature posterior to the occipital condyles, between them and the basal surface of the occipital bone is sometimes substituted for point basion in radiographic studies. However Bolton point suffers from similar difficulties in its location to other bilateral structures.

The nasion-sella turcica line (NSL) is used by the majority of Scandinavian investigators and by many American workers since it has certain advantages. The NSL depends on the location of points nasion and sella, both of which are median sagittal points not involving double images. In addition nasion and sella can be located with low experimental error on both museum and living material. The NSL represents more closely the line of division between facial structures and the anterior cranial base and is therefore more suitable in analysing cranial and facial relationships.

Recently a variation of the NSL was suggested by STRAMRUD (1959) who used point ethmoidale, the lowermost point of the cribriform plate, in preference to nasion, on the grounds that nasion is in reality a facial profile point, subject to the variation caused by appositional growth of the frontal bone. The ethmoidale-sella line may indeed be preferable to others in the investigation of growth patterns of the head.

Objections to the use of the NSL have been raised by MOORREES and KEAN (1958) who correctly point out that the line is subject to variation between individuals in relation to the line of natural head balance. Thus variations in prognathism when measured as the angles between profile lines and NSL will include variations in the angulation of the cranial base line as well. This objection may be valid for any intracranial reference line.

MOORREES and KEAN (1958) devised a modification of Broadbent's cephalometer which allowed orientation of the head in a position of natural balance. The method allowed cranio-facial analysis by the use of a perpendicular to the head balance line, but besides being inapplicable for the study of museum material, the method would be difficult to apply during field work with native subjects. From the experience involved in the present investigation, it is felt that a natural head (and jaw) posture requires complete relaxation on the part of the subject. This may be difficult to obtain in native children and some adults because of language problems and a natural suspicion of scientific apparatus.

DELATTRE and FENART (1960), after some thirty years of investigation, used a "vestibular method" of skull orientation and reference, which depends on the general plane of the semicircular canals. The two workers used this method to analyse phylogenetic and ontogenetic changes in head form of selected primates. The technique itself is complex but merits further consideration. One significant finding of this study was that the occlusal surfaces of the teeth were inclined at a fairly constant angle of 30° to the head balance line in all primates at various stages of growth.

It is apparent that no single intra-cranial reference line is totally satisfactory for use in radiographic cephalometry. This presents a serious handicap in the study of cranio-facial structures of animals and man. Geometric lines constructed from intra-cranial points naturally show wide variation between population groups and even within the same group. The solution may well be in the use of a physiological line which represents the axis of natural head balance as defined first by BROCA (1862).

For the purposes of the present study which centred around the nature of prognathism within adult subjects, the nasion-sella line was chosen as the most suitable. Besides being subject to less experimental error than other reference lines, it has the advantage of more closely dividing the facial structures from those of the brain case. In addition most other studies which were to be used for comparative purposes also employed the nasion-sella line, which although not ideal for all investigations offers the least number of disadvantages when compared with other possible intra-cranial lines.

CHAPTER II

MATERIAL AND METHODS

1. MATERIAL

Linear and angular measurements were obtained from the tracings of lateral head radiographs of 58 young adult Central Australian aborigines - 31 males and 27 females.

The aborigines studied call themselves Wailbri, although they are sometimes referred to as belonging to the Ngalia tribe. TINDALE (1940) has also listed several other alternative names for this particular tribe. Since 1946 they have been congregated at the Commonwealth Government Settlement situated at Yuendumu, 185 miles north-west of Alice Springs (Fig. 7). Prior to this time they lived under primitive tribal conditions and came in contact with white civilization only on rare occasions.

The establishment of a Government settlement has provided an unique opportunity for the anthropological investigation of a geographically isolated tribe, especially in regard to its changing environment. TINDALE (1953)

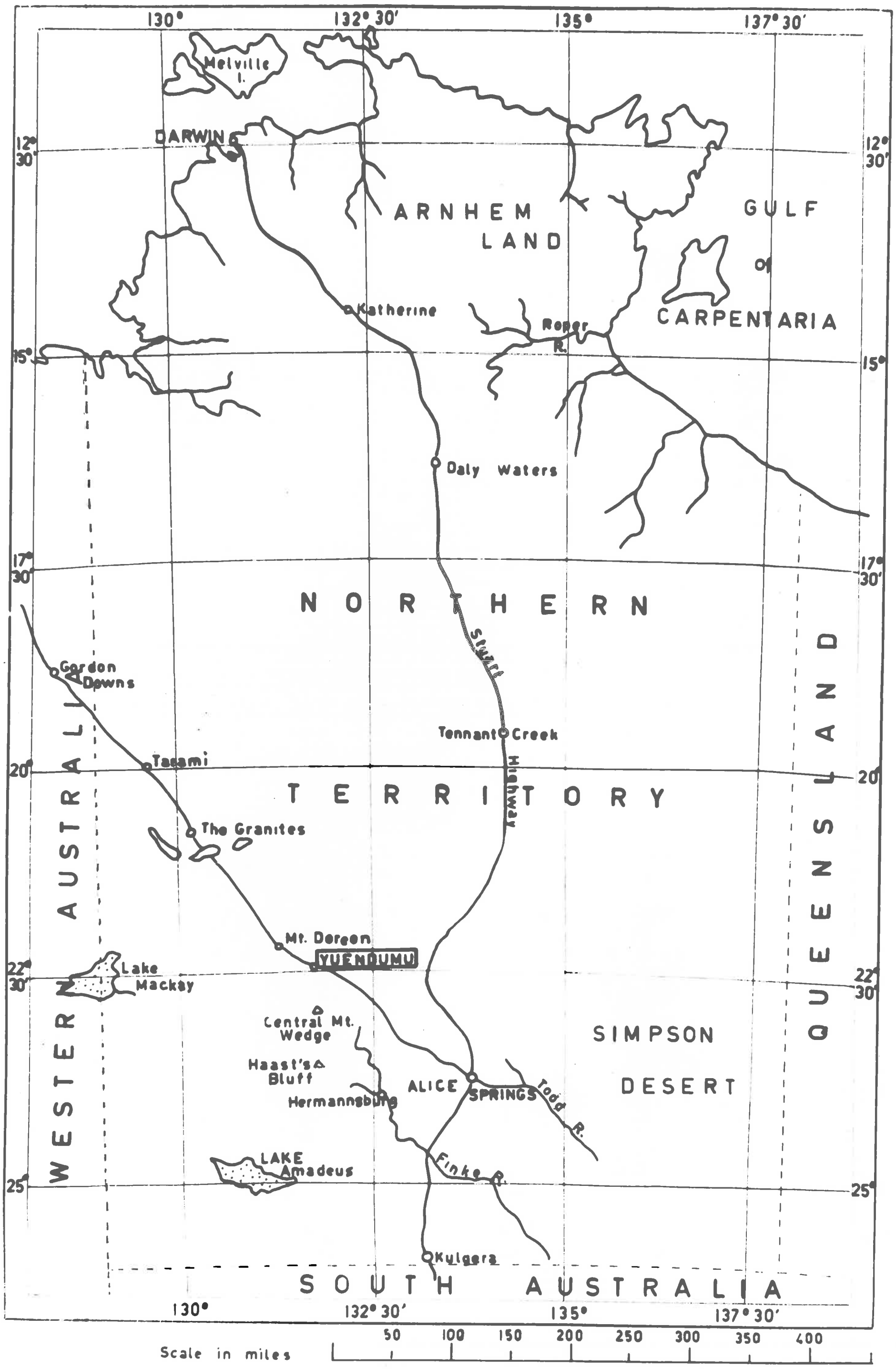


Fig. 7. Map showing location of Yuendumu native settlement.

investigated marriage customs within the tribe and reported that of a total of 166 marriages, only eight per cent were inter-tribal, so that the group can be regarded as relatively homogeneous, at least in recent times. Other aspects of the general physical anthropology of the Wailbri have been published by CAPELL (1952); ABBIE and ADEY (1953a, 1953b, 1955); SIMMONS et al (1954); CLELAND and TINDALE (1954); POIDEVIN (1957); SCHULTZ (1958) and ABBIE (1957, 1961a, 1961b).

Detailed reports on the environment of the Yuendumu natives, their food sources, eating habits and dental conditions have been published by members of the Department of Dental Science, University of Adelaide (CAMPBELL and BARRETT 1953; BARRETT 1953a, 1953b, 1956, 1957a, 1957b, 1958, 1960; CHAN 1955, 1957, 1959, 1960; BARRETT, BROWN and MACDONALD 1962a, 1962b).

Normally the native population at Yuendumu varies in number from 400 - 450 or so, and occasionally the number may rise to 600 with the influx of visitors from neighboring areas. Of this varying number of natives there were only 31 young adult males available for examination at the time of the visit. ABBIE (1961a) has also noted that within a single tribe, about 30 - 40 is the maximum number of young adult males available for examination during a limited period of field investigation.

BOAS (1940) suggested that the most specialised local forms of a population are found within adult males, and for this reason the main investigation centred around this group. In order to study the sexual differences in cranio-facial build, a comparable number of young adult female Wailbri natives were also examined. To preserve homogeneity in the sample, only known members of the Wailbri tribe were accepted for examination, although at the time there were several Pintubi tribesmen living at the settlement.

Selection of the subjects was based on willingness to participate and on conformity with the criteria chosen for young adulthood. There were no records of the actual birth dates of the subjects, so that age estimations were recorded only after consideration of the general physical development, and the dental state of each individual. In the majority of cases, the subjects had been examined by M.J. Barrett on previous expeditions to the settlement, and the records so obtained were consulted before the final age estimates were made. The recorded ages can be considered as close approximations only of the actual chronological ages.

The limits for young adult status were broadly interpreted to include subjects aged approximately from 18 to 30 years, and who in the majority of cases had four erupted third molar teeth. However four adolescent males, with from two to three third molars unerupted, were included in the 16 - 20 years age group, and two males and two females were included in the 31 - 36 age group. The sex and age distribution of the subjects included in the present study is shown in TABLE 1. The mean age of both males and females was approximately 22 years.

Dental state of the subjects

The dental state of the subjects was assessed after the examination of the mouth, dental casts and radiographs. The characteristics noted were: teeth missing, teeth congenitally absent, teeth unerupted, teeth missing because of ceremonial evulsion and teeth lost because of accident or dental caries. These characteristics are summarised in TABLE 2.

It is of interest that over 25 per cent of the male group had lost either a right or left upper central incisor through ceremonial evulsion. CAMPBELL (1925) reported that ceremonial evulsion affected about 11.4 per cent of

TABLE 1

Sex and age distribution of the subjects studied.

Approximate age in years	Number of subjects		
	Males	Females	Total
16 - 20	14	13	27
21 - 25	10	8	18
26 - 30	5	4	9
31 - 36	2	2	4
Total	31	27	58

TABLE 2

Dental state of the subjects studied.

Dental state	Number of subjects		
	Males	Females	Total
Thirty-two teeth present	14	23	37
Two third molars unerupted	2	-	2
Three third molars unerupted	2 *	-	2 *
One third molar congenitally absent	2 *	-	2 *
One tooth missing (ceremonial tooth evulsion)	8 ǂ	-	8 ǂ
One tooth missing	3 ǂ	3	6 ǂ
Two teeth missing	1	1	2
Four teeth missing	1	-	1
Total	31	27	58

* ǂ One subject is included twice in each of the paired categories.

the adult aboriginal population of the continent, so it appears that the ceremony of tooth evulsion as part of the initiation into manhood has increased in frequency in recent years, at least among the Wailbri people.

In addition an assessment of the degree of tooth attrition was made for each subject according to the method of DAVIES and PEDERSON (1955), which provides a more complete estimation of attrition than the method of Broca. The degree of occlusal attrition of first molar teeth of all subjects was recorded in the following categories: 0 - no attrition; 1 - attrition of enamel; 2 - dentine exposed; 3 - secondary dentine exposed. An attrition index was derived for each subject by dividing the total scores by the number of teeth examined. Mean values for the indices of occlusal attrition were then calculated for maxillary and mandibular first molars of each sex and age group. The results are summarised in TABLE 3. The females tended to have higher attrition indices than males in the two higher age groups.

The dental papers listed in this chapter have reported the incidence of dental disease in the Yuendumu group as a whole. In the present study it was noted without detailed oral examination that the incidence of dental caries and periodontal disorders was low; in fact tooth loss from dental caries as apart from accidents occurred

TABLE 3

Mean values for the degree of attrition of maxillary and mandibular first molar teeth of 31 male and 27 female Australian aborigines - after the method of Davies and Pedersen (1955).

Age in Years	Number of Subjects	Number of Max. teeth	Number of Mand. teeth	Attrition index	
MALES					
16-20	13	26	26	1.50	1.69
21-25	11	22	21	1.55	1.95
26-30	5	10	8	1.80	1.75
31-36	2	4	4	2.00	2.00
Total	31	62	59	1.60	1.81
FEMALES					
16-20	12	24	24	1.38	1.46
21-25	9	17	18	1.71	1.72
26-30	4	8	8	2.00	2.00
31-36	2	4	4	2.00	3.00
Total	27	53	54	1.62	1.74

in only six of the 58 subjects, five male and one female. In contrast to this is the finding that eight teeth had been lost by ceremonial evulsion in the male group alone. It would appear then that more teeth had been lost through ceremonial evulsion and accidents than from dental caries.

Interesting dental evidence of the contact of these people with white civilization was the number of subjects who had been treated by visiting Government dentists. Ten male and four female subjects had a total of 16 and 13 amalgam restorations respectively. Many of these restorations were small fillings in the buccal grooves of molar teeth, which again illustrates the low incidence of dental decay in this group.

All the observations concerning the dental state of the subjects were recorded jointly by M.J. Barrett and the author. In the case of occlusal attrition indices, both workers independently recorded observations before the final assessments were made.

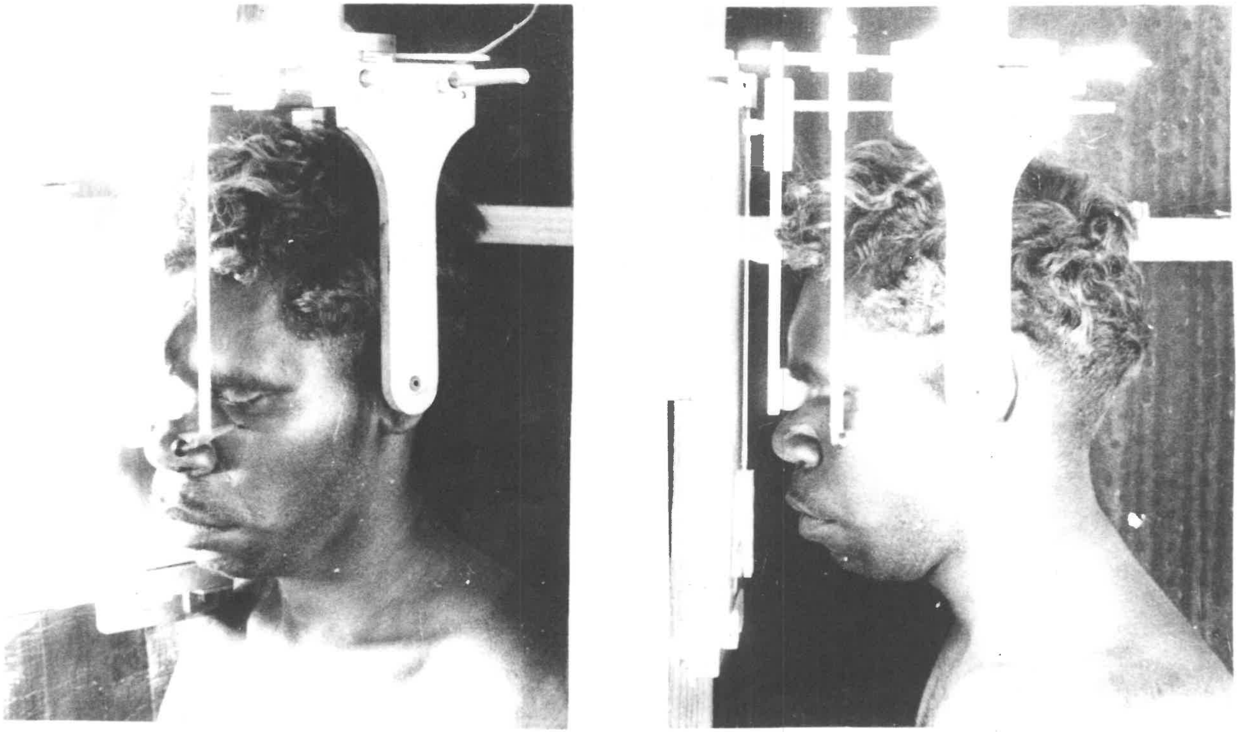
2. RADIOGRAPHIC METHODS

The radiographic methods employed followed closely accepted techniques for cephalometric studies, but certain modifications were made necessary by the nature of the investigation. Very few investigations have employed radiography for anthropological work in the field, so it is considered worthwhile to describe the procedure in some detail.

Cephalostat

The head holding device was constructed according to a design of M.J. Barrett similar to that suggested by BJÖRK (1950). The cephalostat (Fig. 8) weighed about 30 pounds when packed for transportation. Right and left ear rods could be moved simultaneously by a single lever, so that the median sagittal plane remained in the same position for all subjects regardless of age or head-breadth. The ear rods were constructed in metal and embedded in acrylic supports which in turn were fitted into ear rod supports of wood.

A nasion support was provided with vertical and horizontal adjustment, and an orbitale indicator, which consisted of a tapered plastic rod containing a lead marker



a. b.

Fig. 8. Cephalostat with subject positioned for
a. Lateral film, b. Postero-anterior film.

at its apex, was fitted to the framework of the head holder. The orbitale indicator was used in checking head orientation after rotation of the subject for postero-anterior films.

The entire head holder could be rotated on its support through either 45° or 90°, the required angle being located by a locking pin. In the field the cephalostat was securely bolted through its base to a prefabricated Dexion stand. A built-in spirit level on the horizontal arm of the head holder facilitated the alignment procedure.

X-Ray Unit and Power Supply

A Watson Victor Model D3 X-ray unit was modified for use in the field. To simplify transportation to Yuendumu, the X-ray head and control unit were dismantled and subsequently reassembled on a prefabricated Dexion stand. The unit was fitted with a lead cone to minimise scatter radiation.

The power supply available at the settlement was 240 volts A.C. generated by a 20KvA alternating current generator which was powered by a diesel motor. Line voltage was constantly checked during operation of the unit and found to remain reasonably stable.

Mounting Units

Steel stands were prefabricated from Dexion in Adelaide for both the X-ray head and the cephalostat; these were aligned by the method to be described. Once alignment was considered satisfactory, the stands were marked for identification of parts and dismantled. This procedure greatly simplified the installation of the equipment in the field.

Method of Alignment of the Apparatus

Precise testing of the alignment of the anode of the X-ray unit and the ear rods of the head holder was tested by exposing dental films taped to the cassette holder. When right and left ear rod centres and the anode were perfectly aligned, the images of right and left ear rods appeared as concentric circles without distortion in any direction. Once this test was considered satisfactory, the Dexion stands were bolted to the floor of the working area and maintained in these positions for the duration of the investigation.

Throughout the period in the field, test exposures were made on dental films two or three times daily to check the alignment and stability of the apparatus.

Positioning of the Subjects

To aid in the positioning of subjects, an adjustable stool fitted with castors was used in the following procedure:

The subject was first seated on the stool and the back support made comfortable. The height of the stool was then adjusted so that the external acoustic meati were level with a gauge rod which indicated the height of the ear rods of the cephalostat from the floor. The stool and the subject were then moved into position, and by asking the subject to focus his eyes on a spot on the far wall at eye level, natural head position was obtained.

The ear rods were then tightened into position and the nasion support fixed in place so that the subject could not move without exerting force. The use of a position of natural head balance in preference to the Frankfort horizontal provided radiographs with the tongue and pharyngeal wall in a resting position, and also allowed the mandibular rest position and wide open position to be achieved without undue strain.

The orbitale was located by palpation and marked with a skin pencil, and the orbitale indicator positioned.

After three lateral exposures had been made, the orbitale indicator was rotated out of position, and the cephalostat moved through 90° to the P-A position. At the same time the subject was rotated on the stool through the same angle so that the P-A position was achieved without any movement of the head relative to the trunk. As a final check on positioning the orbitale indicator was replaced on the skin mark and the P-A exposure made.

Anode - Median Sagittal Plane - Film Distances

The anode to median sagittal plane distance was kept constant for all subjects at 180 cm. The median sagittal plane to film distance was set for all subjects at 15 cm. For P-A films the porionic plane to film distance was also a constant 15 cm.

The median sagittal plane - film distance of 15 cm. was greater than the distance used by BJÖRK (1950). In trials with European subjects it was found that a MSP-film distance of 10 cm. could be accommodated fairly readily, but very few adult male aborigines could adjust to the shorter distance without severe distortion of the shoulders. This apparent anomaly was due to the relatively short cervical spine, which is a characteristic of the Australian aborigine. (WOOD-JONES, 1938).

The above distances produced a calculated enlargement of 8.3 per cent for linear structures situated in the MSP or projected onto that plane. This figure represents the minimum enlargement factor possible in the present study without increasing the anode - MSP distance to an extent not compatible with field radiography.

To avoid repetitive correction of linear MSP measurements, a leaded millimeter rule was suspended in the MSP to produce an image on the radiograph from which direct recordings could be made (ADAMS, 1940). The radiographic image of the rule was later checked on the lateral plates and was found to provide a stable measure on all films of 8.3 per cent enlargement.

Films and Cassettes

All head exposures were made on Kodax 25cm x 30cm (10" x 12") Blue Brand Safety Film, and alignment tests were made on normal dental films. Unexposed films were kept in a lead-lined box and exposed films were placed in the same box and moved each night to the living quarters where they were stored in light-proof containers in a cool location.

Six Watson Victor Kontak cassettes were used, each fitted with two Du-Pont Stainless Fast Speed intensifying screens. The cassettes were loaded and unloaded in a "dark room" constructed for the purpose within the framework of the cephalostat support. It was considered necessary to use six cassettes so that four exposures could be made in rapid succession without fatiguing the subject. Two loaded cassettes were then available should movement of a subject necessitated a repeat exposure.

Exposure Data

The requirements of X-ray cephalometry are such that the radiographs should be of the best quality and have sufficient contrast for easy identification of landmarks. In addition the exposure time should be as low as possible to avoid excessive dose of ionising radiation as well as to minimise the chance of subject movement.

With these criteria in mind, trial exposures were made on several European subjects in Adelaide before leaving for the field. After examination of the films so obtained the following exposure data were accepted as most suitable for field use with the available equipment:

Lateral plates	78 Kvp	15 Ma	0.5 Sec.
P - A plates	78 Kvp	15 Ma	0.5-0.75Sec.

Suitable radiographs were obtained in the field by using these settings for both adults and juveniles.

Contrast of Soft Tissues

An aluminium wedge 250mm x 65mm x 20mm tapering to 1mm was placed between the facial profile and the film at the time of exposure of the lateral films. The wedge produced a very suitable soft tissue profile shadow, without in any way detracting from the clarity of the underlying bony structures. It was not necessary to use tantalum powder or other radio-opaque materials to show the intra-oral and pharyngeal soft structures.

Types of Radiographs Exposed

Although this thesis deals only with the results obtained from lateral films taken in the tooth position, other exposures were made at the time for future research. Four exposures were made for each subject in the following order:

1. Lateral head film - with mandible in the rest position;
2. Lateral head film - with mandible in the tooth position;
3. Lateral head film - with mandible wide open;
4. P-A film - with mandible in the tooth position.

The rest position and tooth position of the mandible were considered in the sense defined by BRILL et al (1959). Rest position - "That vertical postural position of the mandible governed by muscle tonus."

Tooth position - "That vertical and horizontal position of the mandible in which the cusps of the mandibular and maxillary teeth intercuspidate maximally." The tooth position corresponds with the position of centric occlusion of other writers. All the lateral head films were exposed with the left profile towards the anode.

Any recording of the mandibular rest position requires complete relaxation on the part of the subject, so that conscious interference from cortical brain levels is minimal. Because of language problems it was difficult to convey to the native subjects the idea of a rest position, but it was found that they assumed a natural postural position of the mandible quite readily if no verbal instructions were given. For this reason the rest position films were exposed first, and if possible without the subject's awareness that a film was being taken.

The tooth position radiographs offered some difficulty since a significant number of Australian aborigines have occlusal relationships which vary from the classical concept of centric occlusion. This results from a disparity in the widths of upper and lower dental arches, which prevents maximum interdigitation on right and left sides simultaneously. BARRETT (1958) first described this type of segmental occlusion which has also been noted in another group of Central Australian aborigines by HEITHERSAY (1961). Tooth position exposures were made only after the position had been checked.

Identification of Films

All radiographs with the exception of a few test films were packed for development on return to Adelaide, so that a system of film identification was needed.

Lead numbers corresponding to the subject's expedition number were positioned on the cassettes prior to exposure; rest position films were marked with a lead shot and double determination films were identified by the letter R.

After exposure, the cassettes were unloaded and the films placed in manilla folders bearing the name and expedition number of each subject. At the time of development in Adelaide, details of name, age group and number were contact printed on each film in a position predetermined at the time of exposure by a lead masking sheet.

This method of film identification, together with detailed field records, enabled dental casts, radiographs, photographs and somatometric data to be linked for each subject with little chance of error.

Development Data

All films were developed in Kodak liquid X-ray developer Type 2, and fixed in Kodak liquid X-ray fixer according to the recommended time-temperature method 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.

Precautions against Overexposure to Radiation

The X-ray unit was monitored in Adelaide and found to deliver a skin dose of one roentgen (1r) per ten seconds, at a distance from the anode equivalent to the facial profile. Scatter radiation amounted to six milliroentgens per 250 seconds, and members of the team working in the vicinity of the machine were given monitor badges which were also placed in strategic positions around the work area. The monitor films were later developed at the same time as a set of standards which had received known doses of from 0 to 100 mr. The highest exposure registered for the entire three week field period was one of 12.5 mr, from a film placed immediately adjacent to the X-ray unit.

The majority of subjects received four exposures each of 0.5 seconds which delivered a total skin dose of 0.2r to the head region. Thirteen of the male subjects each received a further two exposures one to three weeks later during a series of double determinations, which resulted in an additional dose of 0.1r to the head.

The exposure figures determined in the present study compare favourably with those published recently by PADEN (1960) who measured an exposure of 0.146r per film, which he found could be reduced to 0.046r per film when proper filtration and exposure settings were used.

It can be concluded that adequate safety precautions were taken in the present project and that since the recorded doses are well within accepted safety levels, no subject or dental worker suffered overexposure to ionising radiation.

3. REFERENCE POINTS AND REFERENCE LINES

The lateral head radiographs taken in the tooth position were traced onto 0.05 mm thickness Permatrace film with the aid of a specially constructed viewing table which was fitted with controlled illumination and a Stufeka drafting machine. The reference points and lines listed below were transferred from the radiographs to the tracings.

The reference points defined, except where otherwise indicated, are from a list of reference points for lateral head roentgenogram interpretation, used at the Orthodontic Department of the Royal Dental College, Copenhagen, and quoted by LINDEGÅRD (1953). All reference points are situated in the median sagittal plane or are projected onto that plane. In cases of double projection midpoints were used.

Reference Points (Figs. 9a and 13)

ARTICULARE (ar): point at the junction of the contour of the external cranial base and the dorsal contour of the condylar processes, projected in MSP.

BASION (ba): the perpendicular projection of the anterior border of the foramen magnum (endobasion) on a tangent through the lower contour of the foramen in MSP.

GNATHION (gn): the lowest point on the symphysis of the mandible in MSP.

GONIAL TANGENT POINT (tgo): the junction of the basal tangent and the ramal tangent of the mandible, projected in MSP.

INFRADENTALE (id): the highest and most forward projecting point on the mandibular alveolar process in MSP.

INCISION INFERIUS (ii): the midpoint of the contour of the incisal edge of the more prominent lower central incisor projected in MSP.

INCISION SUPERIUS (is): the midpoint of the contour of the incisal edge of the more prominent upper central incisor projected in MSP.

———————————— (io): normal projection of incision inferius on the occlusal plane.

NASION (n): the most anterior point of the naso-frontal suture in MSP.

POGONION (pg): the most anterior projecting point on the chin in MSP.

PROSTHION (pr): the lowest and foremost projecting point of the maxillary alveolar process in MSP.

PTERYGOMAXILLARE (pm): a point representing the dorsal contour of the maxilla at the nasal floor level, projected in MSP. The point is located on the dorsal contour of the maxilla, upwards, forming the anterior border of the pterygopalatine fossa, where it intersects the contour of the hard and soft palates.

SELLA (s): the centre of the bony crypt forming the sella turcica. The surface of the sella turcica is determined independently of the contours of the clinoid processes, and is limited upwards by a line from tuberculum sellae to dorsum sellae. The centre is defined as the midpoint of the greatest diameter from tuberculum sellae.

SPINAL POINT (sp): (Acanthion) the apex of the anterior nasal spine.

SUBSPINALE (ss): the most posterior point on the outer contour of the maxillary alveolar process in MSP.

In addition the following two points which are not illustrated were located for the section on errors of the methods:

ORBITALE (or): the lowest point on the contour of the infraorbital margin, projected in MSP.

PORION (po): the highest point on the shadow of the ear rods (WERNER, 1955).

<u>Reference Lines</u> (Fig. 9b)

NASION-SELLA LINE (NSL): the horizontal line passing through points nasion and sella.

NASION-SELLA PERPENDICULAR (NSP): the vertical line passing through sella and perpendicular to NSL.

NASAL LINE (NL): the straight line passing through the spinal point and pterygomaxillare.

OCCLUSAL LINE (OL): the straight line passing through incision superius and the distal cusp summit of the first upper molar, or, when this tooth is missing, the mesial cusp summit of the second upper molar.

MANDIBULAR LINE (ML): the line drawn through the lowest point at the symphysis, touching the mandibular border at the angle region. (BJÖRK et al, 1956; SARNÄS, 1959).

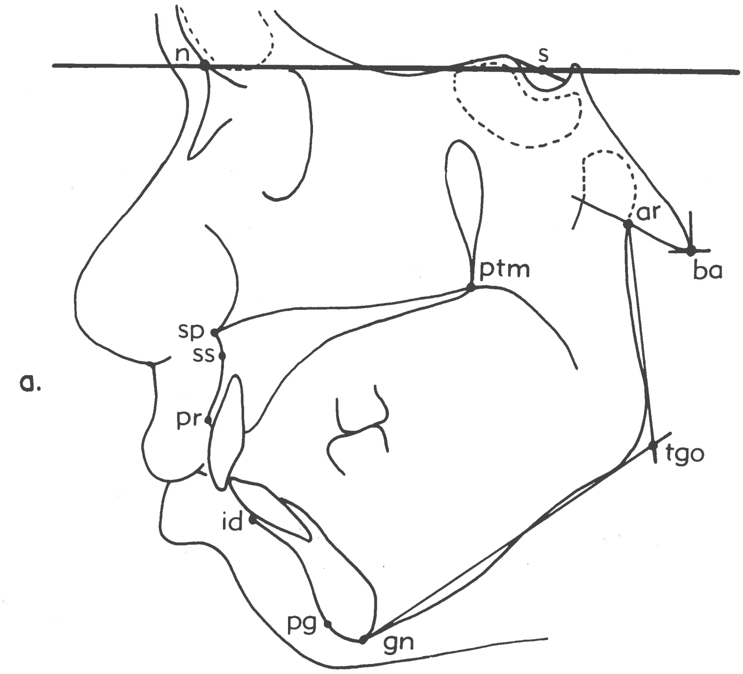
The mandibular line was constructed according to the above definition in preference to the methods described by LINDEGARD (1953), BJÖRK and PALLING (1954) and SALZMANN (1960) which utilise lines either tangential to the lower border of the mandible, or through the radiographic gonion. In the group studied there was often evidence of marked appositional bone growth along the lower mandibular border, which then assumed a marked convexity along its middle third, thus rendering difficult the construction of an accurate tangent to this border.

CHIN LINE (CL): a line from infradentale through pogonion. (BJÖRK and PALLING, 1954)

UPPER INCISOR AXIS (IL_s): a line from incision superius (is) through the apex. (BJÖRK and PALLING, 1954)

LOWER INCISOR AXIS (IL_i): a line from incision inferius (ii) through the apex. (BJÖRK and PALLING, 1954)

FRANKFORT HORIZONTAL (FH): (cephalometric) a line drawn through points orbitale and porion. (WERNER, 1955)



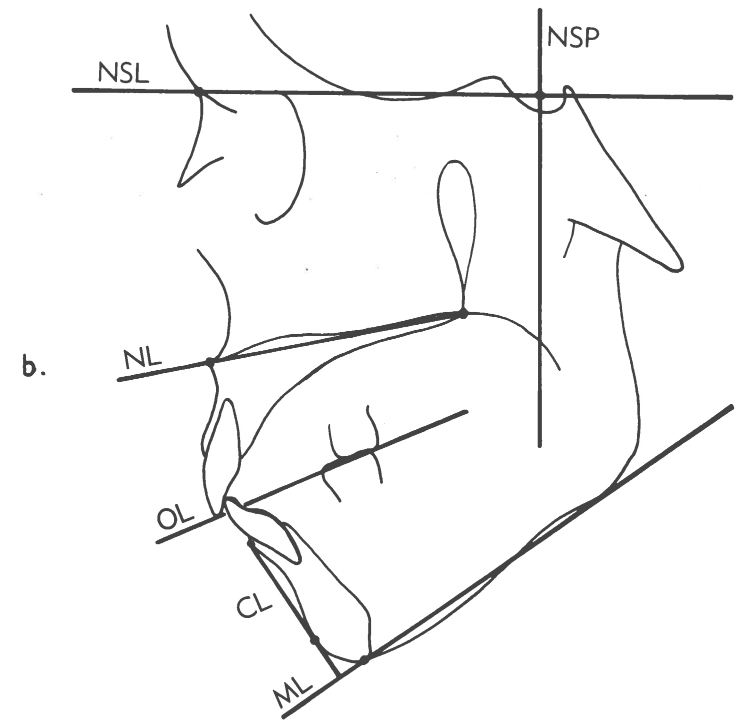


Fig. 9. Reference points and lines.

4. VARIABLES STUDIED (Figs. 10 to 14)

Angular readings, made to the nearest 0.5 degree, were recorded directly from the tracings, whereas all linear MSP readings, recorded to the nearest 0.5 mm, were made with callipers and a rule which had been engraved to correspond with the projected image of the millimeter rule. In this way all linear readings were corrected for the calculated 8.3 per cent enlargement, which was verified on each film by examination of the projected millimeter image.

All linear and angular variables used refer to radiographic shadows of corresponding bony structures, and although their values would closely approximate those obtained by classical craniometry, they should not be regarded as exactly identical. Where indicated, one linear measurement has been expressed as a percentage of another to provide certain indices.

<u>Facial and alveolar prognathism</u>

MAXILLARY BASAL PROGNATHISM (s-n-ss): the angle formed by the cranial base and a profile line through nasion and subspinale.

MAXILLARY ALVEOLAR PROGNATHISM (s-n-pr): the angle formed by the cranial base and a profile line through nasion and prosthion.

MANDIBULAR BASAL PROGNATHISM (s-n-pg): the angle formed by the cranial base and a profile line through nasion and pogonion.

MANDIBULAR ALVEOLAR PROGNATHISM (s-n-id): the angle formed by the cranial base and a profile line through nasion and infradentale.

The four prognathic angles listed above are defined according to BJÖRK (1950) with the exception that subspinale is substituted for the spinal point in the measurement of maxillary basal prognathism.

SAGITTAL JAW RELATION (ss-n-pg): calculated as the degree by which the angle of maxillary basal prognathism exceeded that of mandibular basal prognathism. The angle ss-n-pg indicates the antero-posterior relationship of the jaw bases.

MAXILLARY ALVEOLAR PROGNATHY (pr-n-ss): calculated as the degree by which the angle of maxillary alveolar prognathism exceeded that of maxillary basal prognathism. The angle pr-n-ss indicates the protrusion of the upper alveolar margin in relation to its base (BJÖRK and PALLING, 1954).

MANDIBULAR ALVEOLAR PROGNATHY (id-n-pg): calculated as the degree by which the angle of mandibular alveolar prognathism exceeded that of mandibular basal prognathism. The angle id-n-pg indicates the protrusion of the lower alveolar margin in relation to its base (BJÖRK and PALLING, 1954).

PROFILE ANGLE (n-ss-pg): measured as the angle between profile lines joining nasion-subspinale and subspinale-pogonion, registered at subspinale. The angle n-ss-pg indicates the degree of facial convexity (BJÖRK, 1955).

RADIOGRAPHIC GNATHIC INDEX: calculated as a percentage according to the expression:-

$$\text{Gnathic index} = \frac{\text{basion - prosthion line}}{\text{basion - nasion line}} \times 100$$

$$\text{or } \frac{\text{ba-pr}}{\text{ba-n}} \times 100$$

The angles of maxillary basal and alveolar prognathism were also measured from the Frankfort horizontal and expressed as the angles n-ss/FH and n-pr/FH respectively.

The angulation of the Frankfort horizontal to the nasion-sella line was measured and designated FH-NSL.

All angular measurements involving the use of the radiographic Frankfort horizontal were included solely for the section on errors of the methods, where errors in the use of FH and NSL are compared.

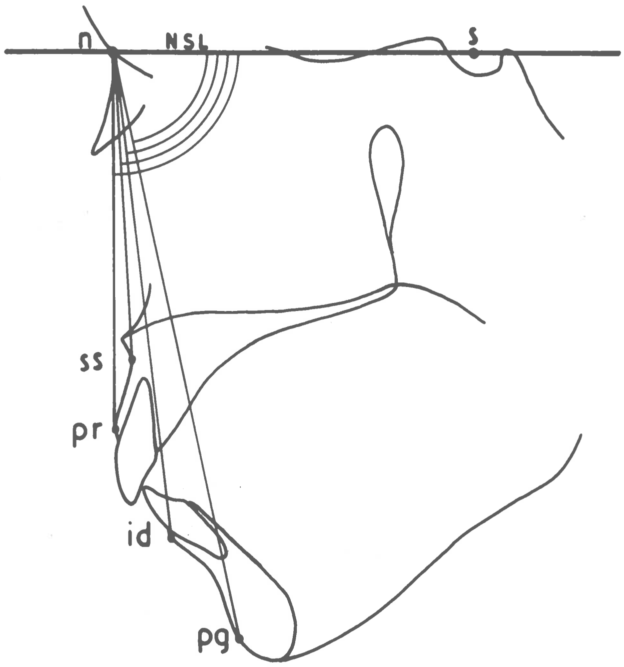


Fig. 10. The angles of prognathism.

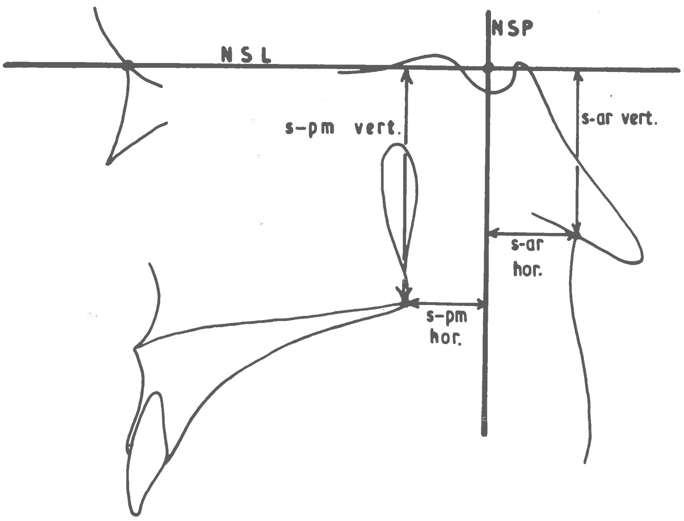


Fig. 11. Method of measuring the posterior upper face height and the projected distances, s-pm hor., s-ar hor. and s-ar vert.

Upper and Lower Jaws

MAXILLARY LENGTH (ss-pm): the distance between subspinale and pterygomaxillare.

For the section on errors of the methods, the maxillary length was also measured as the distance between spinal point and pterygomaxillare.

RAMUS HEIGHT (ar-tgo): the distance between gonial tangent point and articulare.

CORPUS LENGTH (pg-tgo): the distance between gonial tangent point and pogonion.

TOTAL MANDIBULAR LENGTH (pg-ar): the distance between pogonion and articulare.

Linear measurements which express the size of the mandible utilise sagittal projections of bilateral points articulare and gonial tangent, and are therefore not necessarily identical to distances measured between the same points directly on a skull. Obviously the inclination of the corpus and ramus to the median sagittal plane will determine the radiographic projection of these points.

GONIAL ANGLE (ar-tgo-gn): the angle formed by a line tangent to the mandibular ramus and the mandibular line.

CHIN ANGLE (CL-ML): the angle formed by the chin line and the mandibular line. The chin angle provided a further indication of mandibular alveolar prognathism independent of the mandibular base.

JOINT ANGLE (s-ar-tgo): the angle formed by a line tangent to the mandibular ramus (ar-tgo) and the lateral cranial base line joining sella and articulare. The angle s-ar-tgo provided an indication of the angular relationship of the mandible to the lateral cranial base.

MAXILLARY PROTRUSION (s-pm horizontal): the projected distance of point pterygomaxillare to the nasion-sella perpendicular. The distance s-pm hor. indicated the horizontal position of the upper face in relation to the anterior cranial base.

POSTERIOR UPPER FACE HEIGHT (s-pm vertical): the perpendicular distance from pterygomaxillare to the NSL. The distance s-pm vert. indicated the vertical position of the upper face in relation to the anterior cranial base.

The position of the lower jaw in relation to the anterior cranial base was measured as the horizontal and vertical distances from articulare to NSP and NSL, which were expressed as the projected distances s-ar hor. and s-ar vert. respectively.

The length of the upper jaw in relation to the lateral cranial base length was calculated as the ss-pm length expressed as a percentage of the n-ar length, and expressed as ss-pm/n-ar.

The length of the lower jaw in relation to the lateral cranial base length was calculated as the pg-ar length expressed as a percentage of the n-ar length, and designated pg-ar/n-ar. As an additional index of mandibular length in relation to lateral cranial base length, the corpus length (pg-tgo) was calculated as a percentage of the n-ar length and designated pg-tgo/n-ar.

The projected images of structures situated laterally vary according to their inclination to the median sagittal plane, and indices calculated from cephalometric radiographs may not be identical to conventional craniometric indices, since on X-rays the linear measurements used may vary independently. However in the case of the jaw bases in relation to the lateral cranial base, the independent variation is probably slight, especially since point articulare is common to both mandible and lateral cranial base.

INCLINATION OF UPPER JAW BASE TO NSL (NL-NSL): the angle between the nasal line and the anterior cranial base.

INCLINATION OF LOWER JAW BASE TO NSL (ML-NSL): the angle between the mandibular line and the anterior cranial base.

INCLINATION OF UPPER JAW BASE TO OL (NL-OL): the angle between the nasal line and the occlusal line.

INCLINATION OF LOWER JAW BASE TO OL (ML-OL): the angle between the mandibular line and the occlusal line.

INCLINATION OF UPPER TO LOWER JAW BASE (NL-ML): the angle between the nasal and mandibular lines.

Facial Heights

The total face height was subdivided by the nasal line into the upper face, between NSL and NL, and the lower face between NL and ML. The lower face was further subdivided by the occlusal line into maxillary lower face between NL and OL, and mandibular lower face between OL and ML.

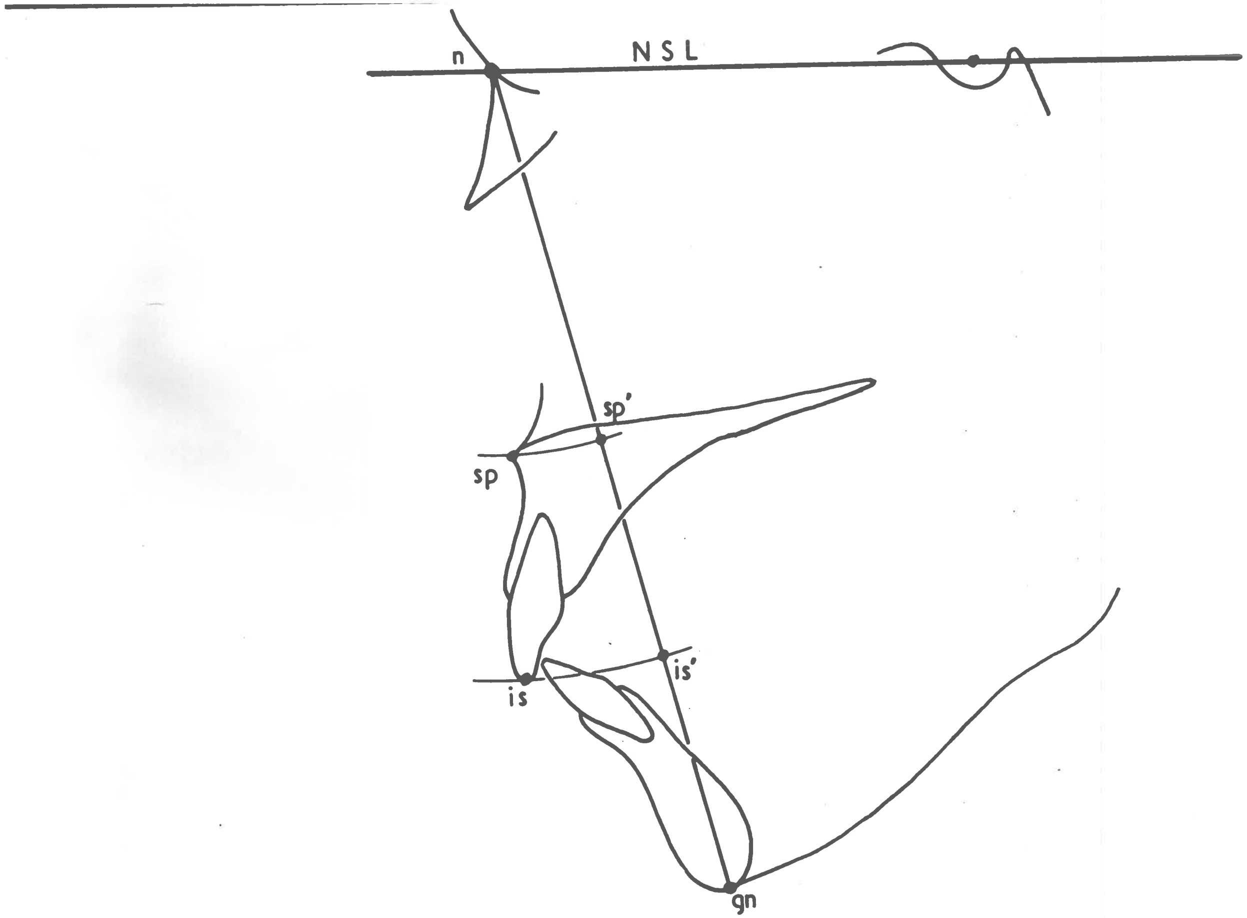


Fig. 12. Method of constructing points sp' and is' for the measurement of facial heights.

The subdivisions of the facial height were determined by the method of LINDEGÅRD (1953) as follows (Fig. 12): Points nasion and gnathion were joined by a straight line, the n-gn line, along which the distances n-sp and n-is were marked in order to construct new reference points designated sp' and is' respectively. This method permitted five separate face heights to be measured.

MORPHOLOGICAL FACE HEIGHT (n-gn): the distance between nasion and gnathion.

UPPER FACE HEIGHT (n-sp): the distance between nasion and spinal point.

TOTAL LOWER FACE HEIGHT (sp'-gn): the distance between constructed point sp' and gn.

MAXILLARY LOWER FACE HEIGHT (sp'-is'): the distance between constructed points sp' and is'.

MANDIBULAR LOWER FACE HEIGHT (is'-gn): the distance between constructed point is' and gn.

In addition the upper face height was expressed as a percentage of the morphological face height and designated n-sp/n-gn.

Incisor Relationships

INCLINATION OF THE UPPER CENTRAL INCISORS (IL_s-OL): the angle between the upper incisor axis and the occlusal line.

INCLINATION OF THE LOWER CENTRAL INCISORS (IL_1-OL): the angle between the lower incisor axis and the occlusal line.

INTERINCISAL ANGLE (IL_s-IL_i): the angle between upper and lower incisor axes.

OVERBITE (ii-io): the distance between incision inferius and the normal projection of incision inferius on the occlusal line.

OVERJET (is-io): the distance between incision superius and the normal projection of incision inferius on the occlusal line.

Cranial Base

In the present study the cranial base was considered to consist of two components: a median cranial base situated in the median sagittal plane and limited anteriorly nasion and posteriorly by basion; a lateral cranial base, to which the mandible is articulated, limited anteriorly by nasion and posteriorly by articulare. Articulare is situated on the lateral cranial base and is a reasonable indication of the lateral limits of the base (BJÖRK, 1947).

TOTAL MEDIAN CRANIAL BASE LENGTH (n-ba): the distance between nasion and basion.

TOTAL LATERAL CRANIAL BASE LEN GTH(n-ar): the distance between nasion and articulare.

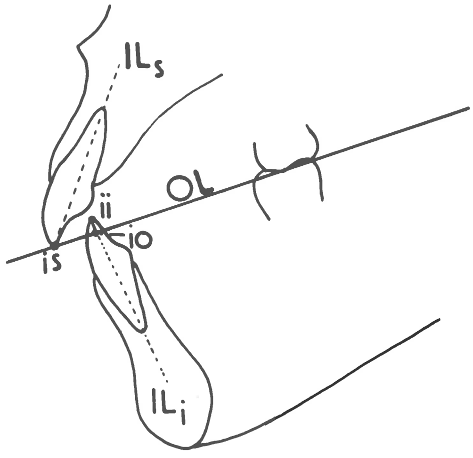


Fig. 13. Reference points and lines within the bite.

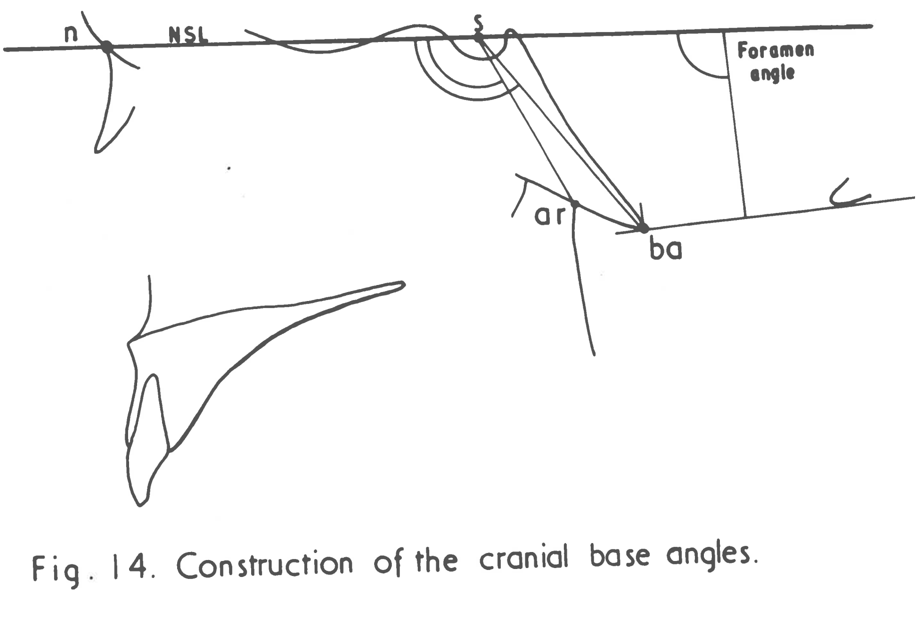


Fig. 14. Construction of the cranial base angles.

ANTERIOR CRANIAL BASE LENGTH (n-s): the distance between nasion and sella.

POSTERIOR MEDIAN CRANIAL BASE LENGTH (s-ba): the distance between sella and basion.

MEDIAN CRANIAL BASE ANGLE (n-s-ba): the angle between NSL and a line joining sella and basion. The angle n-s-ba indicates the shape of the median cranial base.

POSTERIOR LATERAL CRANIAL BASE LENGTH (s-ar): the distance between sella and articulare.

LATERAL CRANIAL BASE ANGLE (n-s-ar): the angle between NSL and a line joining sella and articulare. The angle n-s-ar indicates the shape of the lateral cranial base.

DIFFERENCE IN CRANIAL BASE ANGLES (ar-s-ba): calculated as the degree by which the median cranial base angle exceeds the lateral cranial base angle. The angle ar-s-ba provides an additional indication of the position of the mandible (as measured on the mandibular neck) in relation to the median cranial base.

FORAMEN ANGLE: the angle between the head balance axis (a perpendicular to the line tangent to the lower contour of the foramen magnum in MSP) and the NSL. The foramen angle indicates the inclination of the foramen magnum to the cranial base, and indirectly the balance of the head upon the cervical spine (BJÖRK, 1955).

5. GENERAL STATISTICAL METHODS

Male and female mean values were compared using Student's "t-test" with 56 degrees of freedom. A difference between such mean values was declared significant (denoted **) if the probability that it would be exceeded by chance was less than one per cent ($p < 0.01$). A difference between mean values was declared almost significant (denoted *) if the probability that it would be exceeded by chance was greater than one per cent but less than five per cent ($0.01 < p < 0.05$).

Associations between pairs of variables were investigated by calculating total correlation coefficients. A total correlation coefficient was declared significant (**) if the probability that it would be exceeded by chance was less than one per cent, and almost significant (*) if the probability lay between one and five per cent. Fisher's table of r values, with 29 degrees of freedom for males and 25 degrees of freedom for females, was used to determine the probability.

Partial correlation coefficients were calculated to test the association between two variables (1 and 2) independent of a third variable (3), according to the formula:

$$r12.3 = \frac{r12 - r13.r23}{\sqrt{(1 - r_{13}^2)(1 - r_{23}^2)}}$$

where $r_{12.3}$ is the partial correlation coefficient,

r_{12}, r_{13} and r_{23} are total correlation coefficients between the variables concerned.

Fisher's table of r values, with 28 degrees of freedom for males and 24 degrees of freedom for females, was used to determine the significance of partial correlation coefficients, which were denoted significant (**) or almost significant (*), as for the total coefficients.

The terms significant and almost significant are used in the text to mean the same as the common expressions "significant at the one per cent level" and "significant at the five per cent level" respectively.

Data relating to errors of estimation (CHAP. III) and the regression analysis (CHAP. VI) were treated by specific statistical methods which are described in the appropriate sections.

The following terms and symbols are used in the text and tables:

Mean - arithmetic mean of a series of measurements;

ε(M) - standard error of the mean;

s - sample standard deviation;

Range - Minimum and maximum values of a series of observations, or the size of the interval between these values;

t - value of "t" computed from Student's "t-test";

r - coefficient of correlation;

♂ - male subjects;

♀ - female subjects

Except where otherwise indicated the sample number was 31 males and 27 females.

Statistical texts used for reference were those of FISHER (1946), MORONEY (1951), FISHER and YATES (1957), GARN (1958) and BAILEY (1959).

CHAPTER III

ERRORS OF THE METHODS

Whenever measurements are used in scientific research limitations in techniques give rise to errors of estimation. The various sources of systematic and accidental errors involved in cephalometric radiography have been investigated by BJÖRK (1947), FRANKLIN (1952), THÖRNE (1953), WEHNER (1955), NEVAKARI (1956), TALLGREN (1957) and HALLETT (1959).

The use of cephalometric radiography provides the only method of examining the cranio-facial structures of living subjects with any degree of thoroughness and accuracy , and must therefore be recognised as an important research method in physical anthropology, orthodontics and related fields. However the use of any technique can only be justified if the errors of estimation do not seriously affect true values.

It would be anticipated that errors involved in the radiography of a group of subjects living under near-tribal conditions, where research conditions are at a minimum, would be larger than those associated with normal clinical use of the technique under more favourable conditions. Since it appears that the extent of errors in field investigations of this nature has not previously been appraised, the methods of analysing the errors of estimation in the present study are described in some detail.

In the present study errors arose from two main sources: the field methods and the measurement methods. Field method errors included those caused by difficulties in positioning and fixing the subjects in the cephalostat, difficulties in persuading the subjects to hold their mandibles in the tooth position, movement of the subjects during exposure of the films and errors in radiographic projection. Measurement method errors included those caused by difficulties in identifying and locating measuring points and reference lines on the radiographs and transferring them to tracings, and those caused by inaccuracies in measuring instruments and the manner in which they were used by the investigator.

Method of Investigation

To arrive at an estimate of the magnitude of the experimental errors and the extent by which they affect the results, two series of double determinations were made. The statistical analysis of the data followed the method of DAHLBERG (1940).

SERIES 1

Twelve male subjects (38.7 per cent of the sample) were selected at random for repeat tooth position radiographs which were taken by the same worker approximately two weeks after the first series were obtained. Angular and linear measurements were recorded from the repeat radiographs and compared with those obtained from the initial series for each subject.

The revealed errors were expressed as the mean of the difference (M diff.1), the standard error of the mean difference (εM diff.1) and the standard deviation of a single determination (s_1) according to the following formulae:

$$M\ diff.1 = \frac{\Sigma d}{n}$$

$$\varepsilon M\ diff.1 = \sqrt{\frac{\Sigma d^2 - (M\ diff.1)^2}{(n - 1)}}$$

$$s_1 = \sqrt{\frac{\Sigma d^2}{2n}}$$

where d = difference in readings between initial and repeat films of the same subject.

n = number of double determinations.

2n = number of single determinations.

Series 1 estimates include field method errors as well as measurement method errors, and the standard deviation s_1 has been designated the <u>total experimental error</u>. In Series 1 estimates, the probability that a single determination will not deviate more than ± 1 s_1 from its real value is approximately 67 per cent.

SERIES 2

Twelve tooth position radiographs were selected at random (38.7 per cent of the male sample) some three months after initial measurements had been obtained from their tracings. Repeat tracings and measurements were made by the same observer, and the repeat measurements were compared with the initial ones for each subject.

The revealed errors were expressed as the mean of the differences (M diff.2), the standard error of the mean difference (εM diff.2) and the standard deviation of a single determination (s_2) in the same way as for Series 1. Series 2 estimates refer to measurement errors only and the standard deviation s_2 has been designated the <u>measurement error</u>. In Series 2 estimates, the probability that a single determination will not deviate more than ± 1 s_2 from its real value is approximately 67 per cent.

Student's "t-test" was employed to test the hypothesis that a mean difference did not differ significantly from zero. The five and one per cent levels of probability were chosen for this test and the differences designated almost significant or significant accordingly.

A significant mean difference indicated an experimental error (or bias) in the technique. For example an error caused by slight differences in the manner of positioning subjects during the repeat series of radiographs, or an error due to variations in the selection of radiographic reference points or lines during the repeat tracings and measurements of radiographs.

Since Series 1 estimates include errors caused by subject positioning and those arising from tracings and measurements, while Series 2 estimates refer to measurement errors only, it is possible to obtain an estimate of the subject positioning error from the formula:

$$s_p = \sqrt{s_1^2 - s_2^2}$$

where s_p = subject positioning error,
s_1 = total experimental error,
s_2 = measurement error.

In a similar way an estimate of the true standard deviation between individuals may be obtained from the formula:

$$s_i = \sqrt{s^2 - s_1^2}$$

where s_i = estimate of true standard deviation between individuals,

s = observed standard deviation between individuals (sample standard deviation),

s_1 = total experimental error.

Results

The general dispersions of the estimates in Series 1 and Series 2 are shown graphically in Fig. 15. In Series 1 the mean difference of the 528 double determinations when considered together was -0.03 ± 0.61 degrees or mm, and the standard deviation of a single determination was ±1.42 degrees or mm. In Series 2 the mean difference of 528 double determinations considered together was 0.00 ± 0.03 degrees or mm, and the standard deviation of a single determination was ± 0.80 degrees or mm.

The mean differences and their standard errors for each angular variable studied in Series 1 and Series 2 are shown in TABLE 4. Similar data for linear variables are shown in TABLE 5.

The total experimental errors (s_1), the measurement errors (s_2) and the derived positioning errors (s_p) for angular variables are summarised in TABLE 6, while corresponding data for linear variables are shown in TABLE 7. The observed standard deviations between individuals (s), which were obtained from TABLES 8,9 and 16 to 21, and the estimated true standard deviations between individuals (s_1) are included in TABLES 6 and 7 for comparison with the "within individuals" variations s_1, s_2 and s_p.

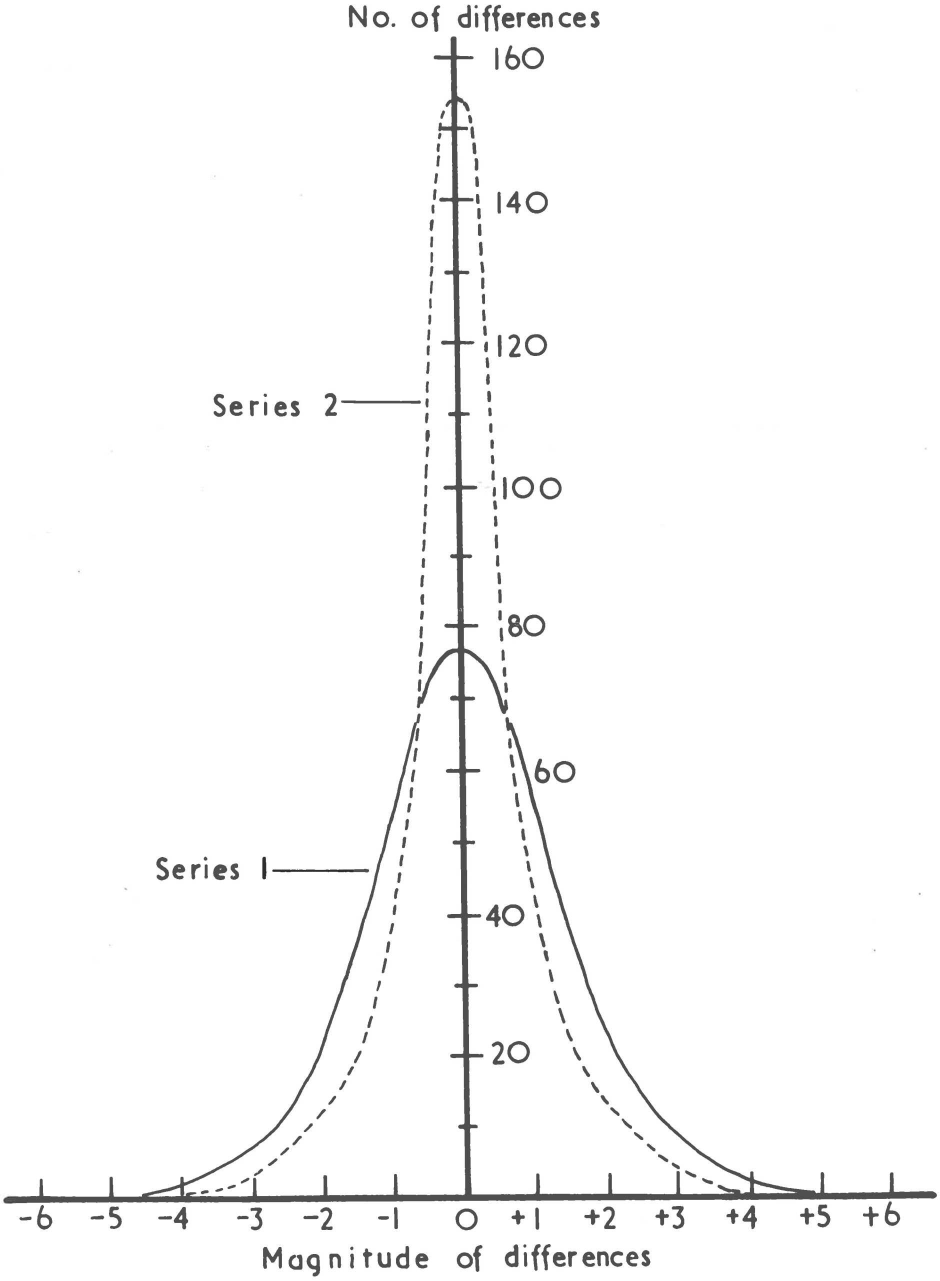


Fig. 15. Distribution of differences in 528 double determinations in Series I and 528 double determinations in Series 2.

TABLE 4

Means of the differences in angular measurements obtained from cephalometric radiographs of 12 males in Series 1, and 12 males in Series 2.

Measurement	Series 1			Series 2		
	M diff.1	±	εM diff.1	M diff.2	±	εM diff.2
s-n-ss	+ 0.04	±	0.50	+ 0.04	±	0.17
s-n-pg	+ 0.08	±	0.34	+ 0.04	±	0.19
s-n-pr	+ 0.63	±	0.31	+ 0.13	±	0.19
s-n-id	- 0.08	±	0.37	+ 0.21	±	0.16
FH/NSL	- 0.75	±	0.56	- 0.13	±	0.14
n-ss/FH	- 0.71	±	0.76	- 0.21	±	0.27
n-pr/FH	- 0.13	±	0.53	0.00	±	0.32
n-ss-pg	+ 0.04	±	0.65	+ 0.29	±	0.35
s-ar-tgo	- 1.29	±	1.22	- 0.21	±	0.33
ar-tgo-gn	+ 1.00	±	0.73	- 0.08	±	0.21
Chin angle	0.00	±	0.23	- 0.17	±	0.14
IL_s/OL	- 0.79	±	0.84	- 0.42	±	0.65
IL_i/OL	+ 0.38	±	0.81	+ 0.54	±	0.73
IL_s/IL_i	- 0.42	±	1.45	+ 0.17	±	0.71
n-s-ba	0.00	±	0.37	+ 0.21	±	0.23
n-s-ar	+ 0.63	±	0.80	+ 0.29	±	0.23
Foramen angle	- 0.42	±	1.05	- 0.38	±	0.40
NL/NSL	- 0.67	±	0.54	+ 0.17	±	0.46
ML/NSL	+ 0.13	±	0.22	+ 0.08	±	0.15
NL/OL	+ 0.71	±	0.46	- 0.33	±	0.60
ML/OL	+ 0.04	±	0.33	+ 0.33	±	0.45
NL/ML	+ 0.79	±	0.42	- 0.08	±	0.54

TABLE 5

Means of the differences in linear measurements obtained from cephalometric radiographs of 12 males in Series 1, and 12 males in Series 2.

Measurement	Series 1		Series 2	
	M diff.1	± εM diff.1	M diff.2	± εM diff.2
n-ba	- 0.29	± 0.22	- 0.08	± 0.24
pr-ba	+ 0.33	± 0.30	+ 0.21	± 0.25
ss-pm	- 0.88	± 0.50	- 0.46	± 0.32
sp-pm	- 1.08	± 0.75	- 0.50	± 0.27
ar-tgo	- 0.42	± 0.66	+ 0.50	± 0.16 *
pg-tgo	- 0.33	± 0.30	+ 0.21	± 0.10
pg-ar	- 0.50	± 0.38	+ 0.25	± 0.19
s-pm vert.	0.00	± 0.28	- 0.33	± 0.26
s-pm hor.	+ 0.83	± 0.42	+ 0.33	± 0.28
s-ar vert.	+ 0.25	± 0.47	- 0.38	± 0.19
s-ar hor.	+ 0.42	± 0.54	0.00	± 0.17
Overbite	+ 0.08	± 0.24	+ 0.17	± 0.13
Overjet	+ 0.79	± 0.32 *	+ 0.04	± 0.14
n-s	- 0.38	± 0.21	- 0.04	± 0.16
s-ba	+ 0.17	± 0.37	- 0.29	± 0.30
s-ar	+ 0.38	± 0.62	- 0.13	± 0.31
n-ar	+ 0.17	± 0.52	- 0.13	± 0.15
n-gn	- 0.21	± 0.39	+ 0.04	± 0.16
n-sp	- 0.79	± 0.42	+ 0.08	± 0.36
sp'-gn	+ 0.50	± 0.63	- 0.08	± 0.40
sp'-is'	+ 0.58	± 0.47	- 0.25	± 0.46
is'-gn	- 0.08	± 0.37	+ 0.17	± 0.19

* Almost significant.

TABLE 6

Errors in angular measurements obtained from cephalometric radiographs of 12 males in Series 1, and 12 males in Series 2. The observed standard deviation between individuals s, the estimated true standard deviation s_i, the total experimental error s_1, measurement error s_2 and positioning error s_p are shown.

Measurement	s	s_i	s_1	s_2	s_p
s-n-ss	3.80	3.61	1.17	0.40	1.10
s-n-pg	4.02	3.94	0.80	0.45	0.66
s-n-pr	3.67	3.57	0.86	0.45	0.74
s-n-id	3.85	3.75	0.88	0.40	0.78
FH/NSL	2.36	2.00	1.23	0.44	1.15
n-ss/FH	4.46	4.05	1.86	0.65	1.74
n-pr/FH	4.38	4.20	1.24	0.75	0.99
n-ss-pg	5.05	4.82	1.52	0.84	1.27
s-ar-tgo	9.10	8.57	3.06	0.78	2.96
ar-tgo-gn	5.89	5.59	1.86	0.50	1.79
Chin angle	4.81	4.78	0.54	0.35	0.40
IL_s/OL	5.65	5.26	2.05	1.55	1.34
IL_i/OL	6.00	5.68	1.92	1.75	0.79
IL_s/IL_i	9.19	8.54	3.41	1.67	2.98
n-s-ba	4.23	4.13	0.88	0.55	0.69
n-s-ar	5.21	4.84	1.92	0.59	1.83
Foramen angle	5.22	4.60	2.48	0.97	2.28
NL/NSL	3.48	3.21	1.36	1.09	0.81
ML/NSL	4.81	4.78	0.53	0.35	0.39
NL/OL	4.17	4.00	1.19	1.43	-
ML/OL	5.16	5.10	0.77	1.08	-
NL/ML	3.93	3.76	1.13	1.28	-

TABLE 7

Errors in linear measurements obtained from cephalometric radiographs of 12 males in Series 1, and 12 males in Series 2. The observed standard deviation between individuals s, the estimated true standard deviation s_i, the total experimental error s_1, measurement error s_2 and positioning error s_p are shown.

Measurement	s	s_i	s_1	s_2	s_p
n-ba	4.22	4.19	0.55	0.61	-
pr-ba	4.46	4.39	0.75	0.60	0.45
ss-pm	2.85	2.53	1.32	0.81	1.04
sp-pm	2.93	2.22	1.91	0.72	1.77
ar-tgo	4.32	4.02	1.57	0.52	1.49
pg-tgo	3.87	3.80	0.74	0.27	0.69
pg-ar	5.54	5.46	0.95	0.48	0.82
s-pm vert.	2.52	2.44	0.65	0.66	-
s-pm hor.	2.55	2.28	1.14	0.69	0.91
s-ar vert.	2.95	2.74	1.11	0.51	0.99
s-ar hor.	3.34	3.09	1.27	0.41	1.20
Overbite	2.15	2.08	0.56	0.32	0.46
Overjet	2.04	1.81	0.93	0.34	0.87
n-s	3.16	3.11	0.55	0.37	0.40
s-ba	3.28	3.17	0.87	0.73	0.47
s-ar	3.34	3.00	1.48	0.73	1.29
n-ar	3.78	3.57	1.22	0.37	1.16
n-gn	7.13	7.07	0.92	0.38	0.83
n-sp	3.95	3.79	1.13	0.85	0.74
sp'-gn	5.11	4.87	1.53	0.94	1.20
sp'-is'	2.78	2.52	1.17	1.10	0.41
is'-gn	3.70	3.59	0.87	0.46	0.74

Discussion

The dispersion of the differences in Series 1 estimates included a smaller percentage of zero and low magnitude differences than that of Series 2. This indicates that positioning a subject for cephalometric radiography involved errors in addition to those resulting from tracing X-rays, locating landmarks and measuring variables.

Since the recorded differences were distributed fairly evenly each side of zero, the mean differences were of low order; in fact only one linear measurement and two angular measurements had mean differences which exceeded one degree or mm. Employment of the "t-test" revealed that in Series 1 the mean difference of the linear variable overjet(+0.79 ± 0.32 mm) differed from zero at the almost significant level. In Series 2, the mean difference of the linear variable ramus height (+0.50 ± 0.16 mm) differed from zero at the same probability level.

The two almost significant mean differences could reasonably regarded as spurious, since it is not unusual to obtain by chance one or two significant values during a series of, in this case 44, double determinations. Therefore the results indicate that sample means were not seriously affected by experimental errors.

It is interesting to observe that when positioning errors were calculated, they exceeded the measurement error for most linear and angular variables. Thus the manner in which a subject is positioned for radiography may be a source of error which is usually greater than the error involved in tracing and measuring radiographs. This potential source of error has been largely overlooked in previous studies based on X-ray cephalometry.

In the present investigation, the total experimental errors were of low magnitude when compared with the observed variances between individuals, so that the observed standard deviations closely approximated the estimated true standard deviations. It can be reasonably concluded that experimental errors were unlikely to affect true dispersions between individuals.

Closer examination of the results revealed that the highest experimental errors resulted from the use of certain reference points or lines. The more variable of these merit further discussion.

FRANKFORT HORIZONTAL

In the present study the total experimental errors involved when measuring the angulation of the profile lines n-ss and n-pr to the Frankfort horizontal (1.36 and 1.24 respectively) were greater than the errors found when the same profile lines were measured from the nasion-sella reference line (1.17 and 0.86 respectively). These errors may be expressed as percentages of the sample means for the angles concerned to indicate the following: the probability that single determinations of the angles n-ss/FH and s-n-ss will not vary from their true values by more than 2.0% and 1.3% respectively is 67 per cent. The same probability exists that single determinations of the angles n-pr/FH and s-n-pr will not vary from their true values by more than 1.3% and 0.9% respectively.

It may be concluded that the Frankfort horizontal was less suitable than the NSL for a reference line, due to its greater variability within the individual. If the usual definitions of points orbitale and porion (see CHAP. 2) are accepted for radiographic studies, it is difficult to locate the Frankfort horizontal with any constancy or precision on radiographs of the same individual taken at different times. KOSKI and VIROLAINEN (1956) showed that the actual bony orbitale did not correspond with the radiographic shadow of the lowermost point on the infraorbital margin. The same workers found that the position of the ear rods within the external acoustic meati varied from time to time, however carefully the investigator worked. From the writer's own observations it would appear that the variations in ear rod positions are increased when working with children, especially when language problems are superimposed. Alternative definitions of radiographic points orbitale and porion are not without criticism, and it would appear that if the Frankfort horizontal is necessary in analyses, then more accurate radiographic landmark indicators should be used.

The present study confirms criticisms of the Frankfort horizontal when used in cephalometric radiography of living subjects, on the grounds of difficulty in consistent location of the ear rods within the external acoustic meati.

SUBSPINALE and SPINAL POINT

Most investigators would agree that subspinale (Downs point A) is difficult to locate precisely on radiographs. This problem was increased in the subjects examined by the thick soft tissue profile, and the deep furrows between upper lip and cheeks which were superimposed upon subspinale. Similar difficulties arose when locating spinal point. When upper jaw length was measured as sp-pm the total experimental error of 1.91 exceeded that of the m easurement ss-pm (1.32), so that subspinale was preferred as the anterior profile point of the upper jaw base.

Quite apart from difficulties in the location of spinal point, it is usually regarded as an unsuitable maxillary basal point because of variation in the length of the anterior nasal spine between different population groups. In the Australian aborigine, the anterior nasal spine is well known to be diminutive and in some cases almost non-existent (FENNER, 1939). The substitution of subspinale for spinal point in the measurement of maxillary basal prognathism was also suggested by BJÖRK (1950).

POSITION of the MANDIBLE

Variations in the antero-posterior position of the mandible were reflected in the experimental errors in measurements involving the use of reference point articulare, which is situated on the dorsal contour of the condylar process, and thus depends on consistent location of the mandible in the tooth position.

In European subjects marked variation in articular e within individuals would not be expected because of fairly precise location of the tooth position due to cuspal interdigitation. In fact TALLGREN (1957) found articulare reasonably constant from time to time in a group of Finnish women.

However, in many of the subjects examined a disparity between upper and lower arch widths prevented total cuspal interdigitation on each side of the jaws at the one time (BARRETT, 1958; HEITHERSAY, 1960). This type of segmental occlusion prevented the location of a precise tooth position in some subjects. The difficulty was increased if marked attrition had taken place, or if language problems were involved. It was not surprising therefore that variations in the tooth position of the mandible caused errors in measurements employing articulare.

It is interesting to review the conclusions of the Research Workshop on Cephalometrics, reported by SALZMANN (1960). The Workshop concluded that the more variable points in radiographic interpretation were: 1) Bolton point, 2) basion, 3) porion, 4) pterygomaxillary fissure, 5) orbitale, 6) spheno-occipital synchondrosis, 7) gonion, 8) anterior nasal spine, 9) posterior nasal spine and 10) points A and B (subspinale and supramentale). The factors contributing to variability were reported by the Workshop to include variation in the intervals between observations in longitudinal growth studies, enlargement and distortion due to lack of standardisation of the distances between target, subject and film, variation in the positioning of the subject and lack of consistent occlusal relationships and postural relationships of the head.

Of the landmarks considered by the Workshop as being variable, Bolton point, spheno-occipital synchondrosis and point B have not been used in the present study. Porion and orbitale were used and found to be excessively variable; anterior nasal spine has been used to construct the nasal line and to obtain data for comparative purposes; the constructed point pterygomaxillare was used in preference to the posterior nasal spine although the two closely correspond; a constructed point, gonial tangent point, was used instead of gonion. Points basion and A (subspinale) were used in this study since no other comparable reference landmarks were considered more suitable or less variable.

Conclusions

The use of radiographic methods in physical anthropology is justified provided that errors of estimation do not seriously affect true values. Systematic and accidental errors have been investigated in the present study, and it has been shown that such errors do not seriously affect the results. The linear and angular measurements recorded in the following sections are therefore reasonably close to their true values.

CHAPTER IV

BASAL AND ALVEOLAR PROGNATHISM

Growth patterns of various parts of the cranio-facial complex determine the shape of the facial profile. The genetic background of the individual and environmental factors influence growth of the head region, and KROGMAN (1958) described the "bio-genetic potential" which is concerned with time and sequence, form and proportion in the organisation of growth.

The facial skeleton is closely associated anatomically and during growth with the cranial base, which separates it from the brain case, but while the face as a whole conforms to the general growth pattern of the body, the more accelerated neural growth associated with the brain and its protecting bones must have a decided influence on the cranial base. These considerations make for complexity in the understanding of relationships between these parts both in the growing and the adult skull.

Prognathism is but one characteristic determined by interaction of the factors mentioned, and although it may be measured in a variety of ways, little understanding of its nature is gained without simultaneous analysis of other cranio-facial associations.

The term basal prognathism is used to convey the concept of protrusion of the whole facial structure, whereas alveolar prognathism relates to prominence of the alveolar bone. The two types of prognathism are not necessarily concurrent in any one individual and to further subdivide them, profile points as described in CHAP. II were chosen to represent maxillary and mandibular points on basal and alveolar bone. In the present investigation the term facial prognathism, as used by BJÖRK (1951), refers to basal prognathism.

Values for basal and alveolar prognathism within the group under observation have been determined, and the data obtained provide further evidence of differences in prognathism between ethnic groups, and variations in prognathism within Yuendumu aborigines.

<u>Method</u>

The variables studied which are defined in CHAP. II and listed in the Appendix Glossary of Terms were:

s-n-ss	s-n-pr	s-n-pg	s-n-id	pr-n-ss	id-n-pg
ss-n-pg	n-ss-pg	ba-pr	ba-n	FH/NSL	n-ss/FH
n-pr/FH	Radiographic gnathic index				

The mean values of the prognathic angles were compared with the results obtained by similar methods for a different group of Central Australian aborigines (CRAVEN, 1958); a caucasoid group (BJÖRK, 1947; BJÖRK and PALLING, 1954); a mongoloid group (KAYUKAWA, 1957) and a negroid group (BJÖRK, 1962).

The mean values for gnathic indices were compared with those obtained from direct measurements of skull material of Australian aborigines by DUCKWORTH (1904), BÜCHNER (1912), CAMPBELL (1925), ABBIE (1947) and MILICZEROWA (1955). The gnathic indices were also compared with those of other ethnic groups reported by BÜCHNER (1912) and JØRGENSEN (1953).

Results

Angular measurements of prognathism and alveolar prognathy are summarised in TABLE 8. Distributions of the prognathic angles and gnathic indices are shown diagrammatically by way of histograms in Figs. 16 and 17. Measurements of sagittal jaw relation, profile angle, basi-prosthionic length, basi-nasion length and the derived gnathic indices are summarised in TABLE 9, and the angles involving the use of the Frankfort horizontal are given in TABLE 10.

Correlations within the prognathic angles and between these angles and other variables are shown in TABLE 11. Correlations between maxillary alveolar prognathism and the cranial base length and upper facial length are shown in TABLE 12.

The prognathic angles obtained from the Yuendumu subjects are compared with those of other groups in TABLE 13. Gnathic indices obtained in the present study and those from other groups of Australian skulls are compared in TABLE 14, and a comparison is made between gnathic indices of several other ethnic groups in TABLE 15.

TABLE 8

Angular measurements of prognathism and alveolar prognathy are recorded in degrees, for 31 males and 27 females. Values of t for the difference of means are included.

Variable		M	±	ε (M)	s	Range	t
Max. prognathism							
s-n-ss	♂	87.1	±	0.68	3.8	79.5-97.0	0.95
	♀	88.0	±	0.64	3.3	81.5-93.0	
s-n-pr	♂	91.8	±	0.66	3.7	84.0-99.0	1.72
	♀	93.5	±	0.73	3.8	87.0-102.5	
Mand. prognathism							
s-n-pg	♂	81.3	±	0.72	4.0	74.0-92.5	1.12
	♀	82.5	±	0.79	4.1	74.0-91.0	
s-n-id	♂	86.5	±	0.70	3.9	79.0-96.0	0.73
	♀	87.3	±	0.78	4.0	80.0-95.5	
Alveolar prognathy							
pr-n-ss	♂	4.6	±	0.33	1.8	2.0- 8.5	1.73
	♀	5.4	±	0.33	1.7	2.5-10.0	
id-n-pg	♂	5.2	±	0.28	1.5	3.0- 8.0	1.14
	♀	4.7	±	0.31	1.6	1.5- 9.0	

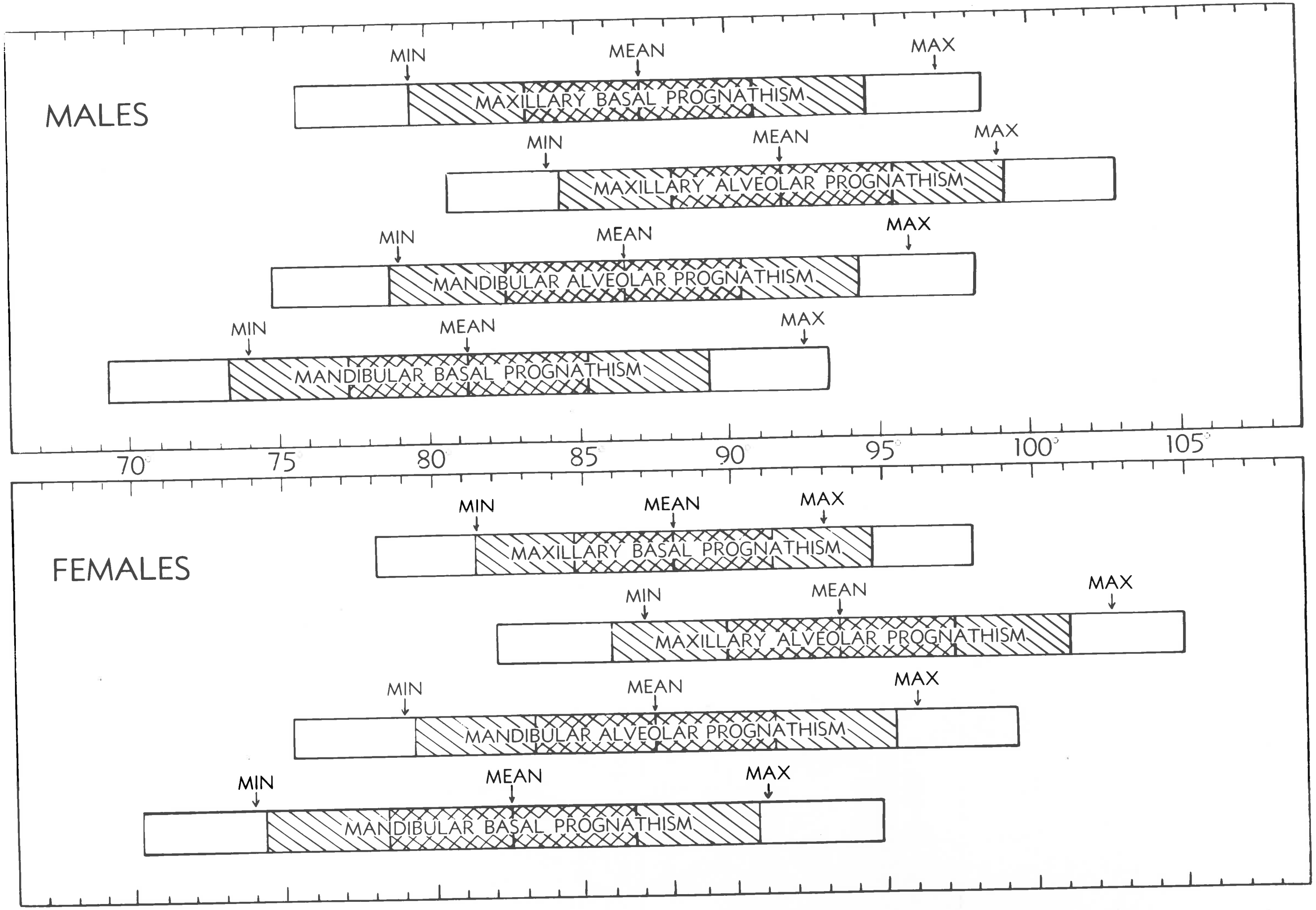


Fig. 16. Histogram showing the mean values of angular measurements of prognathism and the variations expressed as ± 1, 2 and 3 standard deviations for 31 males and 27 females. Recorded maxima and minima are also shown.

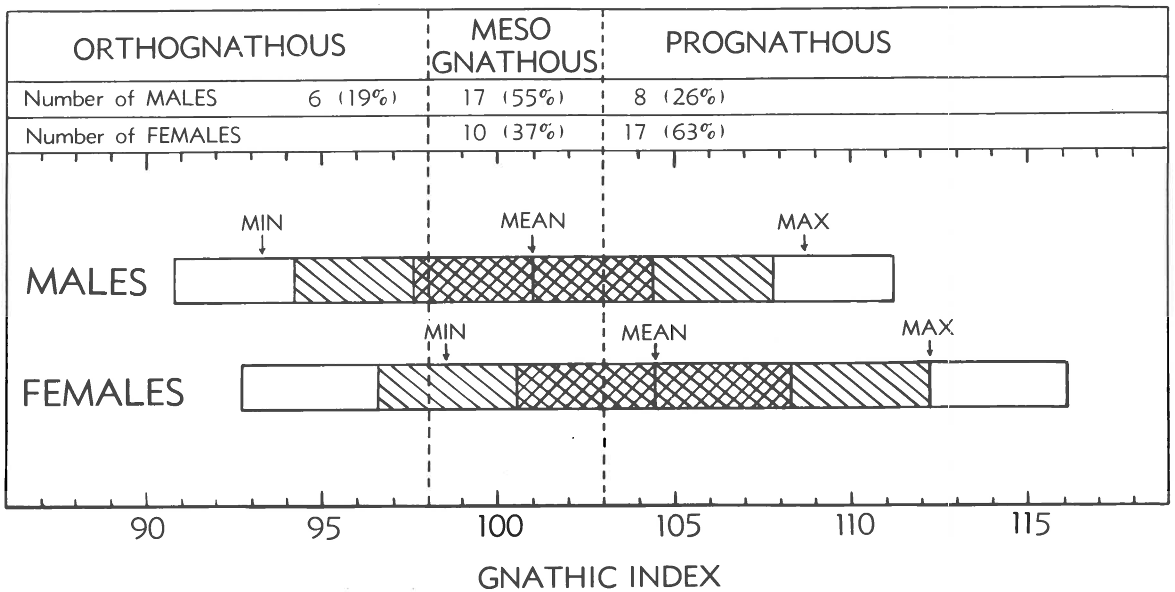


Fig. 17. Histogram showing mean values of gnathic indices and the variation expressed as ± 1, 2 and 3 standard deviations for 31 males and 27 females. Recorded maxima and minima are shown and the frequency distribution of subjects into orthognathous, mesognathous and prognathous categories is tabulated.

TABLE 9

Measurements of sagittal jaw relation and profile angle are recorded in degrees, and measurements of basi-prosthion and basi-nasion lengths are recorded in mm for 31 males and 27 females. Values of t for the difference of means are included.

Variable		Mean ± ε(M)	s	Range	t
ss-n-pg	♂ ♀	5.8 ± 0.48 5.6 ± 0.63	2.6 3.3	-1.0 – 13.0 -0.5 – 14.0	0.34
n-ss-pg	♂ ♀	169.1 ± 0.91 169.4 ± 1.28	5.1 6.7	156.0 -181.5 150.0 -181.0	0.08
ba-pr	♂ ♀	106.4 ± 0.80 102.4 ± 0.94	4.5 4.9	98.0 -114.0 93.0 -115.5	3.21**
ba-n	♂ ♀	105.4 ± 0.76 98.2 ± 0.66	4.2 3.5	95.5 -112.5 92.5 -106.5	7.03**
Radiographic Gnathic index	♂ ♀	101.0 ± 0.61 104.4 ± 0.76	3.4 3.9	93.3 -108.7 98.5 -112.2	3.49**

TABLE 10

Measurements of the angulation of NSL and FH and the angles n-ss/FH and n-pr/FH are recorded in degrees for 31 males and 27 females. Values of t for the difference of means are included.

Variable		M	± ε(M)	s	Range	t
NSL/FH	♂	4.7	± 0.42	2.4	0.0 - 10.5	0.32
	♀	4.9	± 0.76	3.9	-3.0 - 12.0	
n-ss/FH	♂	91.8	± 0.80	4.5	84.5 -106.0	1.07
	♀	92.9	± 0.70	3.7	85.0 - 98.5	
n-pr/FH	♂	96.4	± 0.79	4.4	89.0 -108.0	1.82
	♀	98.4	± 0.71	3.7	92.0 -104.5	

TABLE 11

Correlations within prognathic angles and between these angles and cranial base length, upper facial length and gnathic index, for 31 males and 27 females.

Variable		s-n-ss	s-n-pr	s-n-pg	s-n-id
s-n-ss	♂	-	+0.88 **	+0.77 **	+0.79 **
	♀	-	+0.89 **	+0.64 **	+0.71 **
s-n-pr	♂	+0.88 **	-	+0.84 **	+0.92 **
	♀	+0.89 **	-	+0.73 **	+0.84 **
s-n-pg	♂	+0.77 **	+0.84 **	-	+0.93 **
	♀	+0.64 **	+0.73 **	-	+0.92 **
s-n-id	♂	+0.79 **	+0.92 **	+0.93 **	-
	♀	+0.71 **	+0.84 **	+0.92 **	-
ba-n	♂	-0.30	-0.36 *	-0.44 *	-0.41 *
	♀	+0.02	-0.02	-0.02	-0.03
ba-pr	♂	+0.33	+0.30	+0.09	+0.16
	♀	+0.52 **	+0.59 **	+0.24	+0.40 *
Gnathic	♂	+0.78 **	+0.82 **	+0.64 **	+0.70 **
index	♀	+0.64 **	+0.75 **	+0.32	+0.53 **

** Significant
* Almost significant

TABLE 12

Correlations between maxillary alveolar prognathism, cranial base length and upper facial length, for 31 males and 27 females.

Variable		s-n-pr	ba-n	ba-pr
ba-n	♂	-0.36 *	-	+0.58 **
	♀	-0.02	-	+0.61 **
ba-pr	♂	+0.30	+0.58 **	-
	♀	+0.59 **	+0.61 **	-
ba-n independent of ba-pr	♂	-0.69 **	-	-
	♀	-0.59 **	-	-
ba-pr independent of ba-n	♂	+0.67 **	-	-
	♀	+0.76 **	-	-

** Significant
* Almost significant

TABLE 13

Mean values (Mean) and standard deviations (S) of angular measurements of prognathism, alveolar prognathy and profile angle in subjects of different population groups.

Material and Author	s-n-sp Mean S	s-n-ss Mean S	sn-pr Mean S	s-n-pg Mean S	s-n-id Mean S	pr-n-ss Mean S	id-n-pg Mean S	n-ss-pg Mean S
AUSTRAL. ABOR. Brown 1962 31 M Young Adults	88.7 4.0	87.1 3.8	91.8 3.7	81.3 4.0	86.5 3.9	4.6 1.8	5.2 1.5	169.1 5.1
AUSTRAL. ABOR. Craven 1958 9 M 20 F Adoles.	86.8 4.4	-	94.2 3.9	83.0 3.7	88.7 3.6	-	‡ 5.7 -	-
SWEDE Björk 1947 281 M Young Adults	88.2 4.2	-	84.8 4.1	81.7 4.4	82.3 4.4	-	-	177.0 7.0
SWEDE Björk & Palling 1954 243 M Young Adults	* 87.1 3.7	82.0 3.7	* 84.3 3.7	80.7 3.9	* 81.6 3.7	2.3 1.0	0.9 1.7	177.7 6.1
JAPANESE Kayukawa 1957 39 M and F Adoles.	87.7 3.8	83.0 3.3	85.5 3.1	79.6 3.1	82.4 2.8	‡ 2.5 -	‡ 2.8 -	-
BANTU Björk 1962 * 212 M Young Adults	* 88.8 4.0	* 86.8 4.9	* 90.6 3.7	* 82.0 4.0	* 86.1 3.8	‡ 3.8 -	‡ 4.0 -	-

* Data supplied by personal communication (By courtesy M.J. Barrett.)
‡ Calculated from data supplied.

TABLE 14

Gnathic indices of Australian aborigines.

Material	Author	Males		Females		Unsexed	
		M	s	M	s	M	s
Aust. abor. (Yuendumu) 31M 27F	BROWN 1962	101.0	3.4	104.4	3.9		
Aust. abor. Crania 73M 33F	Various authors to 1904 DUCKWORTH	100.4	-	103.1	-		
Aust. abor. Crania 19M 3F	DUCKWORTH 1904	102.2	-	102.7	-		
Aust. abor. Crania 88	BÜCHNER 1912					102.4	4.1
Aust. abor. Crania 110	CAMPBELL 1925					104.3	-
Aust. abor. Crania 50M 50F	ABBIE 1947	102.3	3.7	103.8	3.8		
Aust. abor. Crania 37M 21F	MILICEROWA 1955 *	101.4	5.6	101.6	4.0		

* Indices calculated from data provided by present author.

TABLE 15

Gnathic indices of various population groups.

Material	Author	Males M	Males s	Females M	Females s	Unsexed M	Unsexed s
African negroes 36	BÜCHNER 1912					104.4	-
Melanesians 58	BÜCHNER 1912					103.4	-
Tasmanians 21M 11F	BÜCHNER 1912	102.3	-	101.6	-		
Tasmanians 66	Various cit. BÜCHNER					102.1	4.8
AndAmese 19	BÜCHNER 1912					101.3	3.6
Hindus 29	BÜCHNER 1912					98.7	-
Chinese 32	BÜCHNER 1912					97.9	4.0
N.E. Greenland Eskimo 18M 22F	JØRGENSEN 1953	97.8	5.2	96.5	3.3		
Inugsuk Eskimo 80M 70F	JØRGENSEN 1953	97.4	3.9	98.0	3.4		
Europeans 184	BÜCHNER 1912					96.2	-
Veddahs 6	BÜCHNER 1912					96.0	2.8
Modern Italian 50	BÜCHNER 1912					95.9	3.5
Kap York Eskimo 5M 3F	JØRGENSEN 1953	95.0	-	96.4	-		

Discussion

The mean values of angular measurements of basal and alveolar prognathism for Yuendumu male subjects were lower than those for female members of the tribe. Although the sex differences were not statistically significant , they indicate that within the tribe studied, females tend to be more prognathous than males, especially in the maxillary alveolar region. This observation was confirmed by the finding of a higher mean angle of maxillary alveolar prognathy in the females. Although mandibular alveolar prognathism was slightly higher in the female subjects, mandibular alveolar prognathy was lower than in the male group, being associated with the more protrusive chin of the females.

Apart from an indication that maxillary basal prognathism was more variable within the male group, there were no marked sex differences in variability of other prognathic angles. No statistically significant differences were found between male and female mean values for sagittal jaw relation or profile angle, but these characteristics showed greater variability within the female group.

When the radiographic gnathic index was used as a measure of maxillary alveolar prognathism, a statistically significant sex difference was revealed, with the female mean index greater than that of the males. The upper facial length ba-pr, and the cranial base length ba-n were greater in males than in females, the difference in mean values being statistically significant.

The fact that sex differences were more obvious when the gnathic index was employed can be explained by the fact that angular measurements of prognathism are expressions of facial shape, which varies little between sexes in comparison with facial size, which is expressed by linear variables and indices.

Although the mean value for gnathic indices of male Yuendumu subjects fell within mesognathous limits, approximately one-fifth (19 per cent) of the number examined were orthognathous, and about one-quarter (26 per cent) prognathous (Fig. 17). In contrast no female subject examined was in the orthognathous range, approximately two-fifths (37 per cent) were mesognathous and more than three-fifths (63 per cent) prognathous. An examination of the individual gnathic indices reported by ABBIE (1947) showed that only four per cent of 50 female Australian crania fell within orthognathous limits while 62 per cent were prognathous. The observation that Abbie's highest individual gnathic index was one of 113.7 recorded from a female cranium is of interest since in the present study the highest individual index was 112.2 and also female.

Mean values for gnathic indices do not indicate the nature of variations in prognathism since a high index may arise by an increase in upper facial length, a decrease in cranial base length or both. In addition upper facial length includes three components; the maxillary base, maxillary alveolus and the protrusion of the maxillary body anterior to point basion, all of which may vary independently. Similarly the cranial base length depends partly on the anterior and posterior cranial base lengths and partly on the angle of deflection of the posterior segment, all of which again may vary independently.

The absolute difference between male and female mean values for cranial base length exceeded the sex difference in mean values of upper facial length. This indicates that the lower gnathic index of males is associated largely with the relatively long cranial base length in this sex.

When the Frankfort horizontal was employed as a reference line, the prognathic angles n-ss/FH and n-pr/FH were again greater in the female group but the differences in mean values were not significant. The variability of the prognathic angles did not differ greatly whether they were measured from the FH or from NSL. Therefore BJÖRK'S (1950) finding that the prognathic angles were more variable when measured from NSL than when measured from FH is not confirmed by the results of the present study.

All of the prognathic angles were significantly inter-correlated within the male and female groups. The finding of a high coefficient of correlation ($r = +0.77$) between maxillary and mandibular basal prognathism in the male subjects confirmed BJÖRK'S (1950) postulate that the coefficient value of $r = +0.62$ which he found in Swedish males between the same variables+, would be exceeded in a group exhibiting less "racial admixture".

+Björk measured maxillary basal prognathism as the angle s-n-sp. Within the male aborigines investigated, the correlation coefficient between the angles s-n-sp and s-n-pg ($r = +0.78$) was almost the same as that between s-n-ss and s-n-pg. It is of interest that LINDEGÅRD (1953) reported a correlation coefficient of $r = +0.68$ between the angles s-n-ss and s-n-pg in Swedish males.

Relationships between prognathic angles and the cranial base and upper facial lengths were revealed by correlations between these variables. When used as an indication of maxillary alveolar prognathism, the angle s-n-pr was almost significantly correlated in a negative direction with cranial base length in the male group, and significantly correlated with upper facial length in the female subjects. Prognathism is associated with both cranial base and upper facial lengths, but since the two latter variables themselves were significantly correlated in a positive direction, the relationships become difficult to analyse.

The associations between maxillary alveolar prognathism and cranial base length were increased in both sexes when the variation caused by upper facial length was eliminated by partial correlation. In a similar way, the partial correlation between upper facial length and maxillary alveolar prognathism independent of cranial base length was significant in both sexes.

The revealed correlations between maxillary alveolar prognathism, cranial base length and upper facial length indicated that while an increase in upper facial length would tend to increase alveolar prognathism, the association was less marked if cranial base length was simultaneously increased. Furthermore an increase in the angle of maxillary alveolar prognathism would follow a reduction in cranial base length, but would be less if accompanied by a reduction in upper facial length. The correlations also suggest that the larger mean angle of maxillary alveolar prognathism in females was associated with an upper facial length larger in relation to the cranial base length than it was in males.

Differences between ethnic groups were shown by a comparison of the mean values for the angles of prognathism and alveolar prognathy, obtained by the Björk method (TABLE 14.). A striking characteristic of both Australian aboriginal groups and the South African Bantus was the marked alveolar prognathism of both jaws, in comparison with Swedes and Japanese. Alveolar prominence was shown by the angles s-n-pr, s-n-id and by the measures of alveolar prognathy pr-n-ss and id-n-pg. Mean values indicated that the Australian aborigines had greater alveolar development independent of the jaw bases than the Bantus. It is interesting that mean values of alveolar prognathy in the mandible exceeded those of maxillary alveolar prognathy in Australians, Japanese and Bantus, but the reverse condition existed within Swedes.

The assessment of ethnic group differences in maxillary basal prognathism is made difficult if dissimilar reference points are used. The mean angles s-n-sp were remarkably constant in value and variability in all groups, but the use of the angle s-n-ss to measure maxillary basal prognathism revealed that Australian aborigines and Bantus were more prognathic in this region than Swedes or Japanese. The evidence suggests that while spinal point is fairly constant in its relation to the cranial base, ethnic g roup differences in maxillary alveolar development cause inter-group variations in the sagittal position of subspinale. Since the length of the nasal spine also varies considerably in different groups, subspinale is considered to be a more suitable reference point to assess inter-group differences in basal prognathism of the upper jaw.

The mean angles of mandibular basal prognathism showed no marked differences in values or variability between the four ethnic groups compared, but the profile angle was some eight degrees more acute in Australian aborigines than it was in Swedes.

The mean values of gnathic indices of the Yuendumu group compare closely with those calculated from direct measurements of Australian crania by various authors (TABLE 14). Where authors have sexed their cranial material, the female specimens show the larger mean gnathic index.

A comparison with findings for other ethnic groups (TABLE 15) shows that the mean values for gnathic indices of Australian aborigines fall within the upper limits of those reported.

Sex Differences in Prognathism

Sex differences in prognathism are revealed by the data published by several authors and it is generally accepted that females tend to be more prognathous than males of the same ethnic group. The sex differences are more apparent when such measures as the gnathic index are used.

MARTIN (1928) considered that prognathism in the female was a secondary sexual characteristic, a view taken by ABBIE (1947) who showed male and female differences in gnathic indices and in facial angles of Australian crania.

Some authors have employed the craniometric methods of Martin to investigate facial dimensions and shape, and their findings also indicate that females of other groups are more prognathous than males. SCHREINER (1935) measured male and female Lapp crania from seven regions and reported that in 127 male and 112 female crania, the mean total profile angles were 85.2 degrees and 84.8

degrees respectively. The mean alveolar profile angle of 73.5 degrees for females (108 crania) was also more prognathous than the male mean angle of 75.0 degrees (123 crania).

WAGNER (1937) measured the total profile angles of 41 groups of oceanic peoples. Of the 26 groups which included male and female specimens, 18 groups showed a more prognathous angle in the female, although in some cases the sex differences were slight. The same author cited a similar finding of SARASIN (1916) who investigated cranial specimens from New Caledonia and the Loyalty Islands.

Norwegian crania from 14 districts were studied by SCHREINER (1939) who found in the female skulls from 11 districts a more prognathous mean total profile angle, and in 12 districts the mean alveolar profile angle was also more prognathous in the female specimens. When the districts were grouped together, the mean total profile angles of 608 male and 587 female crania were 84.9 degrees and 83.6 degrees respectively. The mean alveolar profile angles for 525 male and 480 female crania were 80.8 degrees and 78.0 degrees respectively. Again the sex differences in prognathism were more marked in the alveolar region.

Crania from the Sogn district of Norway were investigated more recently by SCHREINER (1951) whose results confirmed his previous findings. The total profile angle was measured on 76 male and 68 female crania and mean values of 85.0 degrees and 83.9 degrees respectively were reported. The sex difference was more marked in the alveolar region with mean alveolar profile angles of 78.1 degrees and 74.0 degrees for 69 male and 59 female crania.

The Eskimo skeleton was studied by JØRGENSEN (1953), who showed that female skulls from the Inugsuk area were more prognathous than male specimens of that district. The mean alveolar profile angles for 73 male and 58 female crania were 78.2 degrees and 75.2 degrees respectively.

In relation to sex differences in the facial profile it is interesting that DELATTRE and FENART (1960) noticed similar characteristics in male and female anthropoid skulls. They reported that in the female skull the alveolar point was higher and more anterior than in the male, and that the female facial profile line from orbital entrance to alveolar point was more oblique.

Thus the observation of a sex difference in prognathism within the Australian aborigines is well supported by similar reports concerning several other ethnic groups.

Conclusions

Facial and alveolar prognathism have been investigated in a group of Central Australian aborigines comprising 31 young adult male and 27 young adult female members of the Wailbri tribe. The average age of both groups was about 22 years.

The most striking characteristic observed in the subjects was the prominence of the alveolar regions of the jaws. The alveolar prominence was demonstrated by comparing the prognathic angles obtained by Björk's radiographic method with values found by the same method for other population groups. No marked differences between groups were found in the mandibular basal region, but maxillary basal prognathism when measured by the angle s-n-ss was pronounced in the Yuendumu subjects and in South African Bantus.

In addition the mean values for gnathic indices reported by the present and previous authors show that the Australian aborigine has a high index in comparison with most other groups which were compared.

Full consideration of the nature of prognathism is not possible at this stage, but the findings so far indicate that while both cranial base length and upper facial length are associated with variations in prognathism, there are differences in these associations between males and females of the tribe under investigation.

The second observation reported was that adult females of the Yuendumu tribe tend to be more prognathous than adult males, and that this characteristic is most apparent in the maxillary alveolar region. The finding of a sex difference in alveolar prognathism is supported by other authors who have used craniometric methods to study other population groups, and different tribes of Australian aborigines. The results of the present and previous studies indicate that the greater prognathism of the female is a secondary sexual characteristic which resides in the basal and alveolar regions of the jaws, being most apparent in the maxillary alveolar region.

CHAPTER V

SEX DIFFERENCES IN CRANIO-FACIAL STRUCTURES

In the preceding chapter, facial and alveolar prognathism in young adult male and female members of the Wailbri tribe of Central Australia were discussed. Differences in prognathism between several ethnic groups, as well as sex differences within the tribe under observation were reported. In order to clarify male and female differences in cranio-facial form, and to obtain information necessary to investigate the nature of variations in prognathism within the male subjects, other variables were measured and subjected to statistical analysis.

Method

The variables studied which are defined in CHAP. II and listed in the Appendix Glossary of Terms were:

JAW BASES: ss-pm, ar-tgo, pg-tgo, pg-ar.

MANDIBULAR ANGLES: ar-tgo-gn, CL-ML, s-ar-tgo.

JAW POSITIONS: s-pm hor., s-pm vert., s-ar hor., s-ar vert.

JAW PROPORTIONS: ss-pm/n-ar, pg-ar/n-ar, pg-tgo/n-ar, ss-pm/ pg-tgo.

INCLINATIONS OF JAW BASES: NL-NSL, ML-NSL, NL-OL, ML-OL, NL-ML.

FACIAL HEIGHTS: n-gn, n-sp, sp'-gn, sp'-is', is'-gn, n-sp/n-gn.

INCISOR RELATIONSHIPS: IL_s-OL, IL_i-OL, IL_s-IL_i, ii-io, is-io.

CRANIAL BASE: n-ba, n-s, s-ba, n-s-ba, n-ar, s-ar, n-s-ar, ar-s-ba, Foramen angle.

Results

The results are summarised in TABLES 16 to 21. Male and female differences in cranio-facial form are illustrated in Figs. 18 and 19 which are drawn from mean values for both sexes, and by way of cephalometric polygons shown in Figs. 20 and 21 which illustrate male and female mean values and ± two standard deviations for both sexes.

TABLE 16

Maxillary and mandibular dimensions, and angular measurements related to the mandibular profile are recorded in degrees and mm for 31 males and 27 females. Values of t for the difference of means are included.

Variable		Mean ± ε(M)	s	Range	t
Jaw bases					
ss-pm	♂	52.1 ± 0.51	2.9	46.5 - 56.5	2.74**
	♀	50.1 ± 0.51	2.7	44.5 - 56.0	
ar-tgo	♂	48.7 ± 0.78	4.3	39.5 - 59.5	2.98**
	♀	45.1 ± 0.91	4.7	36.0 - 54.5	
pg-tgo	♂	80.7 ± 0.70	3.9	71.0 - 89.0	4.69**
	♀	76.1 ± 0.71	3.7	69.5 - 84.5	
pg-ar	♂	111.1 ± 1.00	5.5	101.1 -123.0	4.88**
	♀	104.1 ± 1.02	5.3	93.0 -114.5	
Mand. angles					
ar-tgo-gn	♂	120.7 ± 1.06	5.9	106.5 -132.0	0.79
	♀	121.8 ± 0.92	4.8	114.0 -136.0	
CL-ML	♂	85.0 ± 0.86	4.8	72.5 - 96.0	0.74
	♀	86.0 ± 1.08	5.6	72.0 - 99.0	
s-ar-tgo	♂	149.5 ± 1.63	9.1	130.0 -178.5	1.88
	♀	145.6 ± 1.22	6.3	130.0 -159.0	

TABLE 17

Jaw positions and jaw proportions are recorded in mm and percentages for 31 males and 27 females. Values of t for the difference of means are included.

Variable		Mean ± ε(M)	s	Range	t
<u>Jaw Positions</u>					
s-pm horiz.	♂	17.1 ± 0.46	2.5	11.5- 20.5	2.14 *
	♀	15.7 ± 0.46	2.4	12.0- 20.0	
s-pm vert.	♂	42.9 ± 0.45	2.5	36.5- 48.0	4.68**
	♀	40.3 ± 0.31	1.6	37.5- 43.5	
s-ar horiz.	♂	17.6 ± 0.60	3.3	9.0- 25.5	1.06
	♀	16.7 ± 0.56	2.9	11.0- 23.5	
s-ar vert.	♂	28.1 ± 0.53	3.0	23.0- 34.0	4.44**
	♀	24.9 ± 0.49	2.5	19.0- 29.0	
<u>Jaw proportions</u>					
ss-pm/n-ar	♂	56.6 ± 0.49	2.7	51.4- 64.1	1.80
	♀	57.9 ± 0.51	2.6	50.0- 62.2	
pg-ar/n-ar	♂	120.6 ± 1.04	5.8	112.0-134.1	0.26
	♀	120.2 ± 1.20	6.2	106.7-130.8	
pg-tgo/n-ar	♂	87.7 ± 0.86	4.8	77.6- 97.3	0.10
	♀	87.8 ± 0.80	4.1	81.4- 97.1	
ss-pm/pg-tgo	♂	64.7 ± 0.68	3.8	58.7- 71.1	1.32
	♀	66.0 ± 0.79	4.1	56.8- 73.4	

TABLE 18

Inclinations of the nasal and mandibular lines to each other, to the occlusal line and to the NSL are recorded in degrees for 31 males and 27 females. Values of t for the difference of means are included.

Variable		Mean ± ε(M)	s	Range	t
NL-NSL	♂	6.9 ±0.63	3.5	-2.0 - 13.0	1.04
	♀	7.8 ±0.50	2.6	4.0 - 14.0	
ML-NSL	♂	32.0 ±0.86	4.8	24.5 - 44.0	0.65
	♀	31.1 ±1.12	5.8	17.5 - 43.0	
NL-OL	♂	8.6 ±0.75	4.2	1.5 - 17.0	0.76
	♀	7.9 ±0.73	3.8	0.5 - 15.5	
ML-OL	♂	16.5 ±0.93	5.2	7.5 - 26.0	0.85
	♀	15.5 ±0.72	3.7	8.0 - 21.0	
NL-ML	♂	25.1 ±0.71	3.9	16.0 - 37.0	1.58
	♀	23.4 ±0.87	4.5	13.5 - 32.5	

TABLE 19

Facial height dimensions and the percentage of upper face height to morphological face height are recorded in mm and percentages for 31 males and 27 females. Values of t for the difference of means are included.

Variable		Mean ± ε(M)	s	Range	t
n-gn	♂	119.2 ± 1.28	7.1	100.0 - 132.5	6.64**
	♀	108.3 ± 0.95	4.9	99.5 - 125.0	
n-sp	♂	49.4 ± 0.71	4.0	35.0 - 55.5	2.60*
	♀	47.1 ± 0.43	2.2	42.5 - 51.0	
sp' - gn	♂	69.8 ± 0.92	5.1	59.0 - 77.0	7.03**
	♀	61.2 ± 0.79	4.1	56.0 - 75.0	
sp' - is'	♂	32.5 ± 0.50	2.8	26.0 - 37.0	3.42**
	♀	29.9 ± 0.59	3.1	26.0 - 37.0	
is' - gn	♂	37.3 ± 0.66	3.7	30.5 - 44.0	7.06**
	♀	31.3 ± 0.50	2.6	26.5 - 38.0	
n-sp/n-gn	♂	41.4 ± 0.44	2.5	35.0 - 46.6	3.66**
	♀	43.6 ± 0.36	1.8	39.6 - 47.2	

TABLE 20

Incisor relationships are recorded in degrees for 31 males and 27 females. Values of t for the difference of means are included.

Variable		Mean ± ε(M)	s	Range	t
IL_s - OL	♂	59.4 ± 1.01	5.6	45.0 - 71.5	2.78 **
	♀	55.7 ± 0.83	4.3	48.5 - 67.5	
IL_i - OL	♂	65.1 ± 1.08	6.0	54.5 - 82.5	3.79 **
	♀	58.8 ± 1.30	6.8	47.0 - 70.5	
IL_s - IL_i	♂	124.6 ± 1.65	9.2	107.0 -145.0	4.35 **
	♀	114.5 ± 1.59	8.3	101.5 -133.0	
Overbite	♂	1.7 ± 0.39	2.2	-2.0 - 9.0	0.29
	♀	1.5 ± 0.27	1.4	-0.5 - 5.0	
Overjet	♂	2.5 ± 0.37	2.0	-2.0 - 6.5	1.41
	♀	3.2 ± 0.39	2.0	0.0 - 9.5	

TABLE 21

Cranial base measurements are recorded in mm and degrees for 31 males and 27 females. Values of t for the difference of means are included.

Med. Cranial Base		Mean ±	ε(M)	s	Range	t
n-ba	♂	105.4 ±	0.76	4.2	95.5-112.5	7.03**
	♀	98.2 ±	0.66	3.5	92.5-106.5	
n-s	♂	70.5 ±	0.57	3.2	61.0- 76.5	5.75**
	♀	66.3 ±	0.44	2.3	62.0- 71.0	
s-ba	♂	45.5 ±	0.59	3.3	39.0- 53.5	5.80**
	♀	41.0 ±	0.47	2.5	36.5- 46.0	
n-s-ba	♂	129.6 ±	0.76	4.2	121.5-138.0	1.47
	♀	131.3 ±	0.93	4.9	126.5-148.0	
Lat. Cranial Base						
n-ar	♂	92.2 ±	0.68	3.8	83.5-101.0	6.07**
	♀	86.7 ±	0.58	3.0	82.5- 93.0	
s-ar	♂	33.4 ±	0.60	3.3	26.5- 39.0	4.13**
	♀	30.1 ±	0.52	2.7	26.0- 35.0	
n-s-ar	♂	122.0 ±	0.94	5.2	110.0-134.0	1.35
	♀	123.9 ±	1.04	5.4	116.0-140.0	
ar-s-ba	♂	7.6 ±	0.47	2.6	3.5- 16.5	0.21
	♀	7.4 ±	0.44	2.3	4.0- 12.5	
Foramen angle	♂	91.7 ±	0.94	5.2	83.0-104.0	2.29*
	♀	88.9 ±	0.75	3.9	82.0- 97.0	

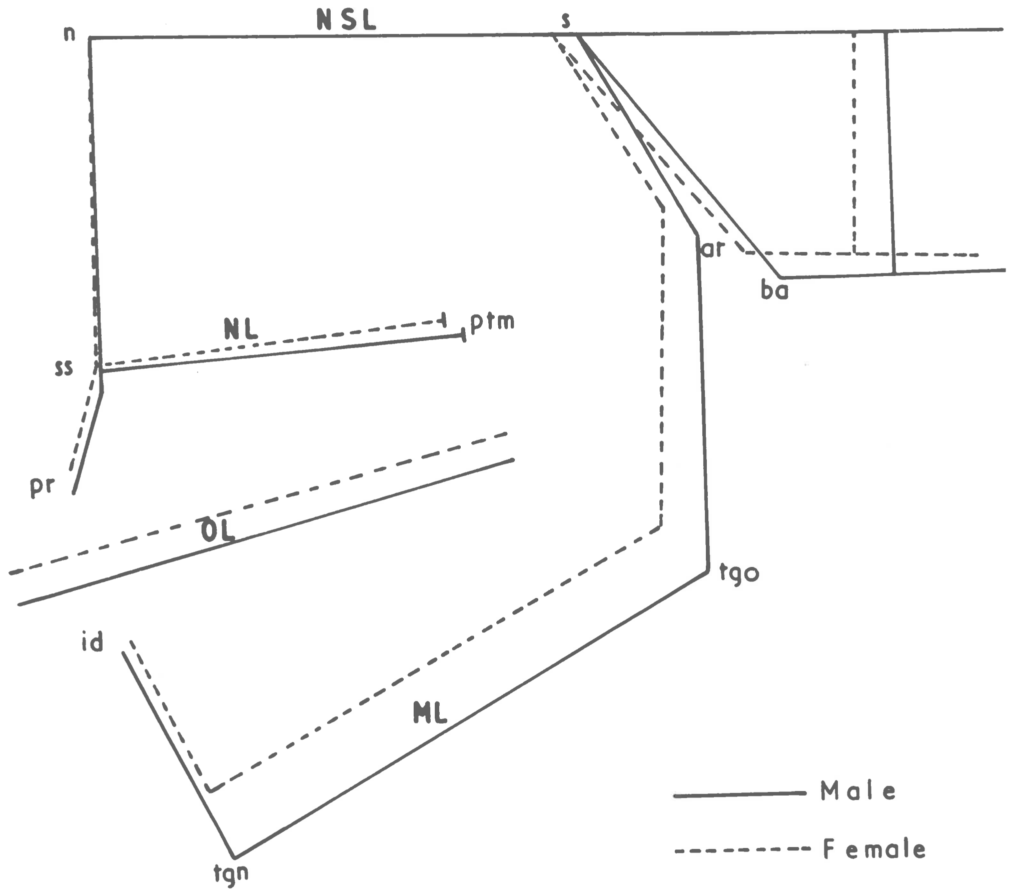
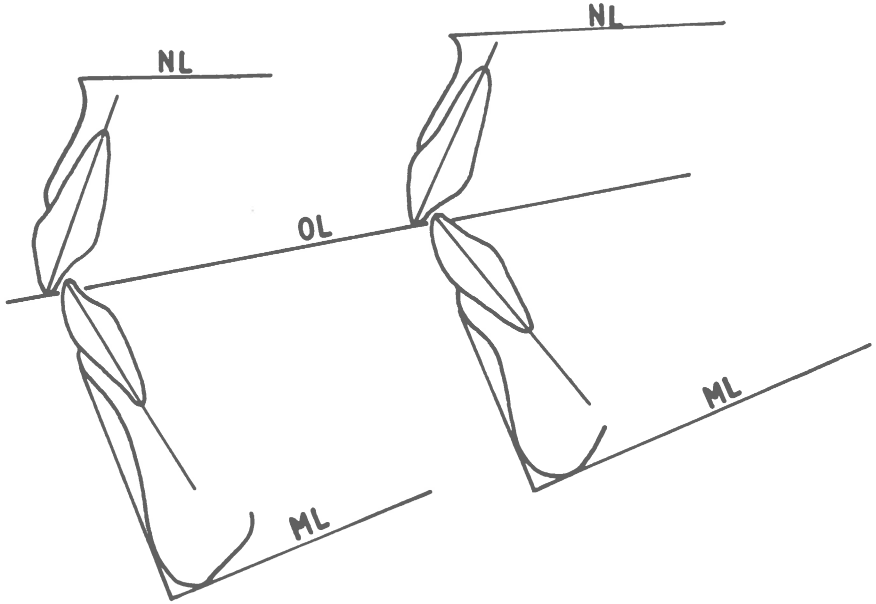


Fig. 18. Comparison of the mean facial outlines of young adult male and female members of the Wailbri tribe of Central Australia.



MALE FEMALE

Fig. 19. Comparison of mean interincisal angles and inclinations of the incisors to OL in young adult male and female aborigines.

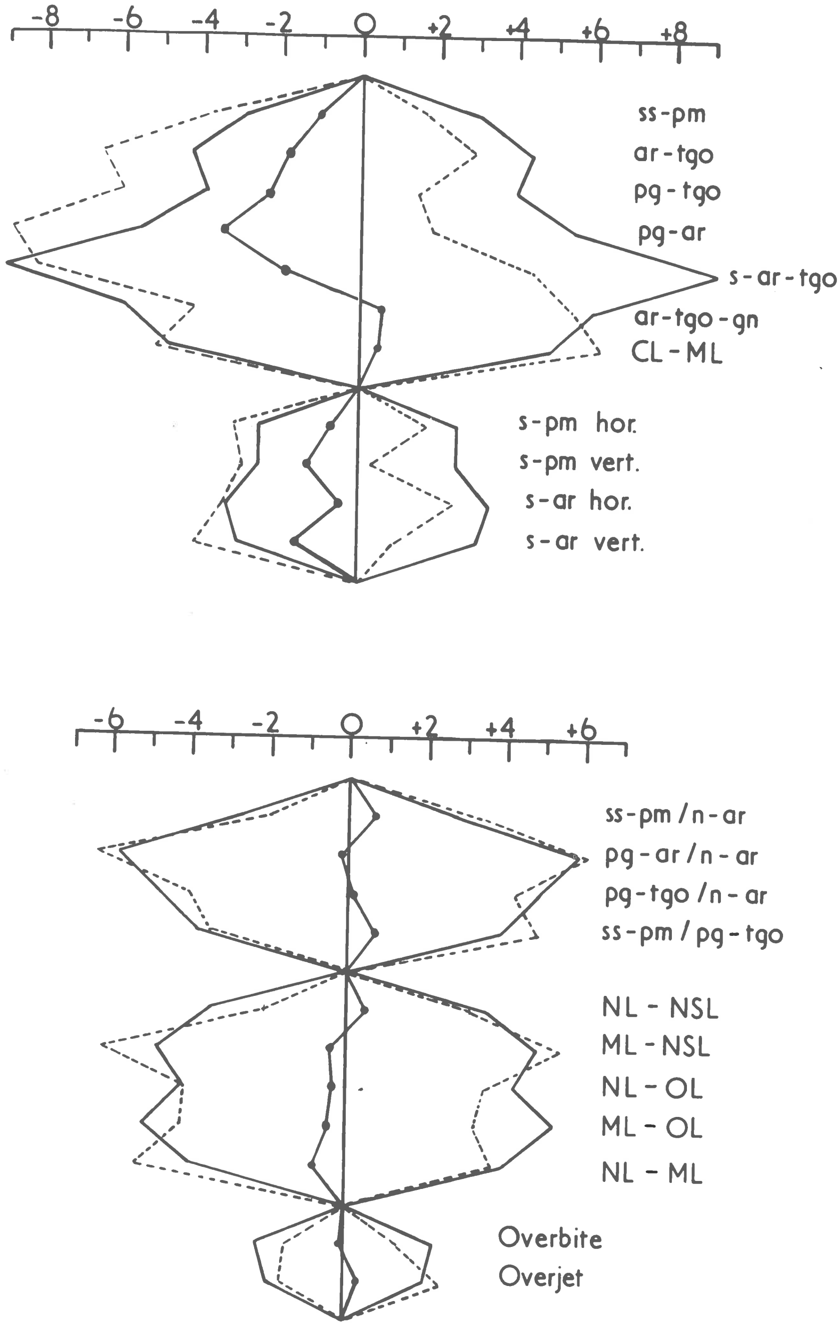


Fig. 20. Standards of cranio-facial dimensions for young adult males and females. Female means (•——•) and the limits of ±2 standard deviations (-----), are superimposed on polygons enclosing ±2 standard deviations of the male measurements (——). Male means are represented by the vertical line. One unit = 1°, 1mm, or 1%.

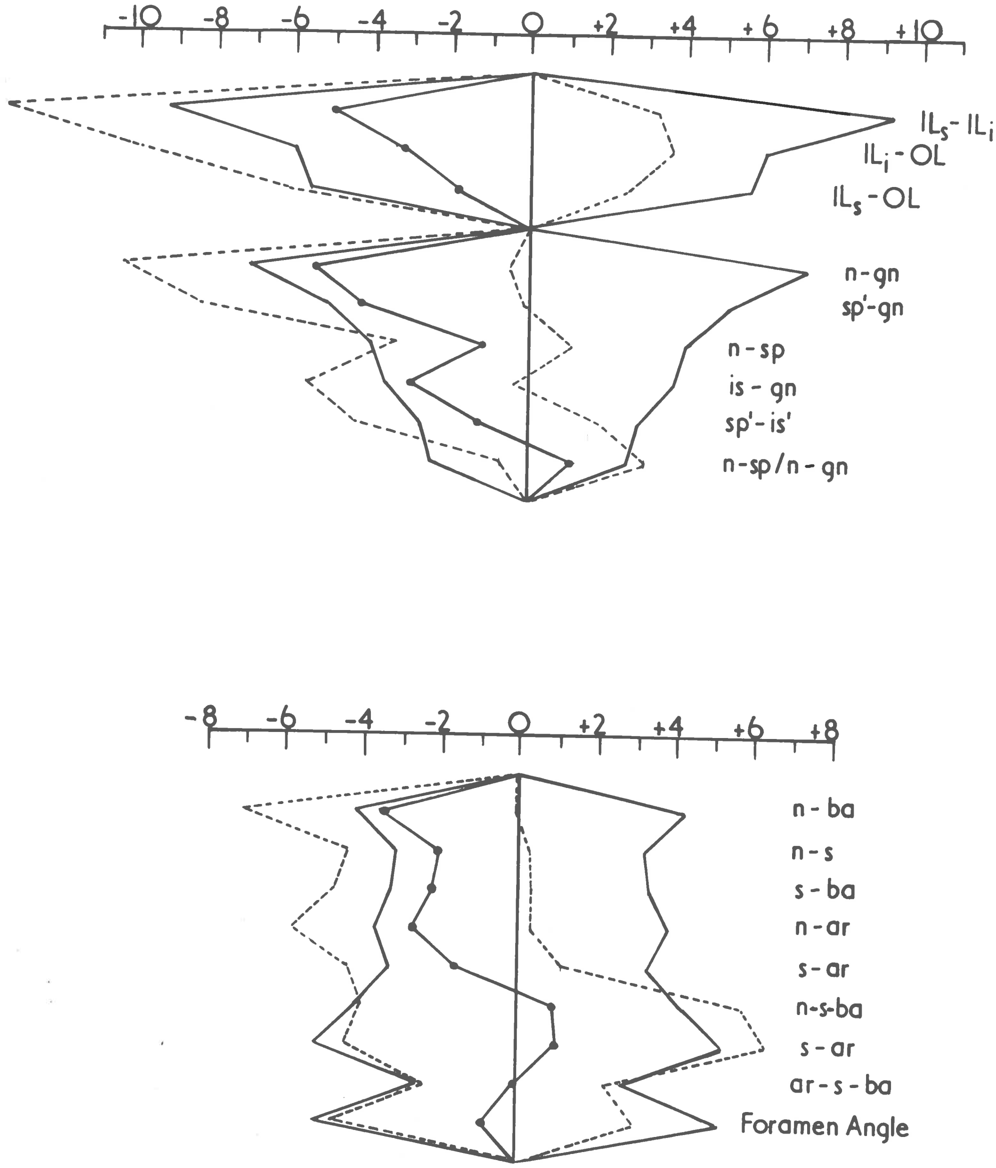


Fig. 21. Standards of cranio-facial dimensions for young adult males and females. Female means (•——•) and the limits of ± 2 standard deviations (----), are superimposed on polygons enclosing ± 2 standard deviations of the male measurements (———). Male means are represented by the vertical line. One unit = 1°, 1mm, or 1%.

Discussion

Analysis of the data revealed that as a general rule linear dimensions were significantly greater in males than they were in females. On the other hand there were no statistically significant differences between sexes in most angular and proportionate measurements. Thus within the group under observation, male and female facial profiles are similar in shape and proportion, but different in size as would be expected by relative genetic homogeneity and by sex differences in the duration of facial growth.

Only three linear variables, overbite, overjet and s-ar hor. failed to show significant sex differences in their mean values. The angular variables IL_s-OL, IL_i-OL, IL_s-IL_i and foramen angle, three of which show incisal relations, had mean values which were significantly smaller in the female group than in the males. In addition the proportion between upper and total facial heights was significantly greater in females.

When the standard deviations or coefficients of variation (the latter were calculated but are not included in the Tables) were used as indications of variability, 30 measurements showed greater variability within males, but only 10 measurements were more variable in females.

This finding is in accord with the expectation of less variability in females due to cessation of skeletal growth at an earlier chronological age. Of the linear, angular and proportionate measurements showing greater variability in females, seven (ar-tgo, CL-ML, pg-ar/n-ar, ss-pm/pg-tgo, ML-NSL, NL-ML and IL_1-OL) involve mandibular variables; two (n-s-ba and n-s-ar) relate to the shape of the median and lateral cranial bases; one (sp'-is') is the maxillary component of lower face height.

The differences in variability between sexes are shown diagrammatically by means of polygons in Figs. 20 and 21, and the similarity in shape but difference in size of the facial complex of males and females is illustrated in Fig. 18 where male and female facial profiles drawn from mean measurements, have been superimposed along the NSL and registered at nasion.

Certain sex differences merit further consideration.

JAW BASES

Linear dimensions relating to the mandible (ar-tgo, pg-tgo, pg-ar and s-ar vert) showed greater absolute sex differences than those relating to the upper jaw (ss-pm, s-pm hor., and s-pm vert.). Thus the lower face showed more obvious sex differences than the upper face.

Similar sex differences were illustrated by SARNÄS (1957) who used X-ray cephalometry to study a group of Indian Knoll skulls.

The observation that sex differences in size are more apparent in the lower face than in the upper face may be partly explained by the finding of KROGMAN (1938) who reported that during adolescence, the anterior growth of the lower face is more marked in males than it is in females, so that females retain a more juvenile facial appearance. Differences in the growth rates of alveolar and basal portions of the mandible may also play a part in this regard. Despite differences in growth, the jaw bases retain a similar proportion to each other and to the cranial base in both sexes.

Within the female group, the mean angle s-ar-tgo was nearly four degrees more acute than the corresponding male mean angle. This difference which lies between the ten and five per cent probability levels, substantiates the conclusion of BJÖRK (1950) that a prognathic build may arise from changes in the shape of the facial skeleton which cause the angle formed by the mandibular ramus and cranial base to diminish.

With the exception of the angle NL-NSL, the mean angles which express the inclinations of the jaw bases to each other, the occlusal line and the nasion-sella line, were more acute in the females, indicating that these lines tend to greater mutual parallelism in females than they do in males.

FACIAL HEIGHTS

All components of facial height were greater in males than in females, the most marked sex differences existing in mean values for morphological face height, lower face height and mandibular lower face height. One point of special interest was the finding of a significant sex difference in the proportion n-sp/n-gn.

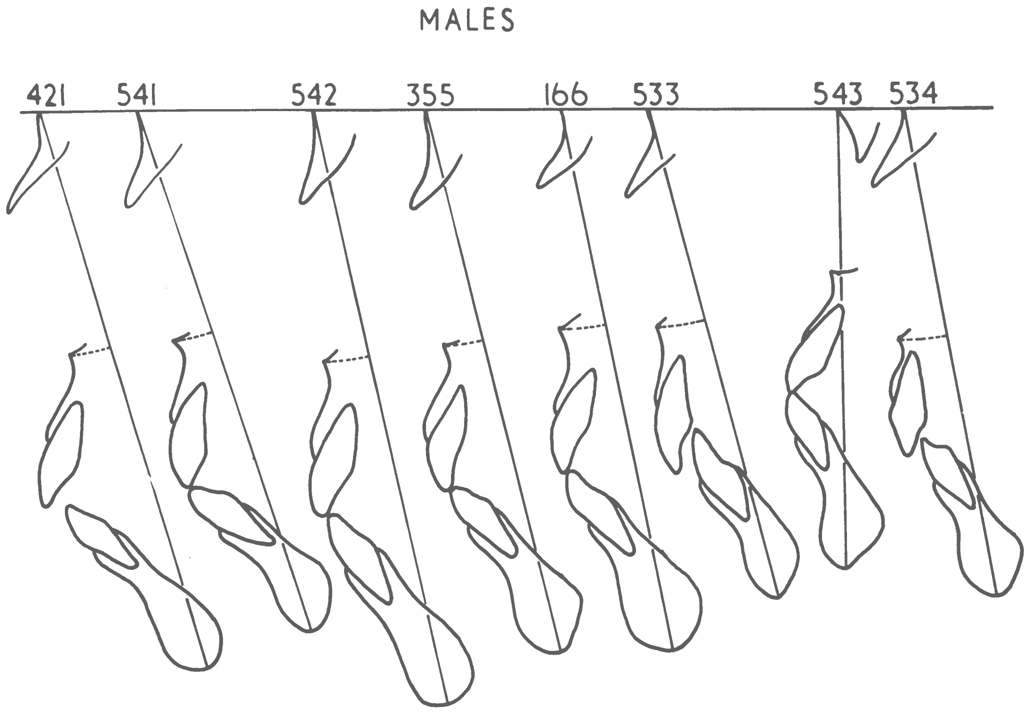
Previous investigations have revealed that the upper facial height bears a very constant relationship to the total face height regardless of age, sex or degree of tooth attrition in all population groups. In this regard BRASH (1924) reported a figure of 42.9 per cent for this relationship, and BRODIE (1940) showed that the upper face/total face proportion became stabilised after 1½ - 2 years at 40 per cent, and quoted that two of his students, Thompson and Stapf obtained mean values of 43± 0.8 per cent for the proportion in 40 cases of Class III malocclusion.

Subsequently HERZBERG and HOLIC (1943) measured 326 adult skulls from many localities and reported a mean value of 43.5 per cent, with a range of 37.5 - 51.4 per cent for the n-sp/n-gn ratio. SARNÄS (1957) measured n-sp and n-gn heights on Indian Knoll skulls from North America and showed a significant correlation of r = +0.57 between the two variables in 24 male skulls within the 20 - 29 years age group, whereas in 35 female skulls of similar age the correlation was r = +0.69. In addition, within the same age group Sarnas calculated a mean n-sp/n-gn ratio of 44.2 per cent for males, and 43.5 per cent for females.

BJÖRK (1947) and LINDEGÅRD (1953) investigated Swedish adult males and from their data can be calculated mean values of 42.9 and 43.8 per cent respectively for the proportion n-sp/n-gn. CRAVEN (1958) provided mean values for the upper face/total face proportion of 42.9 per cent and 43.8 per cent for male and female Australian aborigines respectively.

The findings of the present study agree closely with figures previously reported, and the low variability of the n-sp/n-gn ratio within the Yuendumu group is indicated by an empirical range of 11.6 per cent for males and 7.6 per cent for females. The variables n-sp and n-gn were significantly correlated in the present subjects with coefficients of r = +0.71 in males and r = +0.56 in females. The variations in facial heights are clarified by consideration of several individual subjects of both sexes.

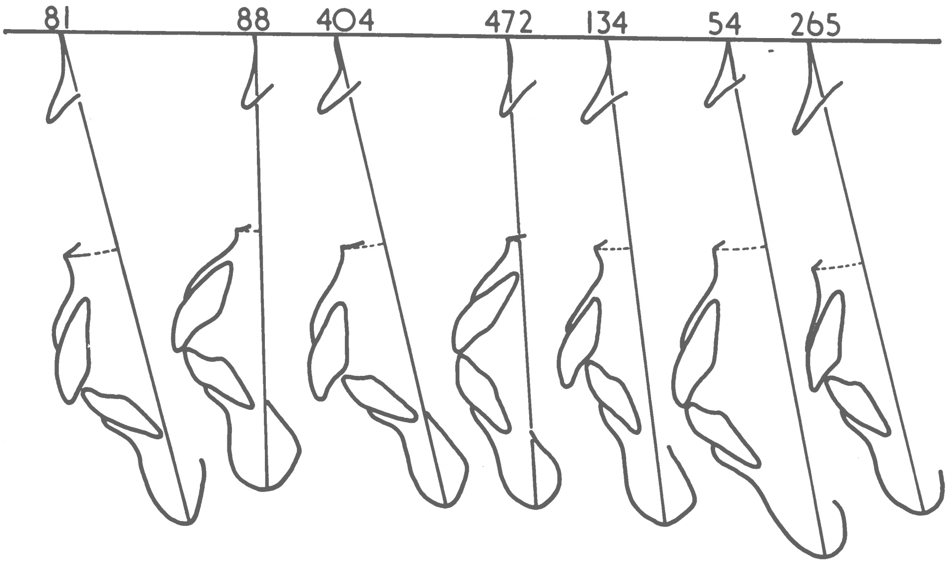
Fig. 22 illustrates variations within the male group of facial height measurements. Subjects 421, 541, 542, 355 and 166 although differing in both upper facial and total facial heights, retain proportionate values very close to the male mean for n-sp/n-gn. Subject 534 shows the maximum upper face/total face ratio of 46.6 per cent which is associated with a slightly greater than average n-sp height, and a reduced n-gn height. Subject 543 shows a reduction in both n-sp and n-gn heights, together with the minimum n-sp/n-gn ratio of 35.0 per cent. In this subject there is marked under-development of the entire upper facial complex which has resulted in the short upper face height as well as the depressed nasal bridge. The malformation may be congenital since it was noticed in other aborigines at Yuendumu not included in this study. Exclusion of subject 543 from the series would reduce the empirical range for n-sp/n-gn in males to 8.3 per cent, but would hardly affect its mean value.



	Group mean	421	541	542	355	166	533	543	534
n-sp mm.	49.4	52.5	50.5	55.5	51.0	48.5	47.0	35.0	51.0
n-gn mm.	119.2	127.0	120.5	132.5	122.5	121.5	111.0	100	109.5
$\frac{n-sp}{n-gn}$ %	41.4	41.3	41.9	41.5	41.6	39.9	42.3	35.0	46.6
Overbite mm.	1.7	0.5	0.0	0.5	0.0	1.0	9.0	0.0	3.0

Fig. 22. Variations in anterior facial heights within young adult Wailbri males.

FEMALES



	Group mean	81	88	404	472	134	54	265
n-sp mm.	47·1	48·5	42·5	46·0	44·5	45·5	45·5	50·0
n-gn mm.	108·3	111·0	99·5	106·0	103·0	106·5	115·0	106·0
$\frac{n-sp}{n-gn}$ %	43·6	43·7	42·7	43·4	43·2	42·7	39·6	47·2
Overbite mm.	1·5	1·5	0·5	3·0	0·0	5·0	1·5	2·0

Fig. 23. Variations in anterior facial heights within young adult Wailbri females.

Subject 533 shows the interesting combination of a short n-sp height and a n-gn height which is considerably reduced by the maximum recorded overbite of 9.0mm. The resultant n-sp/n-gn proportion is close to the male mean and much higher than it would be had the overbite been closer to the male mean of 1.7mm.

Fig. 23 illustrates various combinations of upper face height, total face height and overbite within the female group. In subjects 81, 88, 404 and 472 the proportions n-sp/n-gn are close to the female mean although the subjects differ in individual values for n-sp, n-gn and overbite. In subject 88 the profile also shows marked alveolar prognathism and the female maximum angle of basal mandibular prognathism. Subject 134 has an overbite of 5.omm (maximum for females) which appears to have reduced the morphological face height to a dimension compatible with upper face height, since in this subject the n-sp/n-gn proportion is close to the female mean. The combination of a short upper face height and a long total face height is shown in subject 54, where the minimum n-sp/n-gn ratio for females is recorded. The maximum proportion for females is present in subject 265 who shows the combination of large n-sp and small n-gn heights.

It would appear that since the variation in the proportion of upper face height to total face height was low in both sexes, factors operate to preserve the facial proportions within relatively narrow limits. The degree of overbite of the incisors may be one such factor. Furthermore the data obtained from Yuendumu indicated a sex difference in the proportion n-sp/n-gn. The smaller mean proportion in males as well as the greater variability in the ratio and in overbite within this sex may be explained by the adolescent spurt in growth of the lower face, which is more marked in males (KROGMAN, 1938; NANDA, 1955; DOWNS, 1956; BAMBHA, 1961).

Not only is the variability of the upper face/total face ratio low within a single population group, but evidence obtained from several other investigators suggests that the ratio is relatively constant in other ethnic groups as well.

INCISOR RELATIONSHIPS

In support of the finding that females of the group under investigation were more prognathous in the alveolar region than males of the same group, was the observation that the mean angular inclinations of the upper and lower central incisors to each other and to the occlusal plane differed significantly between sexes. The more acute

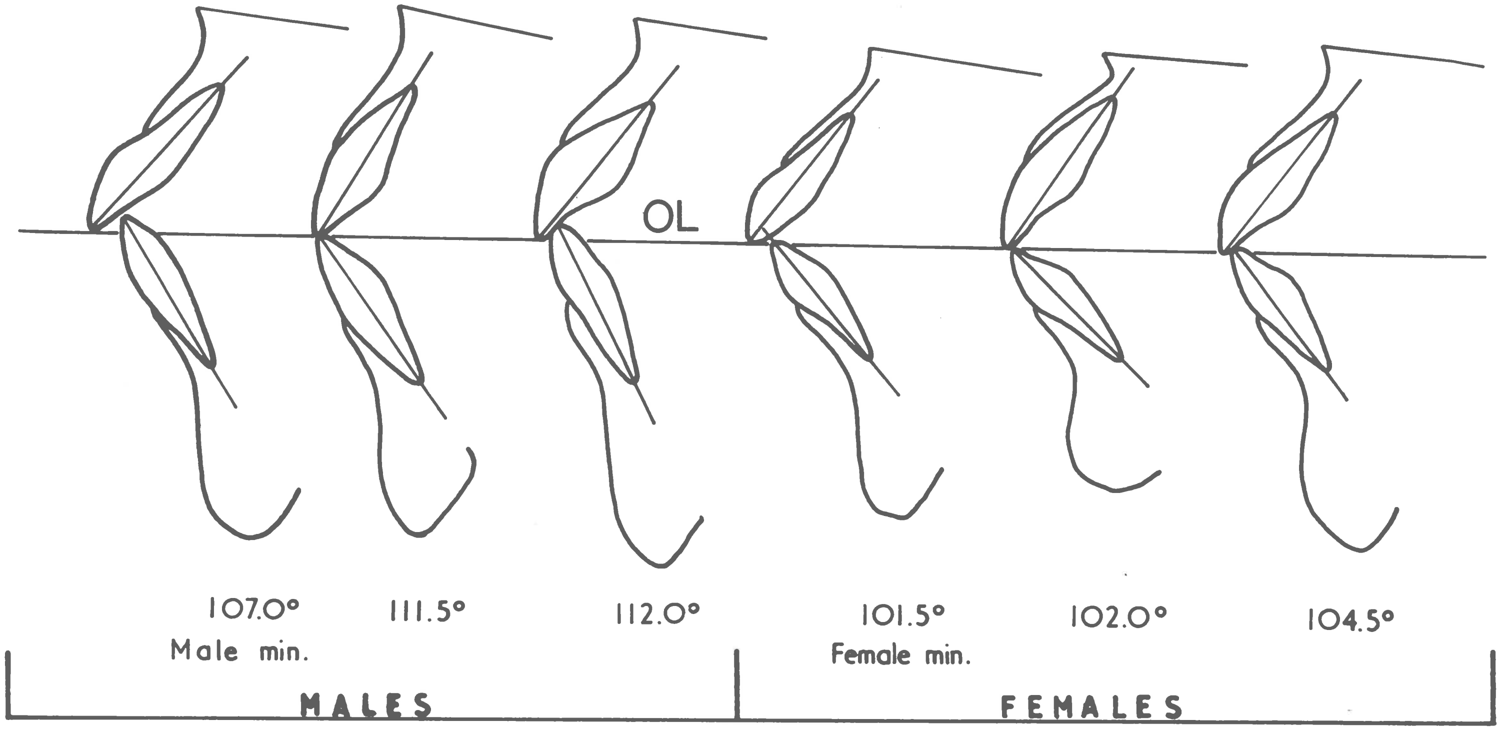


Fig. 24. Tracings of males and females showing the smallest interincisal angles within their groups. Note that the angles are more acute in the female subjects.

incisal inclinations in females are illustrated in Fig. 19 which shows male and female mean diagrams, and in the tracings of three male and three female subjects who show the smallest interincisal angles within their respective groups (Fig. 24).

CRANIAL BASE

All linear components of the median and lateral cranial bases showed significantly larger mean values in males than in females. Furthermore the variability of the lengths n-ba, n-s, s-ba, n-ar and s-ar was greater in the male group. The shape of the cranial base as denoted by the angles n-s-ba and n-s-ar did not differ significantly between males and females although the latter group showed slightly more obtuse mean cranial base angles.

Similar sex differences in mean values and variability of cranial base dimensions were reported by CAMERON (1926a, 1926b) in his craniometric studies. SARNÄS (1957) and CRAVEN (1958) reported more obtuse angles of cranial base deflection in females than in males, within their respective groups.

An interesting finding was a sex difference in mean values of the foramen angle. The difference, which was almost significant, resulted from a female mean angle which was 2.8 degrees more acute than the male mean. This indicated that within the female group, the foramen magnum was directed more anteriorly in relation to the NSL than it was in males. Further investigation is required to show if this sex difference is associated with earlier cessation of growth at the sphenooccipital synchondrosis in females.

Comparison with Data Obtained by CRAVEN (1958)

The results of the present study supplement those published by Craven, who used cephalometric X-ray films (obtained by Heath of Melbourne) to investigate a group of Central Australian aborigines from Hermannsburg and Haast's Bluff (see Map- Fig. 7). The age and sex distributions of Craven's sample were as follows:

Age	Male	Female	Total
4-11	12	15	27
12-20	9	20	29
	21	35	56

Although the material made available to Craven included fewer subjects who could be classed as young adult, a comparison of his mean values with those obtained from radiographs of young adult Wailbri natives of Yuendumu is of interest. Such a comparison is summarised in TABLE 22.

TABLE 22

Comparison of data obtained from two cephalometric radiographic studies of Central Australian aborigines.

Author Sample Age Tribe		Present (1962) 31M 27F Young adult Wailbri		CRAVEN (1958) 21M 35F 4 - 20 years Pintubi and Pitjandjara	
Variable		Mean	s	Mean	s
n-s-ar	♂ ♀	122.0 123.9	5.2 5.4	116.7 119.9	5.8 5.1
s-ar-tgo	♂ ♀	149.5 145.6	9.1 6.3	150.4 148.4	9.6 9.9
ar-tgo-gn	♂ ♀	120.7 121.8	5.9 4.8	124.4 122.8	7.1 6.6
CL-ML	♂ ♀	85.0 86.0	4.8 5.6	86.6 87.9	4.4 5.8
NL-NSL	♂ ♀	6.9 7.8	3.5 2.6	6.2 7.6	2.6 3.4
ML-NSL	♂ ♀	32.0 31.1	4.8 5.8	32.5 31.1	5.7 5.7
OL-NSL	♂ ♀	15.5 * 15.7 *	- -	15.8 16.5	4.5 3.9
IL_s-IL_i	♂ ♀	124.6 114.5	9.2 8.3	117.0 114.3	7.9 8.6
n-sp/n-gn	♂ ♀	41.4 43.6	2.5 1.8	42.9 43.8	1.8 1.9

* Obtained from mean values of NL-NSL and NL-OL.

In general the mean values and standard deviations correspond fairly closely in both groups, and furthermore with the exception of two variables, female mean values of the two studies agree more closely than male means. This may be explained by the age distribution of Craven's sample and by his higher percentage of adolescent females.

The difference between male and female mean values for the gonial angle (ar-tgo-gn) between the two studies may be due partly to slightly different interpretations of the mandibular line, and partly to different age grouping of the subjects. The higher mean value of the gonial angle reported by Craven was obtained from a male sample of younger mean age than the subjects included in the author's material, and current thought indicates that the gonial angle decreases with age within Australian aborigines (MURPHY, 1957).

Conclusions

Mean values of linear dimensions relating to the face and cranial base were greater in male than in female members of the Yuendumu tribe, but there appeared to be little evidence of differences in facial shape as expressed by angular variables. Most dimensio ns were more variable within the male group due to the longer period of active facial growth in this sex.

It is interesting that despite sex differences in the size of the cranio-facial components, the proportions between jaw base lengths and the cranial base length remained similar in both sexes. The sex difference in the upper face/total face proportion has been explained by the pubertal growth spurt in the lower face which is more marked in males than it is in females.

The sex differences in mean values and variability reported in this chapter, are supported by those calculated for a different group of Central Australian aborigines by CRAVEN (1958).

CHAPTER VI

THE NATURE OF VARIATIONS IN FACIAL PROGNATHISM WITHIN MALES

Since X-ray cephalometry was introduced as a diagnostic and research tool in the investigation of craniofacial relationships, numerous studies have thrown light on problems of discrepancies in the size and position of the jaw bases and the resultant effects upon dental occlusion, especially as these problems apply to the practice of orthodontia. Relatively few workers have been interested in purely morphological aspects of prognathism, or in the relationship between prognathism and other metrical characters of the face and cranial base.

BJÖRK (1947) applied X-ray cephalometry to study the nature of variations in prognathism within a single population group. This original study of Swedish boys and young adult males, and the follow-up studies by the same author (BJÖRK, 1950; 1951; 1953; 1955a; 1955b; 1955c; 1960; BJÖRK and PALLING, 1954) have greatly increased the understanding of morphology and growth of the craniofacial complex in Europeans.

The main conclusions of BJÖRK in relation to individual variations in prognathism are quoted from one of his earlier papers (BJÖRK, 1950) since they have a direct bearing on the present study.

"A prognathic facial build may arise in different ways:
a) due to a shortening of the cranial base.
b) due to angular bending of the cranial base.
c) due to changes in the shape of the facial skeleton which cause the angle formed between the ramus and the cranial base to diminish.
d) due to increased jaw length.

These different causes of prognathism may combine in various ways, and the effect of one or more causes which are active simultaneously may be compensated by one or more of the other factors having a counteracting effect, i.e. they tend to cancel each other out................"

"A varying degree of prognathism within a population is mainly due to variations in size and shape of the cranial base. Even within the same ethnic group the prognathism is found to serve as a measure of the characteristic facial formation."

"The varying degrees of prognathism observed in a given racial group are not very intimately connected with the size of the jaws. The degree of individual prognathism is thus seen mainly to depend upon the degree of prominence of the facial skeleton as a whole due to the shortening or deflection of the cranial base, foramen magnum being displaced forwards on the underside of the skull................"

"On an average prognathism affects both jaws equally, total prognathism. In certain cases maxillary prognathism is greater than the mandibular prognathism, while in others it is the converse, accompanied by corresponding changes in the occlusion..............."

"The difference between maxillary and mandibular prognathism is partly due to the varying size of the jaws, and partly to the variations in length of the cranial base which joins the two jaws..............."

"The correlation between maxillary and mandibular prognathism appears to diminish as a result of racial admixture..............."

Björk also showed that the length and height of the face vary inversely so that marked prognathism is associated with a small anterior face height. In addition the prognathic face tended to be squarish, with nasal, occlusal and mandibular lines more parallel than in the triangular face showing a lesser degree of prognathism.

LINDEGÅRD (1953) who also studied Swedish males, confirmed many of Björk's observations and although the nature of prognathism does not receive special consideration in his study, the author was able to demonstrate significant correlations between maxillary basal prognathism (s-n-ss) and the upper jaw length (positive), anterior upper face height (negative), maxillary protrusion (positive), median cranial base angle (negative) and other components of the posterior cranial base. Lindegard also offered the view that the mandibular alveolar process develops partly to compensate for variations in the relationship between cranial and jaw bases.

SARNÄS (1957) who radiographed a group of North American skulls concluded that increased prognathism was associated with increased cranial base deflection and that both these characters decreased with age from childhood to adulthood.

The association between prognathism and the size and shape of the cranial base has evoked considerable interest and controversy over the years. VIRCHOW (1857) and others at that time considered that the degree of prognathism was dependent upon the extent of cranial base deflection at the pituitary fossa, through the agency of a relative shortening of the cranial base length. However WELCKER (1862) observed that progressive reduction in prognathism was concurrent with increasing deflection of the cranial base in an ascending series of primates including Negroes and Europeans, and concluded that the degree of prognathism was determined by the extent of cranial base flattening. HUXLEY (1866) examined two skulls which showed similar cranial base angles, but which differed in prognathism and decided that the cranial base angle was not necessarily related to prognathism.

In more recent times WAGNER (1937) investigated Oceanic skulls but could find no association between the degree of prognathism and the cranial base inclination. He therefore concluded that it is more likely that prognathism is determined by the intrinsic growth of the facial skeleton.

The noted anthropologist WEIDENREICH (1941) studied this problem and although he acknowledged that correlations exist between the face and cranial components, stated that "the correlation between brain, cranial cavity and face, particularly the jaws, is quite independent of the form of the base and merely conditioned by the relative size of the two constituents of the skull."

SCOTT (1953), a dental anatomist from Belfast, studied measurements from 700 crania but could reveal no relationships between the cranial and facial skeletons, although only a limited number of variables were included in this study. However Scott did suggest that the cranial base length was closely related to the anterior projection of the upper face, expecially during growth.

Björk, Lindegård and Sarnäs (see above) all agree that within subjects of a single ethnic group, an increased cranial base deflection i.e. a smaller angle between anterior and posterior segments of the cranial base, tends to increase prognathism, but they have shown that numerous compensating factors may be involved so that the relationship is not always straightforward.

It would appear then that some of the differences in thought about affinities between facial prominence and cranial base form may have arisen through lack of knowledge of growth patterns in these regions, and confusion between evolutionary changes and variations within specific groups. In addition alveolar prognathism was seldom considered separately from basal bone (or facial) prognathism, and the relationships between alveolar prominence, incisal inclinations, tooth size and tooth occlusion in general were largely unknown.

It seems reasonable to assume that prognathism is not necessarily a primitive feature although of course primitive hominids usually show prominent jaws. Rather it may be considered a specialised characteristic such as is seen in the prognathic jaws of certain anthropoid apes. It may well be that certain non-prognathic human groups (e.g. Europeans) because of phylogenetic changes now show less specialisation of the jaws than prognathic groups (e.g. Negroes).

The data collected for the present study afforded an opportunity to investigate the nature of variations in facial prognathism within the young adult males of a representative group of Australian aborigines. It was of interest to apply Björk's conclusions to an ethnic group which besides showing alveolar and upper facial prognathism as a physical characteristic, is less modified by genetic and modern environmental influence than Swedes.

Method

In order to investigate the nature of variations in prognathism within young adult males of the group under investigation, total correlation coefficients were calculated between the angles s-n-ss, s-n-pg (representing maxillary and mandibular basal prognathism) and other cranial and facial variables. Partial correlations were calculated in certain cases where it was thought additional information could be obtained.

To aid in the investigation of variations in the sagittal jaw positions, a method of regression analysis was applied. This statistical technique was employed in X-ray cephalometry by LINDEGÅRD (1953) and is described in detail by SARNÄS (1959). The methods and terminology of these authors has been retained to calculate two quantities:

1) the residual of maxillary basal prognathism on mandibular basal prognathism, denoted Fs-n-ss(s-n-pg),
2) the residual of mandibular basal prognathism on maxillary basal prognathism, denoted Fs-n-pg(s-n-ss).

Within the present group, maxillary and mandibular basal prognathism were significantly correlated with a coefficient of $r = +0.77$ (see Chap. 4). This association is satisfied by the regression equations:

$$Y = 10.06 + 0.82X \quad \text{and}$$

$$X = 27.73 + 0.73Y$$

where Y = mandibular basal prognathism and X = maxillary basal prognathism. The regressions of s-n-ss on s-n-pg, and s-n-pg on s-n-ss are shown in Figs. 25 and 26 where the measurements have been plotted around the regression line and lines enclosing one and two standard deviations of the dependent variable around the regression line.

When s-n-pg is denoted the independent variable, expected values of s-n-ss can be calculated for each subject according to the regression equation. The difference between this expected value of s-n-ss and the true s-n-ss value is termed the residual value of maxillary basal prognathism on mandibular basal prognathism (Fs-n-ss(s-n-pg)). In a similar way residual values of Fs-n-pg(s-n-ss) can be calculated from the difference between true s-n-pg values and those computed from the regression of s-n-pg on s-n-ss, this time with s-n-ss as the independent variable.

A positive residual Fs-n-ss(s-n-pg) in a particular subject indicates that the upper jaw base in prognathic in relation to the lower jaw. A positive residual Fs-n-pg(s-n-ss) indicates that the mandibular base is prognathic in relation to the upper jaw. Negative

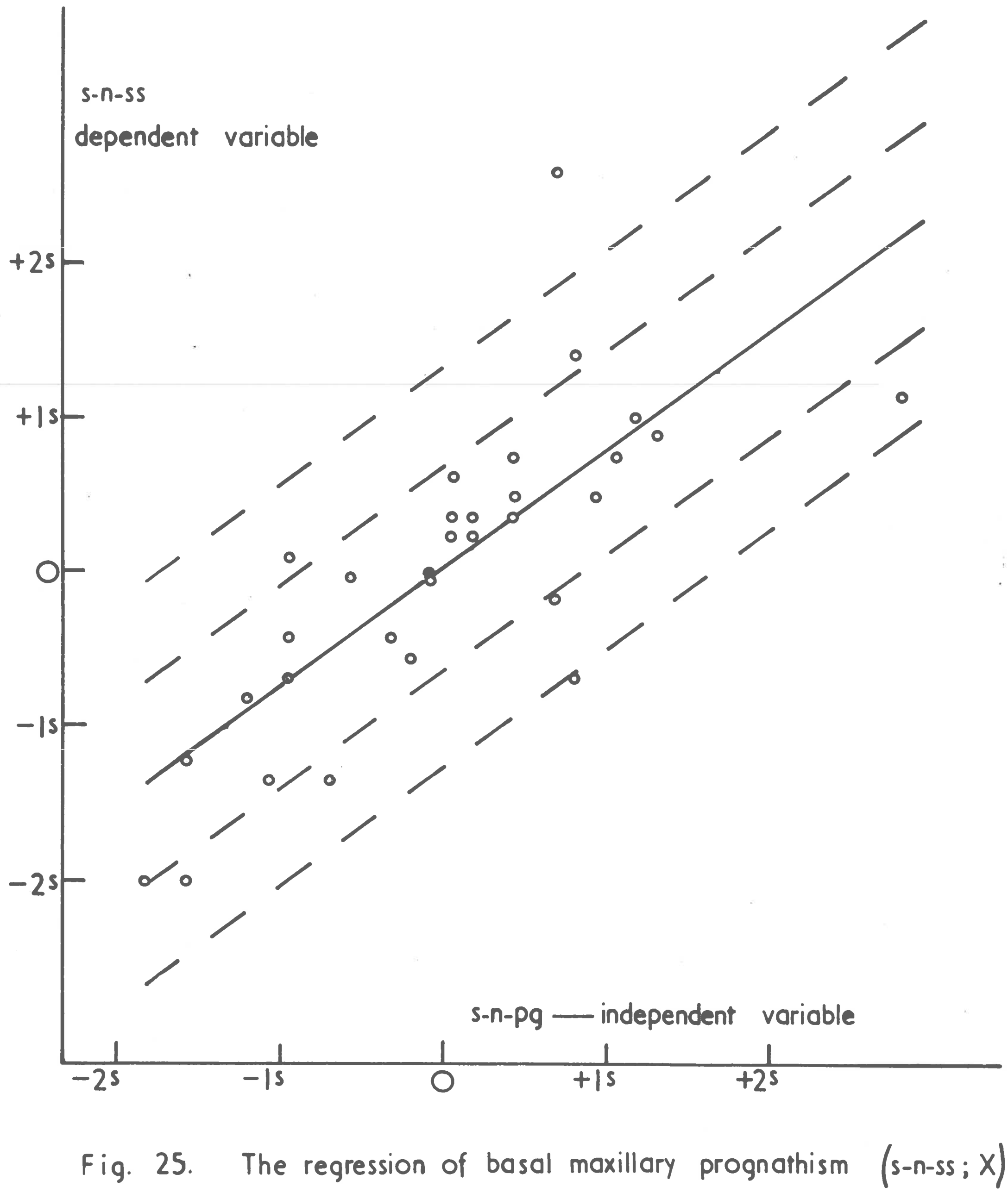


Fig. 25. The regression of basal maxillary prognathism (s-n-ss; X) on basal mandibular prognathism (s-n-pg; Y).

——— Regression line $X = 27.7 + 0.7Y$.

– – – One and twice the standard deviation (2.5 and 5.0 degrees) of basal maxillary prognathism around the regression line.

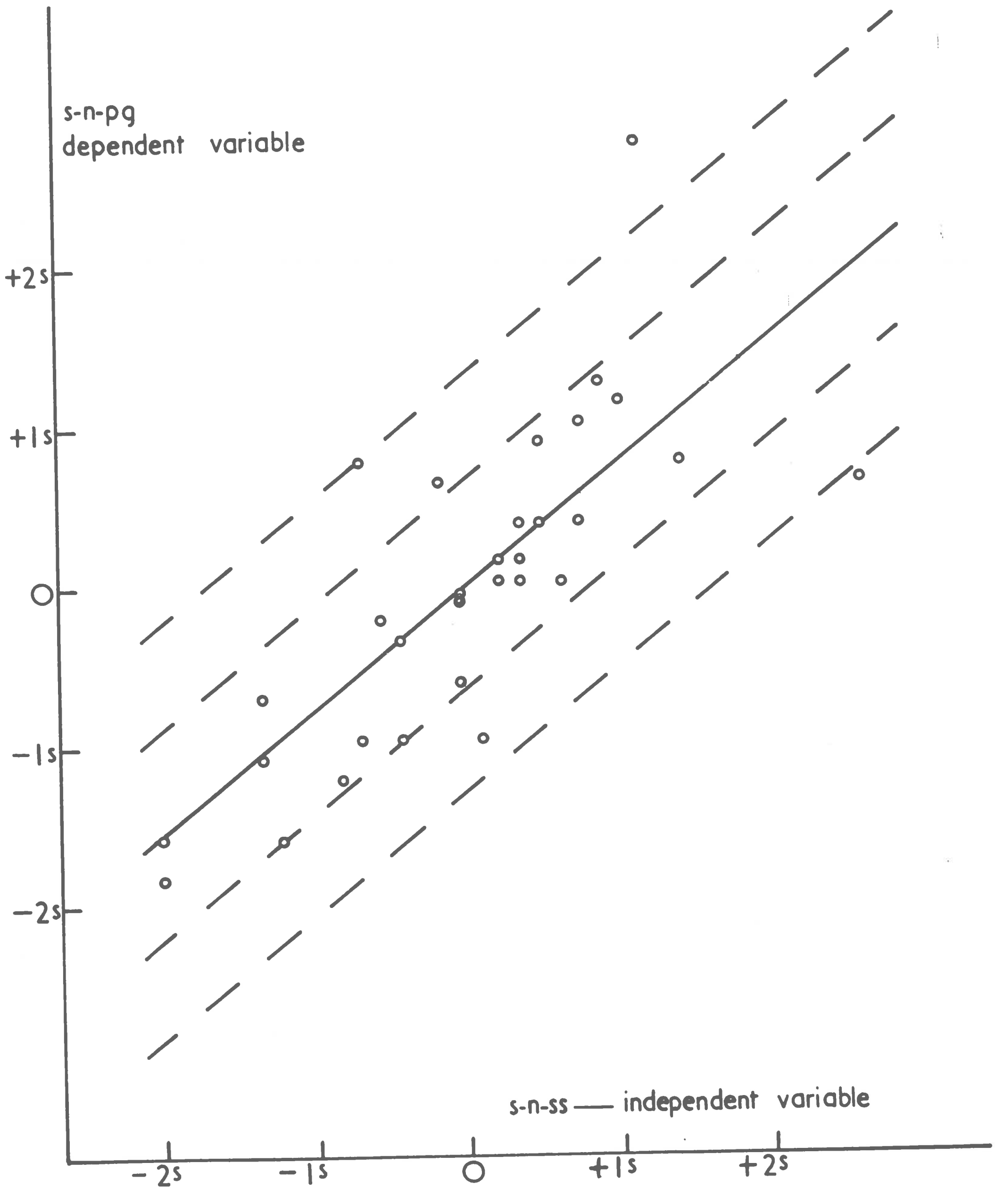


Fig. 26. The regression of basal mandibular prognathism (s-n-pg ; Y) on basal maxillary prognathism (s-n-ss;X).

——— Regression line $Y = 10.1 + 0.8X$.

– – – One and twice the standard deviation (2.6 and 5.2 degrees) of basal mandibular prognathism around the regression line.

residuals indicate that the jaw base concerned is retrognathic in relation to the opposing jaw. For these reasons the residuals Fs-n-ss(s-n-pg) and Fs-n-pg(s-n-ss) are termed "relative maxillary prognathism" and "relative mandibular prognathism" respectively.

The value of residual analysis lies in the possibility of eliminating in turn the variation produced by s-n-ss or s-n-pg by keeping them independent. In effect this means the examination of a population with varying s-n-ss angles but constant s-n-pg angles or vice versa. By this method discrepancies in the sagittal relationship of the jaw bases could be examined.

In the present study, both series of residuals were normally distributed as judged graphically, and were therefore subjected to further statistical analysis like any other characteristic.

Although biological interpretation of correlations must be approached with caution since no real knowledge of cause and effect can be obtained through them, the associations revealed by the correlations computed were of interest and were compared by illustrating facial polygons of several selected subjects within the male group.

In the comparisons the actual values of the variables concerned were converted to "sigma units" by expressing the deviations from the mean as standard deviation units (GARN, 1958). Thus a dimension which was two standard deviations higher than the mean was given the value of +2 sigma units; a dimension which was two standard deviations lower than the mean was given the value of -2 sigma units. In this way all variables whether linear, angular, large or small were adjusted to a scale which allows differences between individuals to be studied more easily.

Results

Standard deviations and ranges for the residuals Fs-n-ss(s-n-pg) and Fs-n-pg(s-n-ss) are summarised in TABLE 23.

Significant and almost significant correlations between s-n-ss, s-n-pg and other cranio-facial variables are shown in TABLE 24. Non-significant correlations between the above variables are listed in Appendix TABLE 29. Significant and almost significant correlations between the residuals and cranio-facial variables are shown in TABLE 25, while non-significant correlations between these variables are listed in Appendix TABLE 29. Correlations within and between the cranial base, jaw bases and angles of prognathism are shown in TABLE 26.

TABLE 23

Standard deviations and ranges of the residuals Fs-n-ss(s-n-pg) and Fs-n-pg(s-n-ss) representing relative maxillary and mandibular basal prognathism. Recorded in degrees for 31 males.

Residual	s	Range
Fs-n-ss(s-n-pg)	2.5	-5.00 - +7.87
Fs-n-pg(s-n-ss)	2.6	-5.36 - +7.64

One property of residuals is that their mean value is zero, so that means and standard errors of the means are not included.

TABLE 24

Correlations between the angles of basal prognathism and cranio-facial variables for 31 males.

s-n-ss			s-n-pg		
ss-pm	+0.46	**	pg-ar	+0.45	**
s-pm hor.	+0.49	**	s-pm hor.	+0.47	**
ss-pm/n-ar	+0.69	**	ss-pm/n-ar	+0.36	*
pg-ar/n-ar	+0.39	*	pg-ar/n-ar	+0.68	**
s-ar-tgo	-0.38	*	s-ar-tgo	-0.50	**
n-gn	-0.47	**	n-gn	-0.48	**
sp'-is'	-0.50	**	sp'-is'	-0.47	**
NL/NSL	-0.48	**	NL/NSL	-0.74	**
ML/NSL	-0.58	**	ML/NSL	-0.72	**
sp'-gn	-0.39	*	n-sp	-0.62	**
			ss-n-pg	-0.41	*
			n-ss-pg	+0.42	*
			n-ba	-0.44	*
			CL-ML	-0.39	*
			overjet	-0.39	*
			NL/OL	-0.40	*
			pg-tgo/n-ar	+0.39	*
			Foramen angle	-0.48	**

** Significant
* Almost significant

TABLE 25

Correlations between the residuals Fs-n-ss(s-n-pg) and Fs-n-pg(s-n-ss) and cranio-facial variables for 31 males.

F s-n-ss(s-n-pg)			F s-n-pg(s-n-ss)		
pr-n-ss	-0.58	**	id-n-pg	-0.41	*
ss-pm	+0.53	**	ar-tgo	+0.43	*
CL-ML	+0.41	*	pg-ar	+0.46	**
sp'-gn	-0.42	*	CL-ML	-0.54	**
is'-gn	-0.41	*	overbite	-0.42	*
ss-pm/n-ar	+0.64	**	overjet	-0.46	**
ss-pm/pg-tgo	+0.49	**	n-sp	-0.59	**
			is'-gn	+0.42	*
			NL/NSL	-0.58	**
			ML/NSL	-0.42	*
			NL-OL	-0.37	*
			ss-pm/pg-tgo	-0.45	**
			pg-ar/n-ar	+0.61	**
			Foramen angle	-0.48	**

** Significant
* Almost significant

TABLE 26

Total and partial correlations between the angles of prognathism, jaw dimensions and the median cranial base for 31 males.

Variable	n-s	n-ba	n-s-ba
ss-pm	+0.50 **	+0.53 **	+0.20
s-pm hor.	+0.42 *	-0.06	-0.63 **
ar-pg	+0.23	+0.22	+0.07
s-n-ss	-0.20	-0.30	-0.10
s-n-pg	-0.23	-0.44 *	-0.18
s-n-ss indep. of ss-pm	-0.56 **	-0.73 **	-0.28
s-n-ss indep. of s-pm hor.	-0.52 **	-0.31	+0.31
s-n-pg indep. of ar-pg	-0.54 **	-0.62 **	-0.24
n-s	-	+0.70 **	-0.21
n-ba	+0.70 **	-	+0.16
n-s-ba	-0.21	+0.16	-

** Significant
* Almost significant

Discussion

The total correlations calculated between the angles of facial prognathism (s-n-ss and s-n-pg) and other variables indicate that within the males of the present group, certain characteristics were associated with each of these angles.

Total facial prognathism (i.e. maxillary and mandibular basal prognathism combined in the one individual) was usually seen in conjunction with a small angle between the mandibular ramus and the lateral cranial base, a large maxillary protrusion, a small total face height, a small maxillary lower face height, greater parallelism between the nasal, mandibular and nasion-sella lines and jaw bases which were long in relation to the lateral cranial base length.

Variables in addition to those listed above were found to be associated with either of the angles s-n-ss or s-n-pg individually. Thus a large s-n-ss angle was usually combined with a long upper jaw base and a short lower face height. A large s-n-pg angle was found in conjunction with a long total mandibular length, a corpus length which was long in relation to the lateral cranial base, a short median cranial base, a small foramen angle, parallelism between nasal and occlusal lines, a small chin angle, a small angle of sagittal jaw relation and a flattening of the facial profile.

If the significant correlations are taken as a guide, then the most striking characteristics associated with maxillary basal prognathism were the length and protrusion of the maxillary base and its length in relation to the lateral cranial base, the total anterior face height and the inclinations of the nasal, mandibular and nasion-sella lines to each other. In the case of mandibular basal prognathism, strong affinities were seen with the total mandibular length, both absolute and in relation to the lateral cranial base, protrusion of the maxillary base, the angulation of the ramus to the cranial base, facial height components, inclinations of the nasal, mandibular and nasion-sella lines to each other and the angle which the foramen magnum axis makes with the nasion-sella line.

From these observations it may be suggested that four morphological characteristics are usually associated with high total facial prognathism within the males of the group under investigation:

1) Jaw bases which are long both absolutely and in relation to the lateral cranial base length;

2) A maxillary base which is noticeably protruded anterior to the NSP line;
3) Short anterior face height components especially the total face height and maxillary lower face height;
4) Small angles between the nasal, mandibular and nasion-sella lines, i.e. a more squarish face.

More variables were associated with the sagittal position of the lower jaw than with the upper jaw position. This could be explained by the disparity in growth rates of these regions and the more complex pre- and post-natal development of the mandible.

One surprising finding in the light of other investigations was the almost complete lack of correlation between the angles of maxillary and mandibular basal prognathism and the cranial base characteristics n-s, s-ba, n-ba, s-ar, n-ar, n-s-ba and n-s-ar (see Appendix TABLE 30). A significant correlation between s-n-pg and the foramen angle and an almost significant correlation between s-n-pg and n-ba were the only associations revealed between the prognathic angles and the cranial base. Thus mandibular but not maxillary basal prognathism appears to be associated with two cranial base variables only, the cranial base length and the angulation of the foramen magnum to the NSL. The closer anatomical relationship between the mandible and the cranial base through the temporomandibular joint may offer an explanation for this.

In an endeavour to further clarify the relationship between prognathism and the cranial base within the Yuendumu males, total and partial correlations were computed between the variables concerned (TABLE 26). A significant correlation was found between the angle n-s-ba and s-pm hor. Thus a small cranial base angle (i.e. greater cranial base deflection) was associated with increased maxillary protrusion which in turn was highly correlated in a positive direction with maxillary and mandibular basal prognathism. However the angle n-s-ba was only slightly correlated with the angles s-n-ss and s-n-pg, although the correlations were increased when the variations caused by the jaw base lengths were eliminated by partial correlation.

The upper but not the lower jaw base length was positively and significantly associated with both n-s and n-ba lengths. With the exception of an almost significant correlation between n-ba and s-n-pg, neither maxillary nor mandibular basal prognathism showed any strong association with n-s or n-ba, although by elimination of variations caused by jaw lengths and maxillary protrusion, significant negative correlations were revealed between both prognathic angles and the cranial base lengths. Within the cranial base, only n-s and n-ba were highly correlated.

From the revealed associations it may be suggested that, in the Central Australian tribe investigated, the relationship between cranial base and prognathism is similar to that found in the Swedes providing that the variation produced by the jaw dimensions is eliminated. Thus a short cranial base (either n-s, n-ba or both) tends to increase the relative jaw lengths and in turn facial prognathism. The same shortening of the cranial base however is associated with shortening of the upper jaw base which tends to counteract the prognathism by reducing it.

It is apparent that the interdependence of cranial and facial components and the complex nature of their interaction prevents any precise statement on the relationship between facial prognathism and the cranial base. This relationship appears to be overshadowed by the jaw size and in the case of the angle n-s-ba by the maxillary protrusion, so that no strong total correlations were revealed between the cranial base and the angles of facial prognathism as they were within the Swedish groups. However there were almost significant negative correlations between total median cranial base length, mandibular basal prognathism and the two angles of alveolar prognathism (see Chap. IV).

An explanation for the difference between Swedes and Australian aborigines in the relationship between facial prognathism and the cranial base form is suggested by considering that the face of the caucasoid group ceases its forward growth at a stage when it is underdeveloped when compared with the more prognathic face of the Australian. The different genetic makeup of the two groups must also be considered. In the Australian subjects, the associations between cranial base and the angles of prognathism are somewhat obscured by the anterior growth of the face away from the cranial base, so that jaw size, relative jaw size and especially maxillary protrusion become dominant factors in determining the final degree of prognathism attained by the jaws.

Data to be obtained from future growth studies may reveal a higher correlation between cranial base form and facial prognathism within growing aboriginal subjects, and will determine if any such correlation decreases with age, especially during the pubertal growth in length of the face.

Correlations between the residuals Fs-n-ss(s-n-pg) and Fs-n-pg(s-n-ss) and other variables showed that three characteristics were almost significantly or significantly correlated with both residuals. High relative maxillary prognathism or low mandibular relative prognathism was usually found in conjunction with a large chin angle, a small mandibular lower face height and an upper jaw base which was large in comparison with the mandibular corpus length.

Besides those listed above, relative maxillary prognathism was also correlated with maxillary alveolar prognathy, upper jaw length, total lower face height and the upper jaw length relative to the lateral cranial base. In addition, other variables were correlated either almost significantly or significantly with relative mandibular prognathism. They were total mandibular length, ramus height, overjet, overbite, lower jaw length relative to the cranial base, upper face height, the angles ML-NSL, ML-NSL and NL-OL, the foramen angle and mandibular alveolar prognathy.

Using significant correlations as a guide, the variables most strongly associated with increased relative maxillary prognathism were an upper jaw base which was long both absolutely and in relation to the lateral cranial base , an upper jaw base large in relation to the mandibular corpus length and low upper alveolar prognathy.

Large relative mandibular prognathism (i.e. protrusion of the lower jaw anterior to its expected position in relation to the upper jaw) was most strongly associated with a mandibular base which was long absolutely and in relation to the lateral cranial base, a mandibular base length/maxillary base length ratio larger than average, a small chin angle, low overjet, small upper face height, more parallel nasal and nasion-sella lines and a forwardly inclined foramen magnum axis.

It may be postulated that within the Yuendumu males, discrepancies in the sagittal jaw positions were associated with disharmony in the size relationship of the jaw bases to each other and to the lateral cranial base length which led to one jaw being either prognathic or retrognathic in respect to the other. The data also suggest that high maxillary prognathism if accompanied by a relatively low mandibular prognathism was compensated to some extent by a decrease in upper alveolar prognathy and an increase in the chin angle, both of which would tend to decrease the effect on incisal relationships of jaw base discrepancies.

In a similar way a discrepancy in the sagittal jaw relationship produced by high relative mandibular prognathism appeared to be compensated by a reduction in mandibular alveolar prognathy, a reduction in the chin angle and a reduction in both overbite and overjet of the incisors, all of which again make for more harmonious tooth relationships. Reverse conditions existed in the case of low relative mandibular prognathism.

In a recent publication BJÖRK (1960) discussed similar modifications of a compensatory nature which occur in normal development of the occlusion. He suggested that discrepancies in the sagittal jaw relationship lead to modification of the alveolar arches by the action of the lip and tongue musculature, and by forces involved in intercuspidation.

ANALYSIS OF INDIVIDUAL SUBJECTS

In the following section, males whose facial builds illustrate some of the characteristics which have been discussed have been selected to demonstrate more clearly the relationships which exist between prognathism and other features of cranio-facial morphology within young adult male Central Australian aborigines.

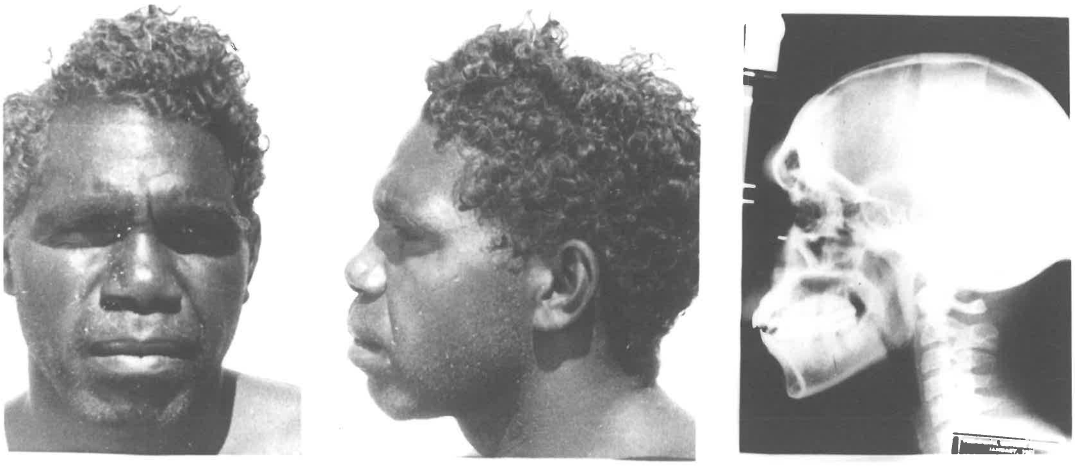
The facial diagrams were traced from the radiographs of the subjects concerned, and in the accompanying graphic representations, the variables illustrated were transformed to sigma units.

Subject 421   Age c. 27 years   Fig. 27

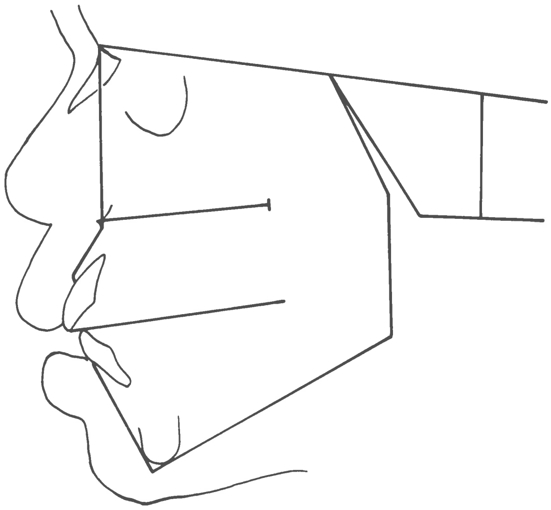
Although subject 421 is prognathic by European standards, within the native group studied he demonstrates low total facial prognathism, i.e. the angles s-n-ss and s-n-pg are both low.

The jaw bases are short and combined with a long cranial base so that the jaw sizes in relation to the cranial base length are correspondingly low. Maxillary protrusion is low and other associated characteristics are obtuse inclinations between nasal, mandibular and nasion-sella lines, long morphological face height and rather large joint and foramen angles.

In subject 421 the jaw bases which are small in relation to the lateral cranial base, are the low maxillary protrusion appear to be deciding factors associated with low facial prognathism.



421 ♂



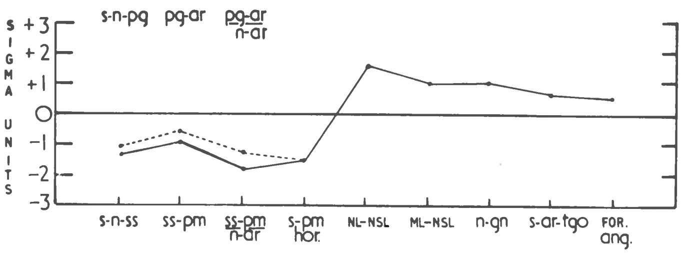
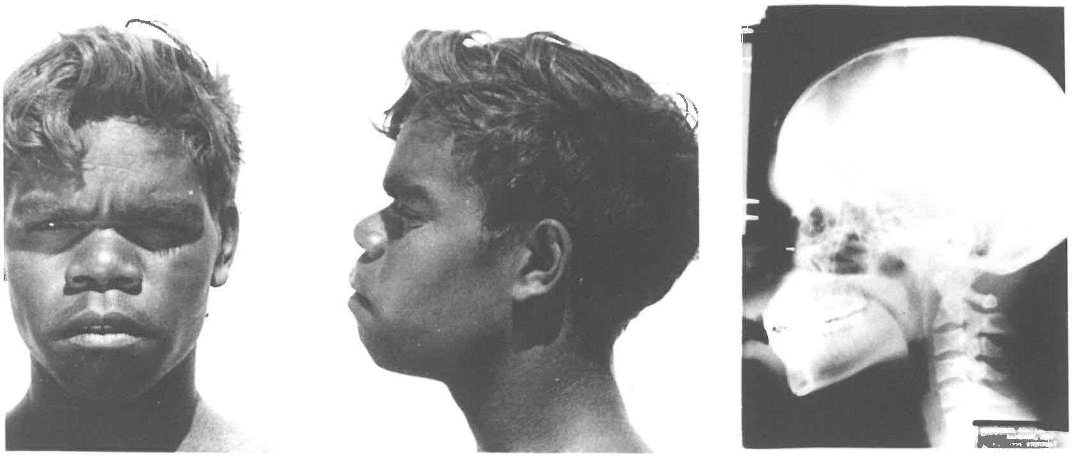

s-n-pg
pg-ar
pg-ar / n-ar
SIGMA UNITS
+3
+2
+1
0
-1
-2
-3
s-n-ss
ss-pm
ss-pm / n-ar
s-pm hor.
NL-NSL
ML-NSL
n-gn
s-ar-tgo
FOR. ang.

Fig. 27.

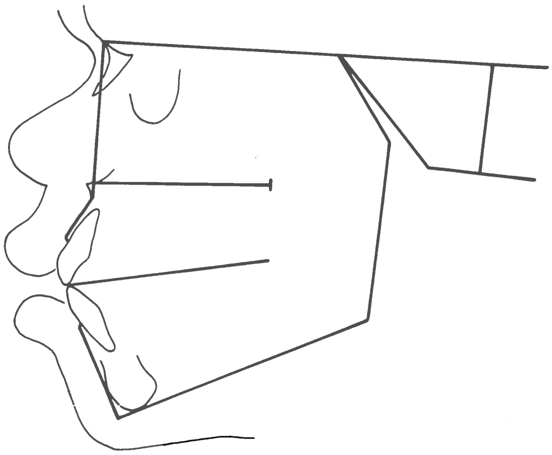
<u>Subject 532</u> Age c. 18 years Fig. 28

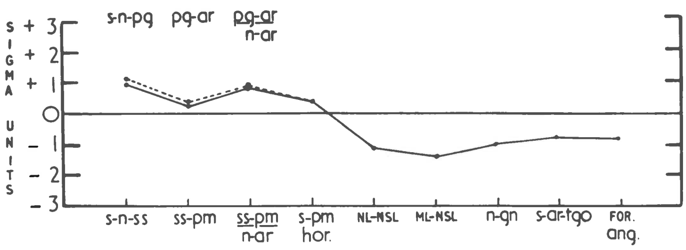
The high total facial prognathism is associated with jaw bases which are slightly larger than average and a short cranial base, so that jaw lengths in relation to cranial base length are high. Maxillary protrusion, to the extent of +0.4 sigma units, is combined with acute joint and foramen angles, as well as relative parallelism between the nasal, mandibular and nasion-sella lines. The anterior face height is low in this subject. The morphological characteristics show the reverse trends to those of subject 421 although in both cases the jaw bases are in harmony with each other in their sagittal positions.

Harmony in the lengths of the maxillary and mandibular bases and their uniformly large lengths in relation to the lateral cranial base length are associated with the high total facial prognathism of this subject, who also demonstrates no discrepancy in the sagittal jaw relation.



532 ♂

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O
-1
-2
-3
s-n-pg
pg-ar
pg-ar / n-ar
s-n-ss
ss-pm
ss-pm / n-ar
s-pm hor.
NL-NSL
ML-NSL
n-gn
s-ar-tgo
FOR. ang.

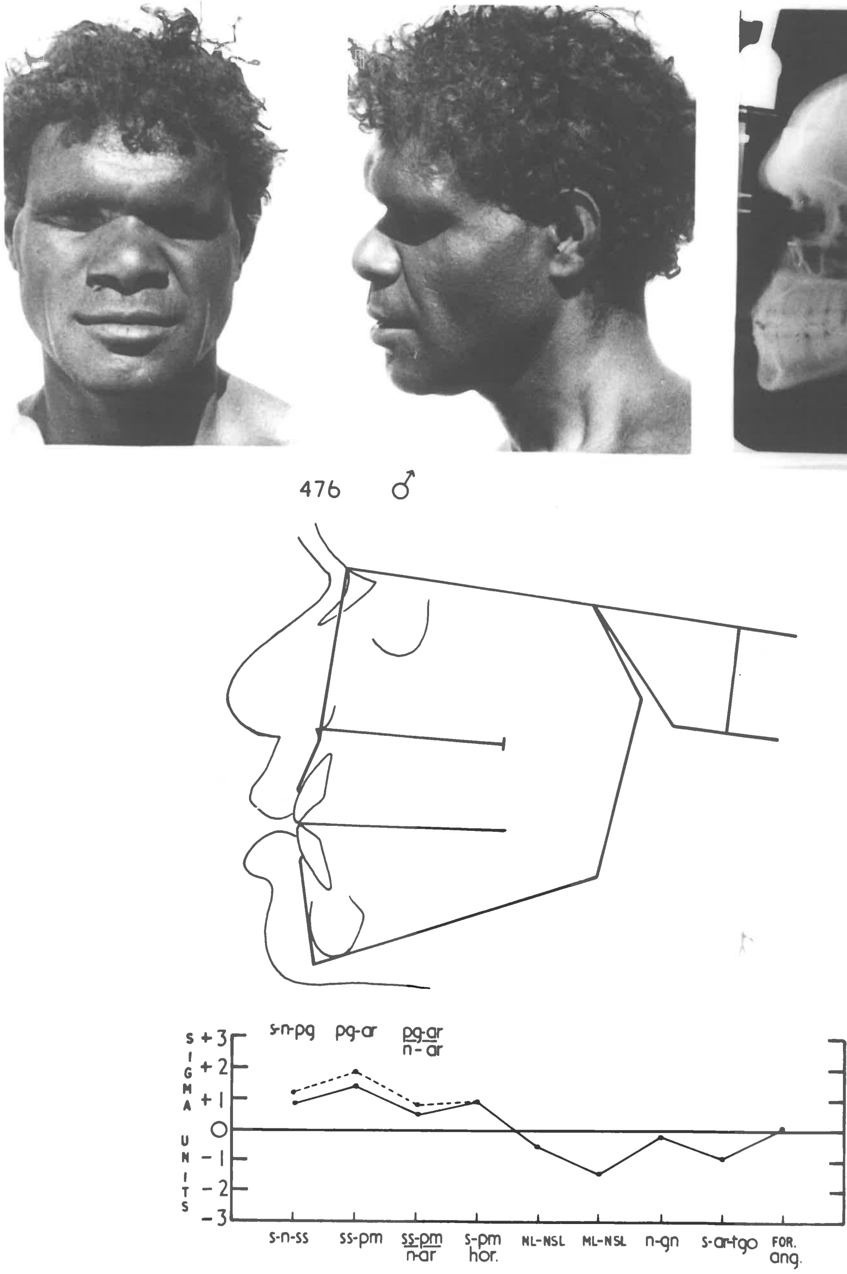
Fig. 28.

Subject 476 Age c. 25 years Fig. 29

Maxillary and mandibular bases are long in this subject but since they are associated with a long cranial base (n-ba = +1.0 sigma units), the relative jaw lengths are reduced somewhat but still are high. Maxillary protrusion is high and the joint angle small. In addition the inclinations of the jaw bases to the nasion-sella line are in accordance with the observation that the prognathic face tends to be squarish in profile.

A slight discrepancy in the jaw base lengths is partly offset by the small chin angle, so that the sagittal incisor relationship remains reasonably harmonious.

Subject 476 illustrates the combination of large jaw bases, long cranial base, maxillary protrusion and a forwardly inclined ramus in association with high total facial prognathism.


476 ♂
s-n-pg
pg-ar
pg-ar / n-ar
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+1
0
-1
-2
-3
s-n-ss
ss-pm
ss-pm / n-ar
s-pm hor.
NL-NSL
ML-NSL
n-gn
s-ar-tgo
FOR. ang.

Fig. 29.

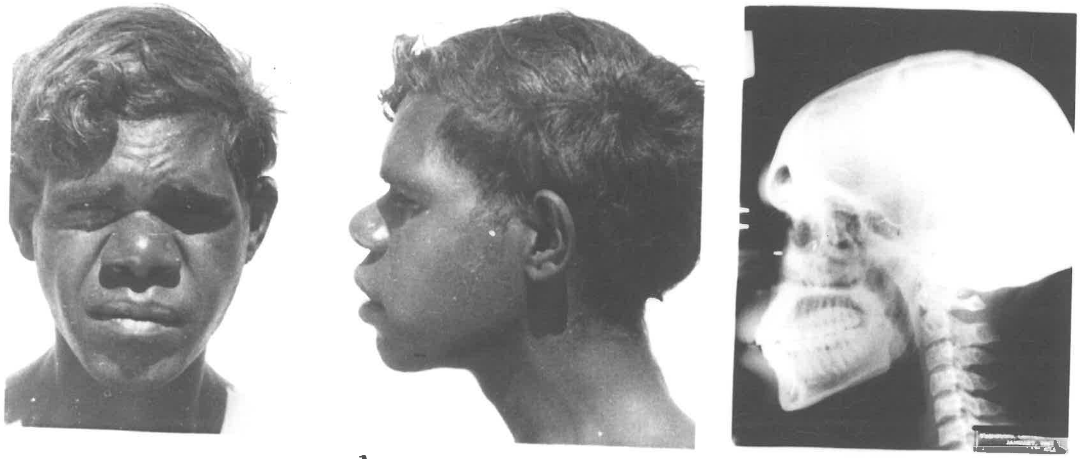
Subject 489 Age c. 20 years Fig. 30

A discrepancy in lengths of the upper and lower jaw bases has been instrumental in producing a large relative mandibular prognathism in subject 489. The residual Fs-n-ss(s-n-pg) is the group minimum of -5.0 degrees, whereas the residual Fs-n-pg(s-n-ss) is high (+5.4 degrees).

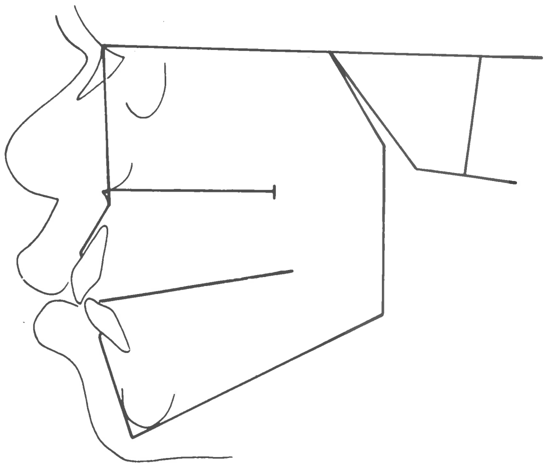
Associated with the small maxillary base is a low value for maxillary protrusion of -1.0 sigma units. The rather acute foramen angle of -1.2 sigma units is present in this subject with the relatively high angle of mandibular basal prognathism.

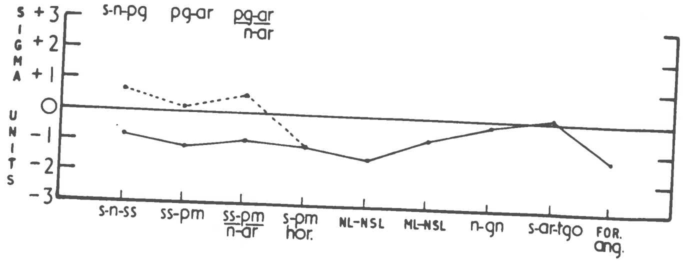
Maxillary alveolar prognathy is marked while the chin angle is small. These characteristics are in keeping with the observation that compensations in the form of the alveolar bone occur in cases of sagittal jaw base discrepancy so that the incisor relationship of this subject can be considered normal.

The morphological features associated with large relative mandibular prognathism in this subject are a discrepancy in jaw base lengths, an acute foramen angle and small inclinations between nasal, mandibular and nasion-sella lines.



489 ♂

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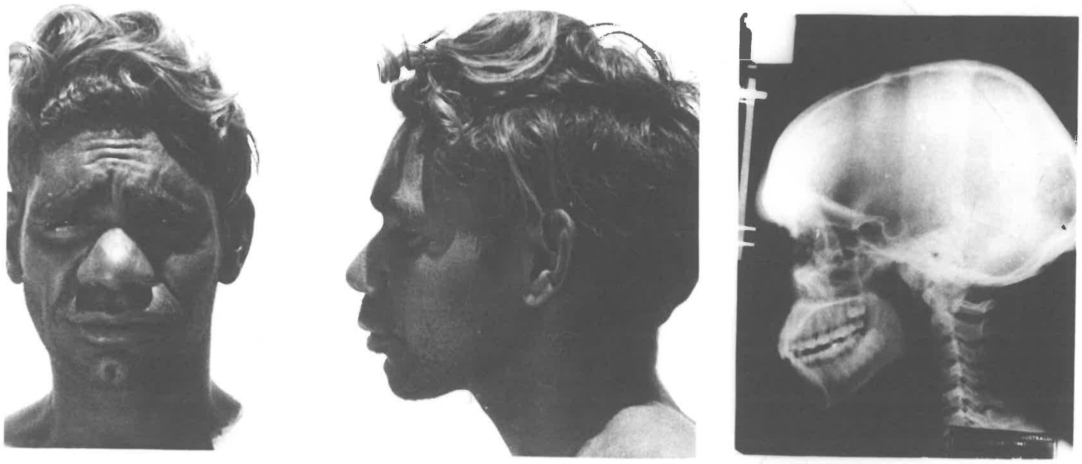
pg-ar
pg-ar / n-ar
s-n-ss
ss-pm
ss-pm / n-ar
s-pm hor.
NL-NSL
ML-NSL
n-gn
s-ar-tgo
FOR. ang.

Fig. 30.

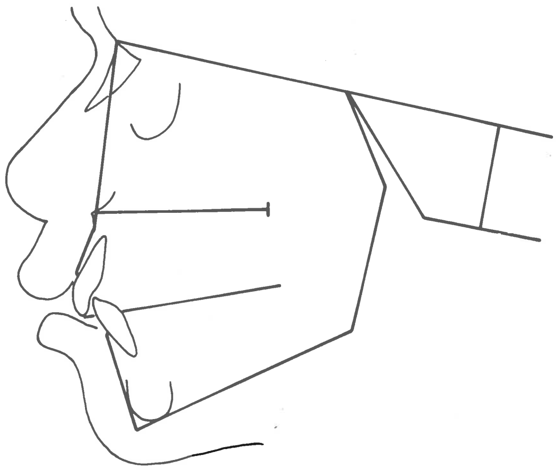
Subject 37 Age c. 18 years Fig. 31

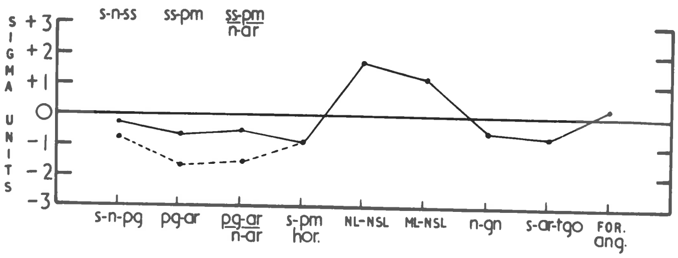
Small jaw bases in conjunction with near-average cranial base length are combined in subject 37. The jaw lengths relative to the cranial base are short and the maxillary protrusion has the value of -0.8 sigma units. The discrepancy in jaw base lengths appears to have been partly compensated by a small joint angle (-0.7 sigma units) so that disharmony in the sagittal jaw relation has been reduced. Nevertheless overbite and overjet values are higher than the means for the group. Associated features are marked inclinations between jaw bases and the nasion-sella line and a short anterior face height.

Jaw bases which are short both absolutely and in relation to the lateral cranial base as well as low maxillary protrusion are associated with low facial prognathism in subject 37. The joint angle is more acute than average for the group and would appear to partly compensate for the discrepancy in jaw base lengths.



37 ♂

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-2
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ss-pm
ss-pm / n-ar
s-n-pg
pg-ar
pg-ar / n-ar
s-pm hor.
NL-NSL
ML-NSL
n-gn
s-ar-tgo
FOR. ang.

Fig. 31.

Conclusions

Within the adult males of the group investigated, variations in basal prognathism occur in many ways. Both jaw bases may be in sagittal harmony, i.e. the angles of maxillary and mandibular basal prognathism are in accord with each other in the one individual. On the other hand discrepancies in the sagittal jaw relationship result when either of the angles of basal prognathism is small or large in relation to the other. Such discrepancies in the jaw bases may be reflected in the relationship of the incisor teeth, but compensation in the form of changes in alveolar development often occurs to varying degrees. As yet, the nature of variations within the bite has not been fully investigated and will require more extensive study in the future.

Of the many characteristics associated with the angles of basal prognathism, correlation coefficients and the examination of profile radiographs of all subjects suggest that the length relationships between the jaw bases and the lateral cranial base are of prime importance in determining the facial profile as indicated by the angles of basal prognathism. In a similar way the length relationship of upper and lower jaw bases to each other is a deciding factor related to harmony or disharmony in the sagittal jaw positions, with or without changes in tooth relationships.

Thus it can be said that the lengths of the jaw bases and particularly the jaw lengths relative to the cranial base length are important in establishing the degree of prognathism. However in contrast to the finding in Swedes, no strong associations were revealed between cranial base length or shape and the angles of prognathism, unless the variations caused by jaw lengths and maxillary protrusion were eliminated by partial correlation. One exception was the marked association between the angle of mandibular basal prognathism and the angle of inclination of the foramen magnum axis. An explanation is suggested on the grounds of close anatomical relationship between these parts of the skull through the temporomandibular joint, so that growth trends in the clivus region of the skull are reflected in the direction of forward displacement of the mandible during its growth. This point merits further investigation.

Other morphological features are associated with either maxillary or mandibular basal prognathism or in some cases with both. But although tempting, it is unwarranted to place any cause and effect relationship on such associations without detailed knowledge of growth patterns of the cranio-facial complex in the Australian aborigine. Complete information in this field is as yet unavailable.

A marked association exists between the forward protrusion of the maxillary complex (as revealed by the linear measurement s-pm hor.) and the angles of basal prognathism, so that a forwardly protruded upper jaw base is usually associated with high total facial prognathism as in subject 532 (Fig. 28). The reverse relationship may occur as in subject 421 (Fig. 27).

The relationship between jaw bases, maxillary protrusion and prognathism is not quite straightforward however since many other variables combine in different ways to alter the facial shape, and in many cases they appear to act as compensatory factors which maintain the sagittal jaw relationship, and hence tooth relationships, within a fairly close range of variation.

The face showing highly developed prognathism usually has a low morphological face height, and from this can be inferred that the length and height of the facial skeleton tend to vary inversely. Certain components of the anterior face show this relationship more precisely.

Again in the prognathic build the angles between nasal, mandibular and nasion-sella lines are usually small, so that the face tends to be more squarish than one showing low facial prognathism. This may be taken as an expression of the direction of facial growth away from the cranial base, during the formative period. In addition the forward displacement of the mandibular ramus away from the cranial base tends to increase total facial prognathism.

A more complete understanding of cranio-facial relationships will only be obtained by careful and controlled longitudinal growth studies by means of cephalometric radiography, dental cast measurement and somatometry - a formidable project when applied to an isolated group such as a Central Australian tribe which is in addition undergoing a changing environment.

CHAPTER VII

VARIATIONS IN FACIAL BUILD BETWEEN TWO ETHNIC GROUPS

Morphological differences between the various groups of mankind have been studied extensively by conventional methods of craniometry and somatometry, but X-ray cephalometry of living subjects has been somewhat neglected to make such comparisons.

BJÖRK (1950) compared the facial structures of young adult males, representative of Swedish and South African Bantu populations. Radiographic methods were employed to elucidate the extent and nature of differences in prognathism between the two groups. Compared with the Swedes, the Bantus had jaw bases which were longer in relation to the cranial base, a flatter cranial base and a more obtuse foramen angle. The ramus was inclined further backwards and the gonial angle was smaller in the Bantus than in the Swedes.

Björk considered that in the Swedes the relatively shorter cranial base length plus the greater cranial base deflection partly compensated for the reduction in jaw size, so that there was little difference in basal prognathism between the groups. Björk's final conclusion was that differences in jaw size were the dominant factors in deciding relative prognathism in Swedes and Bantus.

CRAVEN (1958) compared Australian aborigines with Swedes and drew attention to the marked alveolar prognathism in the aborigine and the associated smaller lateral cranial base angle (n-s-ar) and more obtuse joint angle (s-ar-tgo). A marked similarity in the upper faces of both groups led Craven to suggest a uniformity in upper face which could be characteristic of all human populations.

With the data now available it is of interest to make a more complete comparison of cranial base and facial structures in Australian aborigines and other groups modified by greater genetic admixture and a more refined environment. Only one such group, the Swedish male, has been studied by the methods used in the present investigation in sufficient detail to enable comparisons to be made.

In the present chapter, the data relating to Swedish males have been obtained from four separate studies by

BJÖRK (1947), LINDEGÅRD (1953), BJÖRK and PALLING (1954) and BJÖRK (1955). Since the subjects and methods used in these studies were similar it is reasonable to use data from each source.

In order to compare linear means obtained from different groups of subjects, all linear measurements should be compensated to the same scale of radiographic enlargement. On the radiographs obtained at Yuendumu, linear variables situated in the median sagittal plane were enlarged by 8.3 per cent, but this enlargement was compensated when measurements were taken (see Chap. II). According to the anode-median sagittal plane-film distances used in the Swedish investigations, linear variables in the median sagittal plane were subject to 5.8 per cent enlargement. Both Björk and Lindegård mention enlargement factors of approximately 6 per cent, which were not corrected in the presentation of their linear mean values.

Before comparisons were made, linear means of Swedish subjects were compensated to the same scale of enlargement as those of the aborigines. Thus the values listed for the two ethnic groups should be reasonably close to true un-enlarged values. The stated means and corrected means (Columns 4 and 5 of TABLE 28) are supplied in the table of comparisons, but standard deviations for the Swedish material have not been corrected. Since angular measurements are not subject to serious distortion or enlargement with varying radiographic distances, these do not require correction.

The ideal method for comparing different groups by X-ray cephalometry would be to ensure identical enlargement factors, but as yet no common standards are employed. Even so the method used in the present section is sufficiently accurate to enable linear dimensions to be compared. It should be borne in mind that discrepancies can occur in comparisons of laterally situated structures. For example the median sagittal projection of the mandibular rami depends to some extent on the bigonial diameter even if X-ray distances are constant. If the bigonial diameters of two groups differ greatly, then radiographic measurements are not necessarily identical with true measurements. For this reason all comparisons discussed are based on mean values of sagittal plane projections of structures, whether they are situated in that plane or laterally.

Results

A composite diagram constructed from mean values for Australian and Swedish young adult males is shown in

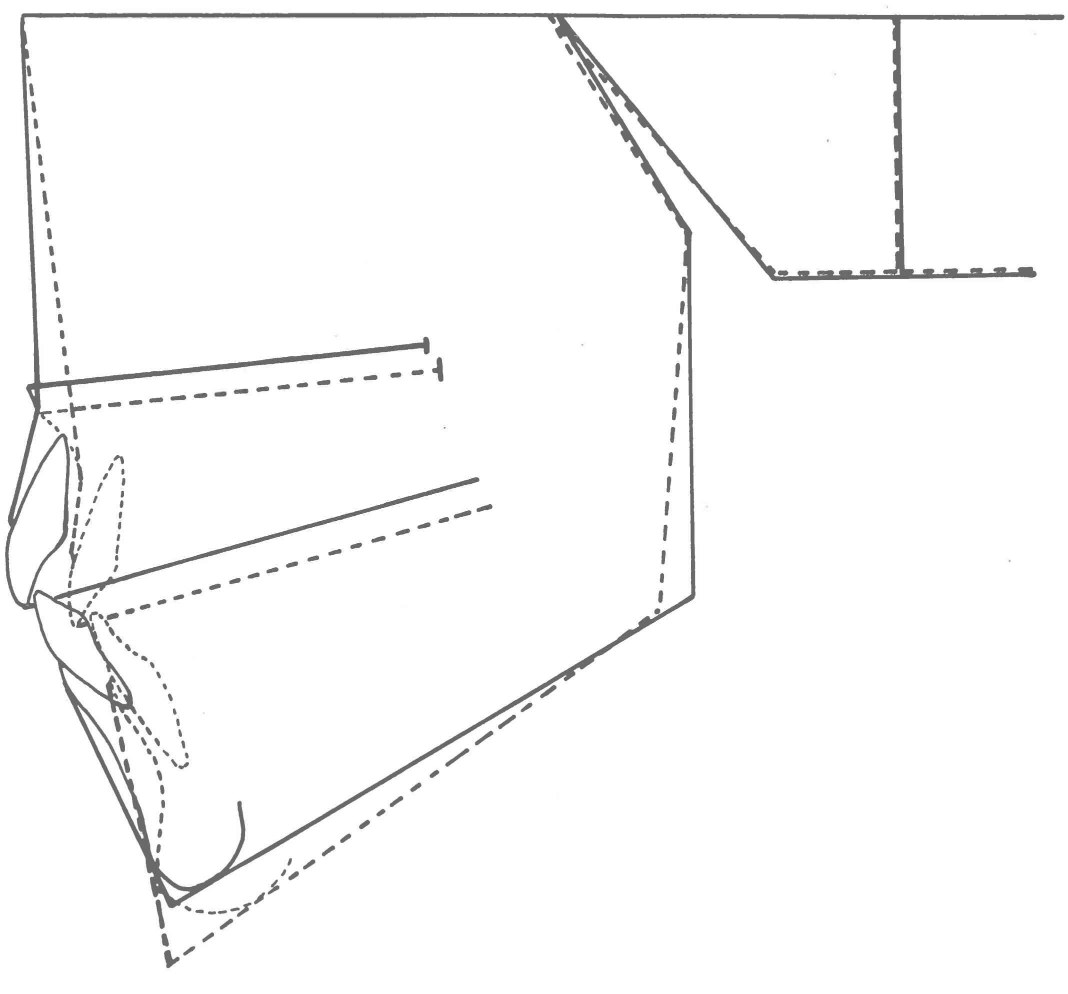

Fig. 32. Comparison of the mean facial outlines of young adult male Central Australian aborigines (———) and Swedes (-----). Linear dimensions have been drawn to the same scale.

TABLE 27

Comparison of angular measurements obtained from 31 young adult Australian males and young adult Swedish males. Means and standard deviations are given.

Variable	Australian		Swede			
	Mean	s	Mean	s	Author *	No.
s-n-ss	87.1	3.8	82.4	3.6	(2)	243
s-n-pg	81.3	4.0	80.7	3.9	(2)	243
s-n-pr	91.8	3.6	84.8	4.1	(1)	281
s-n-id	86.5	3.8	82.3	4.4	(1)	281
pr-n-ss	4.6	1.8	2.3	1.0	(3)	243
id-n-pg	5.2	1.5	0.9	1.7	(3)	243
n-ss-pg	169.1	5.2	177.7	6.1	(3)	243
ss-n-pg	5.8	2.6	1.3	3.0	(3)	243
s-ar-tgo	149.6	9.0	143.3	6.9	(1)	281
ar-tgo-gn	120.7	5.8	130.9	7.3	(1)	281
CL-ML	85.0	4.7	64.2	6.4	(1)	281
IL_s-OL	59.4	5.6	60.3	4.7	(3)	243
IL_i-OL	65.2	5.9	69.8	6.6	(3)	243
IL_s-IL_i	124.6	9.0	130.1	9.0	(3)	243
NSL-NL	6.9	3.4	7.6	3.1	(2)	243
NSL-ML	32.0	4.7	35.4	6.2	(2)	243
NL-OL	8.9	4.5	8.7	3.6	(2)	243
ML-OL	16.2	5.3	19.6	5.3	(2)	243
NL-ML	25.1	3.9	28.0	5.8	(2)	243
n-s-ba	129.6	4.2	131.8	4.6	(2)	243
n-s-ar	122.0	5.1	123.1	5.3	(1)	281
Foramen angle	91.7	5.1	91.8	5.1	(4)	224

* (1) BJÖRK, 1947. (3) BJÖRK AND PALLING, 1954.
(2) LINDEGÅRD, 1953. (4) BJÖRK, 1955.

TABLE 28

Comparison of linear measurements obtained from 31 young adult Australian males and young adult Swedish males. Means and standard deviations are shown. The means but not the standard deviations for the Swedish subjects have been corrected for radiographic enlargement.

Variable	Australian		Swede				
	Mean	s	Stated Mean	Corrected Mean	s	Author*	No.
ar-tgo	48.7	4.3	53.2	50.2	5.2	(1)	281
pg-tgo	80.7	3.8	80.7	76.3	5.2	(1)	281
ss-pm	52.2	2.8	52.8	49.9	2.9	(2)	243
s-pm hor.	17.1	2.5	14.0	13.2	3.1	(2)	243
s-pm vert.	42.9	2.5	48.3	45.6	2.5	(2)	243
n-gn	119.2	7.0	128.9	121.8	6.3	(2)	243
n-sp	49.4	3.9	56.3	53.2	3.0	(2)	243
sp'-gn	69.8	5.0	72.8	68.8	5.6	(2)	243
sp'-is'	32.5	2.7	30.8	29.1	2.9	(2)	243
is'-gn	37.3	3.6	42.3	40.0	3.6	(2)	243
Overbite	1.7	2.1	2.0	1.9	2.0	(1)	281
Overjet	2.5	2.0	3.0	2.8	2.9	(1)	281
n-s	70.5	3.1	73.9	69.8	3.3	(2)	243
s-ba	45.5	3.2	48.9	46.2	2.8	(2)	243
n-ba	105.4	4.2	112.0	105.9	4.4	(4)	234
s-ar	33.4	3.3	37.0	35.0	3.3	(1)	281
n-ar	92.2	3.7	98.1	92.7	4.4	(1)	281

*(1) BJÖRK, 1947. (2) LINDEGÅRD, 1953.
(4) BJÖRK, 1955.

Fig. 32 in which compensation has been made for different enlargement factors. Mean values and standard deviations of measurements relating to both groups are listed in TABLES 27 and 28.

Discussion

When the mean values for the two groups were compared, the most striking feature noticed was the relative protrusion of the mid-facial structures in the Australian aborigines. The prognathic regions involved the maxillary basal point subspinale and the alveolar points of both jaws (prosthion and infradentale). The mean angles of basal mandibular prognathism were almost identical for Swedes and Australians, but associated with the mid-facial prognathism in the aborigines were a more acute profile angle (n-ss-pg), a greater angle of sagittal jaw relation (ss-n-pg) and greater angles of alveolar prognathy.

The angle between the ramus and the lateral cranial base was more obtuse in the aborigines so that the mandible had a rearwards inclination compared with that of the Swedes. The gonial angle was smaller and the chin angle larger in the Australian subjects.

The more prognathic alveolar region of the aborigines was reflected in the smaller interincisal angle in this group. Although the groups hardly differed in the mean angle of upper incisor angulation, the lower incisors were more procumbent in the aborigines. The impression was gained that the greater angle of sagittal jaw relation in the aborigines (5.8 degrees as against 1.3 degrees in Swedes) was compensated largely by the 4.6 degrees increased procumbency of the lower incisors compared with the white subjects.

With the exception of the mean angle NL-OL which was similar in both groups, the other angles expressing inclinations of the nasal, mandibular and occlusal lines to each other and to the nasion-sella line were more acute in the aborigines. This indicates that the jaw bases and the anterior cranial base were more parallel in the Australian subjects, resulting in a squarer face than that of the Swedes.

As far as could be judged by the mean values of linear variables, the maxillary base and the mandibular length were slightly larger in the aboriginal subjects, whereas the mandibular ramus was shorter in this group. Protrusion of the maxillary complex, as denoted by the measurement s-pm hor., was greater in the aboriginal males and when combined with the slightly longer upper jaw base of this group, resulted in point subspinale being more anterior than in the Swedes. The greater maxillary protrusion appears to be an important factor related to the mid-facial prognathism of the Australian subjects when compared with the caucasian group.

The total morphological face height was slightly less in the aborigines as judged by mean values, but greater differences resides in the various components of the anterior face. Upper face height and mandibular lower face height were smaller in the aborigines, whereas maxillary lower face height was somewhat greater in this group, and the mean values for total lower face height were similar in both groups. The height of the posterior face, as measured by s-pm vert., was also shorter in the aborigines.

No great differences were revealed in cranial base dimensions between the two groups. The cranial base angles n-s-ba and n-s-ar were slightly more acute in the aborigines, but there was remarkable uniformity in mean values of linear measurements expressing the size of the cranial base, and in the foramen angle which expresses the inclination of the foramen magnum to the cranial base.

This finding differed from that expected from BJÖRK'S (1950) observation that cranial base and foramen angle differed between Swedes and the more prognathic Bantus.

The shape of the cranial base in man as well as the inclination of the foramen magnum are phylogenetically associated with the attainment of bipedal upright stature, which preceded cerebral enlargement in human evolutionary history. Subsequent changes in jaw size may have been associated with changes in cranial base shape although it seems reasonable to assume that cranial base shape and the inclination of the foramen magnum are primitive human characteristics which would therefore be subject to little variation between present living groups.

Although it was difficult to compare inter-group variability of characteristics since the number of aboriginal subjects available for examination was relatively low, the 31 subjects comprised almost the entire male population within the specified age limits and the ranges given should be reasonably accurate at least for living Wailbri tribesmen.

Although theoretical ranges as indicated by the standard deviations showed little difference between aborigines and Swedes, the observed ranges in nearly every case were much lower in the aboriginal subjects, both for linear and for angular measurements. Lower variability of physical characteristics would be expected in a geographically isolated group such as the Yuendumu natives who until recently lived under tribal conditions.

Conclusions

Variations in the morphological features between Australian aborigines and Swedes were no greater than variations within either group considered separately. Because of this overlap in the ranges of variation of the two groups, there was no single physical measurement which could be taken as characteristic of either group.

However mean values indicated certain differences between Australians and Swedes. The most striking feature was the marked mid-facial prognathism of the aboriginal subjects. This prominence which involves the maxillary base and the alveolar regions of both jaws, was associated with jaw bases which were slightly larger in the aboriginal males. One feature which appeared to be significant in the production of mid-facial prognathism was the greater maxillary protrusion of the aborigines.

The marked alveolar prominence of the Australian native was almost certainly associated with the large teeth and capacious dental arches of this ethnic group (CAMPBELL, 1925). In the aborigines marked procumbency of the lower incisors and the large chin angle partly compensated for the relatively large angle of sagittal jaw relation in this group compared with the Swedes.

The mean facial profile of the aborigines was squarer than that of the Swedes, being associated with a ramus more obtusely inclined to the cranial base, a slightly lower anterior face height and greater parallelism between nasal, mandibular and nasion-sella lines.

Similarities of the mean values and standard deviations of cranial base measurements in the two groups considered was contrary to the differences in these measurements between Negroes and Europeans noted by CAMERON, (1924) and BJÖRK, (1950).

It would appear that the greater maxillary protrusion, large teeth and more capacious dental arches were dominant characteristics associated with mid-facial prognathism in Wailbri males compared with Swedes.

There were no great differences between Swedes and aborigines in cranial base morphology, but the jaw base lengths relative to the lateral cranial base length were slightly greater within the native subjects.

CHAPTER VIII

GENERAL DISCUSSION AND CONCLUSIONS

Thirty years ago radiographic cephalometry was introduced as a scientific method of orthodontic diagnosis and morphological research. Since that time many investigators have employed the method to supplement knowledge of cranio-facial relationships in population groups and to investigate growth trends in various parts of the skull. The majority of such investigations have been concerned with variations in cranio-facial structures within modern caucasoid groups of children at various ages, but several longitudinal studies have provided knowledge of growth patterns of the jaws and associated parts.

Comparative aspects of cranio-facial morphology as revealed by X-ray studies of different population groups have been largely neglected. HUNT (1959, 1961) has ably shown the value of comparative data in the study of changes in the jaws and teeth of modern man living in a civilised environment, and the effect of such changes on the development of occlusion and the aetiology of malocclusions.

The first stage of the radiographic investigation of a geographically isolated group of Central Australian aborigines, living under near tribal conditions, was commenced in January 1961. Besides providing supplementary information for use in current research into the mode of tooth occlusion within this tribe, such a study afforded an opportunity to obtain standards relating to Central Australian aborigines, which could be compared with other groups investigated by similar methods. One advantage of the present study is that the subjects were less modified by genetic admixture and modern environmental influences than most caucasoid groups. The main disadvantages were the relatively small number of subjects available for investigation and the technical and other difficulties involved in cephalometric radiography in the field.

The report deals with the data so far obtained from the examination of profile radiographs of 31 young adult male and 27 young adult female members of the Wailbri tribe. It is convenient to discuss the results under the general headings of:

Basal and alveolar prognathism;
Sex differences in cranio-facial build;
Variations in prognathism within the male subjects;
Differences between Australian aborigines and Europeans.

BASAL AND ALVEOLAR PROGNATHISM

The most striking characteristic observed in the Australian aboriginal males and females studied was the marked prominence of the alveolar regions of the jaws compared with other groups. This feature, which was apparent whether the Björk's angles of prognathism or the gnathic index of Flower were used, was also noted in the data obtained from Bjork's study of South African Bantus.

In contrast to the marked alveolar prominence of the aboriginal and Bantu subjects was the similarity in all the groups compared (Australians, Swedes, Japanese and Bantus) of the angle of mandibular basal prognathism. Maxillary basal prognathism if measured by the angle s-n-sp was also remarkably constant in all groups, but the use of the angle s-n-ss brought out ethnic group differences, corresponding to the differences observed in the upper alveolar region.

SEX DIFFERENCES IN CRANIO-FACIAL BUILD

Many observers have reported that within a single population group, females tend to be more prognathous than males. This sex difference was first shown to apply to Australian aborigines by ABBIE (1947). In the present study the sex difference was most apparent in the maxillary alveolar region. Sex differences in mean values of maxillary alveolar prognathism were significant only when the gnathic index was used to measure this characteristic. The index is a measure of the size relationship between the upper facial length, measured from basion to prosthion, and the cranial base length, measured from basion to nasion. In both sexes upper facial length and cranial base length were significantly correlated, indicating that high values of one were usually associated with high values of the other. However identical changes in upper facial and cranial base lengths would cause little variation in the angle of maxillary prognathism s-n-pr. Disproportional changes in these lengths are reflected as an increase or a decrease in the angle s-n-pr, but are more apparent in the length relationship expressed by the gnathic index.

The greater maxillary alveolar prognathism within the female subjects was associated with an upper facial length which was larger in relation to the cranial base than it was in males. Accompanying alveolar prognathism in the females were more procumbent incisors, especially in the mandible. Since alveolar development is intimately associated with tooth size, the relationships between

dental arch dimensions and lengths of the jaw bases are important and require investigation to provide additional information of sex differences in prognathism.
A preliminary report dealing with tooth dimensions within the Wailbri people has been prepared (BARRETT, BROWN and McDONALD, 1962a).

The data revealed that within the group studied sex differences in the skeletal profile reside predominantly in size rather than shape of the facial components. In addition most measurements whether linear or angular were more variable in males than in the females. This observation may be explained by the longer duration of skeletal growth in the males.

The finding that sex differences were more apparent in the lower face is of interest. There appears to be a difference between sexes in the growth rate of the lower face, but for confirmation of this, data from longitudinal studies are required. Such a sex difference in growth rates of the facial components would also explain the significant difference between males and females in the proportion of upper face height to total face height, this ratio being smaller in males.

VARIATIONS IN PROGNATHISM WITHIN THE MALE SUBJECTS

In general the observations which BJÖRK (1947) made after examining male Swedes may be applied in considering the nature of variations in prognathism within male Central Australian aborigines. However certain points require comment.

The relationship between cranial base shape and size and facial prognathism was not as straightforward in the aborigines as in the Swedes. A short cranial base or an increased cranial base deflection were only slightly associated with increased prognathism within the Australian males, but actual jaw lengths, jaw lengths relative to the cranial base and the extent of maxillary protrusion appeared to be dominant factors determining the degree of facial prognathism. Thus, within the natives studied, Björk's conclusion that the varying degrees of prognathism were not very intimately associated with the size of the jaws did not apply.

The association between mandibular basal prognathism and the angulation of the foramen magnum axis was interesting since it suggested that relationships between the balance of the head upon the cervical spine and the sagittal position of the lower jaw may exist during ontogenetic development. Similar relationships were observed in phylogenetic development by DuBRUL and SICHER (1954).

Within the males, total facial prognathism existed when both jaw bases were harmonious in their sagittal position and both angles of basal prognathism were high. Usually associated with total facial prognathism were jaw bases which were long both absolutely and in relation to the lateral cranial base, and a protruded upper jaw base. Subjects who exhibited high total facial prognathism generally had a reduced morphological face height and more parallel nasal, mandibular and nasion-sella lines.

Reverse conditions existed in males showing low total facial prognathism (i.e. jaw bases harmonious in their sagittal position but relatively retruded). In these subjects maxillary protrusion was low, morphological face height was increased and the nasal, mandibular and nasion-sella lines were more severely inclined to each other.

Differences in the extent and direction of facial growth away from the cranial base may explain the variations in prognathism between different subjects. Thus if growth of the upper face has a strong forward component the maxillary base tends to rotate somewhat, and at the same time the anterior face height is reduced, posterior face height is lengthened and anterior protrusion of the face is increased. The mandible becomes more acutely inclined to the lateral cranial base so that facial morphology in the adult shows high total facial prognathism, short anterior face height and parallelism between jaw bases and nasion-sella line.

Since more variables were associated with mandibular basal prognathism than with maxillary basal prognathism, it was not surprising that discrepancies occurred in the sagittal jaw relationships. An upper jaw base which was long in relation to the mandibular corpus length was usually combined with relative maxillary prognathism, while the reverse relationship existed in subjects showing relative mandibular prognathism.

Although the jaw bases varied in their sagittal relationship to each other, such discrepancies were not always reflected in incisor positions. Disharmony in the length relationship of the jaw bases was compensated by increased or reduced alveolar prognathy, which maintained adequate incisor relations. The interincisal angle was not correlated very strongly with relative prognathism which further confirmed that marked variations in incisal relations do not necessarily follow jaw base discrepancies. In this regard, future investigations may clarify the general associations between tooth diameters and the length of the jaw bases within Yuendumu aborigines.

Although no detailed study was done on the nature of variations in prognathism within the female members of the Wailbri tribe, examination of their head radiographs indicates that such variations follow similar patterns to those revealed within the males.

DIFFERENCES BETWEEN AUSTRALIAN ABORIGINES AND EUROPEANS

When data obtained from Swedish males was compared with the standards for linear and angular variables of the Yuendumu natives, the most striking feature was the greater mid-facial prognathism of the aborigines but associated with similarity in mandibular basal prognathism. Cranial base dimensions were similar in both groups and furthermore the mean upper jaw lengths did not vary as much as the difference in maxillary basal prognathism would suggest. It follows that factors apart from absolute jaw length and cranial base form were associated with the pronounced mid-facial prominence of the Australian aborigines compared with Swedes.

In the aboriginal subjects it is likely that mesio-distal tooth diameters, which are large compared with most population groups, are main factors associated with their marked alveolar prognathism. This latter concept finds support in the work of ABBIE (1952). The more pronounced maxillary protrusion of the native subjects provides an explanation for their greater maxillary basal prognathism, if this character is measured from subspinale, and also incidently is in keeping with the observation that although the length of the anterior nasal spine is subject to great variation between groups, this variation is not seen in the sagittal position of spinal point (i.e. the angle s-n-sp was remarkably constant in all groups compared).

The general impression received was that in Australian aborigines, facial growth may be directed along a more anterior path than it is in Swedes. Such a direction would explain many of the differences in facial form between the two groups considered. Data to be obtained from a longitudinal growth study of Yuendumu children are essential to clarify cranio-facial relationships within this tribe and to provide additional evidence of similarities and differences between the Australian aborigines and other population groups.

CONCLUSIONS

The investigation provided X-ray cephalometric standards, which were previously unavailable, for young adult Central Australian aborigines, and at the same time allowed the following conclusions to be made:

1. Radiographic methods of cranial mensuration provide a satisfactory technique for investigations of cranio-facial morphology in living population groups. The errors of estimation involved in the present study were low in magnitude compared with mean values and natural variation of measurements between subjects.

2. The alveolar portions of the jaws were prognathous in aborigines when compared with Swedes or Japanese. This characteristic, which was also apparent in South African Bantus, was revealed by the use of either the Björk angles of prognathism or the gnathic index of Flower. There was little difference between the groups compared in the angles of mandibular basal prognathism, or in the angles s-n-sp but differences were apparent when the angle s-n-ss was used to measure maxillary basal prognathism. These differences were in keeping with differences between groups in the degree of upper alveolar prognathism.

3. The facial skeletal profiles of male and female subjects of the group studied were similar in shape, but male linear variables were usually significantly larger. Most measurements obtained from males were more variable than similar measurements of females. Many of the sex differences reported could probably be explained by differences in growth rates of the facial components between males and females.

4. The maxillary alveolar region was shown to be more prognathous in females than it was in males. The greater prognathism in females was related to an upper facial length which was longer in relation to the cranial base length than it was in males.

5. Morphological characteristics combined in various ways to effect differing degrees of facial prognathism within the male subjects. The absolute jaw lengths, jaw lengths in relation to the lateral cranial base length and the protrusion of the maxillary base appeared to be dominant factors determining the degree and type of facial prognathism.

6. It is suggested that differences in the direction as well as the extent of facial growth away from the cranial base may give rise to variations in prognathism, since the prognathic face was usually associated with

a small anterior face height and small inclinations between nasal, mandibular and nasion-sella lines.

7. Although discrepancies occurred in the sagittal jaw base relationships these were not usually reflected in incisal positions. Compensatory mechanisms in the form of changes in the amount of alveolar development maintained incisor relationships within acceptable limits. In European subjects it is well known that sagittal jaw base discrepancies are among the causes of malocclusions, and it would appear that compensatory mechanisms are not always as adequate in this group as they are in aborigines.

8. Male members of the tribe differed from Swedish males in the degree of mid-facial prognathism. The more prognathous aboriginal face was combined with slightly longer jaw bases, greater maxillary protrusion and larger mesio-distal tooth diameters. Anterior facial height components tended to be shorter in the aborigines, but there was remarkable similarity in cranial base size and shape of the two populations.

9. Further studies are planned to supplement the information obtained so far. In this regard a longitudinal study of cranio-facial growth in aboriginal children would be most valuable. Such a study has been commenced and will continue for some time.

APPENDIX

TABLE 29

Non-significant correlations between the angles of basal prognathism, the residuals Fs-n-ss(s-n-pg) and Fs-n-pg(s-n-ss) and cranio-facial variables.

Variable	s-n-ss	s-n-pg	F s-n-ss (s-n-pg)	F s-n-pg (s-n-ss)
n-ba	-0.30	-	+0.05	-0.31
ss-pm	-	+0.16	-	-0.32
ar-tgo	+0.03	+0.29	-0.27	-
pg-tgo	+0.21	+0.25	+0.02	+0.17
pg-ar	+0.22	-	-0.21	-
s-ar-tgo	-	-	+0.02	-0.31
ar-tgo-tgn	+0.14	+0.22	-0.04	+0.15
CL-ML	-0.04	-	-	-
s-pm hor.	-	-	+0.21	+0.15
s-pm vert.	+0.09	-0.02	+0.17	-0.14
s-ar hor.	-0.01	-0.02	+0.02	-0.05
s-ar vert.	+0.20	+0.13	+0.15	+0.10
overbite	+0.03	-0.24	+0.33	-
overjet	-0.14	-	+0.24	-
ILs-ILi	+0.09	+0.03	+0.10	-0.05
n-s	-0.20	-0.23	-0.04	-0.10
s-ba	-0.18	-0.32	+0.11	-0.28
n-s-ba	-0.10	-0.18	+0.06	-0.17
s-ar	+0.12	+0.06	+0.11	-0.06
n-ar	-0.18	-0.21	-0.02	-0.12
n-s-ar	-0.08	-0.06	-0.06	-0.01
n-ba	-0.30	-	+0.05	-0.31
Foramen angle	-0.23	-	+0.23	-

TABLE 29 (contd.)

Non-significant correlations between the angles of basal prognathism, the residuals Fs-n-ss(s-n-pg) and Fs-n-pg(s-n-ss) and cranio-facial variables.

Variable	s-n-ss	s-n-pg	F s-n-ss (s-n-pg)	F s-n-pg (s-n-ss)
n-gn	-	-	-0.16	-0.17
n-sp	-0.32	-	+0.24	-
sp'-gn	-	-0.17	-	+0.24
sp'-is'	-	-	-0.21	-0.11
is'-gn	-0.17	+0.12	-	-
NL-NSL	-	-	+0.10	-
ML-NSL	-	-	-0.04	-
NL-OL	-0.20	-	+0.17	-
ML-OL	-0.06	+0.15	-0.27	+0.31
NL-ML	-0.29	-0.23	-0.17	0.00
ss-pm/n-ar	-	-	-	-0.27
ss-pm/pg-tgo	+0.25	-0.08	-	-
pg-tgo/n-ar	+0.33	-	+0.04	+0.24
pg-ar/n-ar	-	-	-0.21	-
ar-s-ba	-0.01	-0.18	+0.21	-0.27

GLOSSARY OF REFERENCE POINTS AND LINES

Reference points

ar - articulare
ba - basion
gn - gnathion
tgo-gonial tangent point
id - infradentale
ii - incision inferius
io - projection of ii on OL
is - incision superius
n - nasion
or - orbitale
pg - pogonion
po - porion
pr - prosthion
pm - pterygomaxillare
s - sella
sp - spinal point
ss - subspinale

Reference lines

NSL - nasion-sella line
NSP - nasion-sella perpendicular
NL - nasal line
OL - occlusal line
ML - mandibular line
CL - chin line
IL_s - upper incisor axis
IL_i - lower incisor axis
FH - radiographic Frankfort horizontal

GLOSSARY OF ANGULAR AND LINEAR MEASUREMENTS

Facial and alveolar prognathism

s-n-ss - maxillary basal prognathism
s-n-pr - maxillary alveolar prognathism
s-n-pg - mandibular basal prognathism
s-n-id - mandibular alveolar prognathism
ss-n-pg - sagittal jaw relation
pr-n-ss - maxillary alveolar prognathy
id-n-pg - mandibular alveolar prognathy
n-ss-pg - profile angle
ba-pr - upper facial length

Upper and lower jaws

ss-pm - maxillary length
ar-tgo - ramus height
pg-tgo - corpus length
pg-ar - total mandibular length
ar-tgo-gn - gonial angle
CL-ML - chin angle
s-ar-tgo - joint angle
s-pm hor. - maxillary protrusion
s-pm vert. - posterior upper face height
s-ar hor.
s-ar vert.

GLOSSARY OF TERMS (contd.)

Inclinations of the jaw bases

NL-NSL - nasal line to nasion-sella line
ML-NSL - mandibular line to nasion-sella line
NL-OL - nasal line to occlusal line
ML-OL - mandibular line to occlusal line
NL-ML - nasal line to mandibular line

Facial heights

n-gn - morphological face height
n-sp - upper face height
sp'-gn - total lower face height
sp'-is' - maxillary lower face height
is'-gn - mandibular lower face height

Incisor relationships

IL_s-OL - upper incisor axis to occlusal line
IL_i-OL - lower incisor axis to occlusal line
IL_s-IL_i - interincisal angle
ii-io - overbite
is-io - overjet

Cranial base

n-ba - total median cranial base length
n-ar - total lateral cranial base length
n-s - anterior cranial base length
s-ba - posterior cranial base length
s-ar - posterior lateral cranial base length
n-s-ba - median cranial base angle
n-s-ar - lateral cranial base angle
Foramen angle - inclination of the foramen magnum axis to the nasion-sella line

BIBLIOGRAPHY

ABBIE, A.A. 1947. Headform and human evolution. J. Anat., 81: 233-258.

- - 1952. A new approach to the problem of human evolution. Trans. Roy. Soc. S. Aus., 75: 70-88.

- - 1957. Metrical characters of a Central Australian tribe. Oceania, 27: 220-243.

- - 1961a. Recent field work on the physical anthropology of Australian aborigines. Austral. J. Science, 23(7): 210-211.

- - 1961b. A preliminary survey of the growth pattern of Central Australian males. Oceania, 31(3): 215-221.

ABBIE, A.A. and ADEY, W.R. 1953a. Pigmentation in a Central Australian tribe, with special reference to fair-headedness. Am. J. Phys. Anthrop., 11: 339-360.

- - 1953b. Ossification in a Central Australian tribe. Human Biol., 25: 265-278.

- - 1955. The non-metrical characters of a Central Australian tribe. Oceania, 25: 198-207.

ADAMS, J.W. 1940. Correction of error in cephalometric roentgenograms. Angle Orthodont., 10: 3-13.

BAILEY, N.T.J. 1959. Statistical methods in biology. New York: John Wiley and Sons Inc.

BAMBHA, J.K. 1961. Longitudinal cephalometric roentgenographic study of face and cranium in relation to body height. J.A.D.A., 63: 776-799.

BARRETT, M.J. 1953a. Dental observations on Australian aborigines: Yuendumu, Central Australia, 1951-1952. Austral. J. Den., 57: 127-138.

- - 1953b. X-occlusion. Dent. Mag. and Oral Topics, 70: 279.

- - 1956. Dental observations on Australian aborigines: water supplies and endemic dental fluorosis. Austral. D.J., 1: 87-92.

- - 1957a. Serial casts of Australian aboriginal children. Austral. D.J., 2: 74.

- - 1957b. Dental observations on Australian aborigines: tooth eruption sequense. Austral. D.J., 2: 217-227.

- - 1958. Dental observations on Australian aborigines: continuously changing functional occlusion. Austral. D.J., 3: 39-52.

- - 1960. Parafunctions and tooth attrition. In Parafunctions of the masticatory system (Bruxism) - Report of a panel discussion. Ed. D. Lipke and U. Posselt. J. West. Soc. Periodont., 8(4): 133-148.

BARRETT, M.J., BROWN, T. and MACDONALD, M.R. 1962a. Dental observations on Australian aborigines: mesio-distal crown diameters of permanent teeth. To be published.

- - 1962b. Dental observations on Australian aborigines: a radiographic study of prognathism. To be published.

BJÖRK, A. 1947. The face in profile. Svensk Tand-lakare Tskr., Suppl. 40:5B. Lund: Berlingska Boktryckeriet.

- - 1950. Some biological aspects of prognathism and occlusion of the teeth. Acta Odont. Scandinav., 9: 1-40.

- - 1951. The nature of facial prognathism and its relation to normal occlusion of the teeth. Am. J. Orthodont., 37(2): 106-124.

- - 1953. Variability and age changes in overjet and overbite. Am. J. Orthodont., 39(10): 779-801.

- - 1954. Cephalometric X-ray investigations in dentistry. Inter. D.J., 4: 718-744.

- - 1955a. Facial growth in man, studied with the aid of metallic implants. Acta Odont. Scandinav., 13(1): 9-34.

BJÖRK, A. 1955b. Bite development and body build. Dent. Rec., 75: 8-19.

- - 1955c. Cranial base development. Am. J. Orthodont., 41(3): 198-225.

- - 1960. Introduction to orthodontics. Ed. A. Lundstrom. Chap. 7. New York: McGraw-Hill Book Co. Inc.

- - 1962. Personel communication by courtesy of M.J. Barrett.

BJÖRK, A. and PALLING, M. 1954. Adolescent changes in sagittal jaw relation, alveolar prognathy, and incisal inclination. Acta Odont. Scandinav., 12(3): 201-232.

BJÖRK, A., JENSEN, E., and PALLING, M. 1956. Mandibular growth and third molar impaction. Acta Odont. Scandinav., 14(3): 231-272.

BOAS, F. 1940. Race, language and culture. New York: Macmillan.

BRASH, C. 1924. The growth of the jaws, normal and abnormal in health and disease. London: The Dental Board of the United Kingdom.

BROADBENT, B. 1931. A new X-ray technique and its application to orthodontia. Angle Orthodont., 1: 45-66.

- - 1937. Bolton standards and technique in orthodontic practice. Angle Orthodont., 7: 209.

BROCA, P. 1862. Sur les projections de la tete et sur un nouveax procede de cephalometrie. Bull. de la Soc. d'Anthrop. de Paris. 3: 514-544. Cit. TOPINARD (1890).

- - 1872. Les Caracteres Anatomiques de l'Homme Prehistorique. Mem. Soc. d'Anthrop. de Paris. 2: 146. Cit. TOPINARD (1890).

BRODIE, A.G. 1940. Some recent observations on the growth of the face, and their implications to the orthodontist. Am. J. Orthodont. and Oral Surg., 26: 741-757.

- - 1941. On the growth pattern of the human head from the third month to the eight year of life. Am. J. Anat., 68: 209-262.

BRILL, N., LAMMIE, G.A., OSBORNE, J. and PERRY, H.T. 1959. Mandibular positions and mandibular movements - A review. Brit. D.J., 106: 391-400.

BÜCHNER, L.W.G. 1912. Study on the prognathism of the Tasmanian aboriginal. Proc. Roy. Soc. Victoria (n.s.)., 25: 135-150.

CAMERON, J. 1926a. Craniometric studies No. 3. The correlation between nasion-pituitary and maximum glabello-occipital length of the skull. Am. J. Phys. Anthrop., 9: 334-338.

CAMERON, J. 1926b. Craniometric studies No. 4. The lengthening of the anterior portion of the cranial base in white races. Am. J. Phys. Anthrop., 9: 338-342.

- - 1930. Craniometric memoirs No. 3. The superior gnathic triangle. A new cranial triangle. Its significance in modern and fossil man, the anthropoids and lower mammals. J. Anat., 65: 122-136.

CAMPBELL, T.D. 1925. Dentition and palate of the Australian aboriginal. Adelaide: The Hassell Press. Keith Sheridan Foundation publication No. 1.

CAMPBELL, T.D., and BARRETT, M.J. 1953. Dental observations on Australian aborigines: a changing environment and food pattern. Austral. J. Den., 52: 1-6.

CAMPER, P. 1791. Dissertation sur les Differences reelles que presentent les Traits du Visage chez les Hommes de differents Pays et de differents Ages. Paris: Cit. TOPINARD (1890).

CAPELL, A. 1952. The Wailbri through their own eyes. Oceania. 23: 110-132.

CLELAND, J.B., and TINDALE, N.B. 1954. The ecological surroundings of the Ngalia natives in Central Australia and native names and uses of plants. Proc. Roy. Soc. S. Aust., 77: 81-86.

COTTON, W.N., TAKANO, W.S., and WONG, W.M.W. 1951. The Downs analysis applied to three other ethnic groups. Angle Orthodont., 21(4): 213-220.

CRAN, J.A. 1955. Notes on the teeth and gingivae of Central Australian aborigines. Austral. J. Den., 59: 356-361.

-- 1957. Notes on the teeth and gingivae of Central Australian aborigines. Austral. D.J., 2: 277-282.

-- 1959. Relationship of diet to dental caries. Austral. D.J., 4: 182-190.

-- 1960. The histological structure of the teeth of Central Australian aborigines and the relationship to dental caries incidence. Austral. D.J., 5: 100-104.

CRAVEN, A.H. 1958. A cephalometric investigation of Central Australian aborigines using a roentgenographic technique. Angle Orthodont., 28: 12-35.

DAHLBERG, G. 1940. Statistical methods for medical and biological students. London: George Allen and Unwin Ltd.

DAVIES, T.G.H., and PEDERSEN, P.O. 1955. The degree of attrition of the deciduous teeth and first permanent molars of primitive and urbanised Greenland natives. Brit. D.J., 99(2): 35-43.

DELATTRE, A., and FENART, R. 1960. L'hominisation du crane. Paris: Editions du Centre National de la Recherche Scientifique.

DOWNS, W.B. 1948. Variations in facial relationships: their significance in treatment and prognosis. Am. J. Orthodont., 34(10): 812-840.

- - 1952. The role of cephalometrics in orthodontic case analysis and diagnosis. Am. J. Orthodont., 38(3): 162-182.

- - 1956. Analysis of the dento-facial profile. Angle Orthodont., 26: 198-200.

DuBRUL, E.L., and SICHER, H. 1954. The adaptive chin. Springfield: Charles C. Thomas.

DUCKWORTH, W.L.H. 1904. Studies in anthropology. Cambridge: University Press.

FISHER, A.K. 1949. Some observations on the use of the term prognathism. J.A.D.A., 38: 611-626.

FENNER, F.J. 1939. The Australian aboriginal skull: Its non-metrical morphological characters. Trans. Roy. Soc. S. Aust., 63(2): 248-306.

FISHER, R.A. 1946. Statistical methods for research workers. Edinburgh: Oliver and Boyd.

FISHER, R.A., and YATES, F. 1957. Statistical tables for biological, agricultural and medical research. Edinburgh: Oliver and Boyd.

FLOWER, W.H. 1897. Catalogue of the specimens in the museum of the Royal College of Surgeons of England. Cit. CAMERON (1930).

FRANKLIN, J.B. 1952. Certain factors of aberration to be considered in clinical roentgenographic cephalometry. Am. J. Orthodont., 38(5): 351-368.

GARN, S.M. 1958. Statistics - a review. Angle Orthodont., 28(3): 149-165.

GRABER, T.M. 1954. A critical review of clinical cephalometric radiography. Am. J. Orthodont., 40(1): 1-26.

HALLETT, G.E.M. 1959. Inherent errors in cephalometric films and their reduction. Trans. Brit. Soc. Orthodont., Edition 1959: 1-10.

HARALABAKIS, H. 1954. Familial resemblances in cranio-facial osteology as revealed by cephalometric X-rays in Greek families. Abst. Am. J. Orthodont., 40(3): 233-234.

HEITHERSAY, G.S. 1961. Further observations on the dentition of the Australian aborigine at Haast's Bluff. Austral. D.J., 6(1): 18-28.

HERZBERG, F., and HOLIC, R. 1943. An anthropologic study of face height. Am. J. Orthodont. and Oral Surg., 29(2): 90-100.

HOFRATH, H. 1931. Die Bedeutung der Roentgenfern- und Abstandsaufnahme fur die Diagnostik der Kieferanomalien. Fortschr. d. Orthodont., 1: 232. Cit. BJÖRK (1947).

HUNT, E.E. Jr. 1959. The continuing evolution of modern man. Symposia Quant. Biol., 24: 245-254.

- - 1961. Malocclusion and civilization. Am. J. Orthodont., 47: 406-422.

HOYME, L.E. 1953. Physical anthropology and its instruments: an historical study. Southwest. J. Anthrop., 9(4): 408-430.

HUXLEY, Th. H. 1866. Uber zwei extreme Formen des menschlichen Schadels. Arch. f. Anthrop., Bd. 1: 481. Cit. OPPENHEIM (1928).

IHERING, Von H. 1872. Uber das Wesen Prognathie und ihr Verhaltnis zur Schadelbasis. Arch. f. Anthrop., 5: 359-407.

JONES, F. WOOD. 1938. The cervical vertebrae of the Australian native. J. Anat., 72(3): 411-415.

JØRGENSEN, J.B. 1953. The Eskimo Skeleton. Contributions to the physical anthropology of the aboriginal Greenlanders. København: C.A. Reitzels Forlag.

KAYUKAWA, H. 1957. Studies on morphology of mandibular overjet. J. Japan Orthodont. Soc., 16(2): 1-25.

KORKHAUS, G. 1936. Die Auswertung des Fernrontgenbildes in der Kieferorthopadie. Fortschr. d. Orthodont., 5. Cit. BJORK (1947).

KOSKI, K., and VIROLAINEN, K. 1956. On the relationships between roentgenologic-cephalometric lines of reference. Acta Odont. Scandinav., 14(1): 23-32.

KROGMAN, W.M. 1938. Dental arch form and facial growth pattern in healthy children from prehistoric populations. Am. D. Assoc. J. and Den. Cosmos, 25: 1278-1289.

- - 1958. Problems in growth and development of interest to the dentist. D. Clin. N. America, July: 497-514.

KROGMAN, W.M., and SASSOUNI, V. 1957. A syllabus in roentgenographic cephalometry. Philadelphia: Philadelphia Center for Research in Child Growth.

LINDEGÅRD, B. 1953. Variations in human body-build. A somatometric and X-ray cephalometric investigation on Scandinavian adults. Acta Psych. et Neurolog. Scandinav., Suppl. 86.

LUNDSTRÖM, A. 1954. Intermaxillary tooth width ratio and tooth alignment and occlusion. Acta Odont. Scandinav., 12(4): 265-292.

LÜTHY, A. 1912. Die vertikale Gesichtsprofilierung und das Problem der Schadelhorizontalen. Arch. f. Anthrop., 39(n.s. 11): 1-87.

LYSELL, L., and FILIPSSON, R. 1958. A profile roentgenologic study of a series of medieval skulls from North Sweden. Sartryck ur Odontol. Tskr., 66(2): 161-174.

MARGOLIS, H. 1940. Standardised X-ray cephalographics. Am. J. Orthodont., 26(8): 725-740.

MARTIN, R. 1928. Lehrbuch der Anthropologie. Jena: Gustav Fischer.

MARTIN, R. (Ed. SALLER, K.) 1957. Lehrbuch der Anthropologie. 3rd Ed. Stuttgart: Gustav Fischer.

MERKEL, F. 1882. Zur kenntniss der postembryonalen entwick lung des Menschlichen Schadels. Festschr. f. Henle. Bonn.

MILICERowA, H. 1955. Crania Australica. Materiały I Prace Antropologiczne Nr. 6. Wrocław: Polska Akademia Nauk Zakład Antropologii.

MOORREES, C.F.A. 1953. Normal variation and its bearing on the use of cephalometric radiographs in orthodontic diagnosis. Am. J. Orthodont., 39(12): 942-950.

MOORREES, C.F.A., and KEAN, M.R. 1958. Natural head position, a basic consideration in the interpretation of cephalometric radiographs. Am. J. Orthodont., 16(2): 213-234.

MORONEY, M.J. 1951. Facts from figures. Harmondsworth: Penguin Books Ltd.

MURPHY, T. 1957. Changes in mandibular form during postnatal growth. Austral. D.J., 2(5): 267-276.

NANDA, R.S. 1955. The rates of growth of several facial components measured from serial cephalometric roentgenograms. Am. J. Orthodont., 41(9): 658-673.

NEVAKARI, K. 1956. An analysis of the mandibular movement from rest to occlusal position. Acta Odont. Scandinav., 14: Suppl. 19.

OPPENHEIM, A. 1928. Prognathism from the anthropological and orthodontic viewpoints. Den. Cosmos,70: 1092-1110.

PADEN, W.M. 1960. A survey of radiation hazards in orthodontics. Am. J. Orthodont., 46(8): 575-587.

PARSONS, F.C. 1930. Alveolar and facial prognathism. J. Anat., 65: 149-151.

POIDEVIN, L.O.S. 1957. Some childbirth customs among the Ngalia tribe: Central Australia. Med. J. Austral., 1: 543-546.

PRITCHARD, J.C. 1843. Researches into the physical history of mankind. Vols. 1-5 (1836-1847). London.

SALZMANN, J.A. 1960. The research workshop on cephalometrics. Am. J. Orthodont., 46(11): 834-847.

SALZMANN, J.A. 1961. (Editor) Transactions of the research workshop on roentgenographic cephalometrics. Philadelphia: J.B. Lippincott Co.

SARASIN, F. 1916-1922. Anthropologie der Neu-Caledonier und Loyalty-Insulaner. Berlin. Cit. WAGNER (1937).

SARNAS, K. 1957. Growth changes in skulls of ancient man in North America. Acta Odont. Scandinav., 15: 213-273.

- - 1959. Inter- and intra-family variations in the facial profile. Odont. Revy, 10: Suppl. 4.

SCHREINER, K.E. 1935. Zur Osteologie der Lappen. Instituttet for Sammenlignende Kulturforskning. Series B XVIII Band 1. Oslo: H. Aschehoug and Co.

- - 1939. Crania Norvegica 1. Instituttet for Sammenlignende Kulturforskning. Series B XXXVI. Oslo: H. Ascheboug and Co.

- - 1951. Anthropological studies in Segn. Skrifter utgitt av Det Norske Videnskaps-Akademi I Oslo: 1. Mat.-Naturv. Klasse. No. 1. Oslo: I Kommisjon Hos Jacob Dybwad.

SCHULTZ, D. 1958. Observations on visual characteristics of Central Australian aborigines. Dioptric News, 13: 43o.

SCOTT, J.H. 1953. The variability of cranial and facial dimensions in modern skulls. Brit. D.J., 94(2): 27-31.

SIMMONS, R.T., GRAYDON, J.J., and SEMPLE, N.M. 1954. A blood group genetical survey in Australian aborigines. Am. J. Phys. Anthrop., 12: 599-606.

STRAMRUD, L. 1959. External and internal cranial base. Acta Odont. Scandinav., 17: 239-266.

SVED, A. 1954. A critical review of cephalometrics. Am. J. Orthodont., 40(8): 567-590.

TALLGREN, A. 1957. Changes in adult face height due to ageing, wear and loss of teeth and prosthetic treatment. Acta Odont. Scandinav., 15: Suppl. 24.

THORNE, H. 1953. The rest position of the mandible and the path of closure to occlusal position. Acta Odont. Scandinav., 11: 141-165.

TINDALE, N.B. 1940. Results of the Harvard-Adelaide Universities Anthropological Expedition, 1938-1939. Distribution of Australian aboriginal tribes: A field survey. Trans. Roy. Soc. S. Aust., 64(1): 140-231.

- - 1953. Tribal and intertribal marriage among the Australian aborigines. Human Biol., 25: 169-190.

TOPINARD, P. 1890. Anthropology. (English Edition) London: Chapman and Hall.

VIRCHOW, R. 1857. Untersuchungen uber die Entwicklung des Schadelgrundes im gesunden und krankhaften Zustande und uber den Einfluss derselben auf Schadelform, Gesichtsbildung und Gehirnbau. Berlin. Cit. OPPENHEIM (1928).

UNESCO PUBLICATION, 1952. The race concept. Results of an inquiry. Paris: Unesco Organisation.

WAGNER, K. 1937. The craniology of the oceanic races. Skrifter utgitt av Det Videnskaps-Akedemi I Oslo: 1. Mat.-Nuturv. Klasse. No. 2. Oslo: I Kommisjon Hos Jacob Dybwad.

WEIDENREICH, F. 1941. The brain and its role in the phylogenetic transformation of the human skull. Trans. Am. Philosoph. Soc., (n.s.) 31(5): 321-442.

WELCKER, H. 1862. Untersuchung uber Wachsthum und Bau des menschlichen Schadels. Leipzig. Cit. BJÖRK (1947).

- - 1896. Das Profil des menschlichen Schadels mit Rontgenstrahlen am Lebenden dargestellt. Correspondenz-Blatt Deutschen Gesellschaft f. Anthrop., 27. Cit. BJORK (1947).

WERNER, H. 1955. Determination of the cephalometric orientation of the jaws. Acta Odont. Scandinav., 13(3): 203-216.

WILDER, H.H. 1920. A laboratory manual of anthropometry. Philadelphia: P. Blakiston's Son and Co.