A COMPARATIVE STUDY OF DENTAL ARCH MORPHOLOGY AND TOOTH OCCLUSION

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Alternate Intercuspation.
SUMMARY

According to generally accepted concepts of tooth occlusion, the upper and lower teeth meet in maximum intercuspation when the jaw is closed into a position that is variously termed tooth position, intercuspal position or centric occlusion. However, it has been reported that some ethnic groups, particularly pre-contemporary, display disparities in the breadths of upper and lower dental arches that prevent the teeth from occluding bilaterally in the well-known cusp to fossa and cusp to ridge relationships. This character, which is termed alternate intercuspation in this study, has not previously been quantified although it has been described in general terms by several previous authors.

The main objective of the investigation was to determine whether a statistically significant difference exists between homologous maxillary and mandibular dental arch breadths within and between Caucasoid and Aboriginal groups, and hence, whether alternate intercuspation is a measurable character.

The results indicate that arch breadths display significant inter-racial variability and sexual dimorphism within each racial group. The differences between homologous upper and lower dental arch breadths were most marked in the premolar regions of the Aboriginal male sample, and it is suggested that alternate intercuspation is a particular feature of the dental occlusion of this group.
This preliminary investigation has established that alternate intercuspation is a measurable character. However, the selection of different descriptive parameters may facilitate the characterization of this condition. Future studies based on analysis of arch shape are planned, and investigations will include comparison of arch shape between related individuals, shape changes with age, and taxonometric comparisons of dental arch shapes.
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SIGNED STATEMENT

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

PETER JAMES TELFER
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CHAPTER I  INTRODUCTION

Modern concepts of functional occlusion are based on the contact relations between the maxillary and mandibular teeth. It is generally believed that maximum interdigitation of the teeth occurs simultaneously on each side of the dental arches in a position variously described as "tooth position", "intercuspal position", or "centric occlusion" (see Figure 1).

However, it has been known for over fifty years that a different form of dental occlusion is frequently observed in some ethnic groups. For example, Barrett (1953) described a condition in many Australian Aboriginals in which maximum interdigitation occurred independently on the right and left sides of the dental arches (see Figure 2). Initially he termed this "X-occlusion", but subsequently referred to the condition as "alternate intercuspation" (1958). Beyron (1964) referred to this dental arch relationship as "incongruent intercuspation". The term "alternate intercuspation" will be used in this report because it aptly describes the type of independent occlusion which can occur on either side of the dental arch but not on both sides together. Furthermore, the adjective "alternate" draws attention to this relationship as an alternative to the usual concept of "normal" occlusion, whereas the Beyron usage of "incongruent" infers a departure from normality. There is no doubt that alternate intercuspation can be regarded as a normal variation of occlusal relationships within the groups that display this condition.
Figure 1. Dental casts of an Aboriginal subject demonstrating bilateral intercuspation according to general concepts of centric occlusion.
left occlusion

right occlusion

Figure 2. Dental casts of an Aboriginal subject demonstrating alternate intercuspsation.
Alternate intercuspation has been noted in various ethnic groups, but there is little information on its frequency, developmental pattern or functional correlates (Beyron 1964). Barrett (1958) reported that when the teeth first attain their positions in the dental arches, the cusp and sulci interlock. With occlusal wear this situation changes to one in which the worn buccal cusps of the lower molars occlude with the worn lingual cusps of upper molars. One opinion is that alternate intercuspation develops functionally as a consequence of prolonged maxillary growth at the palatal suture, which, in conjunction with marked occlusal tooth attrition, brings about a discrepancy in the relative widths of the upper and lower jaws (Hunt 1959). Other authors (Campbell 1946, Poole 1976) have suggested that the main function of cusps is in guiding the erupting teeth into appropriate positions; however the relation between attritional wear on occlusal surfaces and palatal growth remains unclear.

Many investigators have measured the dental arches, and described quantitative changes in arch size and shape. However, a multiplicity of reference points has been used and no standard methods for describing the shape of dental arches or for measuring arch breadth, depth or perimeter have been universally accepted.

In contrast to these metric studies, the condition termed "alternate intercuspation" has merely been noted in particular ethnic groups. However, neither the prevalence nor the variability of the condition has been reported. Further, this form of occlusion has not been quantitatively described for any group, and no standards for defining the condition have been devised. The antero-posterior relation of the upper and lower jaws
in the sagittal plane has been classified by Angle into several classes. Although this relationship is a continuous variable, the division into discrete categories has been useful clinically. Ackermann and Proffit (1969) suggested a more comprehensive classification of malocclusions which embraced sagittal, transverse and vertical relationships of the dental arches. But neither this classification, nor that described by Björk, Krebs and Solow (1964) has been universally accepted for the medio-lateral relationships of the jaws in the coronal plane. This may be because clinicians in Western countries see less variation in this relationship (Moorrees 1957a, Brown 1973). It was not considered appropriate to apply either of these classifications to this study of dental arch relationships. Until more is known of alternate intercuspation, its aetiology and ethnic variability, it is not clear whether metric or non-metric standards are the most appropriate for its description.

This investigation is concerned with some aspects of "alternate intercuspation". In particular, the aims are:

1. to examine relative arch breadths and occlusal relations in young adult Caucasoids and Aboriginals;

2. to determine whether a statistically significant difference exists between maxillary and mandibular arch breadths within and between groups and hence, whether "alternate intercuspation" is a measurable character;

3. to determine the frequency of "alternate intercuspation" in a population of young adult Aboriginals;
4. to evaluate parameters which might describe the presence of 
"alternate intercuspation".

This research is viewed as a preliminary exploration of alternate 
intercuspation to determine the observational parameters that might be 
best suited for more intensive study in the future.
CHAPTER II  LITERATURE REVIEW

INVESTIGATIONS OF DENTAL ARCH BREADTHS

One of the earliest investigations of growth changes in the transverse dimensions of dental arches was carried out by Zsigmondy (1890). He studied 3 subjects during their growth from 6 to 17 years, and found an increase in the transverse width amounting to 1-3 mm.

Pont (1909) investigated the relation between the pooled widths of the four incisors (EI), and the transverse arch size (T) in instances of normal occlusion. He established an index for this relation \( \left( \frac{EI \times 100}{T} \right) \), and produced a table of expected half-widths for the guidance of orthodontists. Harth (1930) modified the index figures of Pont, and confirmed the numerical values for practical purposes. Greve (1933) made a critical analysis of the value of Pont's index by examining 102 normal individuals aged between 10 and 30 years. He was able to demonstrate only a weak statistical correlation between the combined widths of the incisors and dental arch breadth.

Campbell (1925) described various features of the dentition and palate of Australian Aboriginals from an investigation of 630 crania. He found that, on average, dental arch breadth dimensions increased with age, whereas, in contrast, dental arch depths decreased. He noted the frequent occurrence of an edge-to-edge incisor relation in adults, and suggested that the change from a juvenile incisor relationship characterized by overbite and overjet, was associated with tooth
attrition and accompanied by changes in the relative positions of the anterior teeth in the maxillary and mandibular dental arches.

Izard (1927) suggested that the relation between the breadth of the maxillary dental arch and the width of the face was constant, as was the relation between arch depth and face height.

Chapman (1935) studied changes in the dental arches of eight children from birth to adulthood using serial casts. He observed that there was no increase in dental arch breadth between the ages of 2 and 5 years, but thereafter, until age 12, there was an increase, particularly in the maxillary arch.

Goldstein and Stanton (1935) examined 547 sets of dental casts obtained from 300 American children aged between 1 and 11 years. Some subjects were studied longitudinally. These authors reported that generally the dental arch breadth increased between the ages of 3 and 9 years. Attention was drawn to the increase in intercanine breadth related to the eruption of the permanent incisors. The absolute increase in intermolar breadth was greater in the mandible than in the maxilla, as was the rate of increase. Boys exhibited larger arch breadths at all ages with greater fluctuation in the rate of increase, whereas in girls, the arch breadths increased steadily from 2 to 9 years, and at a faster rate. These authors expressed dental arch form as an index of arch breadth over arch depth. This index was used to classify arch form into three subdivisions: dolichuranic or narrow arch, mesuranic or medium arch, and brachuranic or broad arch. Allowance was made for merging between subdivisions.
Seipel (1946) examined positional variations of the teeth of Swedish children and young adults. The sample, consisting of about equal numbers of males and females was divided into groups aged 4 years, 13 years, and 21 years. Intra-oral measurements were obtained directly from each subject. Seipel concluded that between ages 4 and 13 years, the dental arch breadth, measured between the first maxillary premolars, increased slightly more in males than females.

MacConaill and Scher (1949) studied the dental arch form of 25 males and females using dental casts. Dental arch breadths were measured, and mean values of arch breadths between corresponding occlusal points were calculated. These authors suggested that the ideal human dental arch form would conform to the catenary curve. This hypothesis is supported by the histological investigations by Burdi and Lillie (1966) and Burdi (1968). After examining serial sections obtained from human embryos aged 6.5 to 12 weeks in utero, these authors concluded that the dental laminae conformed to a catenary curve, characteristic of the human post-natal dental arch, very early in embryogenesis.

Baume (1950) reported the findings of a longitudinal study of developmental changes in dental arches during the period of the deciduous dentition, the eruption of the permanent first molars, and the replacement of the deciduous teeth by their successors. Measurements were made from dental casts. The arch depth and breadth appeared to remain constant from age four years to the time of eruption of the permanent molars. Baume also reported that the mean increase in intercanine breadth was greater in the maxillary arch than in the
mandibular, and that a greater increase was found in arches which did not exhibit spacing between the deciduous teeth.

Woods (1950) investigated growth changes using a series of lateral and frontal cephalometric radiographs obtained from 14 males and 14 females. The examination intervals were half-yearly from age 3 to 5 years, and yearly thereafter to the age of 15 years. He found that the maxillary intercanine breadth increased with age although a decrease was noted between the ages of 7 and 12 years. The mandibular intercanine breadth remained the same from ages 3 to 15 years, apart from a decrease between 6 and 11 years. The maxillary intermolar breadth increased until these teeth came into occlusion, when the rate of increase diminished. The mandibular intermolar breadth decreased gradually until the molars were in occlusion. The breadth then increased or decreased at a constant rate which varied with the individual. The dental arches of females were observed to be smaller than those of males in all dimensions.

Björk (1953) examined cephalometric radiographs of 243 Swedish males at the age of 12 years, and again at 20 years. The overjet gradually decreased during this period, although pronounced individual variations were noted. This decrease was attributed to a tendency for forward displacement of the mandibular incisors in relation to their maxillary opponents. The overbite also diminished with advancing age. Björk (1955) subsequently reported the association between bite development, dental arch shape, and body build in the same group of 20 year old Swedish males. Skeletal sturdiness was found to be associated with dental arches which were large in all dimensions, with
large teeth, broad maxillary arches compared with mandibular arches, a tendency to scissors bite (buccal occlusion), and with early eruption of the permanent teeth. Slender skeletal construction appeared to be associated with a tendency to cross-bite (lingual occlusion), where the maxillary arch was narrower than the mandibular arch. No correlation was found between skeletal factors and the degree of spacing or crowding of the teeth and no significant relation was found between dental arch shape and a "muscle factor". It is interesting that Björk referred to disparities in upper and lower dental arch breadths in relation to body-build. However, this observation was not specifically linked with the occurrence of alternate intercuspation as defined in this study.

Björk's work tends to support Lindegård's thesis (1953) that individual body build could be described in terms of four variables - length, sturdiness, muscle, and fat factors. The amount of endochondrally formed bone (i.e. the long-bone length, the length factor) and the amount of appositionally formed bone (i.e. the sturdiness factor) were analysed by Lindegård for any correlations with the structure of the skull. An individual with a large length factor and an average sized sturdiness factor was characterized by long extremities, flattened cranial base form, high upper face and long mandible, whereas, in contrast, an individual with a large sturdiness factor, but average sized length factor displayed long hands and long feet, large brain case, large cranial base length and large face length.
Meredith and Cox (1954) measured dental casts obtained from a group of 9 year old "white children", 44 boys and 50 girls, in order to investigate sex differences in intermolar breadths. It was found that the average dental arch breadth was greater in boys than girls, and that the dental arch breadth of the maxilla was greater than that of the mandible.

Moorrees, Grøn, Lebret, Yen and Fröhlich (1969) investigated the relationship between dental development and arch growth. Serial dental casts of 50 boys and 44 girls were examined by the authors who concluded that arch breadth did not alter materially between the ages of 4 and 6 years. However, marked increases in breadth associated with the emergence of the permanent incisors and canines were noted, particularly in the maxilla.

Lavelle and Foster (1969) undertook a cross-sectional study of age changes in human dental arches. They examined 1020 sets of dental casts obtained from 30 British boys and 30 British girls, aged 4 to 20 years. Age changes in dental arch breadth were found to be greater in boys than in girls.

Björk and Helm (1969) discussed the prevalence of malocclusion in particular ethnic groups. Of the anomalies in transverse dental arch relationships, cross-bite was common amongst the Chinese and Danes, 11 per cent and 9 per cent respectively, and scissors-bite in the Chinese and Japanese, 9 per cent and 12 per cent respectively. These authors found that 7 per cent of Aboriginals had a cross-bite and 2 per cent displayed a scissors-bite. Björk and Helm defined these
malocclusions in the terms suggested by Björk, Krebs and Solow (1964), and as indicated above, neither this, nor any other classification of transverse arch relationships has been universally accepted. This lack of uniformity in the description of malocclusions can lead to apparent anomalies. For instance, a relatively low frequency of scissors-bite was reported in Aboriginals, a group which has been shown to display alternate intercuspation. When it is recognised that scissors-bite was defined by these authors as the jaw relationship which occurs when the lingual cusp of the upper premolar or molar occludes buccally to the buccal cusp of its mandibular opponent, it can be seen that this is a malocclusion, whereas alternate intercuspation is a normal variation of occlusal morphology. Hence the classification scissors-bite as used by Björk and Helm (1969) differs from the concept of alternate intercuspation as described in this report.

Lavelle (1972) measured maxillary and mandibular dental arches from British skulls dating from the Anglo-Saxon period, 10-12th century, 15-17th century and 19-20th century. Using multivariate analysis, he found varying patterns of contrast between samples, depending on which dimensions were considered, and he suggested that dental arch changes occurred independently of jaw changes.

Heckman (1973) carried out a longitudinal study of 82 children from birth to 12 years of age. His results confirmed those of Moorrees (1964) in that he found an increase in intercanine breadth related to the eruption of the permanent incisors, and a further increase in breadth at the time of puberty. The intercanine breadth was greater in the maxilla than in the mandible at all ages, and the increases in breadth were more marked in boys than girls.
Björk and Skieller (1974) studied growth in the width of the maxilla by means of metallic implants and frontal radiographs. The shape of distance and velocity curves representing transverse growth in the median suture was similar to the shape of the curve representing the growth in body height, both showing a distinct pubescent growth maximum. The individual time of growth completion in these sutures also coincided with cessation of general body growth. These authors also reported that sutural separation of the maxilla was greater posteriorly than anteriorly, and concluded that the two maxillae rotate in the transverse plane in relation to each other.

Ingervall and Hedegård (1975) investigated malocclusion in 200 Skolt Lapps aged from 8 to 16 years. These authors reported that 9 per cent of subjects exhibited a cross-bite in at least one segment of their dental arches, and 8 per cent had a scissors-bite in at least one segment.

Kisling and Krebs (1976) in a cross-sectional study of 1624 three year old Danish children, found that 214 had a cross-bite and 14 had a scissors-bite.

Lavelle (1976a), comparing malocclusions in various racial groups, reported some interesting variations in the prevalence of cross-bite between these groups. Some 13.6 per cent of male British Caucasoids, 20.4 per cent of female British Caucasoids, 15.0 per cent of Anglo-Saxon skulls, 4.3 per cent of mediaeval skulls, 14.0 per cent of Negroid skulls, and 12.0 per cent of Mongoloid skulls exhibited this condition. The interesting feature of this work is the comparative uniformity of cross-bite prevalence amongst the
contemporary groups, contrasted with the infrequent observation of this occlusal character in the mediaeval skulls. Unfortunately attention was not drawn to the prevalence of alternate intercuspation amongst these groups, nor was the incidence of scissors-bite indicated.

In a further study in 1976(b), Lavelle examined correlations between dental arch breadth and body weight and stature. He measured the inter-canine breadth as a parameter of dental arch size, and found close correlations between maxillary and mandibular arch widths, and that these dimensions were more closely associated with body stature than body weight. Annual increments of stature and body weight, and maxillary and mandibular arch breadth and stature were significantly correlated, although in contrast, the annual increments of maxillary and mandibular arch width and body weight were not significantly correlated. Despite the restrictions imposed by the limited parameter used to describe the dental arches, this study appears to be important in drawing attention to the significant implications which a more exhaustive investigation of correlations between dental arches and body form might have.

Lavelle (1977) reported another interesting investigation in which he measured the dental arches of various ethnic groups of homo sapiens, modern apes and monkeys and several prehistoric groups, including Neanderthal man, Australopithecus and homo erectus. Various statistical techniques were used to compare arch size, arch shape, and areas enclosed by the various reference points. He concluded that, despite some limitations imposed by the lack of homologous
datum points in each primate sample, dental arch form may have taxonomic significance.

There is considerable evidence available on the morphology and growth changes of the dental arches. As already indicated, the lack of a uniform classification makes direct comparison of the results of various studies difficult. Furthermore, a multitude of reference points have been used in measuring dental arch breadths and this further compounds the comparison of findings from different investigations.

In general, previous studies indicate that dental arch breadths increase with age, and particular size increases are associated with the eruption of the permanent incisors and canines, and later with puberty. Dental arch size is associated with various factors related to general body build, although the age changes in these relationships have yet to be characterized. A number of studies have drawn attention to the prevalence of malocclusion in various historic and contemporary groups. Despite the limitations imposed by the non-uniform reference points which have been used, it appears that the tendency for the mandible to be relatively narrower than the maxilla is less apparent in contemporary groups than it was in previous times.

The age changes which occur in dental arch breadths are of relatively small magnitude and the errors involved in measuring the arch breadths may be considerable depending upon whether internal or external anthropometric breadths; or inter-cusp or inter-fossae odontometric breadths, are measured. These two factors limit the emphasis which can be placed on the findings of such investigations.
outside the relatively narrow frame of reference in each study. For instance, the maxillary dental arch breadths measured between the buccal surfaces of the first permanent molars would be expected to be relatively larger in a group displaying teeth which are broad bucco-lingually in proportion to the crown diameter. Comparisons of these arch breadths with those of a group with teeth narrow in the bucco-lingual direction must be carried out with some caution. More reliance on the interpretation of growth changes can be placed on studies which use specific reference points such as metallic implants, or studies which compare the arch breadths at different ages, provided that the same reliable reference points are used throughout the investigation.

ALTERNATE INTERCUSPATION

"Alternate intercuspation" is a term used by Barrett (1958) to describe a dental occlusion wherein maximum interdigitation occurs independently on the right and left sides. Barrett had drawn attention to the condition previously (1953), when the term "X-occlusion" was used.

One of the earliest references to this form of occlusion was made by Ryder (1878) who termed the disparity in width between the upper and lower dental arches of ruminants anisognathism. Turner (1891), reporting on some features of the dentary arcades of Australian Aboriginals, drew attention to a width disparity in the molar regions of the maxillary and mandibular dental arches. Although he did not specify reference points, Turner reported that the mean disparity was
5 mm, with some subjects having a maxillary breadth 8 mm greater than that in the mandible. These figures must be regarded with some caution, since the actual points of reference are not specified, and because the width disparity may be modified by the attritional wear patterns of some Aboriginal dentitions (Murphy 1964). Furthermore, the degree of post-mortem distortion could well affect metric values. Nevertheless, disparity of the order of 5-8 mm would seem to indicate basic incongruence in the breadths of mandible and maxilla, and it may be concluded that Turner was indeed drawing attention to alternate intercuspsation in what is probably one of the first references to this condition in a human population.

Campbell (1925) noted this condition in Australian Aboriginals and subsequently questioned the significance of the concept of centric occlusion in the functioning Aboriginal dentition. He rejected static concepts of occlusion and stated that the relationship between the teeth and the jaws should be considered functionally.

As mentioned above, Barrett drew particular attention to alternate intercuspsation when, in 1953, he presented an exhibit at the Thirteenth Australian Dental Congress. This display consisted of dental casts obtained from Australian Aboriginals from Yuendumu who had this unusual condition. Begg (1965) reported that Barrett had found this condition in about one third of living Australian Aboriginals examined.

In 1958 Barrett presented a more detailed discussion in which he reported that this arch width disparity, apparent in many subjects prior to the eruption of the first permanent molars, usually persisted in the mixed dentition, but the difference was often reduced somewhat when the
permanent incisors erupted. This was explained in terms of the occlusal relations being re-established following the interlocking of cusps and sulci. The arch disparity again became apparent when the cusps had been reduced by attrition. Barrett was unable to completely explain these changes in the dental arches, but suggested that independence of growth mechanisms, and inherited differences in timing of growth activity and tooth eruption may be involved. He further postulated that the natural downward and outward growth of the maxilla may contribute to this disparity, and that occlusal attrition which "unlocks" the occlusion, may contribute to the differential growth. Barrett also drew attention to possible compensatory mechanisms. Occlusal wear on the buccal cusps of the lower teeth and the lingual cusps of the upper teeth may help to maintain occlusal contact despite the disparity in arch breadths. Moreover, the occlusal freedom arising from reduced cusp heights and diminished anterior overbite probably allows wider excursions during mastication. The individual subject would then not suffer any impaired masticatory efficiency from extensive attrition, although the temporomandibular joints may be subject to stresses not experienced in a "normal" dentition.

Heithersay (1961) drew attention to a "curious lack" of a centric occlusion in some Aboriginals examined by him at Haast's Bluff. The severity of the condition varied, and the alternate intercuspation was only noted in casts of adults. It was suggested that more material would be required in order to determine the age at which the condition first appeared.
Figure 3. Location of Yuendumu Settlement.
(Courtesy Dr. J.M. Schulze)
Brown and Reade (1963) indicated that occlusal relationships change throughout life, and mentioned that alternate intercuspation was a feature of the dentition of a significant number of Australian Aboriginals. These authors drew attention to the efficiency of this form of occlusal morphology and considered that

there is no one normal or ideal arrangement of the teeth governed by physical laws, but that the final test of a physiological occlusion is the healthy function of the entire masticatory system.

DENTOFACIAL STUDIES OF AUSTRALIAN ABORIGINALS

1. Yuendumu

The following description of research based on material obtained at Yuendumu provides a reference frame for the present investigation. The general theme of this ongoing research is concerned with dental and craniofacial morphology and growth in Australian Aboriginals.

Yuendumu, a Commonwealth Government Settlement situated about 280 km north-west of Alice Springs in the Northern Territory of Australia was established in 1946 as a ration depot for Aboriginal people who had left their tribal lands. Sited on an Aboriginal reserve of 2500 km², it is controlled by the Welfare Branch of the Northern Territory Administration. The location of the Reserve is shown on the map (Figure 3).

The present population of about 1000 consists mainly of people from the Wailbri tribe, although some are from the Pintubi group. The
traditional nomadic existence was abandoned some years ago in favour of a settlement existence which provided a continuous supply of European foods and other amenities. Although settlement conditions have reduced the need for customary hunting and food gathering, the people are still tribally oriented, holding many traditional beliefs and practising many of the customs of former days (Barrett and Brown 1971).

Yuendumu has been found particularly suitable for dental studies. The settlement is relatively isolated geographically and although the Aboriginals occasionally visit neighbouring areas, the population in fairly static and self-contained, and almost free of non-Aboriginal admixture (Barrett 1965). Although birth dates have not been recorded for all subjects enrolled in surveys, a system of classifying subjects according to eruption status of the teeth has been used for some aspects of the study. This is fully described in Appendix A. In the 1950s and 1960s when most of the material used in this study was obtained, the people were at an early stage of transition from a simple food gathering and hunting existence to the adoption of a European way of life. The conditions at Yuendumu have therefore provided a unique opportunity for dental investigations of a group of people not yet greatly influenced by European customs.

2. Field visits

Visits to Yuendumu for observation of subjects enrolled in the study were made each year from 1961 to 1971 inclusive. Most of the visits were for about three weeks. More limited observations including the collection of dental casts had previously been carried out at Yuendumu
between 1951 and 1960. In addition, the late Dr. M.J. Barrett spent much of 1974 at the settlement, and added to the records previously available.

Three types of records have been collected: first, personal records of the subjects, including family data for genealogical purposes; secondly, records of field observations providing data for analysis - measurements of height, weight and other somatometric characters; observations of oral and dental conditions; and thirdly, copy records of morphological features from which a wide range of data can be derived on subsequent examination and measurement in Adelaide cephalometric and hand and wrist radiographs, photographs and dental casts.

The third type of record is particularly valuable because the material has remained available for study by many investigators over a number of years. These detailed studies would not have been possible but for the foresight of the investigators who obtained these records and data.

A number of investigations of this material have been reported in the past two decades. Representative studies from a more extensive bibliography may be grouped in the following manner:

1 General descriptive

Campbell and Barrett (1953) and Barrett (1953, 1965, 1968) have described the living conditions at Yuendumu and have drawn attention to the general features of the Aboriginal dentition.
2.2 Dentition and dental arches

Tooth occlusion has been investigated by Barrett (1958), Beyron (1964), Barrett (1969), Brown (1969), and dental arch form studies undertaken by Barrett, Brown and Macdonald (1965), Barrett and Brown (1968), Cheng (1972), Proffit and Barrett (1973), and Proffit, McGlone and Barrett (1975). Tooth size studies have been carried out by Barrett, Brown and Luke (1963), Barrett, Brown and Macdonald (1963a), Kuusk (1973) and Townsend (1976).

2.3 Development of the dentition

Tooth formation has been described by Fanning and Moorrees (1969), and tooth emergence by Barrett (1957), Barrett, Brown and Cellier (1964), Barrett and Brown (1966) and Jenner (1972).

2.4 Craniofacial morphology and growth

Various features of craniofacial morphology have been described by Brown (1965, 1973), Barrett, Brown and Macdonald (1963b), Brown and Barrett (1964), Brown, Barrett and Darroch (1965a,b), Gresham, Brown and Barrett (1965) and Barrett, Brown and McNulty (1968).

2.5 General body growth and skeletal maturation

Investigations of general body growth have been reported by Brown and Barrett (1971), Grave (1971), Brown, Barrett and Grave (1971), Brown and Barrett (1972) and Schulze (1973).
Dental diseases and the prevalence of malocclusion

Various aspects of dental diseases have been described by Barrett (1953, 1956), Cran (1955, 1957, 1959, 1960), Björk and Helm (1969), Barrett and Williamson (1972) and Rogers (1973).
CHAPTER III

MATERIALS AND METHODS

STUDY SUBJECTS AND MATERIALS

Dental casts of Aboriginal and Caucasoid subjects were examined in this investigation. The Aboriginal casts included represented all young adult individuals enrolled in the Yuendumu study. Young adult status was determined as described below. Although a few of the Aboriginal casts displayed malaligned or rotated teeth, no attempt was made to exclude those since this might bias the sample. Casts representing Caucasoids were obtained as part of an undergraduate teaching exercise, and the only casts excluded from this random sample of dental students were those representing individuals who had undergone orthodontic therapy.

Dental casts of 158 Aboriginals, 80 males and 78 females, and 57 Caucasoids, 45 males and 12 females, were included in the present investigation. The Aboriginal casts were obtained as described by Barrett, Brown and Macdonald (1963a) and the Caucasoid casts prepared by making irreversible hydrocolloid impressions of the dental arches of selected dental students and subsequently casting these in dental stone. The ages of the Aboriginal males ranged from 14 to 36 years with a mean of 18.9 years, while the females' ages ranged from 13 to 40 years with a mean of 19.3 years. On the other hand the ages of the Caucasoid males ranged from 19 to 26 years with a mean of 20.7 years and the females' ages ranged from 20 to 21 years with a mean age of 20.5 years.
The following criteria were observed in the selection of the Aboriginal subjects:

1. Pure Aboriginal ancestry so far as could be determined.
2. Young adult status as determined by the dental age category defined by the eruption of at least one third molar (see Appendix A).

Caucasoid subjects satisfied similar criteria, namely:

1. Caucasian ancestry.
2. Dental age was within the young adult category, that is, eruption of at least one third molar.
3. Had not undergone orthodontic therapy.

REFERENCE POINTS AND VARIABLES

Measurements of arch breadths have been made in several ways. Anthropologists have usually ascertained the greatest linear dimensions of the dental arches, and are thus interested in overall arch size. On the other hand, odontologists, particularly orthodontists have based their measurements on the assumption that the points defining the maxillary arch breadth line correspond with those defining the mandibular arch breadth line when the upper and lower teeth are brought together in centric occlusion. Thus the measurements obtained by this method have some meaning in relation to function as well as morphology, whereas those obtained by the anthropometric method have little functional significance. Moorrees (1957b) employed an odontometric method of arch breadth measurement in measuring arch breadths of Aleuts.
and used reference points originally introduced by Korkhaus (1939), namely the intersection of the main occlusal grooves of the upper first molars, and the tip of the distobuccal cusp in lower first molars.

Centric occlusion, or intercuspal position, in the Caucasoid dentition is usually accepted as the dental relationship in which the upper and lower teeth attain maximum interdigitation. In this particular relationship various cusps of the lower teeth occlude with specific areas within the fossae of the upper teeth (Ramfjord and Ash 1971).

With the exception of points on the upper and lower central incisors, reference points which correspond to these positions of cusp-fossa contact (Figure 4) in a Caucasoid centric occlusion were selected. Eleven maxillary reference points and eleven homologous mandibular points were selected.

The reference points used in the present investigation include the odontometric reference positions of the first molars employed by Moorrees (1957b), and homologous positions on the other molars, premolars and canines, defined by Wheeler (1974). The contact points of the upper and lower central incisors were also used as reference points in order to obtain additional comparative data on the anterior segments of the dental arches although these data are not central to the main theme of the investigation.

In order to compare homologous breadths in the maxilla and mandible, it is necessary to select upper and lower reference points which would occlude according to generally accepted concepts of intercuspation. If
Figure 4. Reference points.
intercuspal position as defined exists in a particular subject, the discrepancy between homologous upper and lower dental arch breadths would be zero. In a population, even if individual subjects displayed some random variation from these expected contacts, the mean discrepancy within the population should be zero. On the other hand, a significant trend towards a discrepancy between homologous upper and lower arch breadths would indicate a trend for one arch to be broader than the other. In this way alternate intercuspatation can be described metrically.

A variety of points on the maxillary teeth occlude with particular features of their mandibular opponents (Figure 5). The points which were selected were chosen because they could be readily identified and upper and lower points were homologous.

The reference points selected were as follows (Figure 4):

**MAXILLA**

Max 7  
Upper second molar - the centre of the central fossa; specifically, the intersection of the main occlusal grooves.

Max 6  
Upper first molar - the centre of the central fossa; specifically, the intersection of the main occlusal grooves.

Max 5  
Upper second premolar - the centre of the mesio-occlusal fossa; specifically, the intersection of the central occlusal groove and the accessory occlusal grooves in the mesio-occlusal fossa.

Max 4  
Upper first premolar - the centre of the mesio-occlusal fossa; specifically, the intersection of the central occlusal groove and the accessory occlusal grooves in the mesio-occlusal fossa.
Figure 5. Variables measured.

MaxICR - Max Inc right
MaxICL - Max Inc left
3 - Max 3 bdth
4 - Max 4 bdth
5 - Max 5 bdth
6 - Max 6 bdth
7 - Max 7 bdth

ManICR - Man Inc right
ManICL - Man Inc left
3 - Man 3 bdth
4 - Man 4 bdth
5 - Man 5 bdth
6 - Man 6 bdth
7 - Man 7 bdth
Max 3  Upper canine - the centre of the mesio-lingual fossa.
Max 1  Midpoint of contact between the upper central incisors.

MANDIBLE

Man 7  Lower second molar - the cusp tip of the distobuccal cusp.
Man 6  Lower first molar - the cusp tip of the distobuccal cusp.
Man 5  Lower second premolar - the cusp tip of the buccal cusp.
Man 4  Lower first premolar - the cusp tip of the buccal cusp.
Man 3  Lower canine - the cusp tip.
Man 1  Midpoint of contact between the lower central incisors.

NOTE: In the few instances where a cusp tip or fossa had undergone attrition, the centre of the wear facet on the cusp or centre of fossa was selected as the reference point.

Apart from the points on the central incisors, these selected points would be expected to occlude in a centric occlusion (Ramfjord and Ash 1971) and the maxillary arch breadths Max 7 - Max 7, Max 6 - Max 6, etc., should be the same as the corresponding mandibular arch breadths (Man 7 - Man 7, Man 6 - Man 6, etc.).

The following variables, defined in terms of the distances between specified reference points, and illustrated in Figure 5 were selected for measurement (see Table 1).
### TABLE 1

**VARIABLES SELECTED FOR MEASUREMENT**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Designation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Max 7 breadth</td>
<td>The distance between right Max 7 and left Max 7</td>
</tr>
<tr>
<td>2</td>
<td>Max 6 breadth</td>
<td>The distance between right Max 6 and left Max 6</td>
</tr>
<tr>
<td>3</td>
<td>Max 5 breadth</td>
<td>The distance between right Max 5 and left Max 5</td>
</tr>
<tr>
<td>4</td>
<td>Max 4 breadth</td>
<td>The distance between right Max 4 and left Max 4</td>
</tr>
<tr>
<td>5</td>
<td>Max 3 breadth</td>
<td>The distance between right Max 3 and left Max 3</td>
</tr>
<tr>
<td>6</td>
<td>Max Inc right</td>
<td>The distance between right Max 3 and right Max 1</td>
</tr>
<tr>
<td>7</td>
<td>Max Inc left</td>
<td>The distance between left Max 3 and left Max 1</td>
</tr>
<tr>
<td>8</td>
<td>Man 7 breadth</td>
<td>The distance between right Man 7 and left Man 7</td>
</tr>
<tr>
<td>9</td>
<td>Man 6 breadth</td>
<td>The distance between right Man 6 and left Man 6</td>
</tr>
<tr>
<td>10</td>
<td>Man 5 breadth</td>
<td>The distance between right Man 5 and left Man 5</td>
</tr>
<tr>
<td>11</td>
<td>Man 4 breadth</td>
<td>The distance between right Man 4 and left Man 4</td>
</tr>
<tr>
<td>12</td>
<td>Man 3 breadth</td>
<td>The distance between right Man 3 and left Man 3</td>
</tr>
<tr>
<td>13</td>
<td>Man Inc right</td>
<td>The distance between right Man 3 and right Man 1</td>
</tr>
<tr>
<td>14</td>
<td>Man Inc left</td>
<td>The distance between left Man 3 and left Man 1</td>
</tr>
</tbody>
</table>

Seven other values were subsequently derived by computer analysis from the direct measurements to indicate the differences between homologous arch dimensions in the upper and lower dentitions. These new variables then provided a quantification of the relative size of upper and lower arches in defined regions. They were calculated as indicated in Table 2.
TABLE 2

VARIABLES DERIVED BY CALCULATION

<table>
<thead>
<tr>
<th>Variable</th>
<th>Designation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>Max 7-Man 7</td>
<td>The difference between Max 7 breadth &amp; Man 7 breadth</td>
</tr>
<tr>
<td>16</td>
<td>Max 6-Man 6</td>
<td>The difference between Max 6 breadth &amp; Man 6 breadth</td>
</tr>
<tr>
<td>17</td>
<td>Max 5-Man 5</td>
<td>The difference between Max 5 breadth &amp; Man 5 breadth</td>
</tr>
<tr>
<td>18</td>
<td>Max 4-Man 4</td>
<td>The difference between Max 4 breadth &amp; Man 4 breadth</td>
</tr>
<tr>
<td>19</td>
<td>Max 3-Man 3</td>
<td>The difference between Max 3 breadth &amp; Man 3 breadth</td>
</tr>
<tr>
<td>20</td>
<td>MaxIncR-ManIncR</td>
<td>The difference between MaxInc right and ManInc right</td>
</tr>
<tr>
<td>21</td>
<td>MaxIncL-ManIncL</td>
<td>The difference between MaxInc left and ManInc left</td>
</tr>
</tbody>
</table>

This group of variables provided an indication of the congruence or otherwise of homologous maxillary and mandibular arch breadths.

METHODS OF MEASUREMENT

Variables 1 - 14 were measured directly on the casts using a specially modified vernier caliper with a resolution of 0.1 mm. A Helios dial caliper fitted with needle points was modified (see Figure 6) by replacing the dial mechanism with a high precision linear potentiometer wired into an analogue-digital converter unit to effect direct output of metric data onto punched cards through an interface with an IBM 026 card punch as described by Garn and Helmarich (1967). Figure 7 illustrates the system. This procedure enabled tooth measurements to be automatically punched to a predetermined format by merely depressing a foot-operated circuit switch. The operator used Zeiss binocular magnifying
Figure 6. The modified Helios dial caliper.
Figure 7. Semi-automatic system for data acquisition showing analogue-digital converter unit (left)
spectacles with a focal length of 330 mm and a magnification factor of 2 to assist in placement of the needle points.

Two data cards were punched for each subject. The first card was coded with identification data, namely the subject's dental registration number, sex, name and sibling number. The second card contained further identification data, chronological age, dental age (see Appendix A) and systematically recorded arch breadth measurements. When a tooth was missing, the caliper beaks were closed, and a zero value was recorded on the punched card. Missing data points were thus identified and ignored in subsequent computer analyses.

GENERAL STATISTICAL METHODS

The descriptive parameters mean $\bar{x}$, standard deviation $s$, and error of the mean $E\bar{x}$, were estimated according to the usual procedures:

$$\bar{x} = \frac{\Sigma x}{N}; \quad s = \sqrt{\frac{\Sigma (x-\bar{x})^2}{N-1}}; \quad E\bar{x} = \frac{s}{\sqrt{N}}$$

where $x$ is the observed value, and $N$ is the number of observations.

The $F$-ratio test of Snedecor was used to test the significance of differences in variances, and Student's t-test was used to test differences between means.

Measures of skewness and kurtosis were obtained as an aid to assessing the normality of the various distributions. Skewness is denoted $\sqrt{D_1}$ and is calculated from the second and third moments of the deviations from the mean according to the formula:
\[
\sqrt{b_1} = \sqrt{\frac{N \Sigma (x-\bar{x})^3}{[\Sigma (x-\bar{x})^2]^3}}
\]

where the sign of \( \sqrt{b_1} \) is the same as the sign of the third moment.

Kurtosis, is indicated by \( b_2 \) which is computed from the second and fourth moments of the deviations from the mean according to the formula:

\[
b_2 = \frac{N \Sigma (x-\bar{x})^4}{[\Sigma (x-\bar{x})^2]^2}
\]

Tables of Pearson and Hartley (1954) were used to test the significance of departures from normality. Precise estimates of skewness and kurtosis require adequate sample sizes. Nevertheless, the calculations of these statistics in the present study, where large sample sizes were unavailable, provided an indication of the general trends in the shapes of the distributions.

Calculations were carried out on a CDC Cyber 173 computer at the University of Adelaide, via a VDU terminal located in the laboratory where the work was carried out.
CHAPTER IV

ERRORS OF THE METHODS

INTRODUCTION

In biometric research it is essential to determine the reliability of measurement methods, that is, the accuracy with which the same measurements can be made on different occasions. If errors can be shown to have no significant effect on either the group mean values, or the variances of the observations, then it can be assumed that the errors have not biased the true values to any significant extent.

Errors may arise in one of two ways. Systematic errors may be introduced because of limitations in the original records or the measuring apparatus. Accidental errors may be incorporated into measurements because of variations in the observer's measuring technique or registration of the data. Both types of error may be minimised by the use of a standardised procedure for measurement and recording.

The method of measurement selected for the present study minimised systematic errors because the fine points of the calipers could be accurately positioned using the magnifying lenses, and the semi-automatic system permitted measurements to be made with an accuracy of 0.1 mm. The calibration of the system was checked daily. Accidental errors were largely avoided because of the direct recording of measurements. The possibilities of mis-reading the caliper, or incorrectly recording an observation were thus eliminated.
Gross recording errors were detected by calculating the standardised scores for each variable. For this procedure the measurements for each subject were expressed as standard deviation scores about the group mean value for that variable. The observer was alerted by a computer diagnostic that drew attention to any score that was greater than three standard deviation units from the group mean. These limits would be expected to include about 99 per cent of subjects. In these instances, the original measurement was re-checked. Because semi-automatic procedures were used, this type of gross recording error was found to be almost non-existent.

The magnitude of errors and the extent to which they affect results may be assessed by means of replicability studies. In the present investigation the dental casts of 40 subjects were measured on two different occasions and the magnitudes of the errors involved between the two determinations were calculated.

**METHODS**

The following statistical tests were used:

1. The method of Dahlberg (1940) was used to compute the standard deviation of a single determination ($s_1$) according to the formula:

$$s_1 = \sqrt{\frac{\sum d^2}{2N}}$$

Where $d = \text{difference between repeated measurements}$

$N = \text{number of double determinations}$
2. Student's t-test with 19 degrees of freedom was used to determine the significance of the differences between the two sets of mean values. This method is not a particularly sensitive test of measurement errors, as positive and negative differences tend to be self-cancelling, but it was included in the present study for comparative purposes.

3. A further method of assessing measurement errors is to analyse the difference between two determinations on a paired-comparison basis by calculating the mean of the difference (\( \bar{x} \) diff), the standard deviation of the differences (s diff) and the error of the mean differences (Ex diff).

The following formulae were used to determine these error statistics:

\[
\bar{x} \text{ diff} = \frac{\Sigma d}{N}
\]

\[
s \text{ diff} = \sqrt{\frac{\Sigma (d - \bar{x} \text{ diff})^2}{N - 1}}
\]

\[
\text{Ex} \text{ diff} = \frac{s \text{ diff}}{N}
\]

Where \( d \) = difference between two determinations

\( N \) = number of double determinations

The probability that a mean difference differs significantly from zero can be tested using Student's t-test. The value of \( t \) was calculated according to the following equation:

\[
t = \frac{\bar{x} \text{ diff}}{\text{Ex} \text{ diff}}
\]
4. The extent to which the variability due to experimental error
affected the observed variance was indicated by using the generality
that component parts of a variance can be summed to equal the total
variance.

\[ s_o^2 = s_t^2 + s_e^2 \]

where \( s_o^2 \) = observed variance in the sample as determined from
original values. This estimate includes variance due
to measurement error.

\( s_t \) = estimate of the true sample variance.

\( s_e \) = estimate due to experimental error, termed the error
variance.

This value is determined as \( s_1^2 \) where \( s_1^2 = \frac{\Sigma d^2}{2N} \).

RESULTS AND DISCUSSION

The computation of standard scores disclosed very few frank
recording errors. In these instances, the casts were re-measured and
standard scores re-calculated using the new data.

Double determination results, summarized in Table 3, were
reasonably consistent for the various arch breadths measured on
separate occasions. The only significantly different observations
occurred in measuring MaxInc left (p < .01). This may have arisen because
of difficulty in accurately locating the reference point on the upper
left canine. The Dahlberg statistical analysis of these data (see Table 4)
indicated that all variables, with the exception of Max 3 breadth and
Man 5 breadth could be measured with a small degree of error. The error
variance in Max 3 breadth and Man 5 breadth was about $1 \text{ mm}^2$ and may have been due to difficulty in locating the centre of the mesio-lingual fossa on the upper canines, and because of variable wear patterns on the buccal cusp of the lower second premolar. Although these two variables displayed variance of the order of $1 \text{ mm}^2$, this magnitude was small compared with the variance of arch breadth measurements, and the absence of a significant difference between the first and second observations of the variables confirmed that the data obtained were not subject to measurement errors to any noticeable extent.
### Table 3

**Mean Differences Between First and Second Determinations of Dental Arch breadths**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Designation</th>
<th>N</th>
<th>Mean</th>
<th>Error of Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Max 7 breadth</td>
<td>30</td>
<td>-0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>2</td>
<td>Max 6 breadth</td>
<td>40</td>
<td>-0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>3</td>
<td>Max 5 breadth</td>
<td>40</td>
<td>-0.12</td>
<td>0.08</td>
</tr>
<tr>
<td>4</td>
<td>Max 4 breadth</td>
<td>39</td>
<td>-0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>5</td>
<td>Max 3 breadth</td>
<td>39</td>
<td>-0.28</td>
<td>0.23</td>
</tr>
<tr>
<td>6</td>
<td>MaxInc right</td>
<td>30</td>
<td>-0.25</td>
<td>0.15</td>
</tr>
<tr>
<td>7</td>
<td>MaxInc left</td>
<td>31</td>
<td>-0.51**</td>
<td>0.20</td>
</tr>
<tr>
<td>8</td>
<td>Man 7 breadth</td>
<td>30</td>
<td>-0.01</td>
<td>0.09</td>
</tr>
<tr>
<td>9</td>
<td>Man 6 breadth</td>
<td>40</td>
<td>-0.11</td>
<td>0.09</td>
</tr>
<tr>
<td>10</td>
<td>Man 5 breadth</td>
<td>40</td>
<td>-0.21</td>
<td>0.27</td>
</tr>
<tr>
<td>11</td>
<td>Man 4 breadth</td>
<td>40</td>
<td>-0.10</td>
<td>0.06</td>
</tr>
<tr>
<td>12</td>
<td>Man 3 breadth</td>
<td>40</td>
<td>-0.07</td>
<td>0.06</td>
</tr>
<tr>
<td>13</td>
<td>ManInc right</td>
<td>20</td>
<td>-0.01</td>
<td>0.30</td>
</tr>
<tr>
<td>14</td>
<td>ManInc left</td>
<td>20</td>
<td>-0.06</td>
<td>0.19</td>
</tr>
</tbody>
</table>

When N is number of observations.

**Mean value differs significantly from zero at p < .01.**
### TABLE 4

DAHLBERG STATISTICS FOR STANDARD DEVIATION FOR A SINGLE DETERMINATION

<table>
<thead>
<tr>
<th>Variable</th>
<th>Designation</th>
<th>$N$</th>
<th>$S_1$</th>
<th>$S_1^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Max 7 breadth</td>
<td>30</td>
<td>0.32</td>
<td>0.11</td>
</tr>
<tr>
<td>2</td>
<td>Max 6 breadth</td>
<td>40</td>
<td>0.31</td>
<td>0.10</td>
</tr>
<tr>
<td>3</td>
<td>Max 5 breadth</td>
<td>40</td>
<td>0.36</td>
<td>0.13</td>
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<td>4</td>
<td>Max 4 breadth</td>
<td>39</td>
<td>0.40</td>
<td>0.16</td>
</tr>
<tr>
<td>5</td>
<td>Max 3 breadth</td>
<td>39</td>
<td>1.04</td>
<td>1.08</td>
</tr>
<tr>
<td>6</td>
<td>MaxInc right</td>
<td>30</td>
<td>0.59</td>
<td>0.35</td>
</tr>
<tr>
<td>7</td>
<td>MaxInc left</td>
<td>31</td>
<td>0.84</td>
<td>0.70</td>
</tr>
<tr>
<td>8</td>
<td>Man 7 breadth</td>
<td>30</td>
<td>0.34</td>
<td>0.12</td>
</tr>
<tr>
<td>9</td>
<td>Man 6 breadth</td>
<td>40</td>
<td>0.39</td>
<td>0.15</td>
</tr>
<tr>
<td>10</td>
<td>Man 5 breadth</td>
<td>40</td>
<td>1.10</td>
<td>1.41</td>
</tr>
<tr>
<td>11</td>
<td>Man 4 breadth</td>
<td>40</td>
<td>0.26</td>
<td>0.07</td>
</tr>
<tr>
<td>12</td>
<td>Man 3 breadth</td>
<td>40</td>
<td>0.28</td>
<td>0.08</td>
</tr>
<tr>
<td>13</td>
<td>MaxInc right</td>
<td>20</td>
<td>0.92</td>
<td>0.84</td>
</tr>
<tr>
<td>14</td>
<td>MaxInc left</td>
<td>20</td>
<td>0.60</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Where $N$ is the number of observations,

$S_1$ is the standard deviation of a single determination.

$S_1^2$ is the variance.
CHAPTER V RESULTS

DENTAL ARCH BREADTHS

Intra Group Comparisons

Tables 5 and 6 present the average values and standard deviations for dental arch breadths of Aboriginals and Caucasoids. These statistics were derived by the methods described previously. The forms of the distributions were assessed by the statistic $\sqrt{E_1}$, a measure of skewness. Apart from a tendency for some distributions to be skewed to the left for the variables measured in Caucasoids, there was little evidence of generalized departures from normality to warrant transformations of the data or the application of special statistical procedures. The sample sizes were inadequate to assess kurtosis. For this part of the analysis, routine statistical tests based on the assumption of normal distribution were used. Because of the small number of Caucasian females included in the study, comparisons relating to this group must be tentative and regarded with some caution.

Dental arch breadths in different groups may be compared on the basis of mean values derived for the groups separately. Alternatively, a dimorphism index can be used to express the relative differences between groups. In the present study, dental arch breadths were compared using both absolute and relative values.

In each ethnic group the dental arch breadths were greater in males than females for all variables. The sex differences in dental arch size
### TABLE 5

COMPARISON OF MAXILLARY DENTAL ARCH BREADTHS IN ABORIGINALS AND CAUCASOIDS

<table>
<thead>
<tr>
<th>Variable</th>
<th>ABORIGINALS</th>
<th></th>
<th>CAUCASOIDS</th>
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<th>DIFFERENCE&lt;sup&gt;1&lt;/sup&gt;</th>
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<td>Mean (mm)</td>
<td>S.D.</td>
<td>N</td>
<td>Mean (mm)</td>
<td>S.D.</td>
</tr>
<tr>
<td>MAX 7 BDTH</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>♂</td>
<td>80</td>
<td>64.8</td>
<td>2.5**</td>
<td>45</td>
<td>62.7</td>
</tr>
<tr>
<td></td>
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<td>78</td>
<td>62.3</td>
<td>2.3</td>
<td>10</td>
<td>56.1</td>
</tr>
<tr>
<td>MAX 6 BDTH</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>♂</td>
<td>80</td>
<td>59.9</td>
<td>2.8**</td>
<td>45</td>
<td>56.1</td>
</tr>
<tr>
<td></td>
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<td>2.5</td>
<td>10</td>
<td>50.3</td>
</tr>
<tr>
<td>MAX 5 BDTH</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>♂</td>
<td>80</td>
<td>53.6</td>
<td>2.5**</td>
<td>45</td>
<td>49.6</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>78</td>
<td>51.4</td>
<td>2.3</td>
<td>10</td>
<td>44.2</td>
</tr>
<tr>
<td>MAX 4 BDTH</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>♂</td>
<td>80</td>
<td>48.0</td>
<td>2.3**</td>
<td>45</td>
<td>43.3</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>78</td>
<td>45.8</td>
<td>2.2</td>
<td>10</td>
<td>39.0</td>
</tr>
<tr>
<td>MAX 3 BDTH</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>♂</td>
<td>80</td>
<td>41.0</td>
<td>2.4**</td>
<td>45</td>
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<td>78</td>
<td>39.9</td>
<td>2.1</td>
<td>10</td>
<td>33.5</td>
</tr>
</tbody>
</table>

<sup>1</sup> Mean values for Aboriginals and Caucasoids differ significantly for all variables at p < .01

** Mean values for males and females differ significantly at p < .01

* Mean values for males and females differ significantly at p < .05
### TABLE 6

**COMPARISON OF MANDIBULAR DENTAL ARCH BREADTHS IN ABORIGINALS AND CAUCASOIDS**

<table>
<thead>
<tr>
<th>Variable</th>
<th>ABORIGINALS</th>
<th>CAUCASOIDS</th>
<th>DIFFERENCE&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean (mm)</td>
<td>S.D.</td>
</tr>
<tr>
<td>MAN 7 BDTH</td>
<td>♂</td>
<td>80</td>
<td>65.7</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>78</td>
<td>63.3</td>
</tr>
<tr>
<td>MAN 6 BDTH</td>
<td>♂</td>
<td>80</td>
<td>60.4</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>78</td>
<td>58.2</td>
</tr>
<tr>
<td>MAN 5 BDTH</td>
<td>♂</td>
<td>80</td>
<td>51.7</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>78</td>
<td>50.2</td>
</tr>
<tr>
<td>MAN 4 BDTH</td>
<td>♂</td>
<td>80</td>
<td>47.4</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>78</td>
<td>46.1</td>
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<tr>
<td>MAN 3 BDTH</td>
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<td>38.6</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>78</td>
<td>37.7</td>
</tr>
</tbody>
</table>

<sup>1</sup> Mean values for Aboriginals and Caucasoids differ significantly for all variables at p < .01

** Mean values for males and females differ significantly at p < .01

* Mean values for males and females differ significantly at p < .05
were statistically significant at the 1% level for all comparisons except for breadths measured in Caucasoids at the canine and first premolar regions both in the maxilla and mandible. In these instances the differences were significant at the 5% level.

The Caucasoids displayed sex differences in mean values which were of similar magnitude in the mandible and maxilla, ranging from 3.5 mm to 7.6 mm. Sex differences were particularly marked in the maxillary and mandibular molar regions, the differences being of the order of 6 mm. On the other hand, the Aboriginals displayed smaller sex differences which ranged from 0.9 mm to 2.8 mm. Furthermore, in general the differences were more uniform, with a slight tendency to be greater in the maxilla. Sex differences were most marked in Aboriginals in the upper and lower molar regions.

Estimates of the relative levels of dimorphism in arch breadths, expressed as the percentage by which a mean breadth in males exceeded that in females, are ranked according to magnitude in Table 7. In Aboriginals the dimorphism indices ranged from 2.31 to 4.85 with an average value of 3.65, while the Caucasoid values ranged from 10.29 to 14.71 with an average of 12.31. These values confirm the observation that sex differences in the Aboriginal group tended to be greater in the maxilla, whereas in the Caucasoids the dimorphism percentages were of similar order in each arch. In the Caucasoid group, the dimorphism index drew attention to the lower second premolar as the region of greatest percentage dimorphism, whereas the upper and lower molar regions displayed the greatest sex differences in absolute terms.
<table>
<thead>
<tr>
<th>Variable</th>
<th>ABORIGINALS</th>
<th>CAUCASOIDS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dimorphism %</td>
<td>Rank</td>
</tr>
<tr>
<td>MAX 7 BDTH</td>
<td>3.97</td>
<td>4</td>
</tr>
<tr>
<td>MAX 6 BDTH</td>
<td>4.85</td>
<td>1</td>
</tr>
<tr>
<td>MAX 5 BDTH</td>
<td>4.32</td>
<td>3</td>
</tr>
<tr>
<td>MAX 4 BDTH</td>
<td>4.80</td>
<td>2</td>
</tr>
<tr>
<td>MAX 3 BDTH</td>
<td>2.78</td>
<td>9</td>
</tr>
<tr>
<td>MAN 7 BDTH</td>
<td>3.79</td>
<td>5</td>
</tr>
<tr>
<td>MAN 6 BDTH</td>
<td>3.87</td>
<td>6</td>
</tr>
<tr>
<td>MAN 5 BDTH</td>
<td>2.97</td>
<td>7</td>
</tr>
<tr>
<td>MAN 4 BDTH</td>
<td>2.87</td>
<td>8</td>
</tr>
<tr>
<td>MAN 3 BDTH</td>
<td>2.31</td>
<td>10</td>
</tr>
</tbody>
</table>

1 Index of sexual dimorphism calculated as \( \frac{100 \text{ Male mean}}{\text{Female mean}} - 100 \)
The Caucasoïd males displayed the greatest variability of dental arch breadths. For instance, the range of values recorded for molar arch breadths in this group was about 20 mm, while the range for each of the other groups was of the order of 10 mm. The variances of the arch breadths in Caucasoïds were substantially larger than those of Aboriginals for all variables. The greater variability which was displayed by the Caucasoïds may have arisen because of differences in the sampling method used with each group, or may reflect a greater homogeneity amongst Aboriginals. This comparative uniformity of dental arch breadths may be due to inbreeding within the Aboriginal population at Yuendumu.

Townsend (1976) drew attention to the possibility of inbreeding within this group, but stated that information on this was scarce. In each ethnic group the males were generally more variable than females in the size of the dental arches. The observation of greater variability in males is a common finding in anthropometric studies and this is in accord with the expectation of less variability in females due to cessation of skeletal growth at an earlier age (Brown 1965).

Inter Group Comparisons

The Aboriginal males displayed maxillary and mandibular dental arch breadths which were larger than those in Caucasoïd males for all regions measured. The differences in breadths, significant at the 1% level in all cases, ranged from 2.0 mm to 4.7 mm, and were greatest in the upper and lower premolar regions.

A similar inter-racial dimorphism was observed between the female subjects. The differences between the arch breadths of Aboriginal and
Caucasoid females ranged from 6.2 mm to 8.4 mm and were statistically significant at the 1% level in all regions. The magnitude of the inter-racial dimorphism in the females was due to the relatively large dental arches of female Aboriginals. In many instances the Aboriginal females displayed arch breadths which were larger than those of Caucasian males. Attention has previously been drawn to the relatively large dental arches of female Aboriginals (Barrett, Brown and Macdonald 1965).

As a direct consequence of this morphological feature, the sex dimorphism in dental arch breadths was not particularly noticeable in the Aboriginal subjects, a finding referred to above.

**COMPARISONS OF MAXILLARY AND MANDIBULAR ARCH BREADTHS**

The means and standard deviations of discrepancies between maxillary and mandibular dental arch breadths of Aboriginals and Caucasoids are compared in Table 8. These values were derived as the differences between corresponding breadths in the maxilla and mandible as described previously. The forms of the distributions of these variables were assessed by the standard measure of skewness, $\sqrt{b_1}$. The Caucasian males and females and Aboriginal females displayed normal distributions, although the distributions of the discrepancies for Aboriginal males were significantly skewed to the left. That is, the number of subjects exhibiting large positive values was greater than would be expected in a normal distribution. To provide an alternative basis for the comparisons, median values were calculated for each of the samples; these are presented in Table 9. Median values are likely to be more representative of the central tendencies in instances of skewed distributions.
### TABLE 8

**COMPARISON OF DISCREPANCIES BETWEEN MAXILLARY AND MANDIBULAR ARCH BREADTHS EXPRESSED AS MEAN VALUES**

<table>
<thead>
<tr>
<th>Variable</th>
<th>ABORIGINALS</th>
<th>CAUCASOIDS</th>
<th>DIFFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean (mm)</td>
<td>S.D.</td>
</tr>
<tr>
<td>MAX 7 - MAN 7</td>
<td>δ</td>
<td>80</td>
<td>-0.9</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>73</td>
<td>-1.1</td>
</tr>
<tr>
<td>MAX 6 - MAN 6</td>
<td>δ</td>
<td>80</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>78</td>
<td>-1.0</td>
</tr>
<tr>
<td>MAX 5 - MAN 5</td>
<td>δ</td>
<td>80</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>78</td>
<td>0.9</td>
</tr>
<tr>
<td>MAX 4 - MAN 4</td>
<td>δ</td>
<td>80</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>78</td>
<td>-0.1</td>
</tr>
<tr>
<td>MAX 3 - MAN 3</td>
<td>δ</td>
<td>80</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>78</td>
<td>2.3</td>
</tr>
</tbody>
</table>

** Mean values for discrepancies between maxillary and mandibular arch breadths differ significantly from zero at p < .01
* Mean values for discrepancies between maxillary and mandibular arch breadths differ significantly from zero at p < .05
1 Mean values for discrepancies between Aboriginal and Caucsoid males differ significantly at p < .05
2 Mean values for discrepancies between Aboriginal males and females differ significantly at p < .01
3 Mean values for discrepancies between Aboriginal males and females differ significantly at p < .05
<table>
<thead>
<tr>
<th>Variable</th>
<th>ABORIGINALS</th>
<th></th>
<th>CAUCASOIDS</th>
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<th>DIFFERENCE</th>
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</thead>
<tbody>
<tr>
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<td>Median (mm)</td>
<td>N</td>
<td>Median (mm)</td>
<td>ABOR. - CAUC. (mm)</td>
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<tr>
<td>MAX 7 - MAN 7</td>
<td>d</td>
<td>80</td>
<td>-0.5</td>
<td>45</td>
<td>-1.1</td>
</tr>
<tr>
<td>BREADTH</td>
<td>9</td>
<td>78</td>
<td>-0.8</td>
<td>10</td>
<td>-0.5</td>
</tr>
<tr>
<td>MAX 6 - MAN 6</td>
<td>d</td>
<td>80</td>
<td>0.0</td>
<td>45</td>
<td>-1.1</td>
</tr>
<tr>
<td>BREADTH</td>
<td>9</td>
<td>78</td>
<td>-0.9</td>
<td>10</td>
<td>-0.2</td>
</tr>
<tr>
<td>MAX 5 - MAN 5</td>
<td>d</td>
<td>80</td>
<td>2.4</td>
<td>45</td>
<td>0.7</td>
</tr>
<tr>
<td>BREADTH</td>
<td>9</td>
<td>78</td>
<td>1.2</td>
<td>10</td>
<td>1.5</td>
</tr>
<tr>
<td>MAX 4 - MAN 4</td>
<td>d</td>
<td>80</td>
<td>1.2</td>
<td>45</td>
<td>0.0</td>
</tr>
<tr>
<td>BREADTH</td>
<td>9</td>
<td>78</td>
<td>0.0</td>
<td>10</td>
<td>0.0</td>
</tr>
<tr>
<td>MAX 3 - MAN 3</td>
<td>d</td>
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<td>2.4</td>
<td>45</td>
<td>2.1</td>
</tr>
<tr>
<td>BREADTH</td>
<td>9</td>
<td>78</td>
<td>2.4</td>
<td>10</td>
<td>1.8</td>
</tr>
</tbody>
</table>
Intra Group Comparisons

Maxillary dental arch breadths displayed by the Aboriginal males tended to be larger than homologous mandibular arch breadths. The differences between upper and lower breadths ranged from -0.9 mm to 2.5 mm. The largest discrepancy was in the canine region where the difference of 2.5 mm was significant at the 1% level. The 2.0 mm difference observed at the second premolars was also significant at the 1% level, while the only significant negative difference between upper and lower dental arches was -0.9 mm in the second molar region. This value represented a larger mandibular mean breadth, or a tendency towards cross-bite. Overall, the trend towards a narrow lower arch, or alternate intercuspation, was most marked in the canine and second premolar regions.

The Aboriginal females, on the other hand, displayed discrepancies ranging from -1.1 mm to 2.3 mm. In this sample also, the greatest discrepancy between upper and lower dental arch breadths was observed at the canines. This discrepancy of 2.3 mm was significant at the 1% level while the difference of 0.9 mm at the second premolar region was significant at the 5% level. The mandibular breadths in the first and second molar regions exceeded the homologous maxillary breadths by 1.0 mm and 1.1 mm respectively, these values being significant at the 1% level. In other words, there was a significant trend towards molar cross-bite in this sample. The tendency towards a narrow mandibular arch relative to the maxillary arch was thus less marked in the female Aboriginals than in the males of that ethnic group.
Sex dimorphism of dental arch breadth discrepancies in Aboriginals was particularly observed in the premolar regions. In both the first and second premolar regions the males displayed larger differences between upper and lower arches than did females. The values differed significantly at the 1% level at the second premolar, and at the 5% level at the first premolar. In the molar regions the males exhibited a less significant cross-bite tendency, and a more pronounced scissors-bite tendency in the canine region than did females. However, these differences were not statistically significant. Males and females displayed similar variances. Overall, it is suggested that sex dimorphism in Aboriginals with respect to arch breadth discrepancies is most marked in the premolar region. This tends to support the observations of incongruence between the shapes of upper and lower dental arches in some Aboriginal males, evident by inspection of occlusal relations on dental casts of these subjects.

The median values of discrepancies between upper and lower dental arch breadths confirm the sexual differences referred to above. The median values tend to be larger than the mean values presented in Table 8. This trend was particularly noted in the premolar regions of the Aboriginal males. The left skewness of the distribution suggests that such a trend would occur.

The Caucasoid males displayed discrepancies between homologous upper and lower dental arch breadths ranging from -1.5 mm to 2.1 mm. Negative values, or cross-bite tendencies were observed in the molar region, while the largest value was noted at the canines. Although this trend was similar to that observed in the Aboriginal sample, the
arch breadth differences in the Caucasoids were non-significant.
Although the differences between homologous upper and lower dental arch breadths were only slightly larger in Aboriginal than Caucasoid males, the greater values observed in the Aboriginal group may be significant from a functional point of view, especially in relation to the nature of precise cusp-fossa contacts.

Data from the small female Caucasian group are presented for tentative comparisons only; these subjects exhibited a similar trend to the males in the molar region where the mandibular arch tended to be broader than the maxillary. On the other hand, the upper arch tended to be broader than the lower at the premolars and canines. Differences in the mean values for arch breadths were non-significant.

A comparison of Caucasian male and Caucasian female discrepancies suggests that there is little sex dimorphism of these values. Both sexes displayed cross-bite tendency in the molar regions and scissors-bite tendency in the premolar and canine regions. The average discrepancy values and standard deviations were similar in males and females.

Inter Group Comparisons

In each region of the dental arches measured, the Aboriginal males displayed larger mean discrepancies than did Caucasian males. The differences between Aboriginal and Caucasian discrepancies ranged from 0.1 mm at the first premolars to 1.0 mm at the first molars. The differences in the regions of the first molars and second premolars were significant at the 5% level. The discrepancies between upper and lower dental arch breadths therefore display inter-racial dimorphism, and the premolar site is the region of greatest difference.
Median values of upper and lower arch breadth discrepancies confirm the trend suggested by mean values. Because the Aboriginal males displayed significant left skewness in the distribution, the relation of median values to mean values is relatively larger than in Caucasoid males. The median values tend to accentuate the racial differences already described, and draw further attention to the premolar region as the site of greatest difference.

The frequency distributions presented in Table 10 were derived by classifying subjects according to discrepancies between homologous maxillary and mandibular dental arch breadths. The number of subjects in each group displaying positive or negative discrepancies were then expressed as percentages of the total number in each group. This table draws further attention to the regions of the dental arches which might be involved in the racial differences. A similar percentage of Aboriginal and Caucasoid males, 69 and 66 per cent respectively, displayed a cross-bite tendency in the form of negative discrepancies between homologous upper and lower dental arch breadths in the second molar region. At the first molars, on the other hand, 77 per cent of Caucasoid and only 55 per cent of Aboriginal males demonstrated this trend. Furthermore, in the second premolar region, the 88 per cent of Aboriginal males which exhibited positive discrepancies was substantially greater than the 74 per cent of Caucasoid males which displayed this trend. In the region of the first premolars, little more than one half of the Caucasoids displayed positive differences, while a significant percentage, 75 per cent, of Aboriginal males displayed positive discrepancies in this region. In each group, a large percentage of subjects displayed positive discrepancies between upper and lower arch breadths at the canines.
## TABLE 10

FREQUENCY DISTRIBUTION OF SUBJECTS ACCORDING TO THE DISCREPANCIES BETWEEN MAXILLARY AND MANDIBULAR ARCH BREADTHS

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>N</th>
<th>PERCENTAGE OF SUBJECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Discrepancy &lt; 0.0</td>
</tr>
<tr>
<td>MAX 7 - MAN 7 BDTH</td>
<td>Abor. d</td>
<td>80</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Abor. g</td>
<td>78</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Cauc. d</td>
<td>45</td>
<td>66</td>
</tr>
<tr>
<td>MAX 6 - MAN 6 BDTH</td>
<td>Abor. d</td>
<td>80</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>Abor. g</td>
<td>78</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>Cauc. d</td>
<td>45</td>
<td>77</td>
</tr>
<tr>
<td>MAX 5 - MAN 5 BDTH</td>
<td>Abor. d</td>
<td>80</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Abor. g</td>
<td>78</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Cauc. d</td>
<td>45</td>
<td>26</td>
</tr>
<tr>
<td>MAX 4 - MAN 4 BDTH</td>
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<td>Abor. g</td>
<td>78</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Cauc. d</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>MAX 3 - MAN 3 BDTH</td>
<td>Abor. d</td>
<td>80</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Abor. g</td>
<td>79</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Cauc. d</td>
<td>45</td>
<td>9</td>
</tr>
</tbody>
</table>

** Percentages of subjects in the two categories differ significantly at p < .01 according to sign test
A comparison of the female subjects, on the other hand, revealed that the Caucasoids exhibited larger mean discrepancies between homologous upper and lower arch breadths than did the Aboriginals. These differences were of the order of 0.5 mm, although none was statistically significant, possibly because of the small size of the Caucasoid sample.

The median values for discrepancies between upper and lower arch breadths (Table 9) present a similar trend to that suggested by mean values. Although median values tend to be larger than the means, the skewness of the distribution was not significant, hence this tendency is probably not important.

The frequency distribution of subjects according to the discrepancies between maxillary and mandibular arch breadths confirms the observation that both Aboriginal males and females display a cross-bite tendency in the molar region, although the trend was less frequent in the males. On the other hand, a high percentage of males, 88 per cent, demonstrated positive discrepancies in the second premolar region, more so than females, 77 per cent. In the first premolar region, a significant number of males, 75 per cent, displayed positive differences between upper and lower dental arch breadths, whereas there was no significant difference in the percentages of females displaying positive and negative discrepancies. In the canine region, most Aboriginal males and females exhibited positive discrepancies. This frequency distribution confirms the observation that sex dimorphism in discrepancies between upper and lower arch breadths is particularly associated with the premolar regions.
Table 11 summarises the mean and median discrepancies between homologous upper and lower arch breadths in each group included in the study. All groups demonstrated the same ranking: largest discrepancies being observed in the canine regions, and negative values being present in the molar regions, although median values for Aboriginal males do not reflect this trend to any great extent. Furthermore, the mean discrepancies in the molar region were similar in each group. The observation that all groups displayed the same ranking according to discrepancies between homologous breadths of upper and lower dental arches is interesting as a demonstration of similar patterns of congruence between upper and lower dental arches in all groups. It appears, however, that the larger discrepancies observed in particular regions of the arches of some Aboriginal males are related to the presence of alternate intercuspation in these subjects.

COMPARISON OF INCISOR DENTAL ARCH SEGMENTS

Values for breadths of incisor dental arch segments of Aboriginals and Caucasoids are presented in Table 12. As indicated previously, these data are included for comparative purposes and are not central to the study of alternate intercuspation.

Sex dimorphism in these variables was more pronounced in the Caucasoids than in the Aboriginals, and since these variables are partly dependent upon the mesiodistal width of the incisors, this observation might suggest that Caucasoids exhibit greater dimorphism in incisor size than Aboriginals. However, other more extensive studies
**TABLE 11**

COMPARISON OF DISCREPANCIES BETWEEN MAXILLARY AND MANDIBULAR ARCH BREADTHS - RANK ORDER

<table>
<thead>
<tr>
<th>RANK</th>
<th>REGION</th>
<th>MALES</th>
<th></th>
<th></th>
<th>FEMALES</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ABORIGINAL Mean (mm)</td>
<td>Median (mm)</td>
<td>CAUCASOID Mean (mm)</td>
<td>Median (mm)</td>
<td>ABORIGINAL Mean (mm)</td>
<td>Median (mm)</td>
</tr>
<tr>
<td>1</td>
<td>MAX 3 - MAN 3</td>
<td>2.5</td>
<td>2.4</td>
<td>2.1</td>
<td>2.1</td>
<td>2.3</td>
<td>2.4</td>
</tr>
<tr>
<td>2</td>
<td>MAX 5 - MAN 5</td>
<td>2.0</td>
<td>2.4</td>
<td>1.1</td>
<td>0.7</td>
<td>0.9</td>
<td>1.2</td>
</tr>
<tr>
<td>3</td>
<td>MAX 4 - MAN 4</td>
<td>0.6</td>
<td>1.2</td>
<td>0.5</td>
<td>0.0</td>
<td>-0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>MAX 6 - MAN 6</td>
<td>-0.5</td>
<td>0.0</td>
<td>-1.3</td>
<td>-1.1</td>
<td>-1.0</td>
<td>-0.8</td>
</tr>
<tr>
<td>5</td>
<td>MAX 7 - MAN 7</td>
<td>-0.9</td>
<td>-0.5</td>
<td>-1.5</td>
<td>-1.1</td>
<td>-1.1</td>
<td>-0.9</td>
</tr>
</tbody>
</table>
### TABLE 12

**COMPARISON OF INCISOR DENTAL ARCH SEGMENTS**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Aboriginals Males</th>
<th></th>
<th>Aboriginals Females</th>
<th></th>
<th>Caucasoids Males</th>
<th></th>
<th>Caucasoids Females</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean (mm)</td>
<td>S.D.</td>
<td>N</td>
<td>Mean (mm)</td>
<td>S.D.</td>
<td>N</td>
</tr>
<tr>
<td>MaxICl</td>
<td>80</td>
<td>27.8</td>
<td>1.8</td>
<td>45</td>
<td>25.9</td>
<td>4.6&lt;sup&gt;1&lt;/sup&gt;</td>
<td>78</td>
</tr>
<tr>
<td>ManICl</td>
<td>80</td>
<td>25.1</td>
<td>1.5&lt;sup&gt;2&lt;/sup&gt;</td>
<td>45</td>
<td>25.0</td>
<td>2.1&lt;sup&gt;1&lt;/sup&gt;</td>
<td>78</td>
</tr>
<tr>
<td>MaxICR</td>
<td>80</td>
<td>27.8</td>
<td>2.1</td>
<td>45</td>
<td>25.8</td>
<td>4.7</td>
<td>78</td>
</tr>
<tr>
<td>ManICR</td>
<td>80</td>
<td>25.2</td>
<td>1.8&lt;sup&gt;2&lt;/sup&gt;</td>
<td>45</td>
<td>24.8</td>
<td>2.5</td>
<td>78</td>
</tr>
</tbody>
</table>

<sup>1</sup> Mean values for Aboriginals and Caucasoids differ significantly at $p < .01$

<sup>2</sup> Mean values for discrepancies between maxillary and mandibular incisor segment breadths differ significantly from zero at $p < .01$
(Garn, Lewis, Swindler and Kerewsky 1967) have reported greater sex
dimorphism in mesiodistal width of incisor teeth in Aboriginals than
Caucasoids. The small number of Caucasian females does not permit
any real conclusions about relative sex dimorphism to be drawn.

The Aboriginal males and females displayed significantly higher
values for maxillary incisor segment breadths than did their Caucasian
counterparts, although this racial variation was not significant in
mandibular breadths.

In the Aboriginal males and females each maxillary incisor
segment breadth was significantly larger, at the 1% level, than the
corresponding mandibular breadth, whereas this trend was not evident
in the Caucasoids. The Caucasoids then tended to display congruence
in breadth of upper and lower incisor segments while the Aboriginals
displayed broader maxillary incisor segments than mandibular segments.
CHAPTER VI  DISCUSSION

According to commonly held views of dental occlusion, maximum interdigitation of the upper and lower teeth occurs when the jaw closes lightly from its rest position. This concept of intercuspal position, or as it is sometimes termed, tooth position, or centric occlusion, is based on clinical observations of modern man. Moreover, the concept has its origins in the belief that precise anatomical and functional relationships should exist between the cusps, fossae, and other occlusal features of opposing teeth. Modern theories of occlusion, and clinical treatment procedures in all branches of dental practice are based on this concept of opposing tooth relationships.

However, there have been several reports in the literature that draw attention to a different form of occlusal relationship characterised by a disparity in the breadths of upper and lower dental arches so that maximum intercuspation, in the classic sense, can be achieved on either the right or left sides independently, but not on both sides together. This anatomical feature, which is termed alternate intercuspation, has been observed in a number of Australian Aboriginal subjects and the present study aims to elucidate the nature of this form of occlusion.

Previous reports of alternate intercuspation in man are sufficiently frequent to verify its existence as a morphological character rather than as an artifact of observation or a malocclusion. However, its precise
description in metric terms is elusive and no serious attempts have been made to quantify it before this study.

In order to investigate alternate intercuspation more thoroughly, it was considered appropriate, in the first instance, to examine the differences between maxillary and mandibular dental arch breadths measured between homologous points. In this respect, homologous points were considered to be those cusp and fossae points in the maxilla and mandible assumed to be in contact according to conventional concepts of dental occlusion. Thus the degree of alternate intercuspation was directly related to the discrepancy between homologous arch breadths in the maxilla and mandible. The observation that alternate intercuspation was a feature of some Aboriginal dentitions could then be tested by comparing the arch breadth discrepancies in this group with those measured in a control group of Caucasoid subjects.

The findings confirm that alternate intercuspation is indeed a feature of some Aboriginal dentitions, and is particularly frequent in males. This view is based upon the observation that the differences between upper and lower arch breadths were significant in some instances and that a relatively high percentage of Aboriginal males displayed large discrepancies in the occlusal relationships. However, simple comparison of the mean values for the characters measured tended to obscure the trend towards alternate intercuspation in some subjects. It is inevitable that comparisons based on central tendencies provide different information from analyses of individual subjects. In this context, the present study emphasised the difficulties in quantifying alternate intercuspation clinically. On the one hand, discrepancies
between upper and lower dental arch breadths were assumed to be continuous variables and analysed accordingly. On the other hand, this metric procedure did not provide a clear classification of alternate intercuspation in terms of presence or absence. Moreover objective discrimination between subjects according to the degree of alternate intercuspation could not be attempted as any discrimination points along a continuously varying character would be arbitrary to a large extent.

Although the metric analyses disclosed differences in dental arch breadths between Aboriginals and Caucasoids, the variables selected for measurement did not lead to fine discrimination between the groups on the basis of maxillary-mandibular occlusal relationships. Clearly, other methods, both metric and non-metric are required to provide a clearer description of alternate intercuspation.

As described above, the mean arch breadth discrepancies for Aboriginal males indicate that some subjects display substantial differences in maxillary and mandibular breadths, while, in others, the differences may be similar in magnitude to those observed in Caucasoids. The Caucasoid group exhibited greater variability with respect to this character, but the group means indicated that the average differences between homologous breadths of the upper and lower arches were small. While some Aboriginals displayed unique buccolingual occlusal relations, or alternate intercuspation, others have occlusal relations corresponding to the concept of maximum interdigitation inherent in the definition of classic centric occlusion. Although a comparison of mean dental arch breadth discrepancies reflects a difference between the
occlusal relations of the two groups, it does not readily identify reasons for this inter-racial dimorphism. The frequency distributions presented in Table 9 indicate the relatively large number of Aboriginal males displaying marked discrepancies.

The selection of the reference points used in this study was based on the classic anatomical and functional relationships which are thought to exist between cusps, fossae, and other occlusal features of opposing teeth. Attention has been drawn to the clinical variability of these expected contacts between upper and lower teeth (Anderson and Myers 1971). The findings of this study support the suggestion that these relationships do vary clinically. However, the expected cusp-fossae relations between opposing teeth did not vary randomly in all groups. For instance, the Aboriginal male group displayed a significant trend for the buccal cusps of the mandibular teeth to occlude linguually to the central fossae of their maxillary opponents. In other words, although variability in cusp-fossae contacts was noted, this variation was not random in all groups and the Aboriginal males tended to display alternate intercuspation (Figures 8-12).

Although occlusal anatomy consisting of cusps and fossae as found in most primates is by no means characteristic of all species, unilateral articulation, or alternate intercuspation as it is termed here, appears to be a natural form of occlusion in masticatory systems characterized by wide lateral jaw movements (Figure 13). For instance, in selodont artiodactyls, the dominant herbivores, including deer, antelope, cattle (Figure 14), sheep and goats, the lower jaw is narrower than the upper. Masticatory movements require extensive lateral excursions of the
Section through first permanent molars

Section through first permanent premolars

Figure 8. Cross-section through dental casts obtained from an Aboriginal displaying maximum interdigitation in centric occlusion. The casts have been separated slightly for illustrative purposes.
Figure 9. Cross-section through dental casts obtained from a Caucasoid displaying maximum interdigitation in centric occlusion. The casts have been separated slightly for illustrative purposes.
Section through first permanent molars

Section through first permanent premolars

Figure 10. Cross-section through dental casts obtained from an Aboriginal displaying alternate intercuspation with maximum interdigititation on one side only. The casts have been separated slightly for illustrative purposes.
Figure 11. Cross-sections through the first permanent molar area of dental casts obtained from an Aboriginal subject. The casts have been separated slightly for illustrative purposes.
Figure 12. Cross-sections through the first primary molar or first permanent premolar area of dental casts obtained from the same Aboriginal subject as in Figure 11. The casts have been separated slightly for illustrative purposes.
mandible to produce a grinding shear action during food comminution. This seems well suited to shredding tough fibrous food (Lumsden and Osborn 1977). Similarly, alternate intercuspation can be observed in marsupials such as kangaroos, wombats and koalas (Figure 15). This may be an example of convergent evolution. Primates exhibit similar occlusal patterns, and in the gorilla and macaques, for instance, alternate intercuspation can be demonstrated, despite the presence of interlocking canines (Figures 16, 17). In this type of maxillo-mandibular relationship maximum tooth contact occurs on right or left sides alternatively, thus increasing lateral grinding movements which leads to a more efficient masticatory pattern. This mandibular movement pattern may be made more efficient by gradual occlusal attrition which appears to serve as a milling-in procedure. Barrett (1969) drew attention to the functional significance of tooth attrition in Aboriginals and suggested that this permitted the occlusion to wear in. He concluded that this gradual wear process was within the biological capacity of the individual for most of his life and should therefore be seen as normal. Furthermore, the sharp rim of enamel which surrounds the exposed dentine can readily tear into food, functioning most effectively when lateral masticatory movements are used to produce shearing between opposing enamel rims (Lumsden and Osborn 1977). It may be that the presence of alternate intercuspation and attrition such as is observed in groups like Aboriginals may produce an efficient mastication, well suited to shredding the tough fibrous foods which form a large part of the diet of such people.
Figure 13. Aboriginal skull and mandible displaying alternate intercuspation on (a) right side and (b) left side.
Figure 14. Inferior view of the skull and mandible of a cow (*bos*) demonstrating the difference in upper and lower dental arch breadths.
Figure 15. Inferior view of the skull and mandible of a koala (*Phascolarctus*) demonstrating the difference in upper and lower dental arch breadths.
Figure 16. Inferior views of the skull and mandible of a gorilla (gorilla) demonstrating (a) left and (b) right occlusal positions.
Figure 17. Inferior view of the skull and mandible of a macaque (macaca) demonstrating (a) left and (b) right occlusal positions.
Many historic populations and some contemporary groups which still retain primitive dietary habits display this type of maxillo-mandibular occlusal relationship. For instance, Emslie (1952) drew attention to the occlusal surfaces of "old English dentitions", and compared the occlusion with that of herbivores. He noted similar features in the dentition of present day Greenland Eskimos, and illustrated these characteristics with photographs of a skull which displayed alternate intercuspation. Emslie did not specifically refer to this condition, although he mentioned the disproportionate breadth of mandible and maxilla and drew attention to similar features of primate dentitions. Further evidence of the widespread occurrence of alternate intercuspation can be obtained by observing collections of crania such as those held by the South Australian Museum. Amongst the crania displaying this form of occlusal morphology are specimens from the Solomon Islands, New Hebrides, New Ireland, South Africa (Zulu) and New Zealand (Maori).

The comparative frequency with which this form of dental occlusion is observed in crania of historic populations and in a few contemporary groups, and the infrequency with which this condition is observed in modern societies, draws attention to evolutionary trends in dental occlusion. There certainly appears to be a tendency in modern groups for the form of dental occlusion known as alternate intercuspation to be replaced by a form of dental occlusion characterised by a centric occlusion in which the cusps, fossae and marginal ridges of upper and lower teeth interdigitate according to current concepts of articulation. Attention has been drawn to related aspects of the evolution of dental occlusion by such authors as Le Blanc and Black (1973) who demonstrated a greater reduction in the combined crown areas of the maxillary teeth.
than in the crown areas of the mandibular teeth of skulls from the Eastern Mediterranean dating from 7000 B.C. to 1500 A.D. It was suggested that the dissimilar reductions in the upper and lower teeth may have been caused by a difference in selection pressures acting on the mandible and maxilla. Le Blanc and Black proposed that because selection pressures had been eased earlier in the maxilla than in the mandible, the upper jaw would tend to display evolutionary changes to a greater extent. These factors may be important as explanations of the changes in occlusal relationships referred to previously.

Secular changes in head size and form have been reported by Brown (1976) who demonstrated a significant change in some head dimensions of Aboriginals during the period 1930s to 1960s. Similar trends were reported in Western Apaches and Skolt Lapps. In all groups the facial index appeared to be increasing, facial height having increased more than bizygomatic breadth, and there appeared to be a trend towards dolichocephaly. Of particular interest in the Aboriginal group is the increase in bigonial breadth which was relatively greater than the increase in bizygomatic breadth. In other words, the head shape in the coronal plane is altering, the diamond shape being replaced by a squarer form. Whether these changes are associated with the evolutionary changes in the relative size of the upper and lower dental arches remains to be established, but this would appear to be an area which should be investigated further.

The changing dietary patterns which often occur with the transition of populations from a primitive food gathering existence to one in which a variety of processed foods is available are associated with changes in
occlusal morphology. Attrition is a feature of such groups as Australian Aboriginals, Kalahari Bushmen and Eskimos whose food demands heavy vigorous mastication. The pattern and extent of tooth attrition usually changes quite drastically as these groups progressively adopt Westernized food habits. Hunt (1959) has suggested that attrition is associated with alternate intercuspation. He reasoned that the development of attrition permitted the "unlocking" of the cusps and fossae of opposing teeth, thereby permitting prolonged growth in the width of the maxilla. Studies of the growth of the jaws in the coronal plane have not suggested which factors might be responsible for the co-ordination of maxillary and mandibular growth. Furthermore the suggestion that interlocking of upper and lower teeth maintains the parity between maxillary and mandibular dental arch breadths seems rather simplistic (Björk and Skieller 1974, Tracy and Savara 1966, Savara and Tracy 1967). Certainly the changes in dietary habits are dramatic when a group such as Aboriginals changes from a nomadic way of life to a more sheltered settlement existence. The secular changes in head form described by Brown (1976) occurred in one generation. It therefore seems possible that micro-evolutionary changes in dental occlusion may also occur quite quickly, and that changing diet may be one of the factors responsible for this.

Attritional tooth wear is usually associated with alternate intercuspation in producing a very efficient masticatory pattern (Lumsden and Osborn 1977), and the significance of cusps has been questioned by such writers as Campbell (1946) and Poole (1976). These authors have suggested that cusps might function to guide teeth into occlusion, and have no particular function thereafter. Although
this view might seem to support Hunt's hypothesis, such conclusions should be drawn with some caution. Campbell and Poole were both commenting on the masticatory efficiency of dentitions displaying attrition. The fact that many such dentitions also display alternate intercuspation certainly does not establish a cause and effect relation between this form of occlusion and attrition.

It can be seen then, that alternate intercuspation is a form of occlusal relationship displayed by herbivores, primates, and groups of homo sapiens whose dietary requirements demand efficient mastication. The prevalence of this form of occlusion has diminished in modern groups, and this evolutionary trend may be associated with other evolutionary changes in body and head size.

The importance of alternate intercuspation can be demonstrated by indicating various implications of this form of dental occlusion. A study of masticatory efficiency of subjects displaying alternate intercuspation in association with various degrees of attrition may lead to a re-appraisal of current clinical concepts of occlusion such as centric occlusion and cusp forms for restorative dentistry. Research into the inheritance of this form of dental occlusion may shed light on the inheritance of other occlusal forms through the characterization of the determinants of arch form. Comparison of the prevalence of alternate intercuspation in various groups both modern and those of earlier times, should reveal information about the evolution of hominids, and further define the taxonomic significance of dental arch form.

These important implications of research into this type of dental occlusion suggest a number of future investigations. The next stage
may well be to gather data on the dental arches of selected individuals. These data may be in the form of Cartesian co-ordinates assigned to selected anthropometric and odontometric reference points. Analysis of these co-ordinates would permit arch breadths and lengths in specified regions, or areas, or shapes to be computed. Age changes in size and/or shape could be ascertained using transformation of a grid system as suggested by D'Arcy Thompson (1961) and Sneath (1967). A pilot study of such shape comparisons is described in Appendix B.

Mathematical expressions such as polynomials may be used to describe the dental arches (Cheng 1972) or a system of medial axis transformation employed to reduce a complex shape like a dental arch to a simpler form (Oxnard 1973). The use of co-ordinates as described above would permit the arch form to be described mathematically as polynomials, or conic sections, or ellipses (Figure 18). Such expressions may permit a more meaningful description of the arch, since irregularities in arch form caused by individual malplaced teeth could be compensated for mathematically. Minor malalignment of teeth is probably the result of local factors which are not prime determinants of basic arch shape (Smith, Kolakowsky and Bailit 1978).

A comparison of size, shape, and discrepancies between upper and lower dental arches with respect to these parameters in siblings and half-siblings may provide some indication of the mode of inheritance of arch form in general, and alternate intercuspation in particular. Such comparisons may be made difficult by the age changes in arch shape which are suggested by the pilot study described in Appendix B. Comparisons of arch shapes in different subjects will be made more
Figure 18. Computer plot of polynomial equation describing dental arches' perimeters. (From Cheng 1972)
complex by the age changes in shape occurring in each individual. Despite these difficulties, attention should be directed to this area of research.

Studies of arch size and shape within families may provide additional data about genetic aspects of alternate intercuspation, although it is possible that polygenic inheritance will be disclosed, as has been reported for other metric characters of the dentition (Garn, Lewis, Swindler and Kerewsky 1967; Townsend 1976).

A preliminary study of the associations between general body build and dental arch size has been reported by Lavelle (1976b). Previous studies have drawn attention to the relation between dental arch size, skull size and body build (Lavelle 1971; Schulze 1973). Correlations between upper and lower dental arch form and somatic body type, characterized, for example, by the length and sturdiness factors described by Lindegård (1953) could be studied in some detail, and age changes in each elucidated. Moreover, the examination of serial frontal radiographs may provide useful data for correlative studies of dental arch breadths. The genetic aspects of these factors might be investigated subsequently. Furthermore, if dental arch form could be expressed in a standard fashion and correlated with body type, these techniques would be valuable for the study of fossil hominids represented often by only skull and dentition.

The findings of the present investigation indicate that alternate intercuspation is a measurable character, although its precise quantification remains elusive. Previous investigations have drawn
attention to this form of occlusal relationship but there has been no attempt to quantify it. Furthermore, little is known of the genetic, environmental or growth determinants which might be involved.

This preliminary report has outlined the morphological and functional significance of alternate intercuspation, a characteristic of dental occlusion that has received relatively little attention in the past. Avenues for further investigation have been suggested including improved methods for quantifying the character with a view to future comparative and genetic studies.
Modern concepts of functional occlusion are based on the contact relations between the maxillary and mandibular teeth. It is generally believed that maximum interdigitation of the teeth occurs simultaneously on each side of the dental arches in a position often described as centric occlusion.

However, a different form of dental occlusion has been frequently observed in some ethnic groups. This type of maxillo-mandibular relationship, called alternate intercuspation, is a normal form of occlusal morphology and is characterized by interdigitation of the teeth independently on the right or left sides of the dental arches, but not on both sides together. It is associated with disparity in breadth of upper and lower dental arches, the mandible being relatively narrower in relation to the maxilla than it is in dentitions displaying bilateral intercuspation. During the past century a few authors have drawn attention to this type of dental occlusion in pre-contemporary and modern populations in which the character is usually accompanied by progressive tooth attrition and other evidence of vigorous masticatory function.

The present study is the first to attempt to quantify alternate intercuspation as a basis for investigating its determinants and biological correlates. The parameters used to quantify the incongruence of upper and lower dental arches, namely the differences between homologous upper and lower arch breadths, have identified this
form of occlusion with the Aboriginal male sample particularly. Although the measuring methods were useful for a preliminary study of alternate intercuspation, a more precise metric description is required for detailed studies. Furthermore, the formulation of non-metric criteria which could be used to identify the presence or absence of this form of occlusion in particular subjects awaits more extensive investigation.

In order to quantify alternate intercuspation, dental arch breadths were measured between homologous points in the maxillary and mandibular dental arches. These measurements were made for Aboriginal males and females and Caucasoid males and females. If occlusal contacts conformed to generally accepted concepts of centric occlusion, the difference between homologous upper and lower arch breadths would be expected to be zero.

The main findings of this investigation were as follows:

1. In both Aboriginais and Caucasoids, the dental arch breadths were greater in males than females.

2. This sexual dimorphism in dental arch breadths tended to be more marked in the maxilla in Aboriginais, whereas in the Caucasoids the dimorphism was similar in each arch.

3. The sexual dimorphism in dental arch breadths was more pronounced in the Caucasoids, as was the variability in this character.

4. The Aboriginal males displayed the broadest dental arches, followed by Caucasoid males and Aboriginal females. Caucasoid females exhibited the narrowest arches relative to the other groups.
5. Maxillary dental arch breadths in the Aboriginal males tended to be larger on the average than homologous mandibular arch breadths. This trend was most obvious in this group, and thus alternate intercuspation seems to be particularly associated with the Aboriginal males.

6. The region of greatest discrepancy between homologous upper and lower dental arch breadths was the second premolar region of Aboriginal males.

7. All groups demonstrated the same ranking according to discrepancies between homologous breadths of upper and lower dental arches. This varied from a cross-bite tendency in the molar regions to a tendency towards scissors-bite in premolar and canine regions.

This study has identified alternate intercuspation as a particular feature of the dentition of some Aboriginal males and has drawn attention to the second premolar region as the site of particular discrepancy between homologous upper and lower arch breadths. Future investigations including genetic, comparative and growth studies have been suggested. Furthermore, improved methods for quantifying the character have been outlined.

Alternate intercuspation is a characteristic of functional dental occlusion that has received relatively little attention in the past. This study is the first attempt to quantify the character as a basis for investigating its determinants and biological correlates.
APPENDIX A

DENTAL CRITERIA FOR GROUPING
SUBJECTS IN DENTGRO PROJECT

The grouping method is based on stages of dental development as indicated by the number and type of emerged teeth and the state of exfoliation of the deciduous teeth. A tooth is considered to have emerged when any portion of the crown, however small, has penetrated the gingiva and is visible.

<table>
<thead>
<tr>
<th>Code</th>
<th>Dental Group</th>
<th>Stage of Dental Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Infant 1</td>
<td>The period prior to the emergence of the first deciduous tooth</td>
</tr>
<tr>
<td>11</td>
<td>Infant 2</td>
<td>Begins with the emergence of the first deciduous tooth</td>
</tr>
<tr>
<td>12</td>
<td>Infant 3</td>
<td>Begins with the emergence of the first of the deciduous second molars</td>
</tr>
<tr>
<td>21</td>
<td>Infant 4</td>
<td>Begins with the emergence of the last deciduous tooth</td>
</tr>
<tr>
<td>31</td>
<td>Early Juvenile 1</td>
<td>Begins with the emergence of the first permanent tooth</td>
</tr>
<tr>
<td>32</td>
<td>Early Juvenile 2</td>
<td>Begins with the emergence of the first of the permanent maxillary central incisors</td>
</tr>
<tr>
<td>33</td>
<td>Early Juvenile 3</td>
<td>Begins with the emergence of the first of the maxillary lateral incisors</td>
</tr>
<tr>
<td>41</td>
<td>Late Juvenile 1</td>
<td>Begins with the exfoliation of a deciduous canine or molar</td>
</tr>
<tr>
<td>42</td>
<td>Late Juvenile 2</td>
<td>Begins with the emergence of the first of the maxillary second premolars</td>
</tr>
<tr>
<td>51</td>
<td>Adolescent</td>
<td>Begins with the exfoliation of the last of the deciduous teeth</td>
</tr>
<tr>
<td>61</td>
<td>Young Adult 1</td>
<td>Begins with the emergence of the first of the third molars</td>
</tr>
<tr>
<td>71</td>
<td>Young Adult 2</td>
<td>Begins with the emergence of the last of the third molars</td>
</tr>
<tr>
<td>81</td>
<td>Mature Adult</td>
<td>Begins with attainment of approximately 30 years of age</td>
</tr>
<tr>
<td>91</td>
<td>Aged</td>
<td>Begins with attainment of approximately 50 years of age</td>
</tr>
</tbody>
</table>
APPENDIX B

A PRELIMINARY STUDY OF COMPARISONS OF DENTAL ARCH SHAPES

INTRODUCTION

Morphologists have generally described organisms in terms of size or shape, size being more frequently used because it can be expressed readily in quantitative terms. Many taxonomic classifications are based on criteria of shape or shape differences, but because shape is difficult to quantify, subjective assessment has tended to be the usual method for comparisons of this type. However, shape comparisons can be based on more objective criteria and some workers have described geometric and mathematical procedures for describing and comparing shapes.

The artist, Albrecht Dürer is often credited with having introduced the proportional or mesh technique. Certainly his graphic illustrations and adaptation of coordinates to demonstrate variations in facial features (Figure 19) served to popularize the technique. Leonardo da Vinci, a master in the art of perspective advocated a similar method in studies of both human and comparative anatomy (McNulty 1968).

D'Arcy Thompson (1961) drew attention to biological organisms and tissues which conform to precise geometric forms and which could be expressed mathematically. He considered two-dimensional diagrammatic representations of different organisms and derived procedures for comparing these. These comparisons were based on
- Drawing by Albrecht Dürer demonstrating how a difference in facial type means only a difference in scale when the artist employs the network or mesh technique.

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

Figure 19. Examples of Dürer's mesh technique used to describe facial proportions.
(From McNulty 1968)
his well known "transformation grids". By these procedures shape comparisons are defined in terms of the geometric relationships between homologous features of the two diagrams. The reference features on one figure are placed in a net of rectangular equidistant coordinates and the grid is deformed to place the homologous points on the comparative figure in the same position on the grid (Figure 20). A measure of deformation or transformation of the grid to achieve a "matching-up" of homologous points gives an estimate of the shape similarity. An alternative method, mainly developed by Huxley (1932) and known as allometry, defines shape in terms of relationships among a set of lengths of body segments. Huxley's ideas were often applied to relationships observed in growing individuals whereas Thompson's concepts found application in the comparison of different species.

Sneath (1967) applied the ideas of Thompson to develop methods for analyzing trend surfaces. He recognised that in order to compare shapes effectively, account must be taken of differences in overall size. Using this technique, two shapes can be compared objectively by superimposing each so that the centres of gravity coincide. In this procedure, the shapes are brought to the same size by expressing the distances of points from their respective centres of gravity in terms of standard deviation units. The shapes can then be brought into maximum congruence by a process of translation and rotation so that the sum of squares between sets of homologous points is minimised. It follows that if any two diagrams have the identical shape, they can be superimposed precisely. Sneath derived a value $d_n$ as the root mean square distance between homologous points at the best fit between the two diagrams. This value provides a quantitative assessment of the
(a)  

Fig. 176. Human scapulae (after Dwight). (a) Caucasian; (b) Negro; (c) North American Indian (from Kentucky Mountains).

(b)  

(c)  

Fig. 177. Human skull.

Fig. 178. Co-ordinates of chimpanzee's skull, as a projection of the Cartesian co-ordinates of Fig. 177.

Fig. 179. Skull of chimpanzee.  
Fig. 180. Skull of baboon.

Figure 20. Examples of transformation grids.  
(From Thompson 1961)
overall shape similarity of the diagrams, but differs from the value \( d \), given by authors such as Penrose (1954) in that the latter is a coefficient of shape plus size although it can be partitioned into shape and size components.

Goldstein and Johnston (1979) used Sneath's method of shape comparison in comparing the body shape of a child at ages \( t_1 \) and \( t_2 \), and denoted the shape difference as \( D^2_{1,2} \). For a growing child the quantity \( D_{t_1, t_2} \) was a measure of a change in shape between the ages \( t_1 \) and \( t_2 \), and they defined a shape velocity as \( \frac{D_{t_2}}{t_2 - t_1} \). Goldstein and Johnston also used a transformation grid of the type described by D'Arcy Thompson, to compare body outline at different ages (Figure 21). As an extension of their method they fitted polynomial equations to the \( x \) and \( y \) values of the reference points at each age to achieve the transformation. They found that higher order polynomials permitted a more accurate prediction of shape through the development of a more precise transformation grid.

Taylor (1971) developed mathematical techniques to compare two plane shapes which are not definable by explicit mathematical functions. He compared the sagittal shapes of a mandible at various stages of growth by assigning coordinate values to regularly spaced points around the outlines and using Veronese transformation techniques to assess the similarity of the shapes (Figures 22, 23).

Oxnard (1973) recognised that one of the main problems associated with characterizing form is that many methods rely upon the definition of special points. He proposed an alternative system of medial axis transformation which defines a two dimensional form by means of a
Figure 1. Shape outline of a 3½ year-old girl taken from a standardized photograph.

Figure 2. Shape diagrams of a girl aged 3.5 years (continuous) and 19.0 years (dashed) after standardizing for size and orientation. Superimposition is based upon the respective centroids.

Figure 21. Shape diagrams used by Goldstein and Johnston (1978).
Figure 22. Radiographic outline of a mandible at ages 13.6 and 15.6 years.
(From Taylor 1971)
Figure 23. Computer plot of the outline of the mandible shown in Figure 22, using the method of Taylor (1971).
(From Taylor 1971)
medial axis that is obtained as if the shape had been allowed to collapse into itself in a series of steps with a constant velocity in a direction normal to its boundary at every point (Figure 24). This mathematical reduction is achieved without defining any special points around the outline, although objective orientation points or points of biological importance may be incorporated. Oxnard suggested that this technique could be applied to three dimensional figures but drew attention to the computing difficulties of this exercise. The applications of Oxnard's technique remain to be appraised.

Dental arches have been mathematically described by Cheng (1972) who used polynomial expressions to describe arch form (Figure 18). Examining photographs of dental casts obtained in a standard fashion, he assigned Cartesian coordinate values to selected reference points and used these quantities to derive appropriate mathematical expressions of dental arch form. Cheng found that third or fourth order polynomials could adequately describe arch outline in many instances, although higher order expressions were more appropriate in some cases. Interestingly, Goldstein and Johnston found that a third order polynomial was an appropriate expression of body shape.

Iwabayashi (1977) has also discussed fitting various mathematical curves to dental arches. He suggested that the best fit was obtained with the fourth order polynomial equation, although the conic section and elliptic curves were suitable in some instances. The catenary curve was the least appropriate. Iwabayashi concluded that in viewing the form of the dental arch in normal occlusion fitted by fourth degree polynomial equation, the upper arch had a parabolic tendency, while the lower arch tended to be square.
Fig. 24. The process of production of the medial axis transformation demonstrating the intermediate steps that might be used in its manual production. The procedure is, of course, carried out computationally.
(From Oxnard 1973)
Lavelle (1978) compared dental arches from different ethnic groups using datum points defined by tooth centres, contact points and buccal and lingual crown convexities. Multivariate analysis was used to summarize the data and identify the separation between the groups. The advantage of using both odontometric and anthropometric points is that populations can be compared using a variety of parameters.

A number of authors have addressed the problem of comparing dental arch form objectively but an effective method has yet to be devised. Such a method may be appropriate to the present study of relative shape of the upper and lower dental arches, or alternate intercuspation.

MATERIALS AND METHODS

To assess the potential value of methods for quantifying shape similarity, the technique of Sneath (1967) was applied to a longitudinal series of dental casts from a male Aboriginal subject from Yuendumü, Central Australia. The background to Yuendumü and the method of obtaining the casts are described in Chapter 3.

The dental casts representing the dentition at ages 6.2 years, 7.6 years, 9.2 years, 10.9 years, 12.0 years, 13.0 years, 14.0 years, 14.9 years, 16.0 years, 17.0 years and 18.0 years were photographed in a standard fashion, following the method of Cheng (1972). Prior to photography, the casts were aligned so that the occlusal planes were parallel with, and at a standard distance from the film plane of the camera. They were also positioned centrally in relation to the optical axis of the camera lens. The occlusal plane of the maxillary cast was
defined by the depths of the central fossae of the first molars and the lingual fossae of the central incisors, while the lower occlusal plane was defined by the distobuccal cusp tips of the first molars and incisal edges of the central incisors.

The photographic apparatus is shown in Figure 25. It consisted of a rigid framework supporting a machined mild steel reference base and a vertical extension with camera stage on which a 6 cm by 6 cm single lens reflex camera was attached in a fixed position. Illumination was provided by two photographic lamps situated adjacent to the framework.

The base of the photographic apparatus was levelled with the aid of a spirit level and thus became the reference plane.

Two laboratory jacks which incorporated a horizontal base and platform were placed on the base of the photographic apparatus and the levels of the platforms checked to ensure that each was horizontal. By turning the screw mechanism of each jack the height of the platform could be adjusted while the platform remained horizontal (Figure 26.) Each dental cast was attached to a cast surveyor model clamp. Using a special levelling device, the level of the occlusal plane of each cast, defined as described previously, was adjusted to be parallel to the reference plane of the photographic apparatus. The special levelling tripod consisted of two metal points, connected by a screw mechanism which permitted the distance between the points to be varied

---

1 Hasselblad 500C with 120 mm f5.6 Zeiss S planar lens.
Figure 25. The photographic apparatus.
Figure 26. The height adjustment apparatus.
and an extension which formed the third leg of the tripod. A spirit level was incorporated into this device (see Figure 27).

Corresponding upper and lower dental casts attached to model clamps were then placed on the platforms sited on the photographic stand and adjusted by means of the universal joints so that the occlusal planes were level (Figure 26).

A perspex frame (Figure 26) was placed on the reference base. This fitted closely around the laboratory jacks and served to locate the two jacks in a constant relation. The top surface of the frame was made level and a central strut contained a millimetre rule which had been recessed into the perspex so that the gradations on the rule were in the same plane as the top of the perspex frame. The adjustable height mechanism permitted the dental casts to be raised so that the occlusal planes were level with this plane. A further perspex bar could be placed across the top surface of the perspex frame to ensure that each occlusal plane was at the level determined by the perspex frame.

Using this apparatus it was possible to photograph corresponding upper and lower casts on the one frame in a standard fashion. The millimetre rule provided reference scale points which could be used in the event that absolute coordinate values were required. The film used was Kodak EPR 120. A photograph of the dental casts and reference scale is presented in Figure 28.

The film was processed according to the manufacturer’s specifications. The strip of processed film was then mounted in a
Figure 27. The levelling tripod.
Figure 28. Occlusal view of dental casts and reference scale.
projector forming part of a record reader system\(^1\) (Figure 29). Images of the pictures were projected on the screen for recording reference points. The millimetre rule on the perspex frame was recorded in the photographs, and the presence of this scale permitted measurements made on the screen to be converted to millimetres. A sheet of tracing film was placed on the screen and held in place with adhesive tape. The positions of the reference points, which were described in Chapter 3 were recorded on the tracing film with a sharp pencil. Using the millimetre rule image, the positions of points 100 mm apart were also recorded. This procedure was repeated for the dental casts representing the dentition at each age included in the study.

In order to assign cartesian coordinate values to the various reference points the sheets of tracing film with reference points marked were placed on an illuminated viewing screen to which had been attached a sheet of decimal graph paper with scales recorded on the abscissa and ordinate axes. By placing the tracing film over this reference grid, coordinate values could be assigned directly to each reference point. For an extensive series of casts, automatic digitizing methods would be used but for this small series, manual digitizing was carried out.

The shapes of the dental arches at each age were compared according to the method of Sneath (1967) and the following steps were carried out by computer.

\(^{1}\) Superimposition of the coordinate sets on the centres of gravity.

\(^1\) Oscar F/DLF Strip Chart and Film Digitizing System, Computer Industries Inc., Graphics Systems Division, Van Nuys, California.
Figure 29. Oscar strip chart recorder.
Coordinates were expressed as deviations from the centre of gravity and adjusted to standardized form.

Transformation of the second set of coordinates by rotation to minimize the squared sum of the differences between homologous points. The value $d_n$ could then be calculated.

In comparing shapes using the Sneath method, it is essential that the same number of reference points is used for each record. In assessing the similarity of dental arch forms at various ages from 6 to 18 years, the eruption of the second permanent molars at about 12 years of age introduces a differing number of reference points before and after this event. To overcome this problem the arch forms at all ages were compared using reference points on the central incisors and canines, the first and second premolars or deciduous molars, and the first permanent molars. That is, nine reference points were used. A further comparison of arch shapes at ages 13 to 18 was made using these reference points and also the points on the second permanent molars. Eleven reference points were used in these comparisons. The maxillary arch shape at each age was compared with the final arch shape (18.0 years). These comparisons were repeated for the mandibular arch, and, in addition, the shape of the maxillary arch was compared with the shape of the mandibular arch at each age.

ERRORS OF THE METHODS

In developing the methodology already described, particular attention has been directed to possible errors of parallax or errors due to camera misalignment. To detect such errors which might be
introduced using the photographic technique, measurements of arch breadths were made directly on the casts and also from the screen, and these measurements were compared. The breadths measured were the same as the measured variables described in Chapter 3. These measurements were made using a vernier caliper with a resolution of .01 mm. The values obtained from the casts were compared with the measurements from the screen, corrected for magnification using the reference scale. These comparisons were made on a paired-comparison basis by calculating the mean of the differences ($\bar{X}$ diff), the standard deviation of the differences (s diff) and the error of the mean differences (E$\bar{X}$ diff), as described in Chapter 4. The probability that a mean difference differed significantly from zero was tested using Student's t-test, calculated according to the equation:

$$t = \frac{\bar{X} \text{ diff}}{E\bar{X} \text{ diff}}$$

This value was found to be non-significant indicating that no significant error was introduced to metric values in the photographic method described.

RESULTS

Measures of distance, $d_n$ between the initial maxillary dental arch shape (6.2 years) and maxillary arch shapes at later ages are presented in Table 13. Mandibular dental arch shapes at these same ages are compared with the initial mandibular arch shape in this table also. These values are presented graphically in Figure 30(A).
### Table 13

**Comparison of Initial Dental Arch Shape (6.2 Years) with Dental Arch Shape at Various Ages**

(9 reference points)

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Distance - $d_n$ Values</th>
<th>Maxilla</th>
<th>Mandible</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.6</td>
<td>0.0704</td>
<td>0.0806</td>
<td></td>
</tr>
<tr>
<td>9.2</td>
<td>0.0477</td>
<td>0.0849</td>
<td></td>
</tr>
<tr>
<td>10.9</td>
<td>0.0730</td>
<td>0.0825</td>
<td></td>
</tr>
<tr>
<td>12.0</td>
<td>0.0887</td>
<td>0.2226</td>
<td></td>
</tr>
<tr>
<td>13.0</td>
<td>0.0948</td>
<td>0.1686</td>
<td></td>
</tr>
<tr>
<td>14.0</td>
<td>0.0821</td>
<td>0.1065</td>
<td></td>
</tr>
<tr>
<td>14.9</td>
<td>0.0984</td>
<td>0.0977</td>
<td></td>
</tr>
<tr>
<td>16.0</td>
<td>0.1052</td>
<td>0.1092</td>
<td></td>
</tr>
<tr>
<td>17.0</td>
<td>0.1329</td>
<td>0.1118</td>
<td></td>
</tr>
<tr>
<td>18.0</td>
<td>0.1126</td>
<td>0.1225</td>
<td></td>
</tr>
</tbody>
</table>
Figure 30. Comparison of dental arch shapes (9 reference points).
A. Comparison of initial dental arch shape (6.2 years) with
dental arch shape at various ages.
B. Comparison of final dental arch shape (18.0 years) with
dental arch shape at various ages.
C. Comparison of maxillary and mandibular dental arch shapes
at various ages.
With age the shape of the maxillary dental arch becomes progressively more divergent from the initial shape. There is no ready explanation for the marked trend toward the initial shape at ages 9.2 years and 14.0 years, nor for the sharp increase in $d_n$ value at 17.0 years. None of these ages is related to important events in the eruption sequence of this subject's dentition. A similar trend is evident in the progressive changes in the mandibular arch shape. A marked divergence from the initial shape is demonstrated at 13.0 years. The mandibular dentition of this subject is undergoing considerable change during this period with the eruption of the permanent second molars and the exfoliation of the lower right second primary molar and the emergence of its permanent successor. Although the second molars did not provide reference points for this comparison, the results indicate that the time at which these teeth emerge may be one in which arch shape is changing rapidly.

Measures of distance, $d_n$, between the final maxillary arch shape (18.0 years) and maxillary arch shapes at earlier ages are presented in Table 14. Mandibular dental arch shapes at these ages are compared with the final shape of the lower dental arch in this table also. These comparisons did not include reference points on the lower second molars. Figure 30 (B) portrays these values in graphic form. The shape of the maxillary dental arch progressively approaches the final shape between 6.2 and 17.0 years of age. Marked departures from this steady progression are seen at 13.0, 16.0 and 17.0 years, however none of these changes can be readily related to eruption of particular teeth. The mandibular arch on the other hand, was not observed to steadily approach the final shape; rather marked divergences from final shape being demonstrated at 7.6 and 12.0-13.0 years. At 7.6 years the subject's permanent lower incisors were erupting, while the
TABLE 14

COMPARISON OF FINAL DENTAL ARCH SHAPE (18.0 YEARS) WITH
DENTAL ARCH SHAPE AT VARIOUS AGES
(9 reference points)

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Distance - ( d_n ) Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maxilla</td>
</tr>
<tr>
<td>6.2</td>
<td>.1126</td>
</tr>
<tr>
<td>7.6</td>
<td>.1063</td>
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<tr>
<td>9.2</td>
<td>.0942</td>
</tr>
<tr>
<td>10.9</td>
<td>.0766</td>
</tr>
<tr>
<td>12.0</td>
<td>.0825</td>
</tr>
<tr>
<td>13.0</td>
<td>.0414</td>
</tr>
<tr>
<td>14.0</td>
<td>.0587</td>
</tr>
<tr>
<td>14.9</td>
<td>.0519</td>
</tr>
<tr>
<td>16.0</td>
<td>.0258</td>
</tr>
<tr>
<td>17.0</td>
<td>.0605</td>
</tr>
</tbody>
</table>
dentition at 12.0-13.0 years of age displayed the eruption of the lower second premolars and molars. These events may be related to the rapid changes in shape observed in these periods.

The shape of maxillary and mandibular dental arches at each age are compared using $d_h$ values in Table 15. The changes in congruence of upper and lower dental arch shapes with age are summarised graphically in Figure 30(C). The upper and lower arches displayed the greatest difference in shape at ages 7.6 years and 12.0 - 13.0 years. These ages corresponded with the eruption of the mandibular lower incisors, and lower second premolars and molars respectively.

Further shape comparisons were carried out using reference points which included those on the second permanent molars. It was only possible to compare ages 13.0 years to 18.0 years using these data. Distance values, $d_h$ of arch shape at various ages from the final arch shape in maxilla and mandible at various ages are presented in Table 16, and illustrated graphically in Figure 31(A).

Comparisons of maxillary and mandibular arch shapes using all reference points, at each of these ages are presented in Table 17 and Figure 31(B). The comparisons of dental arch shapes with the final shape using all reference points disclose similar trends to those arising from arch shape comparisons which excluded coordinate values for second molar teeth. It appears therefore that the exclusion of the coordinate values of the second molars does not detract greatly from these initial comparisons of dental arch shape. A similar pattern of congruence of upper and lower dental arch shapes is revealed whether coordinate values of second molars are included or not.
**TABLE 15**

**COMPARISON OF MAXILLARY AND MANDIBULAR DENTAL ARCH SHAPES AT VARIOUS AGES**
(9 reference points)

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Distance - $d_h$ values</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2</td>
<td>.1112</td>
</tr>
<tr>
<td>7.6</td>
<td>.1723</td>
</tr>
<tr>
<td>9.2</td>
<td>.1060</td>
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<tr>
<td>10.9</td>
<td>.0919</td>
</tr>
<tr>
<td>12.0</td>
<td>.1857</td>
</tr>
<tr>
<td>13.0</td>
<td>.1535</td>
</tr>
<tr>
<td>14.0</td>
<td>.0613</td>
</tr>
<tr>
<td>14.9</td>
<td>.0850</td>
</tr>
<tr>
<td>16.0</td>
<td>.1037</td>
</tr>
<tr>
<td>17.0</td>
<td>.0710</td>
</tr>
<tr>
<td>18.0</td>
<td>.0630</td>
</tr>
</tbody>
</table>
**TABLE 16**

**COMPARISON OF FINAL DENTAL ARCH SHAPE (18.0 YEARS) WITH DENTAL ARCH SHAPES AT VARIOUS AGES**

(11 reference points)

**DISTANCE - $d_h$ VALUES**

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Maxilla</th>
<th>Mandible</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.0</td>
<td>.0512</td>
<td>.1090</td>
</tr>
<tr>
<td>14.0</td>
<td>.0547</td>
<td>.0491</td>
</tr>
<tr>
<td>14.9</td>
<td>.0630</td>
<td>.0394</td>
</tr>
<tr>
<td>16.0</td>
<td>.0219</td>
<td>.0316</td>
</tr>
<tr>
<td>17.0</td>
<td>.0503</td>
<td>.0226</td>
</tr>
</tbody>
</table>
Figure 31. Comparison of dental arch shapes (11 reference points).

A. Comparison of final dental arch shape (18.0 years) with dental arch shape at various ages (11 reference points).

B. Comparison of maxillary and mandibular dental arch shapes at various ages (11 reference points).
<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Distance - $d_n$ values</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.0</td>
<td>.1250</td>
</tr>
<tr>
<td>14.0</td>
<td>.0675</td>
</tr>
<tr>
<td>14.9</td>
<td>.0792</td>
</tr>
<tr>
<td>16.0</td>
<td>.0804</td>
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<tr>
<td>17.0</td>
<td>.1003</td>
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<tr>
<td>18.0</td>
<td>.0677</td>
</tr>
</tbody>
</table>
DISCUSSION

The purpose of this pilot study of comparisons of dental arch shapes has been to evaluate the suitability of this method for further comparative studies and in particular to delineate problems associated with the system.

The method permits the comparison of upper and lower dental arch shapes at the one age. Because these shapes are defined by homologous points on each arch, these comparisons provide a further method of describing and quantifying alternate intercuspalion. The method of Sneath which has been used in this study standardises the sizes of the shapes being compared, and in fact this may tend to mask part of alternate intercuspalion which appears to be a discrepancy in size as well as shape. Future comparisons of upper and lower arches at the same age may be carried out without compensation for size differences.

It appears that the inclusion of data relating to the second molars is not essential for a meaningful comparison of age changes in dental arch shape. This is a useful finding because the shape comparison method requires the same number of reference points on each figure, and subjects of different ages display a differing number of teeth. It therefore seems reasonable to suggest that future longitudinal studies of dental arch shape might exclude values for second molars since these teeth are not present at early ages, and do not appear to greatly influence shape comparisons.
The precise biological implications of the $d_{hi}$ value remain to be elucidated. This statistic certainly provides a quantitative assessment of similarity between shapes, but in the same way that it is difficult to precisely interpret $d$ values representing distances between populations (Penrose 1954). The biological meaning of $d_{hi}$ is not always obvious. Despite this limitation, this statistic should be applied to further shape comparisons in order to permit further evaluation.

CONCLUSIONS

The main purpose of the study was to assess the potential merit of the methods used to compare different shapes. Therefore, no biological conclusions have been attempted, particularly as the test data were limited to one subject only.

This pilot study has illustrated the application of a method of shape comparison to the field of oro-facial growth and dental occlusion. The method appears to be particularly indicated for longitudinal studies and further investigations may take cognisance of size as well as shape comparisons.


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