

Pleistocene homogeneity and Holocene size reduction: the Australian human skeletal evidence

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For over 250 years European observers have debated the biological origins of the Australian Aboriginals. The central issue in this debate continues to be the observable variation in physical characteristics that have been described for fossil and recent Australian populations. Explanations of this variation are represented by two conflicting groups of hypotheses. Either Australia was colonised by a single group of immigrants with subsequent variation resulting from genetic and environmental factors or there were multiple waves of temporally circumscribed, genetically distinct immigrants.

In general terms the emphasis of this debate is not unique to the origin of the Australians. Wherever the broader issues of the origin of *Homo sapiens* and the rise of regional variation are considered, a central theme is the variation in hominid fossil sequences and living populations (Rightmire 1984; Frayer 1984; Smith 1984). Historically, in Australasia, discussions of these issues have arisen from descriptions of the physical and cultural variation in living, or recently living, populations (Topinard 1872; Lesson 1880; Curr 1883; Klaatsch 1908; Birdsell 1949; Abbie 1968). Emphasis was placed on features such as hair form, skin colour, body build and aspects of skeletal morphology. Critics of this approach (Bodmer and Cavalli-Sforza 1976) point out that most of the polygenic traits used in these comparisons are sensitive to environmental influence. In particular the adaptive relationship between melanogenesis and solar radiation (Loomis 1968; Kligman 1969; Wasserman 1974) and body build and climate (Roberts 1953, 1973; Hiernaux 1968) appear reasonably clear.

More recently attempts have been made to integrate information on the gene frequencies of a wide range of biochemical traits with the earlier models of human dispersion and evolution (Simmons *et al* 1953; Simmons 1976; Kirk 1965, 1976; Blake and Kirk 1975; Curtain *et al* 1976).

Although these data certainly reflect divergence among local populations over relatively short time periods (Balakrishnan *et al* 1975; Birdsell *et al* 1979) there are difficulties in expanding such data to deal with long-term events. The variable alteration of serological trait frequency through selection, mutation and random genetic drift (Crawford 1973; Blake 1979) and the likelihood of relatively recent population movement in South-East Asia and Melanesia (Shapiro 1943; Pietrusewsky 1970, 1971; Brace and Hinton 1981) restrict the value of direct comparisons of living people in this region. Certainly, the extrapolation of detailed chronological frameworks of population movement from such data is unwarranted.

Ideally, proof of the various theories on the origin of the Australians would be provided by the Australasian hominid fossil record. However, problems of dating, interpretation and inadequate samples persist. From the initial descriptions of the Javan *Pithecanthropus* and Wadjak crania by Dubois (1894, 1922), and the Australian Talgai cranium by Smith (1918), there has been a gradual expansion of the hominid fossil record for this region. At the same time increasingly complex arguments for evolutionary continuity within this sequence have been formulated (Klaatsch 1908; Dubois 1922; Weidenreich 1943; Coon 1962; Thorne and Wolpoff 1981; Wolpoff *et al* 1984). These arguments have been complicated by the continuing uncertainty which surrounds the chronology (Brothwell 1960; Koenigswald 1964a; Jacob 1972, 1976; Sartono 1976, 1982) and taxonomy (Steslicka 1947; Koenigswald 1964b; Jacob 1976; Santa Luca 1980; Sartono 1982) of the South-East Asian hominids and the significance of variation within the terminal Pleistocene Australian remains (Macintosh 1967; Thorne 1977; Freedman 1985).

In general, published interpretations of Australian Pleistocene skeletal variation have focused on a single aspect of that variation, predominantly cranial size and gross morphology (Thorne 1976, 1977; Thorne and Wilson 1977; Pietrusewsky 1979). Other aspects of osteological variation, including temporal variation in the expression of discrete osteological traits, tooth size and variation within the postcranial skeleton have received comparatively little attention (Brown 1982; Kennedy 1984; Pietrusewsky 1984; Freedman 1985). This primarily reflects the influence of skeletal preservation in determining methodological approach. Statistical or morphological analyses, no matter how elaborate (Thorne and Wilson 1977; Wilson 1981), are only as good as those data on which they are based. In this instance, the two principal Pleistocene series, Lake Mungo and Kow Swamp (Thorne 1976, 1977), have the dual problems of poor preservation and small sample size. The discovery and description of the Coobool Creek series (Brown 1981a, 1982) allow a more detailed examination of Pleistocene variation, with Kow Swamp and Lake Mungo placed in a broader context. This analysis will concentrate on the features which have been used to define two distinct populations in Pleistocene Australia: the size and morphology of the orofacial skeleton and cranial vault (Thorne 1976, 1977; Thorne and Wilson 1977; Freedman and Lofgren 1979), cranial vault thickness (Thorne 1976, 1977) and tooth size (Wright 1976).

Materials

The material included in this analysis consists of all of the available Pleistocene crania, with the exception of Lake Tandou, and a number of

comparative Holocene samples (Roonka, Broadbeach, Swanport, Murray Valley). The Lake Tandou skeleton, located in the Western Australian Museum, has been described in detail by Freedman and Lofgren (1983) and I will refer to their data where appropriate. The comparative Holocene samples were the best available populations' given the necessity of large sample size, good preservation and adequate temporal control. Due to some inconsistencies in the previously published information and the dictate of uniform methodology, I collected all of those data used in this analysis.

Broadbeach (BB)

The Broadbeach burial ground is located about 1.5km from the coastline at Mermaid Beach in south-eastern Queensland. Between 1965 and 1968 a series of archaeological excavations at the site recovered the partial or complete skeletal remains of more than 100 individuals (Haglund-Calley 1968a, 1968b; Wood 1968; Haglund 1976).

Radiocarbon dating of charcoal found in association with the burials suggests that the site was in periodic use for more than 1000 years, from about 1290 years BP until the contact period (Haglund 1976; Freedman and Wood 1977). Although the remains of a large number of individuals were recovered from the site they are for the most part poorly preserved, with only 18 of the adult crania being reasonably complete. Published analyses of the skeletal material include those of Freedman and Wood (1977), Pietrusewsky (1979, 1984), Brace (1980) and Smith *et al* (1981). Arrangements are presently being made for the reburial of the Broadbeach material.

Swanport (S)

The skeletal materials from Swanport were collected primarily by F.R. Zeitz from a site 10km south-east of Murray Bridge, South Australia, in 1911. Stirling (1911) briefly described the stratigraphy of the site and argued, primarily on the basis of local oral history, that the burials probably overlapped the European contact period. The Swanport material, although undated, is generally accepted as representing a recent population (Howells 1976; Giles 1976; Pietrusewsky 1979, 1984; Brown 1982). Pretty (1977) draws attention to the parallels between the recent material from Roonka and that from Swanport, both in terms of the artifact assemblage and form of the burials. This is supported by a combined metric and non-metric analysis of the crania from these two sites (Pietrusewsky 1984).

Roonka (R)

The Roonka site is located on the Murray River, approximately 5km south of Blanchetown in South Australia. Pretty (1977) has made a preliminary description of the stratigraphy of the site and the artifactual assemblage, and a brief analysis of the burials.

Skeletal remains of more than 120 individuals have been recovered from trench A, with radiocarbon dates indicating a sequence from at least 7000 years until the contact period. The initial reconstruction and description of the material was undertaken by Prokopec (1979), and Pietrusewsky (1984) includes

some of the Roonka crania in his multivariate comparison of Australasian and Pacific populations.

Unfortunately, much of the skeletal material from Roonka is poorly preserved with considerable post-depositional warping and erosion. Extensive reconstruction was often required and few of the crania are now suited to metric analysis. Only eight male crania (6, 37, 48, 66, 89, 91, 104 and 106), which on the basis of Pretty (1977) can be assigned to phase 11 of the site (4000-7000 years BP), will be included in this analysis.

Murray Valley (MV)

A series of 100 crania (47 males and 53 females) from the area between Chowilla and Coobool in NSW form the comparative 'recent' Murray Valley collection. This material was collected by G.M. Black in the period between 1943 and 1950 and forms part of a collection in the Department of Anatomy, University of Melbourne (Sunderland and Ray 1959). Although there are more than 600 crania in the 'Murray Black' collection, many are fragmentary, with poor preservation of the facial skeleton and dentition. The major criteria for selection were preservation and the availability of an associated innominate to assist in sex determination (Brown 1981b, 1982).

No stratigraphical, chronological, archaeological or even precise geographical information is recorded for this collection. Comparison with the dated cranial series from Kow Swamp (Thorne 1975, 1976), Roonka (Prokopec 1979) and Chowilla (Blackwood and Simpson 1973) suggests that the Murray Valley material can be considered to be broadly recent, 5000 to 100 years BP (Brown 1982).

Coobool Creek (CC)

The Coobool Creek crania form part of the 'Murray Black' collection in the Anatomy Department of the University of Melbourne. This material was collected from a site near 'Doherty's Hut' at Coobool Crossing on the Wakool River between Swan Hill and Deniliquin in southern NSW by G.M. Black during 1950. As with the rest of the 'Murray Black' collection, no stratigraphic or detailed locational information is available.

At the present time, there are no radiocarbon dates directly associated with the Coobool Creek skeletal material. Initial attempts at radiocarbon dating of human bone from this site were frustrated by the immersion of all bone in gelatin as a preservative coating, shortly after recovery. Contamination by this modern collagen will make it difficult, if not impossible, to accurately determine the age of this collection. A possible solution will be to identify and distinguish between the specifically human and non-human amino acids within the samples and date the human ones. A uranium thorium date of 12,500 ±400 has been obtained on bone from Coobool Creek 65.

Morphological and metrical comparisons of Coobool Creek with late Pleistocene (Kow Swamp) and recent (Swanport, Roonka, Chowilla, etc) Murray Valley populations clearly link Kow Swamp and Coobool Creek and exclude the others (Brown 1981b, 1982). This comparison suggests that Coobool

Creek is older than Roonka grave 89 dated to 6910 \pm 450 years (ANU --1408) (Pretty 1977:297) and the Wentworth crania excavated by Blackwood and Simpson (1973:105) dated to 5900 \pm 550 years (GaK 1930). The crania from these two sites, Roonka and Wentworth, are morphologically and metrically indistinguishable from recent Aboriginal crania from the same area (Pietruszewsky 1979, 1984; Brown 1982). There are 126 individuals, some represented only by isolated teeth, in the Coobool Creek series. Most of the crania are heavily mineralised and were covered with a thick carbonate crust requiring a prolonged preparation (Brown 1982). Twenty-four male and nine female crania have been cleaned and reconstructed and will be included in this analysis.

Kow Swamp (KS)

Archaeological excavations at Kow Swamp, 10 km south-east of Cohuna in the central Murray River Valley, between 1968 and 1972, recovered the partial skeletal remains of more than 22 individuals (Thorne 1969, 1975, 1976; Thorne and Macumber 1972). Radiocarbon dates on shell from the grave of KS5 of 13,000 \pm 280 (ANU - 1236) and on bone apatite from KS9 of 9590 \pm 130 (ANU - 532) place this population in the terminal Pleistocene (Thorne 1975). Despite extensive reconstruction, the Kow Swamp material is still extremely fragmentary, with only two of the crania, KS1 and KS5, being relatively complete. Preservation is particularly poor for the basicranial areas and post depositional warping is a problem with the cranial vault and mandible of KS1. Data from Kow Swamp crania 1, 2, 5, 7, 8, 9 and 16 will be used here.

Cohuna (C)

The Cohuna cranium was discovered by George Gray in 1925 during the excavation of an irrigation channel close to the northern margin of Kow Swamp (Macintosh 1952b, 1953). The cranium has not been radiometrically dated. Following chemical and physiographic analysis Macintosh (1953) concluded that the cranium had become mineralised on Mount Hope and transported to the discovery site by water action. More recent research (Macumber and Thorne 1975) indicates that mineralisation of the cranium occurred in the soil in which it was found. This is supported by the good preservation of the facial skeleton and vault and the claim that a number of skeletons were originally unearthened, not just a cranial vault. Although discovered in 1925, a detailed description of the Cohuna cranium has still not been published. However, Macintosh (1952c) described the teeth and palate. Morphological and statistical comparisons have placed the Cohuna cranium firmly within the Kow Swamp population (Thorne 1975; Brown 1982) and for the remainder of this analysis it will be included within this series.

Kedor (K)

The Keilor cranium was discovered by James White in October 1940 while excavating a sand deposit near the junction of the Maribyrnong River and Dry Creek, about 2km north of Keilor, Victoria (Mahony 1943:31). This carbonate-encrusted cranium, and the few fragments of femur found near it, were

deposited in the National Museum of Victoria. Preliminary descriptions of the cranium were published by Wunderly (1943) and the teeth and palate by Adam (1943). Both the initial claims for extreme antiquity and Wunderly's description received considerable criticism (Jones 1944; Zeuner 1944; Weidenreich 1945).

Direct radiocarbon dating of the skeletal material was undertaken by N.W.G. Macintosh through the New Zealand Institute of Nuclear Sciences in 1971. Dates on carbonate crust removed from the cranium ranged from 5200 \pm 200 (NZ 1320) to 6800 \pm 100 (NZ 1321) years BP. The femur fragment produced a date of 6790 \pm 50 (NZ 1326) for the external carbonate crust and a bone collagen date of 12,000 \pm 100 (NZ 1327) (Institute of Nuclear Sciences, DSIR). All of the carbonate crust dates simply document the accumulation of secondary carbonates on the bone's surface. The only measure of absolute age is provided by the bone collagen date for the femur. Assuming that the femur fragment and cranium belonged to the same individual, and some support is provided by the similar carbonate dates, then this suggests a shared terminal Pleistocene age for this material.

Lake Mungo 1 and 3 (M1, M3)

Fragmentary skeletal remains of over 40 individuals have been recovered from the Willandra Lakes region. However, only three of these, Lake Mungo 1, 2 and 3, are available for study, with Lake Mungo 2 consisting only of fragments. Most recently Thorne (1984) has described the latest specimen from this area, WLH 50, as 'much more robust and archaic than any Australian hominid found previously'. No evidence in support of this claim has been published.

The calcrete block containing the Mungo 1 cremation was discovered in 1968 by Jim Bowler, deflating out of the Mungo unit at the southern end of 'The Walls of China' lunette, Lake Mungo (Bowler *et al* 1970). Radiocarbon dating of bone fragments from the burial obtained an age of 19,030 \pm 1410 years (ANU - 618A) on bone apatite and 24,700 \pm 1270 years (ANU - 618B) on the collagen fraction. A further date of 26,250 \pm 1120 (ANU -375B) was achieved with charcoal from a hearth stratigraphically equivalent to 15cm above the burial (Bowler *et al* 1972). It was considered that the most reliable estimate for the age of Lake Mungo 1 was 24,500 to 26,500 years BP.

Reconstruction and descriptions of Mungo 1 were undertaken by Alan Thorne (1975), but only limited detailed information has been published (Bowler *et al* 1970; Thorne 1971, 1976, 1977). Preservation of the cranium is poor with the basicranial area, facial skeleton and dentition being particularly fragmentary. The Mungo 3 skeleton was also discovered by Jim Bowler. In February 1974, after prolonged rain in 1973, Bowler noticed the exposed left side of a carbonate encrusted human cranium 500m east of the Mungo 1 cremation site. Later that month the extended burial that was Lake Mungo 3 was excavated by a team from the Australian National University (Bowler and Thorne 1976). This burial has not been directly dated but Bowler and Thorne argue on the basis of geomorphological criteria and stratigraphic association with Mungo 1 that an age of 28,000 to

32,000 years BP is probable (1976:136-138). Although the cranial morphology of Mungo 3 has been used to support arguments for the dihybrid origin of the Australian Aboriginal population (Thorne 1977; Freedman and Lofgren 1983) a description of this individual has yet to be published. As little of the basicranium, right side of the facial skeleton and right side of the vault are preserved detailed comparisons involving this individual are difficult.

Talgai (T)

The classic Australian fossil, Talgai, was discovered in 1884 on the Darling Downs, near Warwick in southern Queensland. After its purchase by the University of Sydney, it was described by Stewart Smith (1918). Although crushed and distorted, Smith was able to conclude that Talgai was a juvenile male of 14 to 16 years. Features indicative of sex were large overall size, especially for the teeth and palate, and the morphology of the vault. Smith argued that although Talgai was undoubtedly of Australian type, palate shape and the size and morphology of the canine teeth were archaic and 'ape-like'. The subsequent reconstruction of the palate by Helman (1934) and description of the dentition by Macintosh (1952a) challenged Smith's observations. Talgai was now placed within the Australian range of variation, although the size of the palate and canine teeth were considered extraordinary.

There are no radiometric dates directly associated with the Talgai cranium although efforts have been made to date the soil horizon from which it supposedly originated. Oakley *et al* (1975) report a date of 11,650 ±100 BP for this horizon. An attempt to clean and reconstruct the cranium by Macintosh was unsuccessful and this individual is now represented by disarticulated and eroded fragments.

Lake Nitchie OV

This unique burial was discovered by Jim Bowler on the north-eastern shore of Lake Nitchie in 1969 and excavated by N.W.G. Macintosh and K.N. Smith in 1970 (Macintosh *et al* 1970). The Lake Nitchie skeleton, and associated pierced *Sarcophilus harrisi* canine tooth necklace, were described in some detail by Macintosh (1971), who reports a bone collagen date of 6820 ±200 for the right femur. On the basis of overall size and dimensions of the fronto-facial skeleton Thorne (1977; Thorne and Wilson, 1977) places Lake Nitchie with the 'robust' group of prehistoric Australian crania (Kow Swamp, Mossiel and Cohuna).

To a large degree the initial interest in Lake Nitchie was a result of Macintosh's (1971) claim of a stature of 187.5cm for this individual. This claim is at best highly inaccurate. Trotter and Gleser (1952) provide regression formulas for calculating stature from adult femur length in American Blacks and Whites. With a maximum femur length of 488mm Lake Nitchie would have had a stature between 173.3cm (American Black formula) and 177.5cm (American White formula). Body proportions in Australian Aboriginals are closer to American Blacks than to American Whites and so the lesser stature estimate is probably the more accurate.

Methods

All dimensions were taken to standard osteological points (Martin and Saller 1957) and measured to the nearest millimetre using standardised equipment (GPM sliding, spreading and co-ordinate calipers). Unmodified SPSSX computer programmes (SPSS Inc 1983) were used to calculate the descriptive statistics. Snedecor's variance ratio test (F value) was used to test the difference between sample variances and Student's t test differences between sample means. Distribution of the variables in relation to the normal curve was analysed using the ShapiroWilk statistic (Shapiro and Wilk 1965) as this provides a more sensitive test than skew or kurtosis for samples smaller than 50. The SHPWILK programme developed by Y. Pittelkow. Computer Services ANU, was employed for this.

Discriminant Analysis

A series of stepwise linear discriminant function analyses were performed to examine the statistical and biological nature of discriminating variables, direction of group differences and the probabilities of misclassification. Following up the timely warnings of Corruccini (1975) particular attention was focused on the underlying statistical assumptions of discriminant analysis. Linear discriminant function analysis assumes equality of variance, linearity and homogeneity of covariance, the observations have a multivariate normal distribution in each population, the groups are discrete and identifiable and the samples are large (Eisenbeis and Avery 1972; Goldstein and Dillon 1978; Lachenbruch and Goldstein 1979). However, there is continued debate over the robustness of discriminant analysis in situations where these criteria are not completely fulfilled.

Even though it appears that performances of the linear discriminant function may be affected by irregularities in covariance (Lachenbruch and Goldstein 1979), the anthropological literature generally assumes that the technique is robust to these and suitable tests are not undertaken. The reason for this is that tests of dispersion homogeneity are powerful and almost always reject the hypothesis (Cooley and Lohnes 1971). With craniometric data, even after extreme data reduction, it is not always possible to obtain equality of covariance between groups. This probably reflects the high variation in cranial size and morphology in most populations, making large samples essential, and improper choice of measurement scale. Fortunately it has been demonstrated that the performance of the linear discriminant function is satisfactory if the covariance matrices are not too different (Gilbert 1969; Marks and Dunn 1974). As irregularities in covariance between populations could be of biological significance, where they occurred, they were examined in detail. A test for equality of covariance matrices, Box's M (Box 1949), and its associated F test, were employed.

The assumption of multivariate normality is central to all multivariate analyses dependent on probability theory (Cooley and Lohnes 1971; Corruccini 1975). In spite of this there appears to be no consensus as to the robustness of multivariate statistics for non-

normal distributions. Mardia (1971) and Blackith and Reyment (1971) suggest that distributional irregularities do not adversely influence statistical distances, others disagree (Vogt and McPherson 1972). This situation is complicated by the fact that there is no recognised test for comparing data with the multivariate normal distribution. Some control on this can perhaps be obtained by limiting the number of observations recorded and by analysing their distribution in univariate space (Sokal and Rolf 1969). Variables were compared with a standard normal distribution using the Shapiro-Wilk test (Shapiro and Wilk 1965). Where large samples were available (>20) only a few variables did not comply with the normal curve. Those that did not, most noticeable in the Coobool Creek material, appeared to deviate for biological and cultural reasons (Brown 1981a).

Linear discriminant functions were calculated using the SPSSX package DISCRIMINANT (SPSS Inc 1983). A stepwise variable selection procedure was employed to select the major discriminating variables and indicate any redundancy. The stepwise procedure chosen was method MAHAL which maximised the Mahalanobis distance between groups. Following Lubischew (1962) and Jolicoeur (1959) correlation between individual measurements and the case's orthogonally projected axis position were used to help interpret the canonical functions. The scattergrams produced for this purpose revealed more meaningful associations than would have been indicated by the canonical functions alone. Probabilities of misclassification, eigenvalues, Wilks Lambda and Chi-square values were examined for each function.

Sex Determination

A high degree of regional and sex based variation in Australian Aboriginal crania makes the accurate determination of sex crucial for interpopulation and temporal comparisons. However, as Hooton (1943) remarked, even with the whole skeleton, sexing is possible in only 90 per cent of cases and this continues to be a source of error. Depending upon the degree of skeletal preservation a variety of techniques were employed to sex the crania used in this analysis.

1. Murray Valley, Broadbeach and Lake Nitchie Sex was determined through an examination of the pelvis and sacrum as the highest levels of accuracy have been obtained using these (Washburn 1984; Phenice 1969). Emphasis was placed on the size and morphology of the acetabulum and greater sciatic notch, morphology of the pubis and sacro-iliac articulation and breadth of the sacrum. This indicated that there were 47 males and 53 females in the Murray Valley sample and 14 males and 4 females in the Broadbeach series. The innominates associated with the Lake Nitchie skeleton are clearly male.

2. Swanport - There are 48 crania in the Swanport sample, seven of which have associated pelvises. Those with a pelvis were sexed using it. The remainder were sexed using the combined morphological and metrical technique developed for Australian Aboriginal crania by Larnach and Freedman (1964; Brown 1981b). In addition, a series of discriminant functions produced from the Murray Valley series were used

to support the Larnach and Freedman results (Brown 1982). Close agreement was obtained between these techniques, although the section point in the discriminant analysis had to be lowered due to the smaller size of the Swanport crania (relative to the Murray Valley). Twenty-five females and 23 males were indicated by the analysis.

3. Coobool Creek - Only four of the Coobool Creek crania used in this analysis have associated innominates complete enough for positive identification of sex. Determining the sex of the 29 isolated crania was complicated by temporal factors, most notably their large size, and the presence of artificial cranial deformation (Brown 1981a, 1982). As a result it is probable that the application of discriminant functions developed on a known-sex modern Aboriginal series would produce erroneous results. Fortunately Thorne (1975) found that in the Kow Swamp crania the development of the five morphological sexing characters used by Larnach and Freedman (1964) was within the modern range, and there is presently no evidence of temporal variation in these features.

The Coobool Creek crania were sexed using the modified form of the Larnach and Freedman technique with the increased class 2 limits for palate and mastoid size (Brown 1981b, 1982). The palate and mastoid processes in these crania are extremely large, in several instances exceeding the previously recorded Australian range. Even using the increased class 2 limits, no crania were found to have class 1 mastoid processes and only two have class 1 palates. Discriminant analysis provided interesting results. Using the section point developed from recent Murray Valley crania, all but four of the Coobool Creek series were classed as male. This is indicative of the size difference between these two populations, six individuals exceeding the 'recent' Murray Valley range, and these results were ignored for the purposes of sex determination.

4. Keilor - Although Keilor has always been assumed to be male (Birdsell 1967; Thorne 1977; Freedman 1985) this issue has not been examined in detail. Wunderly (1943), who originally described it, did not allocate it to either sex. While remarking that in general form it resembles South Australian male crania, and is of large size, he also stated that it had none of the extreme features seen in many Australian male crania (sagittal keeling, muscle attachment and general ruggedness). Thorne (1977: Fig.1), while considering it a male, places it outside the modern male range and almost at the centre of the female distribution. This is used to support his argument for two distinct Pleistocene populations, both of which deviate, in opposite directions, from near-contemporary Australians (1977:189-191). Data are not presented in support of this argument and a comparison of Keilor with a sexed 'contemporary' series does not support Thorne's conclusions. Both in terms of morphology and size, Keilor is a large and robust male, with a discriminant function analysis placing it at the top of the Murray Valley male range (Fig. 1). Only in the areas of glabella prominence and depression at nasion can the Keilor cranium, be considered particularly feminine, or gracile.

5. Mungo 1 and Mungo 3 - Both of the Mungo skeletons are fragmentary, lacking innominates complete enough for sex identification. With one of these, Mungo 1, this does not present a problem as the small size, combined with ultra-feminine morphology, of the cranium make it clear that it is female (Thorne 1975).

Thorne (1977:Fig.1) argues that Mungo 3, a male, is morphologically and metrically outside the range of contemporary male crania and at the centre of the female range of variation. To some degree this designation of Mungo 3 as a male is supported by the anatomy of the surviving innominate fragments. Previously Bowler and Thorne (1976), using the mandible sex technique of Larnach and Macintosh (1971), had sexed this individual as male. With this method, mandibles which obtain a score of 20-33 for the 11 sexing characters are classed as male. The Lake Mungo 3 mandible scored 24, suggesting that this individual was male and by definition within

the male range of variation. Unfortunately only 33 of the 93 mandibles used by Larnach and Macintosh (1971) to develop their sexing technique were of known sex and their results are in doubt, as is that for Mungo 3.

The Lake Mungo 3 mandible can be independently sexed using linear discriminant functions developed from a known-sex Australian Aboriginal series. Using four dimensions, which are preserved in Mungo 3 (symphyseal height, corpus height, bigonial breadth and minimum ramus breadth), standardised discriminant functions were produced from the Murray Valley series (Fig.2). The application of these standardised coefficients to 138 known-sex mandibles from Broadbeach, Swanport and the Murray Valley obtained an accuracy of 80-84 per cent. Mungo 3, with a score of 65.4, is slightly higher than the male mean of 64.3 and at the extreme of the female range of variation. This issue is complicated by the evidence for greater size and robusticity in the

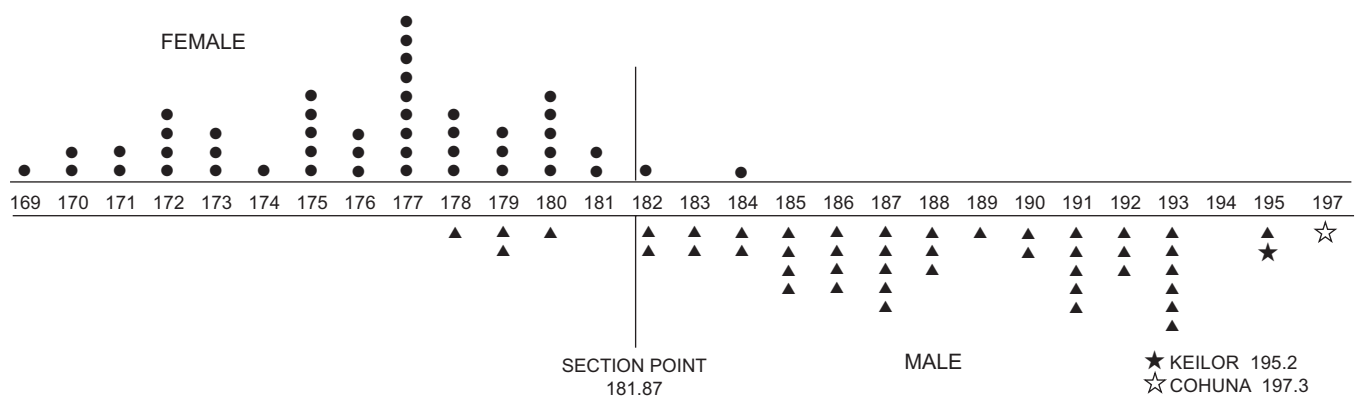


Figure 1. Sex determination of Murray Valley crania using linear discriminant function analysis showing positions of Keilor and Cohuna. Murray Valley females n. 47, X 176.28, s 3.50, Murray Valley males n. 44, X 187.46, s 4.40. The standardised discriminant function coefficients and individual dimensions (mm) of Keilor and Cohuna are: maximum bi-parietal breadth 0.148 (K 142, C 131); glabella-opisthocranion 0.461 (K 197, C 199); basion-bregma 0.457 (K 142, C 142); maximum supraorbital breadth -0.251 (K 116, C 116); nasion-nasospinale 0.200 (K 50, C 54); alveolar breadth 0.320 (K 71, C 74); mastoid depth 0.531 (K 28, C 30).

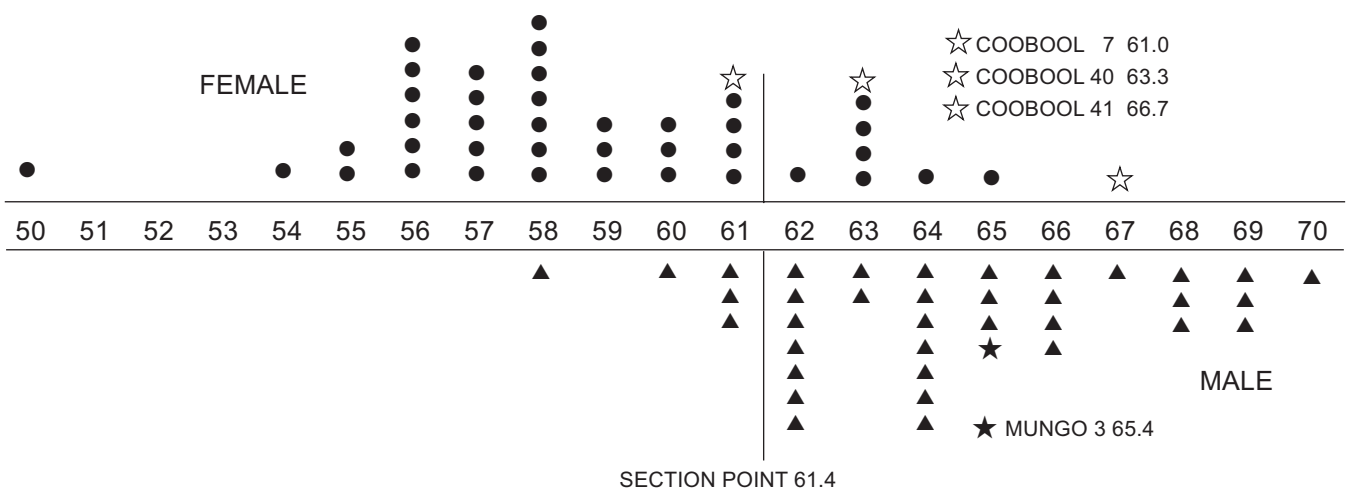


Figure 2. Sex determination of Murray Valley mandibles using linear discriminant function analysis showing positions of Lake Mungo 3 and Coobool Creek 7, 40 and 41. Murray Valley females n. 40, X 58.5, s 2.88, Murray Valley males n. 36, X 64.3, s 2.88. The standardised discriminant function coefficients and individual dimensions (mm) of Lake Mungo 3 are: symphyseal height 0.285 (M 35); corpus height 0.519 (M 33); bi-gonial breadth 0.240 (M 106); minimum ramus breadth 0.404 (M 32).

Pleistocene indicated by Kow Swamp and Coobool Creek. The discriminant functions in Figure 2 can be applied to three of the Coobool Creek female mandibles (7, 40, 41). They obtain scores of 61, 63 and 67 respectively, all within the Murray Valley male range. Although the sex of Lake Mungo 3 remains in some doubt, the innominate fragments combined with the discriminant analysis of the mandible suggest that it is a male, and it will be considered to be a male in this analysis.

6. Kow Swamp, Cohuna and Mossgiel - Thorne (1975) sexed the Kow Swamp crania using the Larnach and Freedman (1964) technique supported by information from the postcranial skeleton. Given the fragmentary condition of these crania, Thorne's assessments are as accurate as the material allows. The adult male Kow Swamp crania comprise KS1, 5, 7, 8, 9, 14 and 15 and the females 4 and 16 (possibly adolescent).

Application of both the Larnach and Freedman method (1964; Brown 1981b) and standardised discriminant function coefficients to the Cohuna cranium indicate that it is male. With the Larnach and Freedman technique, two features, mastoid size and occipital muscle markings, have to be estimated due to postdepositional damage. However, as Cohuna obtains maximum scores (3) for the other five features, giving it a total of at least 17, it is clearly male. Using the standardised discriminant functions developed for sexing Keilor, Cohuna scores 197.3 which is greater than the recent Murray Valley male range (Fig.1). Freedman's (1985) detailed description of the Mossgiel skeleton indicates that this is a male individual. Although postdepositional damage to both innominates prevented their use in sex identification, the application of the Larnach and Freedman techniques to the cranium obtained a score above the female section point.

Cranial Vault Thickness

Thorne and Macumber (1972) describe the major vault bones in the Kow Swamp sample as being uniformly thick, a statement later supported by a comparison of Kow Swamp data with that obtained from a recent museum sample and contemporary Aborigines at Yuendumu (Brown *et al* 1979), where only at lambda did the thickness of the contemporary series approach those of Kow Swamp. Following Brown *et al* (1979) vault thickness in the Coobool Creek crania was initially determined using standardised lateral radiographs. Heavy mineralisation and deposition of carbonate within the diploë, air cells and sinuses resulted in large areas of the vault being radio-opaque. The optimum exposure was 14 minutes at 55kv and 8mA (Picker-Andrex model 30023FT). The focus to mid-sagittal plane distance was fixed at 142.5cm and the mid-sagittal to film distance was 115mm. This resulted in a radiographic enlargement of 4.5 per cent and all measurements were corrected for this.

In order to check the accuracy of this form of measurement a comparison was made between data transcribed from radiographs and those obtained through direct measurement. Thirty 'recent' Murray Valley male crania and the Coobool Creek series formed the control sample. Using a specially modified

vernier caliper the maximum thickness of the cranial vault was measured to the nearest 0.1mm at the following points: on the midline at the midfrontal squama, prebregmatic eminence, the frontal bone near bregma, the right parietal bone near vertex, the occipital bone near lambda, and at the external occipital protuberance. Dimensions recorded directly from the cranial vault were then compared with those obtained from radiographs of the same individuals. A low level of correlation ($r = 0.49-0.67$) was obtained, with significant differences between the two sets of means indicated by Student's *t* ($p = 0.05-0.01$). The mean dimensions recorded from radiographs were consistently lower than those obtained through direct measurement. Although radiographs do provide a gross picture of cranial vault thickness, the manner in which they underestimate actual thickness makes them unsuited for detailed comparison. All of those data included in this analysis were obtained through direct measurement.

Tooth Size

Initial descriptions of the Australian dentition (Turner 1884) noted the high degree of tooth wear, with the rapid loss of hard tissue in the deciduous and permanent dentition (Campbell 1925; Murphy 1964). This is primarily a function of the abrasiveness of the traditional Aboriginal diet, minimal pre-masticatory preparation of food (Beveridge 1883; Campbell 1939), and the use of the teeth as tools (Gould 1968; Barrett 1977). In Australian Aborigines from traditional environments marked occlusal and interproximal wear is a feature of the deciduous and permanent dentitions, prior to the introduction of refined European foods. Murphy (1964) described the reduction in the size of the dental arch which results from interproximal wear and mesial migration. For the permanent teeth this interproximal wear results in a rapid reduction of the mesio-distal crown dimension. However, depending upon individual morphology, the bucco-lingual dimension of most teeth is not reduced by tooth wear until much later in life.

As a result of the effects of interproximal wear the only dental dimension recorded for this analysis was the bucco-lingual crown diameter. The bucco-lingual crown diameter was defined, after Townsend and Brown (1979:20) as 'the greatest distance between the labial or buccal surface and the lingual surface of the tooth crown measured with a sliding caliper held at right angles to the mesiodistal crown diameter of the tooth'. Measurements were recorded to the nearest 0.1mm using a modified Mitutoyo dial caliper with fine, sharpened beaks. Teeth in which the maximum bucco-lingual dimension had been influenced by occlusal attrition or postmortem damage were excluded from the analysis, as were teeth with anomalous crown morphology.

Tooth wear, plus postmortem tooth loss and damage, resulted in the full variable set being recorded for very few dentitions. As a result of the incomplete data set, statistical analyses were confined to univariate and bivariate comparisons. Measurement error was examined using the double determination method of Dahlberg (1940). The magnitude of

measurement error using Dahlberg's statistic ranged from 0.04-0.17mm with 19 of the 32 observations being less than 0.09mm (Brown 1982:257). The mean error of 0.09mm compares favourably with the mean error obtained for the bucco-lingual dimension in other studies: Barrett *et al* (1963) 0.13mm and Townsend and Brown (1979) 0.11mm. A comparison of the two sets of dimensions using Student's t did not produce any significant results.

Cranial Vault Thickness Results

Sources of Measurement Error

All samples, Tables 1 and 2, display considerable variation and to some degree this is a reflection of the architecture of the endocranial surface. Vault thickness dimensions recorded at the midline can be influenced by a number of anatomical features: length and height of the frontal crest, depth of the groove for the superior sagittal sinus, grooves for the meningeal vessels, relationship between the internal and external occipital protuberances and bone growth associated with suture development. Similar factors can influence thickness dimensions recorded from more lateral parts of the vault. Where measurements are recorded from fixed points on the external surface, little control can be gained over this normal source of variation.

Vault thickness may also be influenced by localised trauma or a number of specific pathologies. Fortunately the majority of these have well defined characteristics and are easily recognised. Several haemolytic anaemias increase thickness of the bones in the cranial vault. These changes result from a compression and displacement of the internal and external tables by the proliferating erythroblastic component of the marrow (Caffey 1937). The tabular portion of the bone is thinned and the external table is displaced outward by the expanding diploë. Padgett's disease, rarely seen in people under 40

years of age, may also involve a thickening of the bones of the vault. Associated with this increased thickness is a loss of distinction between the inner and outer tables and greatly increased density. Both radiographic and direct examination of the crania used in this analysis indicated that bone growth was normal, without any indication of pathological association.

Several studies have reported a secular, though uneven, trend towards increasing vault thickness in adults (Todd 1924; Roche 1953, Adeloeye *et al* 1975). Others have been unable to confirm this trend (Tallgren 1974; Smith *et al* 1985). However, it is possible that age-related changes may contribute to the problems associated with comparing small samples. In the present analysis it is unlikely that this was a significant source of error. Both of the major samples, Murray Valley and Coobool Creek, had similar age distributions (Coobool Creek X 36.4, s 11.61; Murray Valley X 34.8, s 10.82).

Sexual Dimorphism

Male and female data from the Coobool Creek and recent Murray Valley populations were analysed separately to assess the extent of sex based variation and aid in the interpretation of isolated fossil material (Tables 1 and 2). Comparison of the male and female mean dimensions using Student's t test indicated a much greater degree of dimorphism in Coobool Creek than in the recent Murray Valley series. With the exception of thickness at lambda, the difference between the male and female means at Coobool Creek were all significant (P = 0.05-0.025). Although each of the male means exceeds those of the females in the Murray Valley series, this is significant at only two points, vertex and the external occipital protuberance (P = 0.025-0.01). The extent of these sex based differences in vault thickness can be quantified using the statistic

		n	\bar{X}	s	Min.	Max.	Mungo 3	Keilor	Mossgiel	Talgai ⁴
Mid-frontal squama	CC	20	10.4	2.41	6.5	16.3				
	KS	4	8.7 ²	1.64	6.7	10.5	10.7	8.9	12.4	4.7
	MV	47	7.8 ³	1.58	3.8	11.8				
Pre-bregmatic eminence	CC	20	11.2	2.29	7.8	15.4				
	KS	4	11.8	2.40	8.7	14.1	9.0	8.7	14.3	-
	MV	47	8.4 ³	1.50	5.4	12.0				
Frontal at bregma	CC	20	10.8	1.93	8.1	14.1				
	KS	4	10.1	1.44	7.3	12.0	7.2	9.1	10.8	9.0
	MV	47	8.9 ³	1.50	5.8	12.3				
Vertex	CC	20	9.2	1.68	6.1	13.7				
	KS	4	9.7	3.04	6.0	12.5	7.1	7.0	12.0	6.0
	MV	47	8.7	1.44	5.8	12.1				
Occipital at lambda	CC	20	12.8	1.76	9.8	17.1				
	KS	5	10.0 ²	2.00	6.9	11.7	8.6	9.1	11.6	7.0
	MV	47	9.9 ³	1.94	6.2	16.5				
Occipital protuberance	CC	20	18.1	2.78	13.0	23.0				
	KS	2	14.3	-	12.8	19.6	14.2	17.0	18.0	14.3
	MV	47	15.1 ²	3.17	9.5	23.2				

Table 1: Cranial vault thickness in Australian Aboriginal male crania from Coobool Creek, Kow Swamp, the Murray Valley, Lake Mungo 3, Keilor, Mossgiel and Talgai (mm). ¹Kow Swamp sample includes Cohuna; ²mean values significantly less than Coobool Creek mean, P = 0.05-0.01; ³mean values significantly less than Coobool Creek mean, P = 0.005-0.001; ⁴juvenile, 14-15 years.

		n	\bar{X}	s	Min.	Max.	Mungo 1	KS 16
Mid-frontal squama	CC	8	8.4	1.73	5.8	10.5	6.5	7.8
	MV	52	7.5 ¹	1.35	4.1	10.4		
Pre-bregmatic eminence	CC	8	8.4	1.07	7.2	9.7	5.9	-
	MV	52	7.9	1.48	3.7	10.4		
Frontal at bregma	CC	8	8.4	1.97	5.8	10.9	5.4	7.3
	MV	52	7.8	1.39	4.7	10.4		
Vertex	CC	8	7.4	0.50	6.9	8.5	5.5	6.9
	MV	52	7.7	1.35	3.4	9.8		
Occipital at lambda	CC	8	11.6	2.07	7.5	13.8	7.2	-
	MV	52	9.7 ¹	1.75	6.1	15.1		
Occipital protuberance	CC	8	15.5	5.33	10.0	23.5	9.9	
	MV	52	13.1 ¹	2.27	8.0	17.7		

Table 2: Cranial vault thickness in Australian Aboriginal female crania from Coobool Creek, the Murray Valley, Lake Mungo 1 and Kow Swamp 16 (mm). ¹mean values significantly less than Coobool Creek mean, P = 0.05-0.01.

developed by Garn *et al* (1964), male X-female X/ female X x 100 (Table 3). These results indicate that at least in the central Murray Valley, there has been a considerable reduction in vault thickness sexual dimorphism over a 10,000 year period.

These results contrast with those obtained in previous analyses of sex based variation in cranial vault thickness (Adeloye *et al* 1975; Brown *et al* 1979; Smith *et al* 1985). In each of these studies, male mean dimensions tended to exceed those of females, however, the differences were rarely statistically significant. Unfortunately comparisons of these results are complicated by differences in the measurement techniques employed. In each instance data were obtained from radiographs, rather than through direct measurements, and Adeloye *et al* (1973) do not appear to have compensated for radiographic enlargement.

Temporal Variation

Thorne (1977:19t) argued that one of the features distinguishing between the crania from Lake Mungo and Kow Swamp, and supporting his argument for contrasting populations in Pleistocene Australia, was cranial vault thickness. Given this statement there are two issues which must be examined: variation within the Pleistocene and possible temporal trends within Australia.

Although supporting data are not presented, Thorne (1977:191) states that 'All the Lake Mungo individuals ... possess very thin cranial vault bones, compared to Late Holocene series. By contrast, all the other early skeletal individuals demonstrate thickened vaults and mandibles. However, when the actual vault thickness dimensions from the Lake Mungo, Keilor and Kow Swamp individuals are examined (Tables I and 2) there appears to be little real support for this contrast'.

Within the Lake Mungo sample there is considerable variation rather than the reported homogeneity. Lake Mungo 3, which on average has a thicker cranial vault than Kow Swamp 1, falls within the Kow Swamp range at all but two points. In one of these, thickness at mid-frontal squama, Lake Mungo 3 exceeds the Kow Swamp range, while at bregma it is slightly below it. In contrast to this, the female Lake Mungo 1 has a cranial vault which is thin when compared to the females from Coobool

	MV	CC
Mid-frontal squama	5.5	23.8
Pre-bregmatic eminence	6.3	33.3
Frontal at bregma	11.5	28.6
Vertex	12.9	24.3
Occipital at lambda	2.0	10.3
Occipital protuberance	15.3	16.8
Mean	8.9	22.9

Table 3: Percentage of sexual dimorphism in cranial vault thickness between males and females at Coobool Creek and the Murray Valley

Creek and Kow Swamp 16. Both the Kow Swamp and Mungo samples fall within the late Holocene range of variation, as defined by the Murray Valley series, as does Keilor. Freedman (1985) presents vault thickness dimensions for Mossgiel and argues that they 'are mostly considerably smaller than those of the available fossil material and fall towards the bottom of the range for recent South Australian males' (:25). It is not clear from his analysis how these data were recorded, however, direct measurement of vault thickness in this individual gives markedly different results (Table 1). Rather than having a relatively thin cranial vault Mossgiel falls in the upper part of the Coobool Creek range.

A temporal trend towards decreasing cranial vault thickness in the central Murray River Valley is indicated by a comparison of Coobool Creek with the recent Murray Valley series. Male mean thickness dimensions at Coobool Creek are significantly greater (P = 0.05-0.001) than those in the Murray Valley, with the exception of vertex. Overall the Kow Swamp sample supports the Pleistocene contrast provided by Coobool Creek, though this is less secure. Given that high levels of variation are associated with cranial vault thickness, it is essential that large samples are used. The range of variation in both the Coobool Creek and Murray Valley samples clearly indicates that two to five individuals from these populations would not provide representative results.

A directional trend towards decreasing cranial vault thickness may be associated with a reduction

in overall skeletal robusticity (Weidenreich 1943; Brown *et al* 1979; Smith *et al* 1985). Size and skeletal robusticity clearly distinguish between the majority of late Pleistocene Australian Aboriginal skeletons and their late Holocene counterparts (Thorne and Wilson 1977; Brown 1981a, 1982; Freedman 1985). Cranial vault thickness may be another expression of this through an allometric association with the size of the cranial vault and axial skeleton. This issue was examined using the Murray Valley skeletons through correlating (Pearson's r) vault thickness dimensions with stature (femur length), skeletal robusticity (femur bicondylar breadth, femur transverse mid-shaft breadth) and cranial dimensions (Table 4). An incomplete data set resulted in a reduced sample size for the correlation matrix.

There is little evidence of a biological association between cranial vault thickness, stature and skeletal robusticity, at least where stature and robusticity are represented by the femur. With a few exceptions levels of correlation were low, non-linear in distribution and often negative. Higher levels of correlation were found between vault thickness and the variables defining the size of the cranial vault, with the exception of facial height (nasion-prosthion). This pattern was more consistent in the male sample with particularly high levels of correlation with cranial height (basion-bregma). Smith *et al* (1985) obtained low to moderate levels of correlation between their cranial vault thickness dimensions and cranial length and height. A stronger association was found between cranial length and vault thickness in males ($r = 0.17-0.41$) than in females ($r = 0.02-0.32$) and correlation with cranial height was of a lower order. This suggests that, although there is considerable variation, larger crania can be expected to have slightly thicker cranial vaults. To some degree the thickened vaults within the Coobool Creek series would be predicted by this allometric association.

Alternative explanations may be provided by increased levels of growth hormone, secretion of excessive amounts of thyrocalcitonin by the para-

follicular cells of the thyroid gland, or that this is one aspect of a genetically determined archaic morphotype. Experimentally, growth hormone has been shown to stimulate bone formation and result in increased bone mass because there is relatively less increase in bone resorption (Harris and Heaney 1969). In humans hyperpituitarism gives rise to either gigantism or acromegaly (Brothwell 1981) and there is no evidence of this in the skeletal material from Kow Swamp or Coobool Creek. It is possible that growth hormones could have acted at a more subtle level, but this would be difficult to detect.

Thyrocalcitonin is important in calcium metabolism, acting in a system of dual control with the secretion of the parathyroid glands, parathormone. Raised thyrocalcitonin output has the effect of reducing blood calcium levels, and of increasing the rate of deposition of calcium salts in skeletal and other tissues (Taylor 1968). Animal skeletons may develop increased bone mass, calcium content, calcium retention and increased osteoblastic activity if thyrocalcitonin output is raised (Simmons 1976). This hypercalcemia may result in calcification of non-osseous tissues and normally the parathyroid gland will adjust for this with reduced levels of parathyroid hormone. Nutritional phosphorus deficiency has resulted in hypercalcemia in experimental animals with impairment of body growth and overall bone growth (Day and McCallum 1939). Histologically there are large numbers of unmineralised osteoids resembling osteomelacia (Baylink *et al* 1971). Microscopic examination of thin sections of cranial vault bone from Coobool Creek indicated that both the spacing and mineralisation of the osteoids and osteoid fragments was normal. Weidenreich (1943, 1946) argued that thickened cranial vault bones, prominent supraorbital, occipital and sagittal tori formed an inter-related system of cranial reinforcement. This was a feature of the crania of many fossil hominids, particularly Asian *Homo erectus*. Bio-mechanical explanations for some individual elements within this system, in particular the occipital torus

Females						Males					
	1	2	3	4	5	6	7	8	9	10	11
1	-	0.74	0.77	0.41	0.43	-0.17	0.04	0.52	0.78	0.40	0.08
2	0.39	-	0.75	0.37	0.10	-0.18	-0.04	0.42	0.73	0.47	0.21
3	0.60	0.41	-	0.30	0.09	-0.42	-0.32	0.28	0.65	0.25	0.09
4	0.19	0.13	0.32	-	-0.07	-0.31	-0.05	0.31	0.24	-0.09	0.43
5	-0.19	-0.02	-0.28	-0.49	-	0.52	0.64	0.60	0.42	0.55	0.12
6	0.19	0.30	0.34	-0.07	0.62	-	0.80	0.17	-0.03	0.36	0.10
7	-0.13	-0.13	0.01	-0.28	0.67	0.74	-	0.49	0.15	0.47	0.38
8	0.45	0.35	0.57	-0.08	0.42	0.58	0.35	-	0.58	0.62	0.43
9	0.16	0.55	-0.12	-0.42	0.32	0.17	0.17	0.13	-	0.58	0.06
10	0.59	0.44	0.07	-0.05	0.51	0.48	0.29	0.47	0.47	-	0.49
11	0.35	-0.04	0.40	0.08	0.11	0.04	0.12	0.60	-0.01	0.32	-

Table 4: Correlation Pearson's r, of vault thickness dimensions with dimensions of the cranial and postcranial skeleton, Murray Valley males and females. Murray Valley males $n = 29$, $r = 0.31$, $P = 0.05$, $r = 0.42$, $P = 0.01$; Murray Valley females $n = 34$, $r = 0.30$, $P = 0.05$, $r = 0.40$, $P = 0.01$. 1: thickness at bregma; 2: thickness at vertex; 3: thickness at lambda; 4: thickness at occipital protuberance; 5: femur length; 6: femur bicondylar breadth; 7: femur transverse mid-shaft breadth; 8: glabella-opisthocranian; 9: basion-bregma; 10: bi-frontozygomatic breadth; 11: nasion-prosthion.

(Owen 1855; Weidenreich 1940; Robinson 1958) appear clear. However, similarly convincing arguments for the development of pronounced cranial vault thickness have not been forthcoming.

It has been suggested that the thickening of the inner and outer tables of the vault, reported by Weidenreich, may have been a response to life threatening injury (Tappen 1969, Wolpoff 1980). Depressed fractures, and other traumatic injuries, are commonly found on the vaults of Pleistocene hominids (Roper 1969). Presumably these are the result of either interpersonal dispute or 'blows to the head received while hunting large mammals with weapons effective only at close range' (Wolpoff 1980:178). The former hypothesis, as a mechanism selecting for increased cranial vault thickness, is supported by data from Australian Aboriginal populations.

Comparison of published data indicates that among living people Australian Aborigines appear to have, by far, the thickest cranial vaults (Roche 1953; Brown *et al* 1979; Smith *et al* 1985). Traditionally, Australian Aborigines, males and females, involved in aggressive dispute will use a substantial wooden implement and strike to the head of their opponent (Meggitt 1962). As they generally faced each other, and were primarily right handed, any resulting injury was most often located on the left side of the cranium. A survey of 430 Aboriginal crania (176 females and 254 males) from NSW, Victoria and South Australia located well demarcated, single or multiple suppressed fractures on 58 per cent of the females and 37 per cent of the males. Seventy-four per cent of these fractures were distributed on the left side of the vault. Extensive bone remodelling, associated with the fractures, indicated that the majority had survived what was often severe trauma. Only rarely, 7 per cent, was the inner table of the vault depressed or perforated, although compression of the diploë and destruction of the outer table was often extensive. The individuals most at risk appear to be the socially less secure, though often more aggressive, young adults who are at their reproductive peak (Meggitt 1962). Surely this form of social interaction must have rigorously selected against those individuals with thinner bones in their cranial vaults.

Tooth Size

Although a considerable amount of information is available on Australian Aboriginal tooth size, there is still an inadequate picture of two of the major areas of contemporary anthropological interest, regional and temporal variation. In much of the early descriptive work (Topinard 1872; Klaatsch 1908; Campbell 1925) limited geographic control was combined with pooled sex samples and these problems persist in more recent research (Macintosh and Barker 1965; Brace 1980). To some degree the apparent limitations of much of the early work are simply a reflection of recent changes in emphasis and the ongoing sampling problems associated with collections of Australian skeletal material. In this respect it is particularly unfortunate that one of the most recent, and potentially most useful, regional surveys of Australian Aboriginal tooth size, that of

Brace (1980), is severely compromised by an inadequate methodology (Brown and Townsend 1980; Koritzer 1980; Roydhouse 1980; Brown 1982).

The most comprehensive and detailed descriptions of Australian Aboriginal tooth size stem from the longitudinal growth study of Walbiri and Pintubi peoples at Yuendumu (Barrett *et al* 1963; Barrett *et al* 1964, Townsend and Brown 1979). Other sexed regional data are provided by Freedman and Lofgren (1981) for Western Australia and Smith *et al* (1981) for Broadbeach, Roonka, Swanport, Anson Bay and Melville Island. Tooth size data have also been presented for some of the 'fossil' Australian crania. Smith (1918) and Macintosh (1952) both describe the dentition of Talgai, Macintosh (1952b) the teeth and palate of Cohuna and Adam (1943) those of Keilor. Although a detailed description of the Kow Swamp dentitions has not been published, Thorne and Macumber (1972) provide data for KS1 and KS5. Most recently Freedman and Lofgren (1979) provide the odontometric data for the Cossack skeleton. Morphological and metrical descriptions of Lake Mungo 1 (Bowler *et al* 1972), Lake Mungo 3 (Bowler and Thorne 1976) and Lake Nitche (Macintosh 1971) dentitions have not been published.

Comparisons of the bucco-lingual crown dimensions for male crania from Coobool Creek with those from other Aboriginal male populations, indicate the large size of the Coobool Creek dentitions (Tables 5 and 6). In particular the maxillary lateral incisor and first molar, and the mandibular premolars and first molar, have mean dimensions which are significantly larger ($P = 0.05-0.001$) than those in the comparative samples. The mean dimensions for three other teeth, maxillary second molar, mandibular canine and second molar, are significantly larger than the means for Swanport, Broadbeach and Roonka. In addition the maximum dimensions for the Coobool Creek mandibular canine and premolars exceed the reported Australian range (Campbell 1925; Barrett *et al* 1964; Freedman and Lofgren 1981). To some degree Kow Swamp follows the megadont trend in evidence at Coobool Creek, however, the sample is too small to provide significant results. The isolated male crania, Talgai and Keilor, and the Mungo 3 mandible, have, with the exception of the Talgai canines, dental dimensions which fall within the Coobool Creek range of variation. The Mungo 3 mandibular teeth either fall within, or exceed, the Kow Swamp range, while the Keilor maxillary tooth dimensions are dispersed around the Kow Swamp range.

Tooth size data for the female groups tends to support those obtained with the males (Tables 7 and 8). With two exceptions, maxillary second molar and mandibular first molar, mean bucco-lingual tooth breadths in the Coobool Creek females either exceed, or equal, those in the other female samples. However, the Coobool Creek sample is relatively small and few of the differences between the means are statistically significant. Several teeth, maxillary lateral incisor and first and second molar, mandibular canine, second premolar and first molar, have Coobool Creek means which are significantly greater ($P = 0.05-0.001$) than one, or more, of the comparative groups. Of these, only the maxillary lateral

incisor has a significantly larger mean than all of the others. The single Kow Swamp female, KS16, does not have notably large teeth.

The Coobool Creek tooth size results provide evidence for increased mean tooth size, particularly for the maxillary lateral incisors, first and second molars and the mandibular canine and premolars, during the terminal Pleistocene. Comparison with Roonka suggests that there was a significant reduction in mean tooth size in the period between 10,000 and 6000 years BP in the Murray River area. However some caution is needed in the interpretation of these results given the recorded Holocene variation in tooth size (Townsend and Brown 1979; Freedman and Lofgren 1981; Smith *et al* 1981) and small sample

sizes. The environmental contribution to tooth size, either prenatal or postnatal in origin (Holloway *et al* 1961; Bailit and Sung 1968; Keene 1971) may be as high as 36 per cent (Townsend and Brown 1978). Low birth weight, prenatal stress and uterine competition amongst twins may result in decreased tooth crown size (Keene 1971; Garn *et al* 1965) while those with higher birth weights tend to have larger teeth (Garn *et al* 1979). It has also been argued that the intake of fluoride or molybdenum during dental development can influence crown size and morphology (Kruger 1962; Goose and Roberts 1979). For example, high fluoride levels in drinking water may be a factor in the relatively microdont condition of the Australian Aborigines from Yuendumu

		CC	MV	SW	BB	RO	KS*	Keilor	Talgai**
11	n	7	32	6	11	4	1		
	X	8.3	8.3	8.2	8.1	8.1	8.2	-	8.6
	s	0.39	0.38	0.70	0.51	0.50	-		
	min	7.8	7.6	7.3	7.2	7.6	-		
	max	8.9	9.1	9.2	8.8	8.7	-		
12	n	9	40	11	17	8	2		
	X	7.8	7.1‡	7.3†	7.0‡	7.1†	7.8	-	-
	s	0.43	0.37	0.62	0.47	0.44	0.28		
	min	7.2	6.3	6.5	6.1	6.4	7.6		
	max	8.6	8.0	8.4	7.8	7.9	8.0		
C	n	11	39	16	19	8	3		
	X	9.8	9.6	9.4	9.5	9.2	9.9	-	11.1
	s	0.53	0.68	0.66	0.73	0.26	1.01		
	min	8.6	8.7	8.0	8.2	8.8	9.3		
	max	10.7	11.2	10.6	11.1	9.6	11.4		
P1	n	9	35	15	19	8	3		
	X	11.0	10.7	10.6	10.6	10.6	10.7	-	11.2
	s	0.48	0.56	0.74	0.64	0.37	0.17		
	min	10.3	9.5	9.5	9.4	9.9	10.6		
	max	11.8	12.0	12.1	11.8	11.1	10.9		
P2	n	11	39	19	16	8	3		
	X	10.8	10.6	10.4	10.6	10.8	10.3	10.7	11.0
	s	0.44	0.60	0.9	0.70	0.51	0.44		
	min	10.1	9.6	8.7	9.6	10.2	9.8		
	max	11.5	12.4	12.3	11.5	11.6	10.6		
M1	n	12	28	19	20	6	2		
	X	13.8	13.2†	12.9‡	13.0‡	13.0†	13.5	13.3	13.1
	s	0.39	0.68	0.72	0.60	0.61	0.42		
	min	13.2	11.4	11.5	11.6	12.4	13.2		
	max	14.4	14.7	14.2	14.1	14.1	13.8		
M2	n	14	37	22	21	8	3		
	X	14.1	13.8	13.5†	13.5†	13.5†	13.9	13.1	13.7
	s	0.82	0.71	0.84	0.75	0.70	0.35		
	min	12.7	12.3	12.3	12.1	12.7	13.6		
	max	15.5	15.7	16.2	14.9	14.9	14.3		
M3	n	16	37	20	21	6	3		
	X	13.1	13.1	12.9	13.0	12.7	13.3	12.8	-
	s	0.85	0.86	0.81	0.88	0.99	0.25		
	min	10.7	11.4	11.1	11.4	11.2	13.0		
	max	14.1	16.3	14.9	14.6	14.2	13.5		

Table 5. Comparison of the bucco-lingual crown dimensions of maxillary teeth from Coobool Creek male crania with those from other Aboriginal male crania (mm). * Kow Swamp (KS1, KS15 and Cohuna); † mean value exceeded by Coobool Creek mean, Student's t probability 0.05-0.01; ** Talgai incisor recorded by Smith (1918) and subsequently lost; ‡ mean value exceeded by Coobool Creek mean, Student's t probability 0.009-0.001.

(Williamson and Barrett 1972; Brown and Townsend 1980). Where tooth size is increased through local environmental factors this would be indicated either by an overall increase in size, or an increase restricted to particular developmental categories. Neither of these conditions is supported by the pattern of tooth size increase at Coobool Creek, where there are no specific developmental links between the categories represented.

One feature which distinguishes the majority of Pleistocene crania from their more recent counterparts, is increased size (Thorne 1976; Thorne and Wilson 1977). Tooth size may be an expression of this through an allometric association with the size of the orofacial skeleton or cranial vault. The biological relationship between tooth size, size of the cranium,

stature and body weight has received considerable attention (Garn and Lewis 1958; Filipson and Goldson 1963; Garn *et al* 1968; Anderson *et al* 1975; Henderson and Corruccini 1976). The original assumption appears to have been that 'in most cases, and especially in Primates, large teeth necessitate large jaws, and large jaws a large body ...' (Weidenreich 1946:60). However, tests of this association have in general only found low levels of correlation between these features. Filipson and Goldson (1963), Lavelle (1974) and Wood (1979) each recorded low levels of correlation between tooth breadth and cranial length and breadth ($r = 0.15-0.20$). Higher levels of correlation were found in pooled sex samples due to the separation of the male and female means ($r = 0.31-0.34$).

		CC	MV	SW	BB	RO	KS*	Mungo 3
I1	n	3	26	6	17	4	-	-
	X	7.1	6.6	6.5	6.6	6.5		
	s	0.15	0.40	0.50	0.40	0.14		
	min	6.9	6.0	6.0	5.8	6.3		
	max	7.1	7.8	7.2	7.4	6.6		
I2	n	6	28	9	19	4	-	-
	X	7.2	6.8	6.6	6.8	6.8		
	s	0.31	0.45	0.45	0.45	0.10		
	min	6.7	6.0	5.8	6.1	6.7		
	max	7.5	7.8	7.2	7.6	6.9		
C	n	13	34	11	23	8	2	
	X	9.2	8.8	8.4‡	8.7†	8.4‡	8.8	
	s	0.44	0.64	0.62	0.42	0.40	-	
	min	9.0	7.6	7.1	8.0	7.8	8.6	
	max	10.7	10.1	9.3	9.5	8.9	8.9	
P1	n	13	35	10	23	8	3	
	X	9.8	9.2‡	9.5†	9.3‡	8.9‡	9.3	9.0
	s	0.51	0.46	0.69	0.50	0.32	0.40	
	min	9.0	8.5	8.0	8.2	8.5	8.9	
	max	10.7	10.4	10.2	10.2	9.4	9.7	
P2	n	15	32	11	19	8	2	
	X	9.9	9.2‡	8.8‡	9.5†	9.1‡	9.2	9.5
	s	0.56	0.58	0.82	0.60	0.62	-	
	min	9.2	8.1	7.1	8.3	8.1	8.9	
	max	10.8	10.6	9.8	10.4	9.9	9.4	
M1	n	7	25		11	19	5	-
	X	12.9	12.4†	12.2‡	12.1‡	12.2 ‡		
	s	0.56	0.58	0.68	0.63	0.55		
	min	12.1	11.4	11.0	10.9	11.6		
	max	13.3	13.5	13.6	13.2	13.0		
M2	n	10	30	13	23	7	-	-
	X	12.5	12.2	11.8†	11.8†	11.7†		
	s	0.45	0.66	0.82	0.71	0.69		
	min	11.8	11.1	10.5	10.5	11.1		
	max	13.0	13.6	13.5	13.5	13.3		
M3	n	14	29	12	24	7	2	
	X	11.8	11.7	11.9	11.5	11.2†	11.9	12.0
	s	0.60	0.73	1.07	0.62	0.73	-	
	min	10.5	9.9	10.4	10.1	9.6	11.6	
	max	12.5	13.3	13.9	12.4	11.8	12.2	

Table 6. Comparison of the bucco-lingual crown dimensions of mandibular teeth from Coobool Creek males with those from other Aboriginal male mandibles (mm). ‡ mean values exceeded by Coobool Creek mean, Student's t probability 0.05-0.01; † mean value exceeded by Coobool Creek mean, Student's t probability 0.009-0.001; * Kow Swamp (KS1, KS5, KS7).

The relationship between the maxillary bucco-lingual crown dimensions and the size of the cranial vault, height of the facial skeleton and size of the palate were examined in Australian Aborigines using the Murray Valley sample (Brown 1982). Apart from a predictable biological association between the size of the dental arch and the teeth it contained (Alveolar length male $X r 0.40$, female $X r 0.37$, pooled $X 0.56$) levels of correlation were low, often negative, and only vaguely linear. Of the cranial size variables, cranial length obtained the highest levels of correlation with tooth breadths (glabella-opisthocranium male $X r 0.27$, female $X r 0.17$, pooled $X r 0.46$). In this instance the pronounced sexual dimorphism in tooth size and cranial length in Australian Aborigines resulted in an inflated pooled sex result. No one tooth in the correlation analysis consistently gained

higher correlations with cranial dimensions than did any other. On this basis, it would seem unlikely that increased mean tooth size in the Pleistocene is simply a reflection of an allometric association with large cranial vaults.

Discriminant Function Analysis

Univariate and morphological analyses of the Kow Swamp and Coobool Creek crania have identified a number of anatomical features which, in combination, indicate that some of these crania have been artificially deformed (Brothwell 1975; Brown 1981b). These features include a lengthened and flattened frontal squama, often with a constriction of the diploë in the middle third and a pronounced prebregmatic eminence. This flattening is also most evident in the middle third where there are often symmetrical depressions bordering the midline.

		CC	MV	SW	BB	YU*	KS 16
I1	n	6	28	10	2	36	
	X	8.0	7.9	7.9	7.0	7.5	7.6
	s	0.42	0.31	0.46	-	0.36	
	min	7.6	7.1	7.3	6.7	6.7	
	max	8.6	8.4	8.7	7.2	8.2	
I2	n	7	36	17	4	36	
	X	7.4	6.8 [‡]	6.7 [†]	6.6 [†]	6.7 [‡]	7.2
	s	0.39	0.39	0.54	0.34	0.49	
	min	6.9	5.8	5.8	6.2	5.7	
	max	7.8	7.7	7.8	6.9	7.9	
C	n	7	42	19	3	36	
	X	9.1	8.8	8.9	8.6	8.7	8.6
	s	0.45	0.49	0.47	0.75	0.38	
	min	8.6	7.7	8.0	8.1	7.8	
	max	9.8	10.0	9.7	9.5	9.5	
P1	n	7	42	16	2	81	
	X	10.3	10.1	10.0	9.5	10.1	10.0
	s	0.35	0.50	0.48	-	0.56	
	min	9.8	9.2	8.7	9.3	8.8	
	max	10.7	11.3	10.5	9.6	11.3	
P2	n	8	49	22	2	81	
	X	10.2	10.0	9.8	9.6	10.1	10.1
	s	0.76	0.52	0.48	-	0.60	
	min	9.4	9.1	8.8	8.9	8.5	
	max	11.3	11.4	10.8	10.2	11.7	
M1	n	7	43	20	4	81	
	X	12.9	12.7	12.6	12.3 [†]	12.2 [‡]	12.3
	s	0.66	0.51	0.58	0.69	0.57	
	min	12.1	11.8	11.9	11.7	10.6	
	max	13.9	13.9	14.1	13.3	14.0	
M2	n	8	49	23	4	36	
	X	13.0	13.1	12.6	12.3	12.4 [†]	13.7
	s	0.74	0.61	0.61	0.85	0.67	
	min	12.1	12.8	11.7	11.2	11.3	
	max	13.8	14.6	14.0	13.2	13.8	
M3	n	7	46	18		4	30
	X	12.3	12.3	11.7	11.7	11.9	
	s	1.32	0.75	0.76	0.71	0.83	
	min	10.0	10.8	10.2	11.1	10.3	
	max	13.8	14.1	13.0	12.7	13.8	

Table 7. Comparison of the bucco-lingual crown dimensions of maxillary teeth from Coobool Creek females with those from other Aboriginal female crania (mm). † mean value exceeded by Coobool Creek mean, Student's t probability 0.05-0.01; ‡ mean value exceeded by Coobool Creek mean, Student's t probability 0.009-0.001; * data from Barrett et al 1964.

Cranial height is increased in relation to length. The antero-posterior curvature of the parietal bones are increased with a more posterior location of vertex. The occipital bone is lengthened (Lambda-opisthion), inion is located closer to lambda and the area of attachment for the semispinalis capitis and trapezius muscles become more rugose and depressed. Angulation, or curvature, of the occipital bone when viewed from a lateral aspect is decreased. In association with the anterior and posterior flattening of the cranial vault there is an increase in cranial breadth (Brown 1981a, 1982).

Others have argued that the presence of some of these traits at Kow Swamp, in particular the overall morphology of the frontal bone, indicates the existence of an archaic morphotype rather than

cranial deformation (Thorne and Macumber 1972; Thorne and Wolpoff 1981). This has been used to provide support for the concept of morphological continuity with the Indonesian region and an ancestor-descendant relationship with Javan *Homo erectus* (Thorne and Wolpoff 1981; Wolpoff *et al* 1984). Some of these features have also been used to distinguish two Australian Pleistocene populations (Thorne 1977; Freedman and Lofgren 1979).

Discriminant function analysis was used to determine whether the unique position of Kow Swamp and Coobool Creek in multivariate statistical analyses (Thorne and Wilson 1977; Pietruszewsky 1979; Brown 1982) was simply a product of cranial deformation and its influence on size relationships and covariation. It is clear that the isolation of those

		CC	MV	SW	BB	YU*	KS 16
I1	n	5	13	6	2	36	
	X	6.4	6.3	6.2	6.2	6.4	6.0
	s	0.60	0.35	0.31	-	0.32	
	min	5.9	5.7	5.7	5.9	5.7	
	max	7.4	7.0	6.8	6.5	7.0	
I2	n	5	28		7 1	36	
	X	6.7	6.6	6.5	6.3	6.6	6.3
	s	0.50	0.40	0.28	-	0.40	
	min	6.2	5.8	6.1		6.0	
	max	7.5	7.6	6.9	-	7.8	
C	n	9	35		13 2	36	
	X	8.5	8.0†	8.1	8.1	8.0 †	7.7
	s	0.59	0.43	0.37	-	0.38	
	min	7.6	7.2	7.6	7.6		7.3
	max	9.3	9.1	8.7	8.6		8.8
P1	n	9	38		12 3	81	
	X	8.9	8.7	8.9	8.2	8.9	8.6
	s	0.39	0.56	0.40	0.80	0.55	
	min	8.3	7.6	8.1	7.3		6.8
	max	9.6	9.6	9.4	8.9	10.2	
P2	n	9	34	10	3	81	
	X	9.2	8.8†	8.6†	8.6	8.9	9.1
	s	0.35	0.59	0.44	0.85	0.51	
	min	8.6	7.3	7.9	7.8		8.0
	max	9.5	10.0	9.2	9.5	10.3	
M1	n	5	26	13	3	80	
	X	11.7	11.8	12.0	11.6	11.4	11.5
	s	0.51	0.55	0.53	0.64	0.51	
	min	11.1	10.6	11.1	11.1	10.2	
	max	12.2	12.9	13.2	12.3	12.6	
M2	n	8	33		15 3	36	
	X	11.9	11.6	11.6	11.0	11.3†	11.4
	s	0.64	0.60	0.57	0.77	0.42	
	min	10.9	10.2	10.7	10.1	10.6	
	max	12.9	12.9	12.8	11.6	12.6	
M3	n	7	42	13	3	30	
	X	11.2	11.0	11.0	10.5	11.2	11.5
	s	0.75	0.75	0.80	0.10	0.57	
	min	9.7	9.2	9.9	10.4		9.9
	max	11.7	12.7	12.6	10.6	12.4	

Table 8. Comparison of the bucco-lingual crown dimensions of mandibular teeth from Coobool Creek females with those from other Aboriginal female mandibles (mm). † mean value exceeded by Coobool Creek mean, Student's t probability 0.05-0.01; ‡ mean value exceeded by Coobool Creek mean, Student's t probability 0.009-0.001; * data from Barrett et al 1964.

variables unaffected by deformation is a necessary prerequisite to morphological analysis of comparative biological relationship. Although this area has received some attention in respect to artificially deformed American Indian crania (McNeal and Newton 1965; Hughes 1968; Cybulski 1975) similar analyses are not available for other populations. McNeal and Newton (1965) document extensive alteration in cranial base morphology, while Hughes (1968) found that basal and facial measurements remain unaffected. With extreme deformation, Cybulski (1975) argues that the effects extend throughout the cranium.

The isolation of anatomical regions least influenced by deformation in the Coobool Creek crania was complicated by temporal factors, most notably large mean size, and the gradation from clearly deformed to undeformed crania. Examination of the descriptive statistics, variance, allometric associations and covariance matrices for these crania indicated fairly uniform morphology in the orofacial skeleton. The same morphological pattern of marked subnasal prognathism, broad and high palates, low and horizontal orbits, robust and deep malars, and great supraorbital breadth were common to both deformed and undeformed crania. Two discriminant analyses were undertaken, the first restricted to the cranial vault and the second to the orofacial skeleton.

Cranial Vault

This analysis was limited to the male samples (Murray Valley, Swanport and Coobool Creek) so that the comparisons could include Cohuna, Keilor and Lake Nitchie. An incomplete variable set excluded all of the Kow Swamp male crania, Lake Mungo 3 and Mossgiel from the analysis. Broadbeach was also excluded because of an incomplete variable set, and a small sample size which resulted in an inversion when the covariance matrices were compared.

This analyses clearly distinguished the Coobool Creek crania from the Murray Valley and Swanport series, with 100 per cent of the Coobool Creek sample being correctly assigned on the basis of the selected variables (Table 9, Fig.3). The distribution of the two recent samples overlapped, 19.6 per cent, with one individual from each falling within Coobool Creek range of variation. Even though there was some overlap, the F statistics associated with Mahalanobis distance indicated that there was a significant difference between all three groups ($P = 0.0002-0.0001$). Inspection of the two canonical discriminant functions indicated that 89 per cent of the variance was accounted for by the first function (Table 10). The principle feature distinguishing the Coobool Creek crania from both of the recent series was large mean size. With the exception of frontal subtense height, the Coobool Creek mean values were significantly greater than the Murray Valley and Swanport means (Table 11). This is combined with shape differences in the frontal and parietal areas. These were examined in detail through reference to the correlation and covariance matrices, and individual scatterplots. A major alteration in the normal pattern of size relationships between the individual skeletal elements, was evident in the Coobool Creek crania. This was reflected both in

high levels of variation and low, or negative, correlations between some variables. Perhaps the most suggestive example was in the correlation between the length of the frontal bone and its

Actual	Predicted		
	CC	MV	SW
Coobool Creek	17 (100)		
Murray Valley	1 (7.5)	34 (85.0)	5 (12.5)
Swanport	1 (6.3)	6 (37.5)	9 (56.2)
Total			60 (82.2)

Actual	Predicted		
	CC	MV	SW
Coobool Creek	13 (92.9)		1 (7.1)
Murray Valley	2 (4.4)	31 (68.9)	12 (26.7)
Swanport	1 (4.8)	3 (14.2)	17 (81.0)
Total			61 (75.3)

Table 9. Discriminant classification matrix of the Coobool Creek, Murray Valley and Swanport male crania, analysis 1 (above) and analysis 2 (below). The top number indicates the actual number classified into that population with the percentage figure in brackets underneath

Eigenvalue	2.66
Canonical correlation	0.85
Percent of variance	89.17
Chi-square	105.01
Degrees of freedom	8
Probability	0.001
Max Bi-parietal	0.57
Basion-bregma	0.52
Bi-sphenion	-0.39
Nasion-bregma	0.38
Frontal subtense H.	-0.59
Max. supraorbital Br.	0.71
Lambda-bregma	-0.52
Parietal subtense H.	-0.30
Eigenvalue	1.51
Canonical correlation	0.77
Percent of variance	80.39
Chi-square	95.20
Degrees of freedom	5
Probability	0.001
Basion-nasospinale	0.23
Max. supraorbital Br.	0.85
Nasion-prosthion	0.57
Orbital height	-0.71
Alveolar length	-0.55

Table 10. Descriptive statistics and standardised canonical discriminant function coefficients for the first functions in Analysis 1 (above) and Analysis 2 (below).

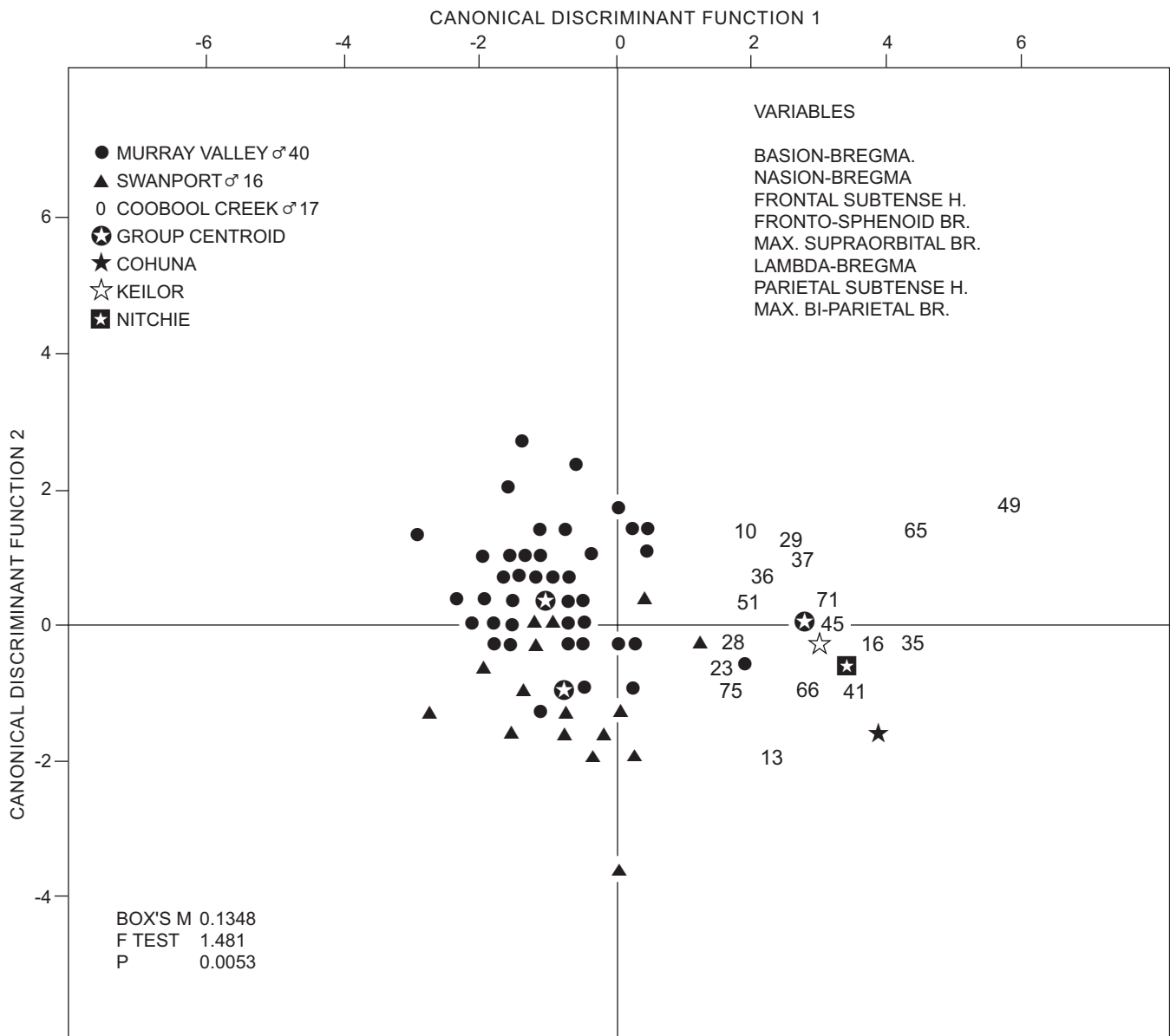


Figure 3. Linear discriminant function analysis of cranial vaults from Coobool Creek, Swanport and the Murray Valley, combined with Keilor, Lake Nitchie and Cohuna.

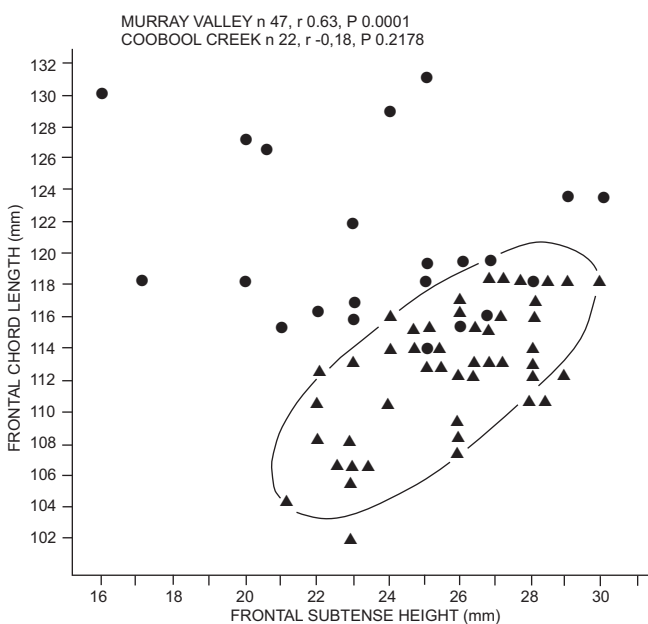


Figure 4. Correlation, Pearson's r , of frontal chord length with frontal subtense height in male crania from Coobool Creek and the Murray Valley. The ellipse circumscribes the 95 per cent confidence limits for the Murray Valley sample.

maximum curvature (subtense height) (Fig.4). In all of the Australian samples examined, excluding Coobool Creek, the relationship between these two variables, in both single sex and pooled sex samples, was reasonably linear, positive and significant ($r = 0.47-0.69$, $P = 0.001$). In general the longer the frontal bone the greater its curvature. With artificial cranial deformation this relationship is lost and when combined with a mixed deformed and undeformed sample, as at Coobool Creek, considerable variation is the result. This also contributed to the inequality in the covariance matrices indicated by Box's M (Fig.3).

The three isolated crania, Lake Nitchie, Cohuna and Keilor were all included in the Coobool Creek group, with classification probabilities of 98-99 per

cent. Large overall size is their principal reason for inclusion in this group. Keilor and Lake Nitchie, which have very similar cranial vault dimensions, share great supraorbital and bi-parietal breadths with cranial heights at the top of the recent range (Table 11). Cohuna, while also a large individual, possesses the extremely long and low frontal of several of the Coobool Creek crania and a cranial height equal to Keilor and Lake Nitchie.

Orofacial Skeleton

Poor preservation restricted this analysis to the Murray Valley, Swanport and Coobool Creek series, plus Keilor and Cohuna. Lake Mungo 3, Mossgiel and the Kow Swamp crania either had fragmentary orofacial skeletons or their basioccipital areas were damaged and basion not preserved. The central

maxillary incisors in Lake Nitchie have been avulsed and the subsequent alveolar resorption has altered the normal position of prosthion.

Eight variables were selected for this comparison, however, the stepwise selection procedure removed alveolar breadth and nasion-basion as they did not significantly improve the Mahalanobis distance (D^2) between groups. Distance between the group centroids in this analysis, as indicated by the classification results and the F test associated with D^2 , was slightly less than that based on the cranial vault variables. Although all but one of the Coobool Creek crania were correctly allocated, 38 per cent of the Murray Valley and Swanport specimens were assigned to incorrect groups (Table 9). The F statistics (D^2) were all significant ($P = 0.0002-0.0001$) and revealed that the two closest groups were Swanport and Murray

		MV	SW	CC	KS	N	K	MO	C
	n	40	16	17	3				
Max. bi-par br.	X	130.6‡	130.4‡	137.6	135.3	141	142	138	131
	s	4.73	2.98	3.92	5.51				
	n	40	16	17					
Basion-bregma	X	133.3‡	129.8‡	140.5	-	142	142	-	142
	s	3.85	4.15	4.88					
	n	40	16	17	4				
Nas-breg (chord)	X	113.4‡	112.2‡	120.2	120.3	122	114	120	126
	s	4.43	3.05	4.50	3.30				
	n	40	16	17	4				
Front. subtense ht.	X	25.7	25.4	22.9*	18.3	29	24	21	18
	s	2.23	2.44	3.54	4.62				
	n	40	16	17					
Bi-sphenion	X	103.8‡	101.3‡	107.7	-	110	108	-	96
	s	3.82	4.46	4.72					
	n	40	16	17	5				
Lambda-bregma	X	117.5†	113.8‡	118.8	119.8	123	119	121	116
	s	4.96	4.72	6.45	4.71				
	n	40	16	17	5				
Pariet. subtense ht.	X	23.4†	22.8‡	24.4	24.4	24	21	24	26
	s	1.90	2.85	3.35	3.97				
	n	45	21	16					
Basion-nasospinale	X	99.0‡	98.5‡	102.9	-	105	103	-	102
	s	3.88	4.30	3.15					
	n	45	21	16	4				
Max supraorb. br.	X	108.6‡	109.5‡	115.2	117.8	122	116	119	116
	s	3.49	3.20	3.72	5.32				
	n	45	21	16	1				
Alveolar length	X	64.3	60.9‡	64.7	65.0	-	64	-	67
	s	3.98	2.52	3.31	-				
	n	45	21	16	3				
Nasion-prosthion	X	70.5‡	67.4‡	74.3	77.0	-	74	-	75
	s	3.95	2.63	2.67	4.0				
	n	45	21	16	5				
Orbital ht.	X	33.0‡	33.8‡	31.0	30.8	32	32	30	30
	s	2.50	2.01	2.19	0.45				

Table 11. Descriptive statistics for the cranial dimensions used in the discriminant function analyses, including those for individual crania from Lake Nitchie, Keilor, Mossgiel and Cohuna. Incomplete data sets excluded some specimens from either analysis 1 (Kow Swamp, Mossgiel) or analysis 2 (Kow Swamp, Lake Nitchie, Mossgiel). † mean value exceeded by Coobool Creek mean, Student's t probability 0.05-0.01; ‡ mean value exceeded by Coobool Creek mean, Student's t probability 0.009-0.001; * Coobool Creek mean value exceeded by Swanport and Murray Valley mean, Student's t probability 0.05-0.01.

Valley ($F = 5.55$), followed by Swanport and Coobool Creek ($F = 18.01$) and Murray Valley and Coobool Creek ($F = 21.05$) (Fig.5).

Inspection of the canonical discriminant functions indicated that the first function accounted for 80.4 per cent of the variance and separated Coobool Creek from the other two groups (Table 10, Fig.5). The Coobool Creek facial skeletons are distinguished by both their size and morphology. Mean facial height (nasion-prosthion), supraorbital breadth, and upper face projection (basion-nasospinale) are significantly greater in the Coobool Creek sample than in either of the comparative groups (Table 11). This is combined with relatively shallow orbits and palates which are not significantly longer than either the Murray Valley or Swanport. Although the Coobool Creek palates are not particularly long, they are extremely broad (CC n.16, \bar{X} 72.4, s 3.66; MV n.45, \bar{X} 69.3, s 3.61; SW n.21, \bar{X} 67.0, s 3.09) and it is the more lateral extension of the alveolar process which accommodates their larger teeth. The standardised canonical functions indicate that the major discriminating variables, for the first function,

were maximum supraorbital breadth and orbital height (Table 10). With negative coefficients, for instance orbital height -0.71 , the higher the value of an individual the less likely it is to belong to that group. Therefore this assists in separating the low orbits at Coobool Creek from the larger orbits in the two recent samples. The negative coefficient for alveolar length discriminates the longer palates from Coobool Creek and the Murray Valley from the Swanport sample.

The two isolated crania, Keilor and Cohuna, were both assigned to the Coobool Creek group with classification probabilities of 98 per cent. In terms of their supraorbital breadth, facial height, orbital height and midface projection (basion-nasospinale) these two individuals are extremely similar, and share the overall Coobool Creek morphological pattern (Table 11). Individual data for the Kow Swamp, Mossgiel and Lake Nitchie crania suggest that, if they had been complete enough for inclusion in the analysis, they also would have been distributed with the Coobool Creek group (Table 11).

Comparison of the plots of the canonical dis-

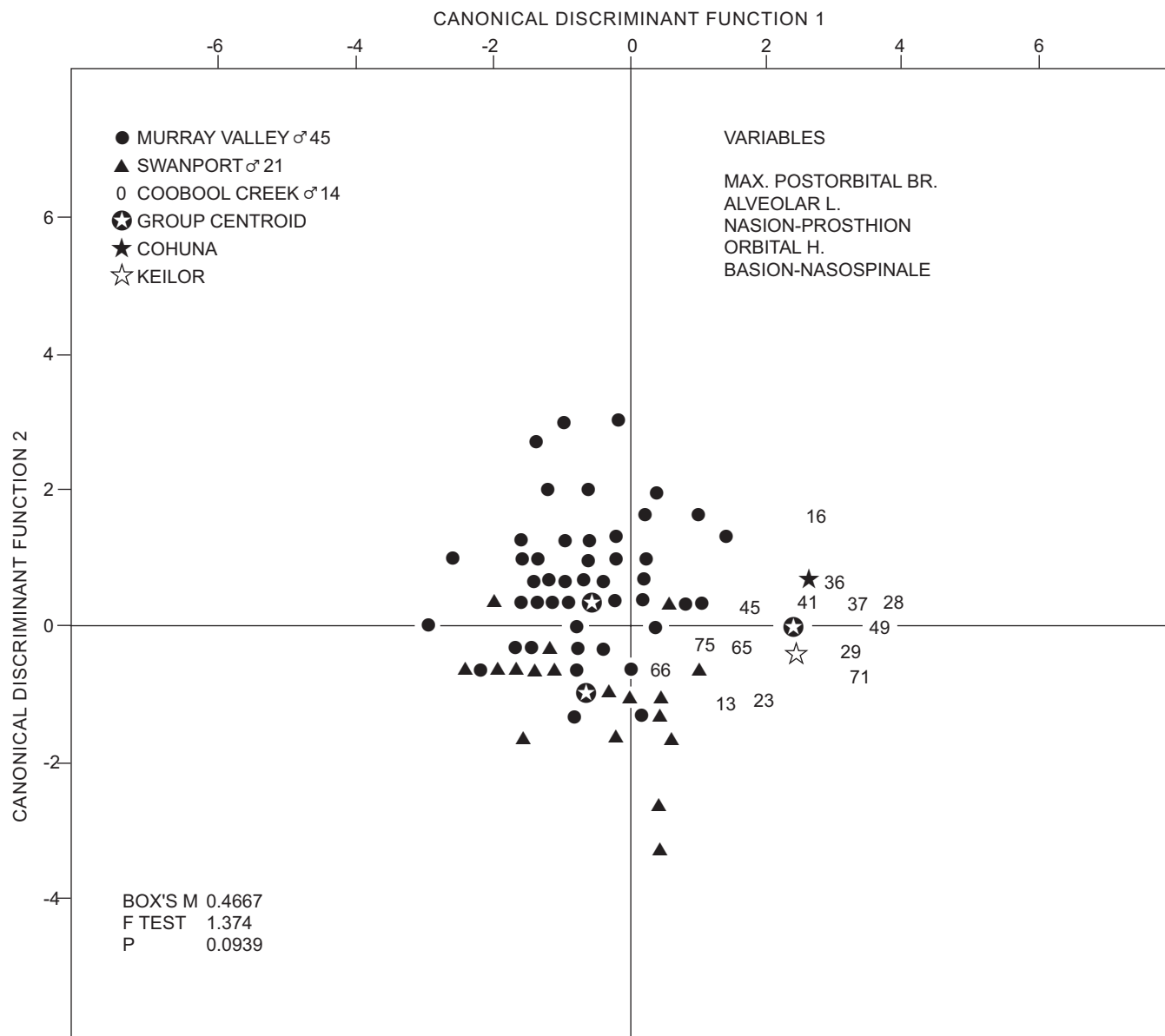


Figure 5. Linear discriminant function analysis of orofacial skeletons from Coobool Creek, Swanport and the Murray Valley, combined with Keilor and Cohuna.

criminant function scores for analyses 1 and 2 (Figs 3 and 5) and the within-groups covariance matrices demonstrated the greater variation within the Coobool Creek sample for the size and morphology of the cranial vault, relative to the facial skeleton. The ellipse defining group membership for the Coobool Creek series, cranial vault variables, is almost as large as that for the combined comparative samples. Decreased variation, with a smaller ellipse circumscribing the sample and a tighter cluster around the group mean (centroid) accompanies the Coobool Creek orofacial variables. If this variation simply reflected a mixed chronological sample from Coobool Creek, and given that there is no absolute or relative temporal control for this site, I would expect a similar pattern of variation in both analyses. The morphological and metrical homogeneity in the orofacial skeletons and their isolation from the two recent samples argues against this. What is more probable is that the unevenly dispersed effects of artificial cranial deformation resulted in the greater variation for the selected cranial vault variables. In this instance the deformation process does not appear to have significantly influenced facial morphology, or size relationships, and there is no subsequent increase in variation.

Lake Mungo 1

Thorne (1977) argued that Lake Mungo 1 could be excluded from a contemporary northern Victorian cranial series in terms of its overall small size, a complex of basal and posterior dimensions and cranial vault thickness. These are unexpected, given that the published data for this individual (Thorne 1976) all fall well inside the range of his comparative sample. Similarly, vault thickness dimensions for Lake Mungo 1 (Table 2) are also within the range of the recent Murray Valley series used in this analysis. As the impression gained from multiple univariate results need not agree with those in multivariate space, the position of Mungo 1, in relation to the female Murray Valley and Coobool Creek samples,

was examined using discriminant function analysis.

All of the dimensions which could be recorded on the Lake Mungo 1 cranial vault, and for which I had comparable data from the Murray Valley and Coobool Creek, were included (Fig.6). Individual data were compared with those in Thorne (1976) and there was close agreement. The analysis correctly identified all of the Coobool Creek crania and only one of the Murray Valley specimens was allocated to the Coobool Creek group (Fig.6). The principal discriminating variables were associated with the size and morphology of the occipital region (opisthion-lambda, lambda-bregma, opisthion-inion, lambda-inion). With the Coobool Creek crania the occipitals are long (opisthion-lambda), however inion is located relatively closer to the foramen magnum than in the Murray Valley series. This is a function of both occipital curvature and nuchal muscle development. The Coobool Creek mean values for all variables were greater than those in the Murray Valley. Comparison of the means using Student's t indicated that the difference was significant (P = 0.01-0.001) for all but three variables (opisthion-inion, basion-sphenobasion, orbital height). Lake Mungo 1 was classified with the Murray Valley sample with a probability of 99.5 per cent. These results, in combination with the vault thickness data (Table 2) indicate that Lake Mungo 1 is neither smaller nor more 'gracile' than contemporary Aboriginal female crania. Size relationships in this individual actually fell closer to the Coobool Creek range than do most of those in the Murray Valley sample.

Discussion

The argument for contrasting biological populations in Pleistocene Australia (Thorne 1977; Thorne and Wilson 1977; Freedman and Lofgren 1979) has defined two groups separated by aspects of their cranial size and morphology (Fig.7). Using a 'near-contemporary' northern Victorian cranial series for comparison, the group composed of Lake Mungo 1, Lake Mungo 3 and Keilor was described as relatively

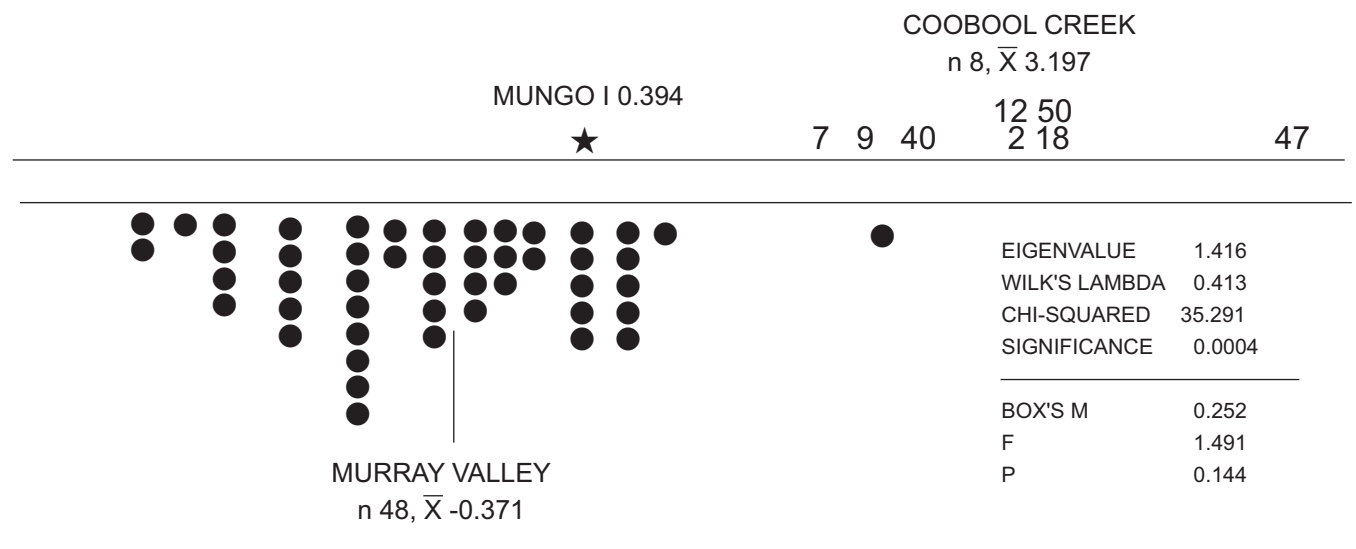


Figure 6. Linear discriminant function analysis of female crania from Coobool Creek and the Murray Valley showing the position of Lake Mungo 1. The standardised discriminant function coefficients are: bi-parietal breadth -0.003; glabella-lambda -0.382; bi-asterion 0.121; maximum supraorbital breadth -0.169; bi-frontotemporale 0.168; opisthion-inion -0.791; opisthion-lambda 1.718; basion-sphenobasion -0.202; lambda-bregma 0.562; lambda-inion -0.847; and orbital height 0.208.

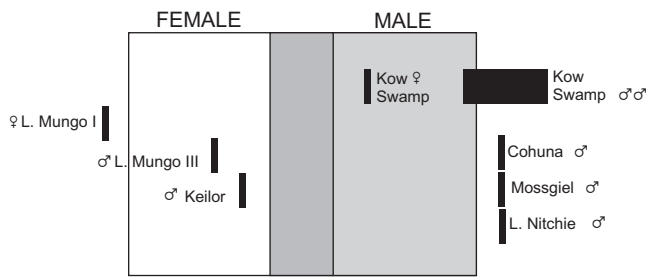


Figure 7. Comparison of south-eastern Australian fossil crania with a near-contemporary Victorian series after Thorne (1977, Fig. 1). The fossil crania lie outside both extremes of the near-contemporary males and females.

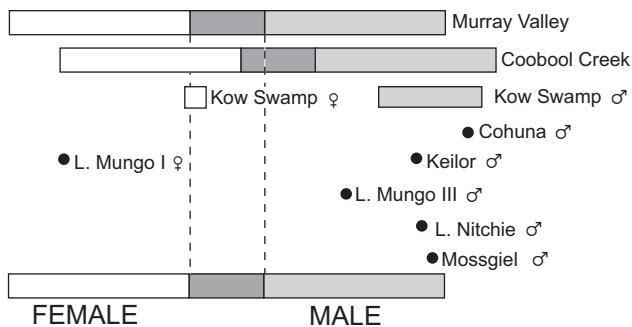


Figure 8. Comparison of south-eastern Australian fossil crania with a 'recent' Murray Valley series based on the combined results of tooth size, cranial vault thickness and linear discriminant analysis of cranial vaults and facial skeletons. The male and female ranges for most osteological features overlap by 10-15 per cent, and this is also in evidence at Coobool Creek.

gracile and modern, while Kow Swamp, Cohuna, Mossgiel and Lake Nitchie were robust and archaic (Thorne 1976, 1977). Only with one group, the Kow Swamp males, was there any overlap with similarly sexed contemporary crania. Lake Mungo 3 'was not available for the analysis' and its location in Fig.7 is indicated by a 'probable' position based on morphological comparison with Lake Mungo 1 (Thorne 1977:190). Keilor, the most complete member of the 'gracile' group, and only male, was placed at the centre of the contemporary female range. This assessment is neither supported by Thorne and Wilson (1977), on which Thorne (1977) was based, nor by the fossils themselves.

Thorne and Wilson (1977) correctly conclude that cranial size in Pleistocene Australians was significantly greater than in Holocene Aboriginals. Support for this was found with Kow Swamp-Cohuna, Mossgiel, Lake Nitchie (a Holocene Aboriginal) and importantly, Keilor. However, they also found that although Keilor was a large individual there were 'facial aspects' which were more consistent with the morphological range of their contemporary series (1977:401). It is therefore surprising that Thorne (1977) excludes Keilor from this identical contemporary series and places it within the female range of variation (Fig.7). Discriminant analysis of the cranial vault (Fig.3) and facial skeleton (Fig.5), combined with vault thickness and tooth size data (Tables I and 5), identifies

Keilor as a member of the 'robust' group of Pleistocene crania. Rather than having a facial skeleton which is morphologically and metrically like recent male Aboriginal crania, Keilor displays the consistent Pleistocene pattern. This combines great supraorbital breadth and facial height, with relatively shallow orbits, a broad fronto-nasal suture and a broad subnasal region. Although the morphology of the supraorbital part of the frontal bone is not markedly masculine in Keilor (low glabella, little depression at nasion, moderate superciliary ridges) it is within the Coobool Creek male range. The Keilor facial skeleton is also not prognathic (gnathic index 100), certainly in relation to Cohuna (gnathic index 106), however there is considerable variation in the degree of prognathism at Coobool Creek (Coobool Creek n.14, X 104.6, s 3.26, range 98-108). In terms of overall morphology and size, Keilor is similar to a number of the Coobool Creek crania which have not had their vault contours influenced by artificial deformation.

Lake Mungo 3 was also considered to fall within the contemporary female range, 'were it not for femoral and pelvic evidence, one could be tempted to diagnose Lake Mungo 3 as female' (Thorne 1977:190). Preservation of this individual is poor and the only quantifiable feature used to support its morphological delicacy is cranial vault thickness. It was argued that all of the Lake Mungo specimens possessed cranial vaults which were thin in relation to both late Holocene series and Kow Swamp. Table 1 indicates that rather than having a thin cranial vault, Lake Mungo 3 is comparable with Kow Swamp and Coobool Creek. This relatively thick cranial vault is combined with a mandible which is metrically at the centre of the Murray Valley male range (Fig.2). At least for these two features, Lake Mungo 3 cannot be included with a 'contemporary' female series (Fig.7). Cranial dimensions and vault thickness data for Lake Mungo 1 also indicate that it is within the 'contemporary' range of variation, although outside Coobool Creek.

In contrast to Thorne (1977), combination of the craniometric, tooth size and vault thickness results suggests a single, homogeneous, Pleistocene population (Fig.8). With the exception of Lake Mungo 1, the most obvious shared feature is increased size. This involves the structure of the dentition and the entire cranium, although there are more marked proportional increases for some anatomical regions (facial skeleton and cranial vault thickness). Associated with this general size increase is a consistent Australian Pleistocene morphology. The principal features of this are great supraorbital breadth and facial height, marked subnasal prognathism, broad palates, low and horizontal orbits and a broad frontonasal suture. The cranial vaults are both long and high with broad zygomatic arches. The bones within the cranial vault are particularly thickened and areas of muscle insertion, especially those in the masticatory complex, are rugose. Variation within the Pleistocene group is present at an individual level large canine teeth in Talgai and a thin cranial vault in Lake Mungo 1) and this is combined with the effects of artificial cranial deformation on cranial morphology and size relationships at Coobool Creek and Kow Swamp.

To what degree this general enlargement in cranial size and robusticity is also reflected in

increased stature cannot be measured directly. Preservation of the non-cranial skeletal elements is poor for all of the Pleistocene collections. This prevents the calculation of individual stature from the dimensions of long bones at either Coobool Creek or Kow Swamp. Stature may be estimated indirectly through the association of cranial vault size (length, breadth and height) with the length of the femur (Table 4). Levels of correlation between these cranial variables and maximum femur length are moderate ($r = 0.32-0.60$) and significant ($P = 0.05-0.01$). From this it can be argued that there is a general trend for stature and head size to increase proportionally. Using femur length data and the regression formula in Trotter and Gleser (1952) male stature in the recent Murray Valley sample averaged 166cm (range 150-181cm) and 157cm (range 142-165cm) for females. With the 5 per cent mean increase in cranial vault size at Coobool Creek this suggests an average stature for males of 174cm and females 165cm.

A directional trend for reduction in the size and robusticity of the orofacial skeleton and dentition has been recorded for a number of human populations during the first half of the Holocene (Le Blanc and Black 1974; Frayer 1977; Carlson and Van Gervan 1977; Smith *et al* 1986; Calcagno 1986). Only in one instance (Scott 1979), where pooled sex and small sample size data were used, has an increase in tooth size over the same period been recorded. In South-West Asia and particularly also in Nubia, this structural reduction has been extended to include cranial vault thickness (Smith *et al* 1985), thickness of humeral cortical bone (Smith *et al* 1984) and size of the cranial vault (Carlson 1976; Carlson and Van Gervan 1977). In all of the published work significant size reduction occurred between 12,000 and 6000 years BP with either negligible or no further changes in the last 4000 years. In Australia, neither the rate nor precise timing of this alteration in dental and cranial structure can be documented in detail. The skeletal material from Roonka and Chowilla, dated to 4000 to 7000 years BP, is morphologically and metrically indistinguishable from recent skeletal material in the same area (Pietruszewsky 1979, 1984; Brown 1982). In the absence of a more detailed chronology for individual skeletons within Roonka phase III it appears that, in south-eastern Australia, the major period of osteological change was between 10,000 and 7000 years BP.

In both South-West Asia and Europe, structural reduction in the human skeleton, particularly the masticatory apparatus, over the last 10,000 years has been seen as an evolutionary response to culture change (Le Blanc and Black 1974; Carlson and Van Gervan 1977; Frayer 1984; Calcagno 1986). The principle area of attention has been the appearance of intensive agricultural systems and improved food technologies. Expressed simply, it has been argued that increasing pre-masticatory preparation of food, for instance boiling in pottery vessels, alters the selective forces acting upon the orofacial skeleton and dentition. From this point a variety of different mechanisms have been proposed to explain the directional structural reduction which may have resulted from it (Brace 1963; Sofaer 1973). Irrespective

of whether this interaction between culture and biology actually accounts for the observable change in structure in South-West Asia and Europe, a different process must have been in operation in Australia. Australian Aborigines were hunters and gatherers during the terminal Pleistocene just as they were at European contact. During that time technological change, at least in so far as it is indicated by the archaeological record, was minimal and unlikely to have influenced the masticatory system. Support for this is provided by observing the high levels of tooth wear which is characteristic of both prehistoric and recent Australian Aboriginal populations (Campbell 1925, 1939). A possible alternative is gene flow into Australia, presumably before 7000 years BP, from a population with smaller body proportions and tooth size. This gains little support from the Australian human fossil sequence where the skeletal material is morphologically Australian throughout (Thorne 1975; Brown 1982).

One process which may have influenced overall body proportions, and eventually tooth size, would be a long-term physiological adaptation to increased Holocene air temperature. Although I will not examine this in detail here, the relationship between body size and mass-specific (or weight-specific) conductance (Gordon 1977) is suggestive. If there was a selective advantage in increased environmental temperatures in having a smaller body, this may have also extended to the cranial vault and facial skeleton. A smaller orofacial skeleton would reduce the developmental areas available for teeth (Sofaer 1973). Where large teeth are present they may experience some difficulty moving into normal occlusion. This in turn could influence physiological function and the general health of the masticatory system. Under traditional Australian Aboriginal dietary conditions selection should, therefore, favour a slight reduction in tooth size to form a balanced occlusion. Sea level data (Chappell and Thom 1977) indicate that the rise in post-Pleistocene air temperatures in the Australian region terminated at approximately 6000 BP. Obviously a high level of correlation does not necessarily imply biological association, but the correspondence of the curves for increasing temperature and decreasing body size are more than a little fascinating.

Conclusion

Analysis of the available terminal Pleistocene human skeletal material from Australia provides little support for the presence of two biologically distinct populations during that time period. Therefore the construction of elaborate schemes of multiple occupations of the Australian continent would, at least on present evidence, seem inappropriate. The reduction in the size and robusticity of the cranial vault and masticatory apparatus in Australia over the last 10,000 years parallels that in other parts of the world. Elsewhere, combinations of culture change and gene flow have been argued to be the driving force behind this process. In this instance, the geographic isolation of Australia, with evidence of extremely limited gene flow from outside, and relative cultural conservatism since initial occupation would make this seem unlikely. Size reduction in Australia may in part be explained by a physiological

response to increased Holocene air temperatures. Due to the interaction between the size of the orofacial skeleton and the developmental areas available for the teeth a directional reduction in the size of the teeth would also have taken place. Under these conditions selection would have favoured smaller dentitions as opposed to the larger, and probably crowded and maloccluded, alternative.

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