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Comparison of cervicovertebral dimensions in Australian Aborigines and Caucasians

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SUMMARY Cervicovertebral dimensions were compared in a group of 30 male and 30 female young adult Australian Aborigines from the Northern Territory, and a control sample consisting of 60 Caucasian dental students from Adelaide, matched for sex and age. Thirty-six variables, 22 cervical and 14 craniofacial, were derived from standardized lateral roentgenograms with the use of a computerized cephalometric system. Vertebral body height and length were significantly greater in Aboriginal males than females for C3 to C7, while dorsal arch height of C1 and C2 displayed the greatest dimensional variability in both sexes. The antero-posterior length of C1, dens height, and body heights of C3 and C4 were significantly shorter in Aborigines than Caucasians for both males and females. Total length of the column from C2 to C6 was approximately 12 per cent shorter in the Aborigines compared with Caucasians. The height of the posterior arch of C1 was significantly correlated with one or both posterior cranial base lengths in Aborigines and Caucasians. Associations were also noted between mandibular lengths and posterior arch heights of the upper two vertebrae.

The results confirm and clarify several previous observations on the relative shortness of the cervical spine in Australian Aboriginals. They also indicate some associations between dimensions of the cervical vertebrae and craniofacial lengths, particularly those representing the posterior cranial base and the mandible.

Introduction

The cervical vertebral column of Australian Aborigines has long been a source of interest to physical anthropologists. Jones (1938) referred to several studies dating from the mid-nineteenth century in which their relatively small cervical vertebrae were compared with those of other populations. He regarded the apparent shortness of the neck to be one of the physical distinctions of Aborigines, but he also believed that individual members of the cervical column displayed varying degrees of relative diminution. For example, he reported the antero-posterior diameter of the atlas in Aborigines to average 42.2 mm, over 3 mm shorter than in Europeans. The axis, however, displayed a greater difference in mean measurements, 41.7 mm in Aborigines and 50.6 mm in Europeans. The length of the entire cervical column in Aborigines was 167.7 mm in males and 156.2 mm in females, equivalent to 7.4 per cent dimorphism. According to Jones the cervical column was consistently shorter in Aborigines but no comparative data were provided.

Abbie (1957), in a metric study of Aborigines from Central Australia, drew attention to their shorter relative sitting height compared with other groups, 46.1 per cent of stature in males and 46.6 per cent in females. The statistical information listed by Eveleth and Tanner (1976) adds emphasis to this observation; practically every other group listed displayed an average relative sitting height over 50 per cent. Abbie's study (1957) did not permit him to determine the relative contributions of the cervical, thoracic, and lumbar regions of the column to the diminished sitting height.

A study of the Aboriginal vertebral column by Tulsi (1972) further elucidated the nature of the smaller dimensions of the column compared with other populations. Although dimensions of individual vertebrae were not shown for groups other than Aborigines, Tulsi's charts clearly show that Aboriginal males were smaller in transverse

breadths and body heights of all vertebrae from the second cervical to the fifth lumbar when compared with American whites and Japanese. Likewise in females the dimensions were smaller in Aborigines than in Japanese. When compared with American whites, the average values in Aboriginal males were smaller for the lengths of the total presacral column, as well as for the cervical, thoracic, and lumbar segments considered separately. The dimorphism percentages between groups for the three segments were 26.6, 17.2, and 23.9 per cent, respectively. Thus, the relatively short cervical column was a dominant feature of the Aboriginal group.

In addition to anthropological interest in the cervical column, craniofacial biologists and orthodontists have described associations between head posture and craniocervical morphology that may affect the pattern of craniofacial growth (Solow and Tallgren, 1976; Solow and Greve 1979; Kylämarkula and Huggare, 1985; Solow and Siersbæk-Nielsen, 1986, 1992; Hellsing *et al.*, 1987; Huggare, 1987, 1991; Cooke and Wei, 1988; Huggare and Cooke, 1994). These studies suggest that posture of the head upon the cervical spine may influence the direction of craniofacial growth, possibly through the soft-tissue stretching hypothesis of Solow and Kreiborg (1977).

Huggare and Houghton (1996) summarized studies of this topic, drawing particular attention to reports of relationships between the morphology of the atlas and cranial base dimensions and flexure. They examined skeletal material representative of prehistoric Polynesian and Thai people to show that height dimensions of the atlas were negatively correlated with cranial base flexure, while some dimensions of the atlas and axis vertebrae were associated with length and height of the mandible, and the gonial angle. These results, they concluded, were indicative of ontogenetic and functional relationships between cranial base and atlas, as well as common growth factors affecting the atlas and mandible.

Solow *et al.* (1982) compared head posture, craniofacial morphology, and selected dimensions of the cervical column in young adult Danish and Australian Aboriginal males. Natural head posture was about 3 degrees lower in the Aborigines and the upper cervical column was inclined more anteriorly. Associated with these findings was the observation that the length of the cervical spine from apex of the axis to the infero-posterior angle of the fourth vertebra was shorter in the Aborigines, the dimorphism between groups being 15.5 per cent. Three dimensions of the posterior cranial base were also shorter in Aborigines, the dimorphism ranging from 9.5 to 14.2 per cent.

To date, most metric studies of the cervical column have been concerned with general descriptions or specific associations between head posture, craniofacial morphology, and the upper cervical vertebrae. However, ethnic variations and the extent of sexual dimorphism in all elements of the cervical column have not been reported previously. Therefore, this metric study aimed to:

1. Quantify the extent of sexual dimorphism in dimensions of the cervical vetebrae within a group of young adult Australian Aborigines.
2. Compare the cervical vertebral dimensions in young adult male and female Australian Aborigines with those of a similarly-aged group of Caucasian dental students.
3. Examine linear relationships between selected cervicovertebral and craniofacial dimensions.

Subjects and methods

The roentgen-cephalometric analysis was performed on standardized lateral head films of young adult Aborigines and Caucasians. The Aboriginal group consisted of 30 males and 30 females, aged between 17 and 21 years, and averaging 18.6 years for males and 18.7 years for females. The records were collected during a longitudinal growth study conducted between 1961 and 1971 (Barrett *et al.*, 1965; Brown, 1974) and selected for the present study if the subjects were of pure Aboriginal ancestry, had confirmed birthdates and no physical deformity. These young adults were members of the Wailbri tribe living at Yuendumu, 295 km to the north-west of Alice Springs in the Northern Territory of Australia.

Records of 30 male and 30 female dental students, aged between 17 and 19 years, and averaging 18.3 and 18.0 years for males and females, respectively, were selected from a

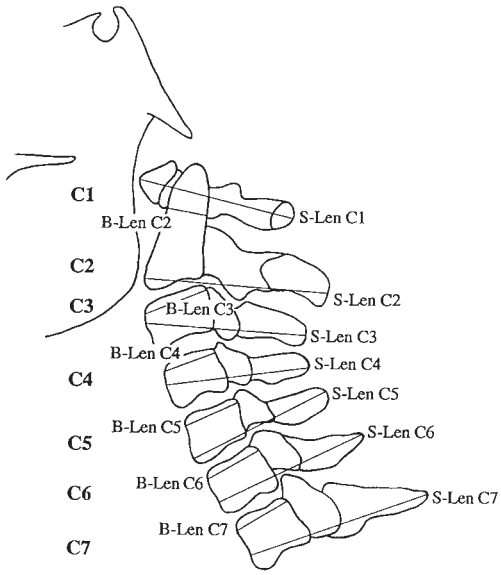

Figure 1 Cervicovertebral horizontal dimensions. S–Len C1 (sagittal length of C1) The distance between the most anterior point on the tubercle of the atlas and the most posterior point on the posterior arch of the atlas. B–Len C2 (width of dens) The distance between the intersection of the anterior and posterior contours of the dens with a line connecting the most inferior points on the anterior and posterior arches of C1.

Sagittal lengths of cervical vertebrae C2–C7 were defined as the maximum length of the vertebra measured from the most posterior point on its spine. S–Len C2 (sagittal length of C2); S–Len C3 (sagittal length of C3); S–Len C4 (sagittal length of C4); S–Len C5 (sagittal length of C5); S–Len C6 (sagittal length of C6); S–Len C7 (sagittal length of C7).

Body lengths of cervical vertebrae C3–C7 were defined as the distance between the antero-superior and postero-superior points on the body of the vertebra. B–Len C3 (body length of C3); B–Len C4 (body length of C4); B–Len C5 (body length of C5); B–Len C6 (body length of C6); B–Len C7 (body length of C7).

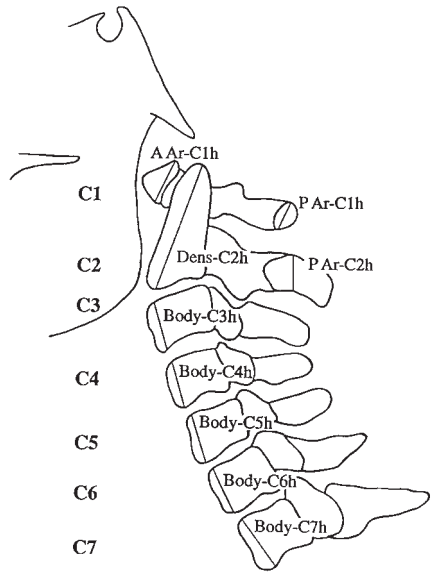

Figure 2 Cervicovertebral vertical dimensions. A Ar–C1h (height of the anterior arch of C1) The distance between the most superior and inferior points on the tubercle of C1. P Ar–C1h (height of the posterior arch of C1) The distance between the most superior and inferior points on the posterior arch of C1. Dens–C2h (height of the odontoid process of C2) The distance between the most superior and inferior points on the odontoid process of C2. P Ar–C2h (height of the dorsal arch of C2) The distance between the most superior and inferior points on the posterior arch of C2.

Body heights of cervical vertebrae C3–C7 were defined as the distance between the most superior and inferior points on the vertebral body. Body–C3h (height of the body of C3); Body–C4h (height of the body of C4); Body–C5h (height of the body of C5); Body–C6h (height of the body of C6); Body–C7h (height of the body of C7).

collection obtained between 1983 and 1993 of all consenting first-year dental students. The criteria for selection of their radiographs were European ethnic origin, confirmed birth-date, and absence of physical deformity. None of the students were receiving orthodontic treatment or had undergone orthognathic surgery in the past.

The seven cervical vertebrae were described by 22 linear dimensions expressing sagittal lengths and heights (Figures 1, 2, and 3). The craniofacial variables were limited to 14 linear dimensions related to the cranial base, maxilla, mandible, and facial heights. Landmarks were digitized from tracings of the radiographs and the variables were calculated using a locally developed computerized cephalometric system which compensated for radiographic enlargement of structures in the median sagittal plane, 8.3 per cent for the Aboriginal records and 8.8 per cent for the Caucasians.

Errors of the method were determined from a series of double determinations carried out on 20 radiographs from the Aboriginal group which were traced and digitized on two occasions. For each variable two statistics were calculated, the mean of the differences between first and second determinations and the standard deviation of a

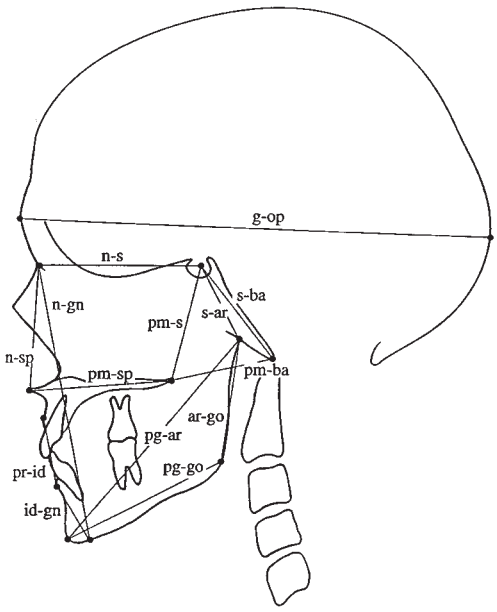

Figure 3 Craniofacial dimensions. Reference points used to determine craniofacial dimensions defined according to Brown (1973). g–op (head length), the distance between glabella and opisthocranion; n–s (anterior cranial base), the distance between nasion and sella; s–ba (median posterior cranial base), the distance between sella and basion; s–ar (lateral posterior cranial base length), the distance between sella and articulare; pm–sp (maxillary length), the distance between pterygomaxillare and spinal point; pg–ar (total mandibular length), the distance between pogonion and articulare; pg–go (corpus length), the distance between gonion and pogonion; ar–go (ramus height), the distance between gonion and articulare; n–gn (morphological face height), the distance between nasion and gnathion; n–sp (upper face height), the distance between nasion and spinal point; id–gn (mandibular face height), the distance between infradentale and gnathion; pr–id (middle face height), the distance between prosthion and infradentale; pm–s (posterior upper face height), the distance between pterygomaxillare and sella; pm–ba (nasopharyngeal depth), the distance between pterygomaxillare and basion.

single determination as described by Dahlberg (1940). The mean differences were small, ranging from –0.25 to 0.90 mm. Of the 36 mean differences, only seven exceeded 0.25 mm in absolute value. The standard deviations of single determinations were also small in magnitude, ranging from 0.19 to 1.47 mm, the latter recorded for the posterior cranial base length s–ba. A further three of the 36 standard deviations exceeded 1.00 mm, those calculated for sagittal length of C5 (S Len C5), height of the dens of C2 (Dens C2h), and upper face height (n–sp). The errors involved in tracing and digitizing radiographs were unlikely to bias the results to any great extent.

Descriptive statistics, including means, standard deviations and coefficients of variation (CV = 100 standard deviation/mean) were calculated for each variable in all groups. Although sample sizes were relatively small, available estimates of skewness and kurtosis detected no significant departures from normality in the distributions. Unpaired *t*-tests were used to compare mean values for Aboriginal males and females. ANOVA was used to compare the means of Aboriginal males and females with those of Caucasian males and females. Percentage sexual dimorphism was quantified according to the formula 100 $(\text{mean}_m - \text{mean}_f)/\text{mean}_f$, for each variable, where mean_m and mean_f are the mean values for males and females, respectively. Associations between variables were quantified by the product-moment correlation coefficient, *r*. Statistical significance was set at $P < 0.05$.

Results

Table 1 presents descriptive statistics for cervical column dimensions in Australian Aborigines and Caucasians. Vertebral dimensions were significantly greater in Aboriginal males than females ($P < 0.05$) for all variables except body length of C2, and posterior arch height of C1 and C2. Percentage sexual dimorphism ranged from 3.1 per cent for posterior arch height of C1 to 9.6 per cent for body height of C6. Posterior arch height of C1 and C2 displayed the greatest dimensional variability in both sexes, the coefficients of variation ranging from 13 to 18 per cent in contrast to the other cervicovertebral variables whose coefficients were generally around 5–9 per cent.

Cervicovertebral dimensions were also significantly greater in Caucasian males than females ($P < 0.05$), the only exception being posterior arch height of C1 and body height of C5. The magnitude of sexual dimorphism in Caucasians tended to be greater than in Aborigines, particularly for vertebral body lengths (10.7–17.2 compared with 3.6–7.9 per cent), posterior arch height of C2 (20.7 compared with 6.5 per cent) and

Table 1 Comparison of cervicovertebral dimensions (mm) between Aboriginal and Caucasian males and females.[1]

Variable	Males						Females					
	Aboriginal			Caucasian			Aboriginal			Caucasian		
	n	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD
Sagittal lengths												
S Len–C1	30	44.1*	2.61	30	48.1	2.58	30	41.6†	2.64	30	45.4	2.75
S Len–C2	30	48.2*	2.08	30	51.9	2.28	30	45.3†	2.01	30	48.0	2.36
S Len–C3	30	44.7	2.82	30	46.0	3.11	30	42.1	2.07	30	43.0	2.34
S Len–C4	30	44.7	3.16	30	46.0	2.40	30	41.8†	2.23	30	43.1	2.16
S Len–C5	29	46.3*	2.85	30	49.0	3.53	30	44.1	2.48	30	44.4	3.26
S Len–C6	29	54.6	3.53	26	54.9	2.64	30	50.9	3.49	26	49.0	4.20
S Len–C7	26	61.7	3.07	3	62.0	3.80	22	56.7	3.01	10	57.2	1.89
Body lengths												
B Len–C2	30	10.2*	0.98	30	11.2	0.97	30	9.9	0.89	30	10.1	0.97
B Len–C3	30	16.1*	1.22	30	15.4	1.41	30	15.2†	1.04	30	13.9	0.95
B Len–C4	30	16.0	0.96	30	15.4	1.36	30	15.2†	1.22	30	13.9	0.80
B Len–C5	30	15.8	1.13	30	15.8	1.37	30	14.8†	1.13	30	14.1	0.92
B Len–C6	29	16.1	1.18	27	16.5	1.32	30	15.1	0.99	27	14.9	2.36
B Len–C7	27	16.7	1.42	5	17.3	0.96	27	15.5	1.19	11	15.3	1.11
Vertebral heights												
A Ar–C1h	30	10.7	0.88	30	10.6	0.94	30	9.9	0.79	30	10.0	0.92
P Ar–C1h	30	9.8*	1.79	30	10.8	2.05	30	9.5	1.36	30	10.1	1.54
P Ar–C2h	30	15.7*	2.31	30	19.0	3.53	30	14.8	1.99	30	15.7	1.81
Dens–C2h	30	33.8*	2.63	30	40.5	2.13	30	31.8†	2.25	30	37.1	2.14
Body–C3h	30	13.4*	1.03	30	15.4	1.26	30	12.3†	1.34	30	14.2	1.21
Body–C4h	30	13.3*	1.02	30	14.5	1.22	30	12.5†	1.17	30	13.5	1.12
Body–C5h	30	13.1	0.97	29	13.6	1.22	30	12.2†	0.99	29	13.0	1.09
Body–C6h	29	13.2	1.04	17	13.6	1.11	29	12.0	1.20	21	12.6	1.17
Body–C7h	25	13.8	0.91	–	–	–	22	13.1	0.76	–	–	

[1]Mean values for Aboriginal males and females differ significantly ($P < 0.05$) for all variables except B Len–C2, P Ar–C1h, P Ar–C2h. Mean values for Caucasian males and females differ significantly ($P < 0.05$) for all variables except P Ar–C1h, Body–C5h

*Difference between mean values for Aboriginal and Caucasian males significant at $P < 0.05$.

†Difference between mean values for Aboriginal and Caucasian females significant at $P < 0.05$.

body height of C7 (17.2 compared with 5.6 per cent). As with the Aborigines, posterior arch height of C1 and C2 in males and females displayed very high variability compared with the other cervicovertebral dimensions, the coefficients of variation ranging from 11.5 to 18.9 per cent.

Ethnic differences in cervicovertebral morphology were evident, particularly in the upper segments of the column. Sagittal lengths tended to be shorter in the Aborigines compared with Caucasians; lengths of C1, C2 and C5 were significantly smaller in Aboriginal males ($P < 0.05$), while sagittal lengths of C1, C2, and C4 were significantly smaller in Aboriginal females ($P < 0.05$). In contrast, several vertebral body lengths were greater in the Aborigines. For example, the body length of C3 was significantly larger in Aboriginal males than Caucasian males ($P < 0.05$), while body lengths of C3–C5 were significantly larger in Aboriginal females ($P < 0.05$). The vertebral body lengths in Aborigines, therefore, tended to make up a greater percentage of the total sagittal length than in Caucasians.

Variation between the Aboriginal and Caucasian groups was particularly evident in the heights of the upper cervical vertebrae. Apart from the height of the anterior arch of C1 which was similar in mean value for each ethnic group,

Table 2 Correlations between cervicovertebral and craniofacial dimensions in Australian Aboriginal males and females.

	Aboriginal males (n = 30)							Aboriginal females (n = 30)						
	A Ar–Clh	P Ar–Clh	P Ar–C2h	Dens–C2h	S Len–C1	S Len–C2	B Len–C2	A Ar–Clh	P Ar–Clh	P Ar–C2h	Dens–C2h	S Len–C1	S Len–C2	B Len–C2
Cranial lengths														
n–s														
s–ba		0.57*								0.46*				
s–ar	0.55*							0.39*	0.65*	0.51*		0.37*		
g–op							0.37*		0.51*			0.61*		
pm–ba														
Jaw lengths														
pm–sp									0.38*					
pg–ar									0.51*					
pg–go									0.49*					
ar–go														
Facial heights														
n–gn												0.38*		
n–sp		–0.43*												
id–gn								0.46*						
pr–id														
pm–s	0.61*											0.41*		

*Correlation coefficient differs significantly from zero at $P < 0.05$.

both in males and females, all arch heights and body heights were smaller in the Aborigines, several of the mean differences being significant. For both sexes, dens height and the body heights of C3 and C4 were significantly smaller in Aborigines compared with Caucasians. In addition, the body height of C5 was significantly shorter in Aboriginal females. The differences in vertebral body heights between groups were most marked in the dens and C3, but they became progressively less in the succeeding vertebrae down to C6. Between C2 and C6 the percentage differences reduced from 19.8 to 3.0 per cent in males and from 16.7 to 5.0 per cent in females. Using the mean values as a guide, the total height of the cervical vertebrae from C2 to C6 was about 10 mm shorter in the Aboriginal males and females compared with their Caucasian counterparts, a difference of approximately 12 per cent.

Tables 2 and 3 present correlations between measurements of the first two cervical vertebrae and craniofacial dimensions in Aborigines and Caucasians with coefficients that differed from zero at $P < 0.05$ listed. There were few patterns of association between the variables that were consistent in both groups and in males and females of each group. However, the heights of vertebrae C1 and C2 tended to be associated with cranial lengths, particularly the posterior median and lateral cranial base dimensions s–ba and s–ar, coefficients ranging from $r = 0.37$ to 0.65 in Aborigines and from $r = 0.37$ to 0.54 in Caucasians. Mandibular dimensions tended to be correlated with the posterior arch height of C1 in Aboriginal females, and with the posterior arch height of C2 in Caucasian males with coefficients ranging from approximately $r = 0.40$–0.60. The posterior facial height, pm–s, was also significantly correlated with some vertebral dimensions in Aborigines and, particularly, in the Caucasians, with coefficients ranging from $r = 0.36$–0.61.

Discussion

This metric study of cervical vertebrae revealed that the majority of vertebral dimensions were larger in males than females, a finding common

Table 3 Correlations between cervicovertebral and craniofacial dimensions in Caucasian males and females.

	Caucasian males (n = 30)							Caucasian females (n = 30)						
	A Ar–Clh	P Ar–Clh	P Ar–C2h	Dens–C2h	S Len–C1	S Len–C2	B Len–C2	A Ar–Clh	P Ar–Clh	P Ar–C2h	Dens–C2h	S Len–C1	S Len–C2	B Len–C2
Cranial lengths														
n–s								0.48*			0.41*		0.55*	
s–ba		0.41*							0.53*	–0.38*	0.37*			
s–ar		0.39*						0.47*	0.49*		0.43*			0.37*
g–op						0.66*						–0.45**		
pm–ba					0.41*									
Jaw lengths														
pm–sp									–0.44*					
pg–ar			0.60*											
pg–go			0.50*											
ar–go		0.48*	0.41*										0.37*	
Facial heights														
n–gn	0.45*	–0.39*												
n–sp					–0.39*									
id–gn	0.43*	–0.38*												
pr–id														
pm–s		0.43*					0.36*	0.42*		0.44*	0.37*			

*Correlation coefficient differs significantly from zero at $P < 0.05$.

to both Aboriginal and Caucasian groups. Sexual dimorphism was considerably more marked in the Caucasians with values ranging up to 20 per cent compared with the Aborigines in whom the highest dimorphism value was about 10 per cent. The difference in extent of dimorphism is probably explainable by the relative homogeneity of the two groups. Whereas the Aboriginal subjects were members of a single tribal group from Central Australia, the Caucasian dental students represented a wide range of ethnic diversity, their heritage including backgrounds from Anglo-Saxon and several other European populations. With respect to the Aborigines, the level of sexual dimorphism in the cervical vertebrae, 3.1–9.6 per cent, was similar in magnitude to the dimorphism values calculated from mean values reported by Abbie (1975) for somatometric variables in Aboriginal groups. These latter values ranged from 3.2 per cent for bi-iliac breadth to 11.3 per cent for bi-acromial breadth, with the majority falling between about 5 and 9 per cent.

The finding that relative variability of vertebral dimensions, as measured by the coefficient of variation, was greatest for the posterior arch heights of C1 and C2 in both ethnic groups was not unique to this study. Values calculated from the means and standard deviations reported by Kylämarkula and Huggare (1985), Huggare (1989, 1991), and Huggare and Houghton (1996) reveal similar levels of variability for the dorsal arch height of C1 in other populations. However, this observation is explainable by the small mean values for arch heights of C1 and C2 compared with other vertebral dimensions. Moreover, the measurement errors, assessed as the standard deviation of a single determination, were high relative to the standard deviations of these two vertebral measurements.

Several authors have reported that the cervical vertebral column is shorter in Aboriginal males and females than in Caucasians (Jones, 1938; Tulsi, 1972; Solow *et al.*, 1982). This study adds to these reports by comparing the body heights of individual cervical vertebrae in the two populations. The differences in body heights ranged from 3 to nearly 20 per cent, and averaged about 12 per cent for the total column height from C2

to C6. Size differences were particularly evident in the upper cervical vertebrae. These population differences were similar in magnitude to those reported by the authors referred to above, for example Solow *et al.* (1982) reported a racial dimorphism of 15 per cent for the upper cervical spine length from C2 to C4 when comparing young adult Australian Aboriginal males with Danish dental students. They also drew attention to the shorter length of the posterior cranial base in Aboriginals, suggesting that this structure and the upper cervical bodies were derived from the same primordial tissues and were therefore influenced by similar morphogenetic determination.

Relative shortness of the vertebral column in Aborigines is not confined to the cervical elements however. Abbie (1957) reported on their low relative sitting height concluding that 'It is clear that the Aborigines of both sexes have relatively short trunks and longer legs than almost every other ethnic group.' Furthermore, Tulsi (1972) described shorter presacral lengths in Aborigines for each vertebral region measured on skeletal material.

Previous correlation analyses have indicated the existence of morphological associations between the first and second cervical vertebrae and craniofacial structures (Sandikçioğlu *et al.*, 1994; Huggare and Houghton, 1996). In addition, correlations have been demonstrated between the morphology of the atlas and head posture, a short posterior arch height being found in conjunction with an extended head posture (Kylämarkula and Huggare, 1985; Huggare, 1991). The direction of mandibular growth has also been linked with the morphology of the atlas, a high dorsal arch being associated with a more horizontal growth direction (Huggare, 1989).

In the present study, due to the large number of correlations computed, one would expect some significant correlations due to chance alone. Indeed, this may explain the apparently random distribution of many of the significant values in Tables 2 and 3. Furthermore, the greatest coefficient obtained was 0.66, yielding a corresponding coefficient of determination of about 44 per cent. Therefore, even though many significant values were obtained, a considerable amount of common variation remained unexplained. Nevertheless, evidence of trends in associations was noted in each population, particularly between vertebral heights and measurements of the posterior cranial base and between posterior arch heights and some mandibular dimensions. However, apart from a few instances, these associations were not consistent in both sexes nor in both ethnic groups.

In the female Aborigines and Caucasians, posterior cranial base lengths s–ba and s–ar were clearly associated with heights of the first two vertebral arches and, in the case of the Caucasians, the height of the dens of C2.

Some associations between the posterior arch height of C1 and the posterior cranial base were also present in the males. These relationships point to a morphological, functional, and developmental relationship between the posterior cranial base and the upper cervical vertebrae as outlined by the authors referred to previously. In a few instances, evidence of associations between cranial base dimensions and sagittal lengths of C1 and C2 were also noted, probably indicative of co-ordination in the sagittal growth patterns of the elements concerned.

Significant correlations were found between mandibular length dimensions and the posterior arch height of C2 in the Caucasian males, and the posterior arch height of C1 in the Aboriginal females. These associations were similar to those noted by Huggare and Houghton (1996) who reported that both the posterior arch of the atlas and its sagittal length were significantly correlated with mandibular length and ramal height, indicating a close association in growth mechanisms of the two regions.

An interesting point arising from this study is the question of whether the lengths of the posterior cranial base and upper cervical bodies are expected to follow, or to respond to, cervical postural differences or whether morphogenetic determinants which influence the lengths of these anatomical structures determine head posture and, consequently, craniofacial morphology. This study was limited to a description of ethnic differences between cervical vertebral dimensions and a cross-sectional analysis of relationships between the first two cervical vertebrae and selected craniofacial dimensions. Therefore, no conclusions

were possible concerning growth patterns of the structures studied or relationships between them and head posture.

Future studies should be directed towards quantifying within and between group differences in craniocervical morphology and growth, with the objective of improving the understanding of the extent of environmental and genotypic influences on cervical vertebral growth. A clearer appreciation of these determinants will clarify the complex inter-relationship between form and function in craniofacial and cervical vertebral morphogenesis.

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