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Identifying the Influence of Artificial Neurocranial Deformation on Craniofacial Dimensions

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Abstract When the normal shape of a neurocranium has been altered by cranial deformation many craniofacial measurements can be affected. But, if those measurements less affected by such deformation are identified, they may then become useful in determining the phylogenetic positions of the populations in which artificial neurocranial deformation had been practiced. Univariate comparisons in means between undeformed and deformed skull groups in three American Native populations and the principal component analyses of direct associations between craniofacial measurements and the degree of neurocranial deformation showed that some of the craniofacial measurements are particularly strongly influenced by neurocranial deformation. As a result of excluding such measurements, five sets of craniofacial measurements relatively free of deformation were obtained for the classification of an Australian Pleistocene sample from Coobool Creek. The Mahalanobis' D^2 distances between the undeformed and deformed skull groups in Coobool Creek estimated using the five sets of variables are not significantly different from zero. The typicality probabilities calculated using the three sets of variables showing the highest probabilities for the null hypothesis of D^2 show that Keilor, an Australian Pleistocene individual, belongs to the Coobool Creek population, containing both undeformed and deformed individuals, at the typicality probability of 0.62 to 0.80. If the variables significantly or relatively strongly affected by deformation are excluded from the sets of variables to be used, the sets of remaining variables may be used to reasonably classify the relevant populations.
Key words: Artificial cranial deformation, American Natives, Coobool Creek, Keilor, Typicality probability

Recently, Mizoguchi (2011), using typicality probability, showed that the skull of Keilor, an Australian Pleistocene individual, resembled those of the Jomon people in Japan more than those of Minatogawa I from Okinawa and Liujiang from southern China. However, based on this limited comparison, it is difficult to say that the Australian Pleistocene population is phylogenetically more similar to the Jomon than to other Late Pleistocene and early Holocene populations in the Asian and Australasian region. In order to increase the robusticity of the statistical comparisons, and allow for the morphological variation within Pleistocene Australians (PA), it would be best to include all of the PA crania with adequate preservation. However, phylogenetic comparisons involving a large proportion of the Australian sample are complicated by the affects of neurocranial deformation, which may also extend to the orofacial skeleton and basicranium.

The largest sample from Australian Pleistocene, Coobool Creek (Brown, 1981, 1989) is potentially ideal for conducting an analysis on the phylogenetic relation between the Pleistocene Australian and the Jomon populations. Unfortunately, however, about 40% of the well-preserved

Coobool Creek cranial sample, as well as those from the nearby Pleistocene sites at Kow Swamp and Nacurrie, were artificially deformed during infancy (Brown, 1989, 2010).

Up to the present, many researchers have examined the influence of artificial neurocranial deformation on other substructures such as the face, cranial base, etc. to clarify real phylogenetic relationships between populations, some of which have the tradition of artificial cranial deformation (Brown, 1981, 1989; Droessler, 1981; Anton, 1989; Suzuki *et al.*, 1993; Anton and Weinstein, 1999; Rhode and Arriaza, 2006; Arnold *et al.*, 2008), or to understand the role of biomechanical forces in craniofacial morphogenesis (Schendel *et al.*, 1980; Mizoguchi, 1991; Cheverud *et al.*, 1992; Kohn *et al.*, 1993, 1995; Sardi *et al.*, 2006; Pomeroy *et al.*, 2010; Cocilovo *et al.*, 2011). Consequently, some authors reported that facial measurements are not or only slightly affected by artificial neurocranial deformation (Droessler, 1981; Mizoguchi, 1991; Kohn *et al.*, 1995; Suzuki *et al.*, 1993; Sardi *et al.*, 2006; Pomeroy *et al.*, 2010), while others maintained that both neurocranial and facial measurements are influenced to a considerable extent (Schendel *et al.*, 1980; Anton, 1989; Cheverud *et al.*, 1992; Kohn *et al.*, 1993; Rhode and Arriaza, 2006; Arnold *et al.*, 2008; Cocilovo *et al.*, 2011).

The present study is an attempt to find sets of craniofacial measurements that are either unaffected, or only slightly affected, by neurocranial deformation and are therefore suitable for phylogenetic comparisons. Once identified, these dimensions will be used to determine biological affinities between Australian terminal Pleistocene or early Holocene populations and other various populations, as well as in future tests of phylogenetic relationships. For the initial testing of procedures and identification of dimensions influenced by neurocranial deformation three relatively large samples from the Americas are utilized. They are larger than the largest of Australian terminal Pleistocene and early Holocene samples, i.e., the Coobool Creek sample.

Materials

The data used here are raw measurements of deformed and undeformed skulls reported by MacCurdy (1923), Oetteking (1930), and Droessler (1981). Although these authors listed linear and angular measurements as well as indices, the variables analyzed here are only craniofacial linear measurements.

MacCurdy (1923) described the characteristics of ancient Peruvians from the highlands northwest of Cuzco. The skeletal remains were collected from caverns in several localities, but the "stock is apparently the same as that which left its remains in the caves and *chaukallas* [dwellings or funeral parlors] of the provinces of Yauyos and Huarochiri in the direction of Lima." The number of linear measurements analyzed here is 26 (Table 1). The sample size is 69 for the undeformed skulls and 44 for the deformed skulls in males, and, in females, 40 for the undeformed and 42 for the deformed.

The materials reported by Oetteking (1930) are derived from the North Pacific coast of North America. They consist of the four series that had been collected by 1913: the undeformed, the Cowichan deformation, the Chinook deformation, and the Koskimo deformation series. The Cowichan and Chinook have the anteroposterior form of deformation, while the Koskimo have the conical form of deformation. The undeformed series is the same one as that used in Mizoguchi (1991), namely, American Natives (the Haida and Salish tribes) from the North Pacific coast. The variables used are 18 craniofacial linear measurements (Table 2). The sample size is 44 for the undeformed, 110 for the Cowichan, 58 for the Chinook, and 111 for the Koskimo series in males; and 25 for the undeformed, 33 for the Cowichan, 26 for the Chinook, and 38 for the Koskimo series in females.

Droessler (1981) examined the patterns of biological variations in American Natives from the Late Woodland and Mississippian periods who lived in the west-central Illinois region from about A.D. 600 to A.D.1300. In the present study,

Table 1. Significance tests for the differences in means between the undeformed and deformed skull groups of ancient Peruvians.[1]

Variable	Male						Female					
	Undeformed skulls		Deformed skulls		t-value	t'-value	Undeformed skulls		Deformed skulls		t-value	t'-value
	Mean	n	Mean	n			Mean	n	Mean	n		
Length	179.4	67	173.4	24	4.96***	5.25***	169.5	36	170.0	21	−0.37	−0.36
Breadth	135.5	66	133.5	24	1.89	2.05*	130.1	36	128.3	21	1.35	1.27
Basi-bregmatic height	137.1	67	136.0	24	0.83	1.01	128.6	36	129.8	21	−0.85	−0.84
Cubic root of capacity	111.5	64	110.3	44	2.08*	2.12*	106.7	39	106.7	42	−0.01	−0.01
Maximum circumference	497.5	66	481.6	23	5.12***	5.68***	475.6	35	474.3	21	0.37	0.35
Nasion-opisthion arc	365.7	68	365.3	43	0.19	0.19	352.0	40	354.1	41	−0.79	−0.79
Thickness of left parietal	4.7	69	4.5	44	0.99	1.06	5.1	40	4.7	42	1.38	1.37
Nasion prosthion	67.7	65	68.3	37	−0.69	−0.69	63.1	31	63.2	37	−0.11	−0.12
Maximum bizygomatic diameter	134.8	58	132.5	35	1.86	1.85	122.9	29	123.5	33	−0.63	−0.62
Minimum frontal diameter	92.4	69	90.0	44	2.90**	2.89**	87.0	40	87.5	42	−0.58	−0.58
Breadth of orbit (R.)	37.1	67	36.3	42	2.73**	2.78**	35.2	37	35.4	38	−0.59	−0.59
Height of orbit (R.)	34.7	67	35.3	41	−1.56	−1.46	33.5	38	34.5	38	−2.31*	−2.31*
Length of nose	49.3	68	49.0	43	0.53	0.56	45.7	39	46.1	40	−0.51	−0.51
Breadth of nose	24.2	68	24.4	42	−0.46	−0.49	23.3	38	23.8	38	−1.00	−1.00
Basion to sub-nasal point	88.1	68	87.5	43	0.82	0.87	83.7	38	84.0	40	−0.44	−0.44
Breadth between orbits	24.3	69	24.4	42	−0.17	−0.17	22.2	39	22.8	41	−1.16	−1.16
Basion to prosthion	96.6	66	95.5	37	1.17	1.25	92.2	30	92.5	38	−0.34	−0.34
Basion to akanthion	94.3	68	93.2	43	1.26	1.34	88.7	37	89.1	40	−0.53	−0.52
Basion to nasion	99.2	69	97.8	44	1.77	1.89	93.4	39	93.5	41	−0.04	−0.04
Prosthion to akanthion	20.5	65	20.7	37	−0.44	−0.42	19.0	30	18.8	38	0.27	0.27
Length of palate	45.6	61	45.1	37	1.04	1.08	43.6	31	43.6	36	0.01	0.01
Breadth of palate	40.7	53	39.8	27	1.47	1.52	37.7	28	38.1	26	−0.55	−0.55
Prosthion to sub-nasal point	19.8	64	19.8	37	−0.00	−0.00	18.4	31	18.3	38	0.25	0.24
Mean diameter of foramen magnum	33.0	68	32.2	43	1.76	1.86	30.0	37	30.4	42	−0.83	−0.83
Dental arch length	52.7	59	51.8	35	1.48	1.45	50.4	28	49.9	35	0.73	0.72
Dental arch breadth	64.5	52	63.1	27	1.78	1.89	59.8	29	60.0	27	−0.20	−0.19

[1] Data source: MacCurdy (1923).

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed test.

Table 2. Significance tests for the differences in means between the undeformed and deformed skull groups of American Natives from the North Pacific coast.[1]

Variable	Male						Female					
	Undeformed skulls		Deformed skulls		*t*-value	*t′*-value	Undeformed skulls		Deformed skulls		*t*-value	*t′*-value
	Mean	*n*	Mean	*n*			Mean	*n*	Mean	*n*		
UNDEFORMED vs. COWICHAN												
Length	180.8	34	169.5	82	7.48***	7.16***	168.6	20	161.8	27	3.41**	3.63**
Breadth	142.9	34	151.0	81	−5.21***	−6.15***	137.4	20	144.4	27	−3.68***	−3.92***
Height (ba-b)	134.6	31	131.6	73	2.31*	2.24*	128.9	20	126.4	25	1.35	1.33
Median-sagittal frontal chord	112.3	35	111.0	87	1.30	1.20	106.9	20	107.0	29	−0.10	−0.11
Median-sagittal parietal chord	104.2	33	96.5	83	5.16***	4.60***	102.2	20	90.8	28	5.24***	5.55***
Median-sagittal occipital chord	98.4	33	96.2	76	1.54	1.59	91.7	19	96.0	25	−2.52*	−2.55*
Cranial base length (n-ba)	104.2	32	99.5	73	4.58***	4.94***	97.3	20	94.1	25	3.02**	3.05**
Length of foramen magnum	35.7	30	34.2	70	2.68**	2.91**	34.1	19	33.4	24	0.97	0.97
Width of foramen magnum	30.1	29	29.7	70	0.83	0.81	28.6	19	28.8	24	−0.27	−0.28
Facial length (ba-pr)	102.9	29	101.8	68	1.01	1.01	97.4	18	97.1	21	0.15	0.15
Upper facial height (n-pr)	73.6	33	72.8	80	0.88	0.95	68.8	19	68.7	26	0.14	0.13
Bizygomatic breadth	141.1	27	142.8	65	−1.01	−1.14	129.1	20	133.2	17	−2.33*	−2.36*
Orbital width (mf-ek)	44.3	34	43.5	85	1.87	1.78	41.1	21	41.9	27	−1.55	−1.55
Orbital height	35.5	34	36.1	85	−1.39	−1.42	34.2	20	36.0	27	−3.80***	−3.68**
Nasal width	25.4	31	24.2	83	2.90**	2.75**	24.1	19	23.7	27	0.83	0.81
Nasal height	52.1	33	51.9	83	0.30	0.33	48.2	19	48.9	27	−1.08	−1.09
Maxillo-alveolar length	54.1	30	54.3	78	−0.35	−0.34	51.4	19	51.7	26	−0.27	−0.27
Maxillo-alveolar breadth	66.1	30	63.8	78	2.75**	2.94**	61.5	19	60.3	27	1.15	1.10
UNDEFORMED vs. CHINOOK												
Length	180.8	34	166.7	58	9.82***	9.05***	168.6	20	160.9	25	4.59***	4.67***
Breadth	142.9	34	156.2	58	−10.28***	−10.65***	137.4	20	149.8	25	−7.09***	−7.33***
Height (ba-b)	134.6	31	128.8	57	4.11***	4.07***	128.9	20	121.5	24	3.55***	3.58**
Median-sagittal frontal chord	112.3	35	112.6	58	−0.24	−0.23	106.9	20	107.1	25	−0.18	−0.18
Median-sagittal parietal chord	104.2	33	91.2	58	8.13***	7.56***	102.2	20	87.7	25	9.26***	9.02***
Median-sagittal occipital chord	98.4	33	99.1	57	−0.59	−0.56	91.7	19	96.7	24	−2.74**	−2.79*
Cranial base length (n-ba)	104.2	32	98.6	57	6.03***	6.04***	97.3	20	92.9	24	3.20**	3.32**
Length of foramen magnum	35.7	30	34.3	57	2.72**	2.83**	34.1	19	32.8	24	2.19*	2.12*
Width of foramen magnum	30.1	29	30.4	57	−0.69	−0.63	28.6	19	29.1	24	−0.85	−0.85
Facial length (ba-pr)	102.9	29	101.7	56	0.99	1.03	97.4	18	97.1	24	0.19	0.19
Upper facial height (n-pr)	73.6	33	73.6	56	−0.08	−0.08	68.8	19	69.2	25	−0.30	−0.29
Bizygomatic breadth	141.1	27	141.4	57	−0.26	−0.25	129.1	20	132.6	24	−2.23*	−2.20*
Orbital width (mf-ek)	44.3	34	43.8	57	1.13	1.05	41.1	21	42.0	25	−1.67	−1.70
Orbital height	35.5	34	36.3	57	−2.16*	−2.03*	34.2	20	36.3	25	−3.85***	−3.86***
Nasal width	25.4	31	24.2	57	2.76**	2.67*	24.1	19	22.7	25	2.57*	2.55*

Table 2. (continued).

Variable	Male						Female					
	Undeformed skulls		Deformed skulls		t-value	t'-value	Undeformed skulls		Deformed skulls		t-value	t'-value
	Mean	n	Mean	n			Mean	n	Mean	n		
UNDEFORMED vs. CHINOOK												
Nasal height	52.1	33	53.4	57	−2.25*	−2.23*	48.2	19	49.6	25	−1.71	−1.81
Maxillo-alveolar length	54.1	30	54.2	52	−0.13	−0.13	51.4	19	50.6	25	0.91	0.89
Maxillo-alveolar breadth	66.1	30	66.5	51	−0.42	−0.41	61.5	19	62.9	23	−1.39	−1.33
UNDEFORMED vs. KOSKIMO												
Length	180.8	34	183.2	103	−1.81	−1.63	168.6	20	174.5	38	−3.71***	−3.93***
Breadth	142.9	34	139.6	102	2.97**	3.04**	137.4	20	134.0	38	2.75**	2.64*
Height (ba-b)	134.6	31	131.9	101	2.48*	2.14*	128.9	20	126.6	36	1.51	1.38
Median-sagittal frontal chord	112.3	35	115.1	104	−2.84**	−2.66*	106.9	20	110.9	38	−3.17**	−3.30**
Median-sagittal parietal chord	104.2	33	105.2	103	−0.80	−0.65	102.2	20	99.8	38	1.34	1.39
Median-sagittal occipital chord	98.4	33	102.0	102	−2.61*	−2.74**	91.7	19	100.3	36	−4.88***	−5.22***
Cranial base length (n-ba)	104.2	32	100.6	101	4.68***	4.37***	97.3	20	96.4	36	0.99	0.99
Length of foramen magnum	35.7	30	34.5	102	2.58*	2.61*	34.1	19	32.8	36	2.12*	2.13*
Width of foramen magnum	30.1	29	29.7	102	0.94	0.83	28.6	19	28.4	35	0.38	0.38
Facial length (ba-pr)	102.9	29	100.9	99	2.17*	2.02	97.4	18	98.0	33	−0.48	−0.48
Upper facial height (n-pr)	73.6	33	76.5	101	−3.14**	−3.47**	68.8	19	73.4	33	−3.76***	−3.46**
Bizygomatic breadth	141.1	27	138.4	98	2.10*	2.11*	129.1	20	129.8	36	−0.46	−0.45
Orbital width (mf-ek)	44.3	34	44.3	101	−0.19	−0.19	41.1	21	42.4	36	−2.70**	−2.79*
Orbital height	35.5	34	37.6	101	−5.85***	−5.68***	34.2	20	36.6	36	−4.63***	−4.72***
Nasal width	25.4	31	24.0	101	3.72***	3.29**	24.1	19	23.0	35	2.12*	2.07
Nasal height	52.1	33	53.9	102	−3.08**	−3.19**	48.2	19	50.5	35	−3.45**	−3.64**
Maxillo-alveolar length	54.1	30	54.1	99	−0.02	−0.02	51.4	19	51.8	33	−0.35	−0.36
Maxillo-alveolar breadth	66.1	30	65.2	97	1.15	1.21	61.5	19	62.1	32	−0.60	−0.57

[1] Data source: Oetteking (1930).
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed test.

all the data reported by her were simply divided into two groups: the undeformed and deformed skull groups. The number of craniofacial linear measurements is 32 (Table 3). The sample size is 45 for the undeformed group and 113 for the deformed group in males, and 42 for the undeformed and 146 for the deformed in females.

Finally, 13 undeformed and 9 deformed male skulls from Coobool Creek as well as Keilor, Cohuna, Lake Nitchie, and Kow Swamp 5 (Brown, 1989, 2001) were used in order to confirm the efficiency of the sets of variables less affected by neurocranial deformation in estimating more reliable biological distances between samples/individuals.

Previously, Durband (2008) attempted to identify artificially deformed crania at Coobool Creek by comparing individual specimens of Coobool Creek and deformed Melanesian skulls using Mahalanobis' D^2 distance and canonical analysis. However, there is insufficient information on the Melanesian sample that he used as a criterion for regarding a Coobool Creek cranium as artificially deformed. If undeformed Melanesian crania are also taken into consideration in Durband's scatter diagrams of the canonical variates used as a kind of criterion, it is possible that the diagrams may only show the original difference between the normal Melanesian and the Coobool Creek populations, rather than reveal the difference between undeformed and deformed samples. In the present study, therefore, we adopted Brown's (1989) simple criterion based on frontal curvature index for classifying Coobool Creek individuals into undeformed and deformed groups.

The variance/covariance matrices used in estimating Mahalanobis' D^2 distances between the Coobool Creek male undeformed and deformed sub-samples and other samples/specimens are mean within-group variance/covariance matrices obtained from 47 Murray Valley and 29 Swanport Aboriginal males in Australia (Brown, 2001).

Methods

In order to exclude those variables strongly affected by neurocranial deformation from a set of craniofacial linear measurements, two procedures were followed. The first was a significance test for the difference in means between deformed and undeformed groups using Student's *t*-test for two means with equal variances and/or Cochran's approximate significance test (t'-test) for two means with different variances (Fisher, 1958; Snedecor and Cochran, 1967).

This was followed by a PCA or principal component analysis (Lawley and Maxwell, 1963; Okuno *et al.*, 1971, 1976; Takeuchi and Yanai, 1972) and the succeeding Kaiser's normal varimax rotation (Asano, 1971; Okuno *et al.*, 1971) to identify patterns of association between dimensions. Although these analyses are usually performed under the premise of multivariate normal distribution, one or more variables of ordinal scale for the degree of deformation were added to a set of variables of interval scale, i.e., craniofacial linear measurements in the present study. This is a convenient way to find a gross tendency of the covariation between the degree of deformation and craniofacial measurements. The reasonability of the variables less affected by deformation selected in this way are confirmed later by practically testing the null hypothesis of Mahalanobis' D^2 distance (Rao, 1952; Okuno *et al.*, 1976) between undeformed and deformed groups based on such variables.

The degree of neurocranial deformation in MacCurdy (1923) is defined as follows.

0: Not deformed,
1: Slightly or moderately deformed, or
2: Pronouncedly deformed.

In Oetteking (1930), two kinds of deformation are distinguished: Anteroposterior deformation and conical deformation. The degree of deformation is expressed as follows for both of them.

0: Not deformed, or
1: Deformed.

Finally, in Droessler, (1981), four kinds of deformation were observed: Frontal flattening,

Table 3. Significance tests for the differences in means between the undeformed and deformed skull groups of American Natives from west-central Illinois.[1]

Variable	Male						Female					
	Undeformed skulls		Deformed skulls		*t*-value	*t′*-value	Undeformed skulls		Deformed skulls		*t*-value	*t′*-value
	Mean	*n*	Mean	*n*			Mean	*n*	Mean	*n*		
Glabello-occipital length	183.0	33	180.7	103	1.71	1.71	172.1	25	173.9	135	−1.36	−1.77
Minimum frontal breadth	94.5	37	93.3	107	1.29	1.37	90.8	29	90.5	135	0.29	0.33
Frontal chord	114.2	37	112.9	111	1.59	1.59	108.8	33	108.9	141	−0.05	−0.05
Midfacial breadth	99.3	41	100.5	102	−1.41	−1.29	96.9	33	95.9	137	1.14	1.16
Internal biorbital breadth (IOB)	98.7	38	98.3	101	0.58	0.56	95.1	32	94.9	137	0.31	0.29
Subtense to IOB	18.6	35	18.7	100	−0.15	−0.15	17.0	27	16.9	131	0.19	0.17
Anterior interorbital breadth	20.1	32	19.5	93	1.47	1.57	19.2	29	19.3	128	−0.21	−0.21
Orbital breadth, mf (left)	42.2	35	42.8	95	−2.04*	−2.30*	41.2	30	41.2	133	0.10	0.10
Orbital height (left)	34.4	32	34.5	96	−0.43	−0.44	34.0	30	34.2	134	−0.42	−0.42
Nasal height	53.0	35	52.9	98	0.21	0.20	50.6	32	50.5	125	0.21	0.22
Nasal breadth	25.8	42	25.8	98	−0.21	−0.21	25.3	32	25.7	126	−1.07	−1.16
Dacryal chord	21.5	33	20.5	88	2.13*	2.17*	21.1	28	20.6	121	1.05	1.03
Minimum breadth of nasals	9.2	33	8.9	93	0.89	0.95	9.4	31	9.3	130	0.42	0.41
Breadth of nasal bridge	60.3	39	60.2	102	0.20	0.22	58.4	34	58.7	133	−0.29	−0.31
Biangular breadth	103.7	29	104.6	95	−0.56	−0.61	94.1	31	96.5	115	−2.16*	−2.24*
Breadth of ascending ramus (left)	33.6	42	33.9	107	−0.55	−0.56	31.8	38	32.5	139	−1.45	−1.46
Length of mandible	108.8	32	107.4	91	1.18	1.24	104.5	29	104.3	112	0.18	0.19
Breadth at mental foramen	46.5	33	46.5	102	−0.08	−0.09	45.3	33	44.9	132	0.74	0.77
Maximum condylar length (left)	21.4	35	21.1	93	0.72	0.69	18.9	32	19.1	121	−0.46	−0.43
Malar length, inferior (left)	33.1	42	33.5	99	−0.87	−0.87	30.2	33	31.7	125	−2.89**	−2.74**
Malar length, maximum (left)	52.6	42	53.8	98	−1.97	−2.03*	49.7	35	50.4	125	−1.29	−1.33
Cheek height (left)	23.6	44	24.0	106	−0.98	−0.97	22.3	39	21.8	139	1.24	1.26
Length of occipital condyle (left)	26.6	35	26.3	87	0.63	0.62	24.9	31	24.7	119	0.30	0.30
Breadth of occipital condyle (left)	14.5	35	14.1	88	1.31	1.27	13.9	36	14.0	123	−0.43	−0.50
Biasterionic breadth	107.7	33	107.1	101	0.72	0.69	103.8	25	104.3	131	−0.57	−0.66
Frontal subtense	23.0	38	22.1	108	2.06*	2.19*	22.8	28	22.4	141	0.71	0.73
Frontal subtense fraction	50.9	38	51.5	108	−0.94	−1.01	46.9	28	48.4	141	−2.08*	−2.38*
Parietal chord	110.5	38	110.9	108	−0.34	−0.33	105.7	33	108.0	146	−2.40*	−2.28*
Parietal subtense	22.6	36	24.3	109	−3.02**	−3.03**	22.3	31	23.3	143	−1.98*	−1.92
Occipital chord	101.9	28	99.9	96	1.59	1.44	98.1	24	98.1	122	−0.01	−0.01
Mastoid breadth (left)	33.2	45	33.8	111	−1.05	−0.98	30.6	39	30.6	145	−0.12	−0.10
Mastoid length 2 (left)	46.2	44	46.6	111	−0.59	−0.57	42.9	40	42.5	144	0.60	0.59

[1] Data source: Droessler (1981).
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed test.

bifrontal flattening, occipital flattening, and lambdoid flattening. The degree of the former three flattening is as follows.

0: Absent,
1: Slight,
2: Medium, or
3: Maximum or marked.

The degree of the last or lambdoid flattening is as follows.

0: Absent,
1 and 2: Slight,
3: Medium, or
4: Marked.

Using the sets of variables suggested to be relatively free of deformation by t- and/or t'-tests as well as PCAs, Mahalanobis' D^2 distance was estimated between undeformed and deformed groups in each of the three samples from the Americas. The variance/covariance matrix necessary for the calculation of D^2 distance was obtained from the undeformed group of each sample. In practical calculations, however, theoretically impossible estimates, i.e., negative estimates of D^2 distance may be obtained sometimes due mainly to sampling errors because of small sample size. In such a case, the variance/covariance matrix was replaced by the matrix reconstructed by excluding minor or trivial PCs, namely, by using the reduced number of principal components extracted from the original variance/covariance matrix.

In the next step, variables common to the Coobool Creek male sample and the three respective samples were searched. The univariate differences in means between undeformed and deformed groups were examined also in Coobool Creek using t- and t'-tests. In the comparisons based on the sets of variables relatively free of deformation in both Coobool Creek and any of the three samples, D^2 distances were estimated using the mean within-group variance/covariance matrices obtained from two Australian Aboriginal male samples, Murray Valley and Swanport.

Finally, typicality probabilities of Australian Pleistocene specimens to the Coobool Creek population were estimated using those sets of variables which show the highest probabilities for the null hypothesis of D^2 between the undeformed and deformed skull groups of Coobool Creek. The method used for estimating typicality probability is Campbell's (1984) predictive approach. As regards the sample size of a reference sample, the average sample size across variables of the Coobool Creek male sample, containing both undeformed and deformed individuals, was employed in practice under the assumption that it is the real sample size.

Statistical calculations were executed using programs written by Y.M. in FORTRAN: BSFMD for estimating variances and covariances, COMCOV for calculating mean within-group variance/covariance matrices, STSTBT for Student's t-test and Cochran's approximate significance test (t'-test), PCAFPP for PCA and Kaiser's normal varimax rotation, TSTD2 for calculating Mahalanobis' D^2 distance, and TYPPRB for estimating typicality probability.

The FORTRAN 77 compiler used is FTN77 for personal computers, provided by Salford Software Ltd. To increase efficiency during programming and calculation, a GUI for programming, CPad, provided by "kito," was used.

Results

The results of Student's t-tests and Cochran's t'-tests are shown in Table 1 for ancient Peruvians, in Tables 2 for American Natives from the North Pacific coast, and in Table 3 for American Natives from the west-central Illinois region. The results of PCAs and the rotated solutions for these three samples are separately shown in Tables 4 to 15.

Tables 16 to 18 collectively reveal the lists of variables suggested to be significantly or relatively strongly affected by neurocranial deformation through t- and/or t'-tests as well as PCAs or the varimax rotations in the three samples. Using these lists, variables relatively free of deformation were determined for each American Native sample. In Table 19, the D^2 distances based on such variables relatively free of deformation are

Table 4. Principal component analysis of the correlations between the degree of deformation and neurocranial linear measurements of ancient Peruvian males.[1]

Variable	Factor loadings									Total variance (%)
	PC I	II	III	IV	V	VI	VII	VIII	IX	
Degree of deformation	−0.22	−0.32	0.34	0.13	0.63	0.09	−0.22	−0.24	−0.03	80.16
Length	0.72	0.47	−0.10	−0.13	−0.23	−0.09	−0.07	−0.11	0.02	83.77
Breadth	0.51	0.48	0.00	−0.20	0.29	−0.05	0.22	0.11	−0.04	68.30
Basi-bregmatic height	0.64	0.22	0.13	−0.08	0.05	0.04	−0.49	0.01	0.07	72.46
Cubic root of capacity	0.61	0.62	0.18	−0.18	0.16	−0.00	−0.15	0.12	−0.08	89.06
Maximum circumference	0.71	0.62	−0.07	−0.14	−0.13	−0.10	0.01	−0.13	0.02	95.13
Nasion-opisthion arc	0.39	0.67	0.31	−0.21	0.22	−0.15	−0.03	−0.20	−0.04	84.91
Thickness of left parietal	0.03	0.20	0.09	0.33	−0.30	0.04	0.28	−0.32	0.65	85.67
Nasion Prosthion	0.61	−0.34	0.58	−0.08	−0.01	0.14	−0.02	−0.15	0.05	87.74
Maximum bizygomatic diameter	0.74	0.09	−0.01	0.08	−0.01	0.12	0.21	−0.00	−0.20	65.17
Minimum frontal diameter	0.58	0.34	0.05	0.50	−0.14	−0.17	0.13	0.06	−0.16	80.03
Breadth of orbit (R.)	0.50	−0.15	0.18	0.05	−0.48	−0.05	0.20	0.31	−0.23	73.91
Height of orbit (R.)	0.25	−0.19	0.47	0.21	−0.11	0.35	0.26	−0.12	−0.27	65.64
Length of nose	0.47	−0.20	0.33	−0.10	−0.22	0.37	−0.10	−0.44	−0.12	78.87
Breadth of nose	0.46	0.07	−0.21	0.55	0.36	0.07	−0.03	0.15	0.03	72.40
Basion to sub-nasal point	0.68	−0.45	−0.39	0.13	−0.05	−0.10	−0.20	−0.04	−0.00	88.68
Breadth between orbits	0.27	0.33	−0.00	0.72	0.18	−0.07	−0.05	−0.15	−0.00	76.31
Basion to prosthion	0.74	−0.51	−0.27	0.01	0.02	−0.16	−0.06	−0.07	0.06	90.89
Basion to akanthion	0.70	−0.48	−0.35	0.05	−0.08	−0.12	−0.19	−0.03	0.01	89.48
Basion to nasion	0.80	−0.20	0.01	0.10	−0.21	0.02	−0.34	0.05	−0.15	87.19
Prosthion to akanthion	0.50	−0.28	0.61	0.02	0.13	−0.20	0.05	0.33	0.27	93.84
Length of palate	0.63	−0.27	−0.18	−0.13	0.23	−0.31	0.27	−0.26	−0.02	81.42
Breadth of palate	0.57	0.00	−0.28	−0.03	0.13	0.56	0.13	0.15	0.16	79.58
Prosthion to sub-nasal point	0.53	−0.36	0.57	−0.07	0.08	−0.21	0.06	0.27	0.25	92.54
Mean diameter of foramen magnum	0.39	0.14	−0.17	−0.16	−0.13	0.29	−0.22	0.09	0.38	52.60
Dental arch length	0.58	−0.33	−0.24	−0.30	0.15	−0.22	0.32	−0.25	0.01	82.91
Dental arch breadth	0.59	−0.05	−0.32	−0.13	0.31	0.42	0.25	0.20	0.01	84.64
Total contribution (%)	31.71	12.78	8.81	5.93	5.45	4.59	4.18	3.79	3.64	80.86
Cumulative proportion (%)	31.71	44.49	53.30	59.22	64.67	69.26	73.44	77.23	80.86	80.86

[1] Data source: MacCurdy (1923). The sample size for correlation coefficients varies from 67 to 113.

Table 5. Rotated solution of the first nine principal components extracted from the correlations between the degree of deformation and neurocranial linear measurements of ancient Peruvian males.[1]

Variable	Factor loadings								
	Fac I	II	III	IV	V	VI	VII	VIII	IX
Degree of deformation	−0.05	−0.21	0.19	0.10	0.79	−0.10	0.09	−0.18	−0.19
Length	0.27	0.71	−0.05	0.11	−0.35	0.08	−0.30	−0.09	0.14
Breadth	0.09	0.71	0.12	0.11	−0.06	0.33	0.14	0.09	−0.06
Basi-bregmatic height	0.15	0.51	0.21	0.16	0.04	0.07	−0.58	−0.13	−0.10
Cubic root of capacity	−0.06	0.86	0.16	0.16	−0.08	0.17	−0.21	−0.04	−0.14
Maximum circumference	0.21	0.84	−0.06	0.15	−0.30	0.11	−0.20	−0.05	0.17
Nasion-opisthion arc	−0.08	0.90	0.08	0.07	0.13	−0.07	0.02	−0.09	0.04
Thickness of left parietal	−0.08	0.01	0.03	0.16	−0.07	−0.02	−0.01	−0.05	0.90
Nasion prosthion	0.27	0.15	0.58	−0.04	0.08	0.06	−0.16	−0.64	0.04
Maximum bizygomatic diameter	0.35	0.38	0.11	0.28	−0.27	0.33	0.01	−0.33	−0.06
Minimum frontal diameter	0.13	0.39	0.11	0.66	−0.40	−0.01	0.01	−0.14	0.07
Breadth of orbit (R.)	0.18	0.04	0.34	0.08	−0.69	0.04	−0.02	−0.31	−0.12
Height of orbit (R.)	−0.05	−0.06	0.21	0.15	−0.09	0.11	0.18	−0.73	−0.02
Length of nose	0.22	0.14	0.05	−0.11	0.03	0.04	−0.26	−0.80	0.08
Breadth of nose	0.21	0.08	0.09	0.72	0.07	0.35	−0.09	0.08	−0.04
Basion to sub-nasal point	0.78	−0.09	0.07	0.24	−0.15	0.15	−0.38	−0.06	−0.10
Breadth between orbits	−0.00	0.20	−0.06	0.82	0.08	−0.05	−0.02	−0.05	0.18
Basion to prosthion	0.85	−0.03	0.23	0.12	−0.09	0.17	−0.25	−0.10	−0.05
Basion to akanthion	0.80	−0.08	0.12	0.16	−0.16	0.14	−0.38	−0.08	−0.09
Basion to nasion	0.47	0.17	0.22	0.25	−0.27	0.07	−0.52	−0.34	−0.21
Prosthion to akanthion	0.14	0.11	0.94	0.08	−0.02	0.04	−0.05	−0.13	0.02
Length of palate	0.82	0.25	0.15	0.04	0.04	0.12	0.19	−0.07	0.03
Breadth of palate	0.21	0.13	0.00	0.11	−0.08	0.80	−0.21	−0.15	0.06
Prosthion to sub-nasal point	0.24	0.09	0.91	−0.01	−0.04	0.02	−0.06	−0.17	0.01
Mean diameter of foramen magnum	0.07	0.20	0.03	−0.09	−0.10	0.37	−0.53	0.04	0.21
Dental arch length	0.82	0.20	0.10	−0.15	−0.01	0.19	0.18	−0.08	0.05
Dental arch breadth	0.34	0.19	0.05	0.08	−0.03	0.82	−0.01	−0.07	−0.11

[1] Data source: MacCurdy (1923). The sample size for correlation coefficients varies from 67 to 113.

Table 6. Principal component analysis of the correlations between the degree of deformation and neurocranial linear measurements of ancient Peruvian females.[1]

Variable	Factor loadings									Total variance (%)
	PC I	II	III	IV	V	VI	VII	VIII	IX	
Degree of deformation	0.12	−0.03	−0.01	0.49	0.26	0.42	0.10	−0.24	0.19	60.56
Length	0.66	0.21	−0.41	−0.21	0.14	0.16	0.15	−0.21	0.19	84.64
Breadth	0.49	0.42	−0.09	−0.26	−0.24	−0.37	−0.09	−0.16	0.02	71.96
Basi-bregmatic height	0.45	0.39	−0.24	0.20	−0.34	0.11	−0.10	0.07	−0.45	79.93
Cubic root of capacity	0.78	0.42	−0.18	−0.10	−0.03	0.07	−0.25	−0.18	−0.09	93.91
Maximum circumference	0.73	0.28	−0.39	−0.28	0.08	−0.13	0.12	−0.16	0.15	92.59
Nasion-opisthion arc	0.71	0.28	−0.33	−0.20	0.04	0.34	0.02	−0.03	0.06	85.43
Thickness of left parietal	0.18	−0.01	−0.57	−0.34	−0.13	0.19	0.06	0.55	0.15	85.02
Nasion prosthion	0.48	0.52	0.54	0.06	0.03	−0.02	0.35	0.05	0.07	91.89
Maximum bizygomatic diameter	0.68	0.02	0.23	0.20	−0.02	−0.34	0.14	0.24	−0.00	74.92
Minimum frontal diameter	0.67	0.02	−0.14	−0.01	0.36	−0.23	−0.04	−0.06	−0.27	72.84
Breadth of orbit (R.)	0.54	0.17	0.14	0.29	−0.10	−0.27	−0.33	0.29	0.04	70.82
Height of orbit (R.)	0.24	0.33	0.16	0.61	−0.07	0.32	−0.01	0.16	0.15	72.34
Length of nose	0.27	0.50	−0.03	0.37	−0.08	−0.25	0.42	0.02	0.20	75.12
Breadth of nose	0.29	−0.47	−0.13	0.20	0.44	−0.32	0.12	0.08	−0.17	70.52
Basion to sub-nasal point	0.63	−0.60	−0.04	0.09	−0.28	0.24	0.08	0.00	0.02	90.16
Breadth between orbits	0.50	−0.32	−0.15	0.02	0.30	0.16	0.40	0.03	−0.38	79.65
Basion to prosthion	0.68	−0.57	0.15	0.01	−0.13	0.07	−0.05	−0.12	0.11	86.05
Basion to akanthion	0.63	−0.51	0.07	0.08	−0.41	0.10	−0.02	−0.14	0.08	86.50
Basion to nasion	0.67	−0.06	−0.03	0.23	−0.49	0.03	0.08	−0.10	−0.32	87.53
Prosthion to akanthion	0.36	0.20	0.75	−0.33	0.17	0.24	−0.04	0.03	−0.11	93.04
Length of palate	0.60	−0.35	0.22	−0.09	0.04	−0.33	0.11	−0.21	0.16	73.79
Breadth of palate	0.71	0.01	−0.05	0.13	0.38	0.15	−0.09	0.23	0.07	74.83
Prosthion to sub-nasal point	0.35	0.19	0.79	−0.31	0.09	0.23	−0.08	−0.04	−0.11	95.84
Mean diameter of foramen magnum	0.32	0.02	−0.15	0.40	0.29	−0.07	−0.52	−0.19	0.09	69.41
Dental arch length	0.64	−0.30	0.24	−0.16	−0.24	−0.12	−0.04	0.14	0.25	73.11
Dental arch breadth	0.77	−0.21	0.04	−0.17	0.26	0.05	−0.20	0.25	0.03	83.27
Total contribution (%)	31.08	10.94	9.78	6.78	5.95	5.20	4.05	3.47	3.34	80.58
Cumulative proportion (%)	31.08	42.01	51.79	58.57	64.52	69.72	73.77	77.24	80.58	80.58

[1] Data source: MacCurdy (1923). The sample size for correlation coefficients varies from 38 to 82.

Table 7. Rotated solution of the first nine principal components extracted from the correlations between the degree of deformation and neurocranial linear measurements of ancient Peruvian females.[1]

Variable	Factor loadings								
	Fac I	II	III	IV	V	VI	VII	VIII	IX
Degree of deformation	0.07	−0.06	−0.03	0.75	0.08	−0.04	−0.04	−0.13	0.04
Length	0.87	−0.17	−0.01	0.15	0.14	−0.09	0.02	0.12	−0.02
Breadth	0.57	−0.10	0.08	−0.43	−0.14	−0.28	−0.18	−0.13	−0.20
Basi-bregmatic height	0.30	−0.00	0.00	0.01	0.01	−0.14	−0.15	0.09	−0.81
Cubic root of capacity	0.77	−0.14	0.22	−0.00	0.02	−0.07	−0.34	−0.02	−0.40
Maximum circumference	0.89	−0.17	−0.02	−0.12	0.17	−0.22	−0.08	0.08	−0.04
Nasion-opisthion arc	0.79	−0.17	0.15	0.18	0.08	−0.03	−0.06	0.29	−0.23
Thickness of left parietal	0.31	−0.05	−0.23	−0.14	0.00	0.08	0.08	0.82	−0.04
Nasion prosthion	0.20	−0.03	0.63	0.09	0.01	−0.68	0.01	−0.07	−0.09
Maximum bizygomatic diameter	0.11	−0.39	0.21	−0.12	0.33	−0.56	−0.30	0.04	−0.14
Minimum frontal diameter	0.46	−0.12	0.11	−0.10	0.59	−0.08	−0.30	−0.10	−0.16
Breadth of orbit (R.)	0.06	−0.23	0.13	−0.10	0.04	−0.36	−0.65	0.10	−0.24
Height of orbit (R.)	−0.05	−0.01	0.13	0.59	−0.15	−0.41	−0.28	0.11	−0.29
Length of nose	0.22	0.09	−0.10	0.13	−0.01	−0.81	−0.01	−0.07	−0.11
Breadth of nose	−0.06	−0.21	−0.18	−0.01	0.75	−0.03	−0.19	−0.06	0.14
Basion to sub-nasal point	0.09	−0.86	−0.03	0.18	0.21	0.09	0.04	0.16	−0.19
Breadth between orbits	0.20	−0.26	0.07	0.17	0.75	0.03	0.23	0.10	−0.18
Basion to prosthion	0.14	−0.86	0.13	0.09	0.21	0.08	−0.13	−0.03	−0.00
Basion to akanthion	0.11	−0.90	−0.00	0.07	0.04	0.03	−0.04	−0.02	−0.18
Basion to nasion	0.20	−0.56	0.01	0.01	0.11	−0.20	−0.02	−0.09	−0.68
Prosthion to akanthion	0.07	−0.10	0.96	−0.01	0.03	−0.03	−0.02	−0.03	0.01
Length of palate	0.22	−0.63	0.14	−0.17	0.30	−0.19	−0.10	−0.24	0.22
Breadth of palate	0.37	−0.22	0.23	0.28	0.41	−0.12	−0.42	0.28	−0.03
Prosthion to sub-nasal point	0.05	−0.15	0.96	−0.02	−0.05	−0.01	−0.03	−0.12	−0.02
Mean diameter of foramen magnum	0.22	−0.05	−0.13	0.28	0.12	0.09	−0.69	−0.23	−0.03
Dental arch length	0.15	−0.73	0.23	−0.18	0.03	−0.17	−0.18	0.16	0.08
Dental arch breadth	0.34	−0.44	0.33	−0.02	0.40	0.06	−0.39	0.31	0.03

[1] Data source: MacCurdy (1923). The sample size for correlation coefficients varies from 38 to 82.

Table 8. Principal component analysis of the correlations between the degree of deformation and neurocranial linear measurements of American Native males from the North Pacific coast.[1]

Variable	Factor loadings									Total variance (%)
	PC I	II	III	IV	V	VI	VII	VIII	IX	
Degree of anteroposterior deformation	−0.59	0.63	0.12	−0.10	−0.19	−0.01	−0.16	−0.04	−0.02	83.99
Degree of conical deformation	0.53	−0.66	0.14	−0.01	0.11	−0.18	0.04	0.08	0.08	78.83
Length	0.83	−0.39	−0.08	−0.03	−0.02	0.07	0.11	−0.01	−0.06	85.92
Breadth	−0.33	0.75	0.30	−0.09	−0.13	0.13	−0.02	0.13	0.08	83.50
Height (ba-b)	0.54	0.11	−0.29	0.18	−0.43	0.43	−0.22	0.07	0.01	83.98
Median-sagittal frontal chord	0.61	−0.05	0.10	−0.15	−0.48	0.17	−0.19	−0.05	0.19	74.92
Median-sagittal parietal chord	0.57	−0.44	−0.24	0.17	0.26	0.22	−0.25	0.10	0.23	85.81
Median-sagittal occipital chord	0.42	−0.17	0.14	−0.25	−0.55	−0.05	0.53	0.14	−0.11	90.61
Cranial base length (n-ba)	0.67	0.32	−0.39	0.12	−0.04	0.10	0.00	0.05	−0.37	86.53
Length of foramen magnum	0.37	0.27	−0.00	0.65	0.07	−0.07	0.27	−0.29	−0.11	81.71
Width of foramen magnum	0.21	0.43	0.17	0.61	0.01	−0.11	0.20	0.23	0.33	83.90
Facial length (ba-pr)	0.36	0.50	−0.54	−0.11	0.01	−0.40	−0.03	0.03	−0.16	86.49
Upper facial height (n-pr)	0.75	0.13	0.34	−0.05	0.04	−0.15	−0.24	−0.12	0.01	78.69
Bizygomatic breadth	0.32	0.74	0.13	0.06	0.13	0.29	−0.04	0.10	−0.09	79.53
Orbital width (mf-ek)	0.53	0.27	0.16	−0.23	0.34	0.04	0.12	0.53	−0.01	84.26
Orbital height	0.49	−0.08	0.61	−0.06	0.13	−0.13	−0.10	−0.04	−0.23	71.69
Nasal width	0.20	0.27	−0.14	−0.37	0.45	0.48	0.25	−0.25	0.02	82.93
Nasal height	0.65	0.25	0.47	−0.00	0.01	−0.07	−0.20	−0.20	−0.06	78.43
Maxillo-alveolar length	0.42	0.42	−0.39	−0.24	0.02	−0.47	−0.17	0.02	0.17	83.26
Maxillo-alveolar breadth	0.50	0.38	−0.05	−0.24	−0.02	−0.06	0.28	−0.29	0.38	76.89
Total contribution (%)	27.07	17.48	8.44	6.51	6.13	5.42	4.38	3.47	3.20	82.09
Cumulative proportion (%)	27.07	44.55	52.99	59.50	65.63	71.05	75.43	78.89	82.09	82.09

[1] Data source: Oetteking (1930). The sample size for correlation coefficients varies from 232 to 323.

Table 9. Rotated solution of the first nine principal components extracted from the correlations between the degree of deformation and neurocranial linear measurements of American Native males from the North Pacific coast.[1]

Variable	Factor loadings								
	Fac I	II	III	IV	V	VI	VII	VIII	IX
Degree of anteroposterior deformation	0.04	0.89	−0.10	−0.07	0.07	−0.06	−0.13	−0.08	0.03
Degree of conical deformation	−0.08	−0.79	0.30	−0.06	0.04	−0.15	0.16	0.09	0.11
Length	0.12	−0.73	0.31	0.05	−0.32	0.14	0.28	0.09	−0.06
Breadth	−0.03	0.86	0.05	0.09	−0.03	0.07	−0.02	0.24	0.13
Height (ba-b)	0.13	−0.12	0.03	0.13	−0.88	0.03	0.06	0.03	−0.09
Median-sagittal frontal chord	0.08	−0.17	0.39	−0.10	−0.64	−0.01	0.29	−0.03	0.25
Median-sagittal parietal chord	0.01	−0.76	0.06	0.03	−0.37	0.08	−0.30	0.17	0.09
Median-sagittal occipital chord	0.01	−0.17	0.12	−0.01	−0.17	−0.03	0.91	0.07	0.02
Cranial base length (n-ba)	0.50	−0.16	0.15	0.27	−0.46	0.21	0.10	0.15	−0.45
Length of foramen magnum	0.12	−0.09	0.19	0.82	−0.05	0.11	0.02	−0.16	−0.20
Width of foramen magnum	0.05	0.14	0.06	0.79	−0.07	−0.17	−0.03	0.30	0.23
Facial length (ba-pr)	0.89	0.06	−0.00	0.12	−0.08	0.07	0.03	0.07	−0.18
Upper facial height (n-pr)	0.24	−0.20	0.78	0.11	−0.20	0.05	0.02	0.11	0.10
Bizygomatic breadth	0.17	0.42	0.31	0.32	−0.29	0.35	−0.11	0.39	−0.13
Orbital width (mf-ek)	0.21	−0.11	0.29	0.04	−0.01	0.21	0.10	0.80	−0.01
Orbital height	−0.11	−0.18	0.78	0.01	0.09	−0.04	0.12	0.16	−0.10
Nasal width	0.05	0.01	0.01	−0.06	−0.02	0.89	−0.06	0.15	−0.03
Nasal height	0.12	−0.02	0.83	0.18	−0.18	0.10	0.03	0.06	0.04
Maxillo-alveolar length	0.87	−0.00	0.13	0.00	−0.09	0.02	−0.04	0.11	0.20
Maxillo-alveolar breadth	0.42	0.00	0.23	0.22	−0.12	0.48	0.26	−0.00	0.43

[1] Data source: Oetteking (1930). The sample size for correlation coefficients varies from 232 to 323.

Table 10. Principal component analysis of the correlations between the degree of deformation and neurocranial linear measurements of American Native females from the North Pacific coast.[1]

Variable	Factor loadings								Total variance (%)
	PC I	II	III	IV	V	VI	VII	VIII	
Degree of anteroposterior deformation	−0.53	0.65	0.24	−0.08	0.25	0.07	−0.01	−0.14	85.19
Degree of conical deformation	0.59	−0.50	0.28	0.01	−0.34	0.05	0.11	0.20	84.16
Length	0.74	−0.44	0.01	0.11	0.01	0.29	−0.01	0.13	85.80
Breadth	−0.39	0.74	0.10	−0.12	0.16	0.01	0.22	0.00	79.09
Height (ba-b)	0.49	−0.20	−0.25	−0.11	0.64	−0.14	0.15	−0.28	87.96
Median-sagittal frontal chord	0.48	−0.28	0.23	−0.36	0.38	0.37	0.18	−0.11	80.93
Median-sagittal parietal chord	0.43	−0.56	−0.45	0.20	0.14	−0.13	0.34	0.07	89.43
Median-sagittal occipital chord	0.48	−0.03	0.44	−0.20	0.12	0.56	−0.25	0.03	85.17
Cranial base length (n-ba)	0.71	0.08	−0.29	−0.08	0.17	−0.30	−0.28	0.00	79.23
Length of foramen magnum	0.19	0.24	−0.28	0.72	0.10	0.18	−0.31	−0.16	85.44
Width of foramen magnum	0.26	0.48	−0.20	0.55	0.08	0.39	0.04	0.00	79.60
Facial length (ba-pr)	0.56	0.48	−0.29	−0.34	−0.26	−0.00	−0.25	−0.09	88.71
Upper facial height (n-pr)	0.76	0.13	0.27	0.09	−0.17	−0.27	0.08	−0.16	81.65
Bizygomatic breadth	0.25	0.76	−0.03	−0.01	0.13	0.01	0.28	0.32	83.03
Orbital width (mf-ek)	0.52	0.36	0.21	0.18	0.17	−0.27	0.12	0.31	69.05
Orbital height	0.43	0.30	0.63	0.17	0.05	−0.13	0.05	0.05	71.76
Nasal width	0.29	0.34	−0.48	−0.32	0.08	0.08	−0.20	0.50	84.17
Nasal height	0.58	0.22	0.48	0.09	0.00	−0.26	−0.20	−0.12	74.40
Maxillo-alveolar length	0.60	0.41	−0.30	−0.29	−0.17	−0.01	0.02	−0.35	85.26
Maxillo-alveolar breadth	0.39	0.42	−0.20	0.01	−0.44	0.25	0.43	−0.18	84.43
Total contribution (%)	25.79	18.33	10.21	7.31	6.05	5.80	4.51	4.23	82.22
Cumulative proportion (%)	25.79	44.11	54.32	61.64	67.69	73.48	77.99	82.22	82.22

[1] Data source: Oetteking (1930). The sample size for correlation coefficients varies from 87 to 122.

Table 11. Rotated solution of the first eight principal components extracted from the correlations between the degree of deformation and neurocranial linear measurements of American Native females from the North Pacific coast.[1]

Variable	Factor loadings							
	Fac I	II	III	IV	V	VI	VII	VIII
Degree of anteroposterior deformation	−0.10	0.91	0.01	0.05	−0.12	0.02	−0.00	−0.02
Degree of conical deformation	−0.03	−0.76	0.32	−0.20	−0.12	0.27	0.14	−0.04
Length	0.06	−0.74	0.17	0.16	0.18	0.46	0.08	0.09
Breadth	−0.05	0.82	0.06	−0.01	−0.07	−0.10	0.24	0.19
Height (ba-b)	0.16	−0.15	0.08	0.04	0.89	0.14	−0.08	0.02
Median-sagittal frontal chord	0.01	−0.18	0.08	−0.20	0.44	0.73	0.10	−0.02
Median-sagittal parietal chord	−0.09	−0.71	−0.09	0.06	0.56	−0.18	0.14	0.09
Median-sagittal occipital chord	0.11	−0.11	0.23	0.06	−0.09	0.87	−0.05	0.04
Cranial base length (n-ba)	0.57	−0.30	0.31	0.13	0.37	−0.03	−0.21	0.28
Length of foramen magnum	0.09	−0.04	0.06	0.91	0.03	−0.10	−0.07	−0.04
Width of foramen magnum	0.04	0.11	0.12	0.78	0.01	0.09	0.34	0.20
Facial length (ba-pr)	0.86	−0.00	0.15	0.06	−0.06	0.09	0.15	0.28
Upper facial height (n-pr)	0.36	−0.29	0.73	0.02	0.11	0.06	0.21	−0.10
Bizygomatic breadth	0.11	0.39	0.37	0.15	0.05	−0.02	0.40	0.59
Orbital width (mf-ek)	0.02	−0.02	0.70	0.11	0.15	−0.04	0.09	0.39
Orbital height	−0.04	0.07	0.81	0.04	−0.05	0.21	0.08	−0.02
Nasal width	0.41	−0.01	−0.13	0.05	0.02	0.05	−0.04	0.81
Nasal height	0.27	−0.05	0.78	0.06	−0.00	0.16	−0.11	−0.11
Maxillo-alveolar length	0.81	0.01	0.15	0.05	0.20	0.07	0.35	0.06
Maxillo-alveolar breadth	0.38	−0.04	0.09	0.16	−0.07	0.02	0.81	0.04

[1] Data source: Oetteking (1930). The sample size for correlation coefficients varies from 87 to 122.

Table 12. Principal component analysis of the correlations between the degree of deformation and neurocranial linear measurements of American Native males from west-central Illinois.[1]

Variable	Factor loadings																Total variance
	PC I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	(%)
Frontal flattening	0.07	0.64	−0.11	0.19	−0.10	0.09	0.04	0.11	0.24	0.10	0.21	−0.13	−0.07	−0.13	0.03	0.20	69.13
Bifrontal flattening	−0.02	0.38	0.11	0.12	−0.12	0.27	−0.09	−0.05	−0.31	0.35	0.11	−0.08	0.50	−0.19	−0.25	0.02	84.94
Occipital flattening	−0.09	0.42	0.20	0.47	0.29	0.04	0.11	0.18	0.36	−0.11	0.04	0.23	−0.14	−0.04	−0.05	0.05	79.98
Lambdoid flattening	−0.09	0.28	0.25	0.38	0.24	−0.11	0.17	0.26	0.14	0.22	0.02	−0.14	0.19	0.35	0.31	0.11	82.25
Glabello-occipital length	0.56	−0.40	−0.08	−0.25	−0.14	0.09	0.10	0.19	0.03	0.38	0.00	−0.21	0.02	0.02	0.13	0.04	82.86
Minimum frontal breadth	0.63	−0.21	0.18	0.16	0.05	0.10	−0.25	−0.14	0.11	−0.36	−0.05	0.02	−0.10	0.12	−0.11	−0.02	77.36
Frontal chord	0.44	−0.37	0.19	−0.08	0.32	0.41	−0.12	0.34	−0.16	−0.08	0.02	0.04	−0.12	−0.01	0.08	0.08	82.79
Midfacial breadth	0.50	0.22	−0.36	0.13	0.41	−0.22	−0.01	0.02	−0.16	0.21	−0.02	−0.09	−0.10	0.18	−0.11	−0.13	80.58
Internal biorbital breadth (IOB)	0.78	0.12	0.03	0.19	0.07	0.08	0.04	−0.11	0.07	−0.12	0.05	−0.22	−0.05	0.07	−0.29	−0.02	83.82
Subtense to IOB	0.44	−0.18	0.23	0.12	−0.46	0.34	−0.09	−0.08	0.24	−0.05	0.22	−0.07	0.01	0.13	0.13	−0.07	78.52
Anterior interorbital breadth	0.59	−0.27	0.24	0.22	−0.29	−0.37	−0.16	0.20	0.15	−0.07	0.06	0.04	−0.01	−0.08	0.04	0.01	86.20
Orbital breadth, mf (left)	0.51	0.12	0.00	0.13	0.09	0.40	0.08	−0.36	−0.13	0.04	0.13	−0.21	−0.04	0.32	−0.16	0.05	80.95
Orbital height (left)	0.08	−0.18	0.12	0.46	−0.04	0.41	0.14	−0.15	0.12	0.17	−0.21	0.29	0.23	−0.06	−0.04	−0.09	70.87
Nasal height	0.42	−0.07	−0.08	0.03	−0.25	0.41	0.11	−0.10	0.03	0.20	−0.22	0.39	−0.02	−0.06	0.28	0.03	76.19
Nasal breadth	0.44	−0.16	−0.10	0.30	0.17	−0.40	0.23	−0.09	−0.38	0.03	0.00	0.04	0.18	−0.02	0.22	−0.12	79.88
Dacryal chord	0.53	−0.35	0.10	0.23	−0.18	−0.46	−0.01	0.13	0.09	−0.08	0.10	0.03	0.23	−0.07	−0.16	−0.00	83.54
Minimum breadth of nasals	0.49	−0.12	0.19	0.19	−0.34	−0.31	−0.17	0.06	−0.20	0.16	−0.12	−0.03	−0.17	−0.15	−0.17	−0.02	73.04
Breadth of nasal bridge	0.47	−0.23	−0.25	0.18	0.20	−0.14	−0.25	−0.32	0.01	0.20	0.08	−0.14	−0.12	0.05	0.28	0.18	78.61
Biangular breadth	0.40	0.18	−0.10	−0.20	0.35	−0.10	0.35	−0.38	0.15	−0.17	−0.20	−0.15	0.12	−0.14	0.02	0.13	80.91
Breadth of ascending ramus (left)	0.41	0.40	−0.03	−0.29	−0.08	−0.21	−0.14	0.03	−0.16	−0.01	−0.02	0.21	−0.01	0.14	0.23	0.20	66.71
Length of mandible	0.38	−0.13	−0.03	−0.20	0.08	−0.04	0.33	−0.25	0.08	0.18	0.46	0.40	−0.13	−0.10	−0.15	0.12	85.89
Breadth at mental foramen	0.42	0.18	−0.34	0.02	0.33	−0.01	0.16	0.03	0.05	−0.03	0.22	0.15	−0.04	−0.26	0.13	−0.49	86.43
Maximum condylar length (left)	0.48	0.19	−0.24	0.08	−0.17	−0.14	−0.03	−0.02	0.19	0.13	−0.30	0.32	0.06	0.29	−0.14	−0.00	74.02
Malar length, inferior (left)	0.42	0.27	0.37	−0.27	−0.29	−0.08	0.37	−0.06	−0.14	−0.25	−0.02	0.00	0.12	0.00	0.19	−0.05	83.02
Malar length, maximum (left)	0.41	0.46	0.25	−0.25	−0.20	0.06	0.34	0.22	−0.18	−0.25	0.01	−0.01	0.10	0.24	−0.05	−0.12	89.36
Cheek height (left)	0.42	0.39	−0.41	−0.09	0.02	0.11	−0.20	0.41	−0.17	0.05	−0.02	0.23	−0.06	0.02	−0.14	0.15	85.31
Length of occipital condyle (left)	0.19	−0.20	−0.30	−0.60	−0.06	−0.01	0.20	0.17	0.20	0.09	0.07	0.01	0.01	0.10	−0.16	0.08	69.64
Breadth of occipital condyle (left)	−0.24	−0.48	0.13	−0.05	0.29	−0.13	0.13	0.16	0.21	0.01	0.39	0.13	0.32	0.18	−0.07	0.11	82.67
Biasterionic breadth	0.43	−0.05	−0.04	0.01	0.29	−0.01	0.17	0.23	0.23	−0.02	−0.46	−0.14	0.15	−0.24	−0.09	0.17	75.89
Frontal subtense	0.06	−0.55	0.28	−0.16	0.49	0.17	−0.04	0.04	−0.19	−0.11	−0.21	0.15	0.04	0.13	−0.05	−0.01	81.16
Frontal subtense fraction	0.28	−0.01	0.38	0.22	0.22	0.23	0.14	0.30	−0.37	0.04	0.18	−0.03	−0.19	−0.18	0.01	0.09	72.59
Parietal chord	0.33	−0.03	0.57	−0.44	0.10	−0.03	−0.11	−0.10	0.18	0.39	−0.07	−0.12	−0.01	−0.14	−0.03	−0.08	88.42
Parietal subtense	0.13	0.45	0.67	−0.21	0.19	−0.11	−0.05	−0.05	0.22	0.17	−0.05	−0.01	−0.19	−0.06	0.03	−0.09	88.75
Occipital chord	0.31	−0.22	−0.50	0.06	−0.19	0.31	0.22	0.24	0.19	−0.15	0.04	−0.29	0.02	−0.15	0.12	−0.04	82.72
Mastoid breadth (left)	0.40	0.25	−0.01	−0.12	0.14	0.05	−0.45	−0.17	−0.03	−0.33	0.15	0.10	0.29	−0.23	0.12	0.27	86.36
Mastoid length 2 (left)	0.27	0.21	−0.09	−0.25	0.21	0.13	−0.57	0.14	0.21	0.03	0.08	−0.02	0.24	0.08	0.08	−0.35	83.46
Total contribution (%)	16.41	8.97	6.94	5.97	5.70	5.23	4.52	3.82	3.68	3.39	3.17	3.00	2.61	2.51	2.36	2.13	80.41
Cumulative proportion (%)	16.41	25.38	32.32	38.29	43.99	49.22	53.74	57.56	61.24	64.63	67.81	70.81	73.41	75.93	78.28	80.41	80.41

[1] Data source: Droessler (1981). The sample size for correlation coefficients varies from 103 to 158.

Table 13. Rotated solution of the first 16 principal components extracted from the correlations between the degree of deformation and neurocranial linear measurements of American Native males from west-central Illinois.[1]

Variable	Factor loadings															
	Fac I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
Frontal flattening	−0.09	0.10	0.04	0.13	−0.74	−0.01	−0.10	0.18	−0.07	−0.04	−0.16	0.02	0.10	−0.08	−0.11	−0.06
Bifrontal flattening	−0.09	0.06	0.07	0.04	−0.18	0.08	−0.10	0.02	−0.06	−0.05	−0.04	−0.06	0.87	0.06	−0.00	0.03
Occipital flattening	−0.02	0.01	0.08	0.65	−0.28	0.10	0.06	0.37	−0.17	0.06	−0.07	0.07	−0.12	−0.17	−0.21	−0.14
Lambdoid flattening	−0.04	−0.01	0.11	0.15	−0.15	−0.01	0.11	0.83	−0.08	−0.05	−0.01	−0.16	0.03	−0.03	0.14	0.05
Glabello-occipital length	0.28	0.13	0.09	−0.78	0.06	0.19	0.07	0.03	−0.16	−0.01	−0.09	0.09	−0.03	−0.13	0.09	−0.05
Minimum frontal breadth	0.44	0.55	0.04	0.09	0.23	0.15	−0.28	−0.12	−0.11	−0.04	−0.03	−0.05	−0.25	−0.09	−0.07	−0.07
Frontal chord	0.09	0.19	0.03	−0.24	0.41	0.15	−0.19	0.03	−0.65	0.03	−0.11	−0.01	−0.14	−0.09	−0.12	−0.10
Midfacial breadth	0.06	0.37	0.02	−0.04	−0.04	−0.19	0.08	0.09	−0.02	0.11	−0.50	0.03	0.02	−0.19	0.43	−0.36
Internal biorbital breadth (IOB)	0.37	0.71	0.05	−0.01	−0.11	0.01	−0.07	−0.05	−0.12	−0.15	−0.16	0.06	0.03	−0.28	0.04	−0.17
Subtense to IOB	0.37	0.41	0.02	−0.26	−0.13	0.41	−0.14	0.04	−0.05	−0.16	0.22	−0.02	−0.08	0.26	−0.23	−0.01
Anterior interorbital breadth	0.88	0.05	0.08	−0.10	−0.03	0.09	−0.12	0.05	−0.09	−0.07	−0.03	0.01	−0.17	0.00	0.05	−0.02
Orbital breadth, mf (left)	−0.09	0.84	0.01	−0.09	−0.02	0.14	−0.04	0.01	−0.10	−0.11	−0.07	0.08	0.13	0.00	0.13	0.00
Orbital height (left)	0.08	0.13	−0.09	0.20	0.14	0.69	0.14	0.10	−0.03	0.13	0.14	0.02	0.24	−0.11	−0.05	−0.02
Nasal height	0.01	0.07	−0.00	−0.20	−0.03	0.79	−0.07	−0.12	−0.07	−0.11	−0.19	0.08	−0.06	−0.02	0.08	−0.02
Nasal breadth	0.35	0.05	−0.18	0.01	0.16	0.03	0.02	0.11	−0.07	−0.13	−0.03	0.08	0.06	−0.11	0.72	−0.19
Dacryal chord	0.86	0.05	−0.10	−0.08	0.11	−0.04	−0.05	0.07	0.05	−0.05	0.02	0.16	0.03	−0.14	0.10	−0.05
Minimum breadth of nasals	0.69	0.09	0.18	−0.06	−0.07	0.05	0.12	−0.26	−0.13	−0.03	−0.19	−0.10	0.08	0.05	0.20	0.12
Breadth of nasal bridge	0.19	0.35	0.04	−0.24	−0.05	0.09	−0.28	0.04	−0.00	0.40	−0.06	0.06	−0.21	−0.04	0.51	−0.03
Biangular breadth	−0.14	0.26	0.12	−0.01	−0.03	−0.03	−0.19	−0.07	0.17	−0.23	0.06	0.20	−0.10	−0.66	0.29	−0.09
Breadth of ascending ramus (left)	0.05	−0.02	0.19	−0.09	−0.13	−0.01	−0.38	0.01	0.04	−0.36	−0.50	0.05	−0.10	0.06	0.23	0.05
Length of mandible	0.09	0.14	0.11	−0.10	−0.02	0.13	−0.02	−0.12	−0.07	−0.05	−0.06	0.86	−0.05	0.01	0.11	−0.11
Breadth at mental foramen	0.00	0.07	−0.05	0.02	−0.12	0.06	−0.04	−0.08	−0.09	−0.08	−0.12	0.20	−0.07	−0.14	0.24	−0.83
Maximum condylar length (left)	0.28	0.20	0.01	0.01	−0.05	0.31	0.04	0.05	0.38	−0.09	−0.59	0.04	−0.05	−0.14	0.04	−0.04
Malar length, inferior (left)	0.15	0.06	0.18	−0.07	−0.07	0.09	−0.11	−0.05	−0.03	−0.84	0.07	0.06	−0.02	−0.08	0.12	0.03
Malar length, maximum (left)	0.04	0.20	0.07	−0.03	−0.07	−0.05	0.02	0.07	−0.09	−0.86	−0.24	−0.02	0.08	−0.04	−0.10	−0.08
Cheek height (left)	0.01	0.04	−0.15	−0.09	−0.19	0.00	−0.19	−0.08	−0.20	−0.06	−0.81	0.01	0.10	−0.07	−0.07	−0.17
Length of occipital condyle (left)	−0.05	−0.05	−0.04	−0.57	0.10	−0.13	0.06	−0.09	0.16	−0.10	−0.22	0.36	−0.13	−0.18	−0.24	−0.06
Breadth of occipital condyle (left)	0.08	−0.17	−0.12	−0.08	0.42	−0.20	−0.01	0.46	0.02	0.19	0.27	0.45	0.02	0.05	−0.19	0.00
Biasterionic breadth	0.18	0.03	0.06	−0.12	0.06	0.10	−0.02	0.08	−0.12	0.01	−0.15	−0.09	−0.02	−0.80	−0.01	−0.06
Frontal subtense	−0.06	0.05	0.09	−0.03	0.82	0.05	−0.03	0.02	−0.28	0.09	0.06	0.03	−0.10	−0.14	−0.00	0.04
Frontal subtense fraction	0.11	0.12	0.09	0.09	0.03	0.03	0.05	0.07	−0.79	−0.13	0.00	0.05	0.12	−0.01	0.10	−0.01
Parietal chord	0.15	0.06	0.83	−0.29	0.13	0.04	−0.06	−0.03	−0.07	−0.07	0.09	0.09	0.09	−0.13	−0.06	−0.02
Parietal subtense	−0.01	0.04	0.85	0.23	−0.13	−0.06	−0.03	0.12	−0.10	−0.23	−0.00	−0.00	−0.05	−0.06	−0.08	−0.05
Occipital chord	0.09	0.15	−0.52	−0.48	−0.24	0.17	0.03	−0.07	−0.12	−0.01	0.07	−0.07	−0.15	−0.27	−0.13	−0.27
Mastoid breadth (left)	0.09	0.13	0.03	0.09	−0.04	−0.02	−0.87	−0.11	−0.05	−0.07	−0.12	0.03	0.10	−0.12	0.04	−0.07
Mastoid length 2 (left)	−0.01	0.12	0.26	−0.17	0.09	−0.05	−0.44	0.10	0.14	0.09	−0.25	−0.25	0.09	0.08	−0.22	−0.54

[1] Data source: Droessler (1981). The sample size for correlation coefficients varies from 103 to 158.

Table 14. Principal component analysis of the correlations between the degree of deformation and neurocranial linear measurements of American Native females from west-central Illinois.[1]

Variable	Factor loadings																	Total variance
	PC I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	(%)
Frontal flattening	−0.15	0.58	0.27	0.19	−0.33	0.12	0.22	0.02	0.13	0.05	−0.05	−0.04	−0.18	−0.20	−0.11	0.06	−0.10	76.32
Bifrontal flattening	−0.19	0.12	0.06	0.26	−0.02	−0.29	0.10	0.05	0.27	−0.01	0.39	0.33	0.21	−0.14	−0.49	−0.08	−0.28	94.26
Occipital flattening	−0.04	0.32	0.02	0.26	−0.56	0.05	−0.16	−0.20	0.01	−0.11	0.10	−0.05	−0.19	0.06	−0.03	−0.19	0.27	72.95
Lambdoid flattening	−0.00	0.08	−0.45	0.27	−0.22	0.15	0.15	−0.09	−0.07	0.17	−0.08	0.46	0.08	−0.11	0.39	0.11	−0.24	87.32
Glabello-occipital length	−0.55	−0.32	−0.20	−0.44	0.18	−0.16	0.11	0.26	−0.03	−0.11	−0.10	0.22	−0.04	0.02	−0.00	−0.02	−0.01	85.61
Minimum frontal breadth	−0.63	−0.20	−0.04	0.06	−0.04	−0.19	−0.12	−0.06	0.27	0.09	0.20	−0.26	0.02	−0.18	0.24	−0.18	0.03	81.50
Frontal chord	−0.51	−0.27	−0.23	−0.45	−0.34	0.12	−0.23	−0.02	0.11	0.03	−0.00	−0.03	−0.05	−0.17	−0.15	0.05	0.06	84.71
Midfacial breadth	−0.60	0.07	0.14	−0.12	0.32	0.41	−0.04	−0.17	0.14	−0.06	0.02	0.08	0.05	0.15	0.09	−0.12	−0.18	80.40
Internal biorbital breadth (IOB)	−0.82	0.12	0.21	0.11	−0.02	−0.18	−0.02	−0.05	0.11	0.12	−0.05	−0.11	0.04	0.04	0.11	−0.12	0.06	85.18
Subtense to IOB	−0.42	−0.27	0.11	0.16	0.08	−0.17	−0.05	−0.09	−0.08	−0.47	0.05	0.15	0.26	−0.01	0.06	0.39	0.09	81.73
Anterior interorbital breadth	−0.48	−0.48	0.16	0.55	−0.06	0.05	−0.07	0.06	−0.16	0.06	−0.05	0.05	−0.09	0.01	0.08	−0.13	−0.00	86.07
Orbital breadth, mf (left)	−0.59	0.38	0.28	−0.24	−0.02	−0.14	0.09	−0.01	0.29	−0.01	−0.09	0.02	0.10	0.04	0.00	0.02	0.00	76.19
Orbital height (left)	−0.36	0.09	0.31	−0.15	−0.30	0.08	0.32	0.29	−0.06	−0.19	0.22	−0.23	0.22	−0.02	0.15	0.11	−0.00	76.56
Nasal height	−0.47	0.13	0.21	−0.20	−0.22	0.32	0.02	0.28	−0.07	−0.23	−0.19	−0.16	0.13	0.06	0.05	0.04	−0.11	71.16
Nasal breadth	−0.41	−0.34	0.31	0.06	−0.12	0.15	0.23	−0.15	−0.09	0.21	−0.23	0.15	−0.11	0.27	−0.21	0.04	0.05	75.56
Dacryal chord	−0.37	−0.48	0.24	0.49	0.04	−0.05	−0.13	0.12	−0.09	0.03	−0.18	0.12	0.07	−0.05	−0.18	−0.03	0.11	81.29
Minimum breadth of nasals	−0.35	−0.36	0.16	0.43	0.09	−0.03	0.07	0.26	−0.13	−0.05	0.22	−0.27	−0.27	−0.04	0.03	−0.01	−0.19	79.67
Breadth of nasal bridge	−0.54	−0.21	0.49	−0.01	0.01	0.05	0.08	−0.39	0.15	0.14	0.04	0.09	0.08	−0.03	0.15	0.07	0.03	83.39
Biangular breadth	−0.42	0.15	−0.14	−0.05	−0.11	−0.01	0.04	−0.42	−0.35	−0.20	0.29	0.16	−0.04	−0.01	−0.13	−0.05	0.19	73.90
Breadth of ascending ramus (left)	−0.29	0.27	−0.33	0.30	0.41	0.04	−0.10	0.03	0.29	−0.06	−0.01	0.04	−0.13	−0.21	0.18	−0.09	−0.03	72.00
Length of mandible	−0.46	0.13	−0.06	−0.32	0.24	0.41	0.13	0.12	−0.12	0.18	0.02	−0.04	−0.03	−0.26	−0.26	0.07	0.11	78.85
Breadth at mental foramen	−0.36	0.13	−0.20	0.04	0.38	0.23	−0.09	−0.12	−0.33	0.15	0.44	−0.17	−0.11	0.02	0.03	0.29	−0.06	86.17
Maximum condylar length (left)	−0.47	0.41	0.06	0.05	0.15	0.22	−0.21	0.02	0.06	0.25	0.00	0.10	0.27	0.24	0.03	−0.02	0.06	72.78
Malar length, inferior (left)	−0.53	0.12	−0.36	0.32	−0.08	−0.22	0.03	0.31	0.01	0.29	−0.03	−0.08	0.08	−0.05	−0.05	0.17	0.24	87.06
Malar length, maximum (left)	−0.36	0.27	−0.55	0.21	−0.02	−0.09	−0.20	0.39	0.02	−0.11	−0.13	0.01	0.13	0.13	−0.07	0.07	0.13	84.83
Cheek height (left)	−0.32	0.10	−0.13	0.16	0.24	0.41	−0.40	−0.03	0.08	−0.40	−0.14	−0.03	−0.15	0.06	−0.18	−0.14	−0.12	81.81
Length of occipital condyle (left)	−0.31	0.23	−0.04	−0.10	−0.01	−0.22	0.08	−0.01	−0.57	−0.16	−0.07	0.06	0.24	−0.20	0.10	−0.44	−0.06	87.93
Breadth of occipital condyle (left)	−0.31	0.13	−0.00	−0.12	0.27	−0.09	0.53	0.05	0.14	−0.21	−0.05	0.22	−0.40	−0.15	0.08	−0.01	0.28	87.48
Biasterionic breadth	−0.27	0.06	−0.01	−0.23	−0.34	−0.23	−0.36	0.10	0.09	−0.11	0.27	0.25	−0.27	0.34	0.15	0.07	−0.01	81.42
Frontal subtense	−0.05	−0.58	−0.35	−0.42	−0.03	−0.01	−0.18	−0.20	0.22	0.05	0.06	−0.10	0.17	−0.17	−0.02	−0.11	0.08	85.10
Frontal subtense fraction	−0.34	−0.09	−0.13	−0.04	−0.57	0.33	−0.21	0.01	−0.11	0.07	−0.09	0.14	−0.12	−0.33	0.02	0.11	−0.13	81.36
Parietal chord	−0.43	−0.27	−0.55	−0.10	−0.04	0.04	0.44	0.02	0.04	0.04	0.02	−0.03	−0.10	0.27	−0.03	−0.12	−0.11	88.43
Parietal subtense	−0.22	−0.01	−0.57	0.18	−0.29	0.03	0.40	−0.28	0.05	−0.05	−0.02	−0.26	0.12	0.25	−0.11	−0.03	−0.12	89.27
Occipital chord	−0.30	0.15	0.17	−0.43	0.04	−0.32	−0.19	0.25	−0.27	0.31	0.05	0.08	−0.18	0.11	−0.03	−0.10	−0.16	78.40
Mastoid breadth (1eft)	−0.37	0.33	−0.10	0.05	0.20	−0.28	−0.12	−0.42	−0.22	0.11	−0.24	−0.13	−0.00	−0.02	−0.04	0.10	0.04	71.73
Mastoid length 2 (1eft)	−0.31	0.06	−0.04	−0.11	−0.02	−0.52	−0.09	−0.25	0.02	−0.13	−0.31	−0.20	−0.18	−0.08	−0.07	0.23	−0.32	80.35
Total contribution (%)	17.10	7.50	7.11	6.71	5.56	4.87	4.37	4.11	3.51	3.09	2.86	2.84	2.63	2.54	2.37	2.16	2.05	81.35
Cumulative proportion (%)	17.10	24.60	31.71	38.42	43.98	48.85	53.21	57.33	60.83	63.92	66.78	69.62	72.24	74.78	77.15	79.31	81.35	81.35

[1] Data source: Droessler (1981). The sample size for correlation coefficients varies from 121 to 188.

Table 15. Rotated solution of the first 17 principal components extracted from the correlations between the degree of deformation and neurocranial linear measurements of American Native females from west-central Illinois.[1]

Variable	Factor loadings																
	Fac I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII
Frontal flattening	−0.19	0.06	−0.03	0.21	−0.51	0.16	−0.10	0.40	0.09	−0.01	0.25	0.05	−0.19	−0.12	0.17	0.00	−0.26
Bifrontal flattening	−0.01	−0.09	−0.08	0.05	−0.03	0.10	0.04	−0.04	−0.03	0.01	0.95	−0.04	−0.00	0.04	−0.00	−0.02	0.06
Occipital flattening	0.04	−0.01	−0.07	0.00	−0.82	0.01	0.06	0.02	−0.06	−0.05	−0.02	−0.01	0.06	0.16	0.01	−0.09	−0.02
Lambdoid flattening	0.08	0.04	−0.13	0.06	−0.01	−0.02	0.20	−0.12	−0.05	0.05	0.00	−0.04	0.01	−0.02	0.89	0.00	0.03
Glabello-occipital length	−0.07	−0.13	−0.17	−0.40	0.54	0.11	0.16	0.12	−0.21	−0.07	0.00	0.09	−0.39	0.28	−0.03	−0.01	0.10
Minimum frontal breadth	−0.14	−0.38	−0.10	−0.38	−0.04	0.39	0.14	0.07	−0.05	0.07	0.05	−0.53	−0.05	0.10	−0.09	0.05	0.03
Frontal chord	−0.11	−0.03	−0.11	−0.84	−0.02	0.12	0.10	0.18	0.01	−0.09	−0.01	0.08	−0.03	0.20	0.01	0.06	0.01
Midfacial breadth	0.06	−0.09	0.16	−0.07	0.18	0.63	0.10	0.15	−0.04	−0.48	0.00	−0.02	−0.11	0.04	0.04	0.23	0.03
Internal biorbital breadth (IOB)	−0.26	−0.37	−0.22	−0.08	−0.11	0.66	0.08	0.20	−0.16	0.00	0.05	−0.14	−0.13	0.12	−0.08	0.03	0.01
Subtense to IOB	−0.15	−0.28	−0.06	−0.05	0.12	0.10	−0.04	0.15	−0.04	−0.06	0.08	0.01	−0.06	0.06	0.01	0.06	0.80
Anterior interorbital breadth	0.05	−0.89	−0.06	−0.04	−0.04	0.13	0.07	−0.01	−0.07	−0.08	−0.04	0.01	0.03	0.02	0.12	−0.00	0.11
Orbital breadth, mf (left)	−0.26	0.13	−0.12	−0.05	−0.04	0.64	−0.04	0.35	−0.05	−0.02	0.17	−0.01	−0.24	0.14	−0.11	−0.09	0.02
Orbital height (left)	0.10	−0.06	0.01	−0.01	−0.05	0.15	0.07	0.79	−0.10	0.22	0.04	−0.07	−0.07	0.06	−0.10	0.06	0.14
Nasal height	−0.02	−0.06	−0.09	−0.12	0.01	0.23	0.01	0.72	−0.10	−0.26	−0.13	0.13	0.01	0.05	−0.00	−0.04	0.01
Nasal breadth	−0.03	−0.47	0.15	−0.10	0.00	0.35	0.19	0.05	0.08	0.06	−0.04	0.56	−0.12	0.01	−0.01	−0.03	−0.00
Dacryal chord	0.01	−0.79	−0.16	−0.07	0.05	0.10	−0.13	−0.08	−0.02	−0.07	0.10	0.18	0.04	−0.12	−0.04	−0.13	0.21
Minimum breadth of nasals	−0.05	−0.76	0.02	0.11	0.07	−0.12	0.09	0.21	0.07	−0.05	0.08	−0.22	−0.06	0.06	−0.11	0.23	−0.04
Breadth of nasal bridge	−0.11	−0.34	0.34	−0.18	−0.03	0.68	−0.04	0.09	0.05	0.13	0.03	0.04	−0.10	−0.02	0.03	0.06	0.22
Biangular breadth	−0.06	0.02	0.04	−0.18	−0.35	0.13	0.20	−0.07	−0.42	−0.06	0.11	0.14	−0.17	0.14	0.02	0.40	0.30
Breadth of ascending ramus (left)	−0.07	−0.04	−0.32	0.09	0.03	0.19	−0.00	−0.20	0.04	−0.39	0.08	−0.47	−0.28	−0.12	0.19	0.13	−0.04
Length of mandible	0.07	0.05	−0.16	−0.35	0.15	0.24	−0.07	0.25	−0.10	−0.16	0.04	0.21	−0.30	−0.24	−0.05	0.46	−0.20
Breadth at mental foramen	−0.03	−0.06	−0.10	0.03	0.08	0.12	0.08	−0.01	−0.02	−0.11	−0.04	−0.09	0.02	0.04	0.02	0.89	0.05
Maximum condylar length (left)	0.10	0.07	−0.34	0.10	−0.03	0.67	−0.06	0.07	−0.06	−0.20	0.04	0.07	0.13	0.07	0.05	0.21	−0.06
Malar length, inferior (left)	−0.12	−0.27	−0.79	−0.09	−0.06	0.16	0.15	0.05	0.00	0.19	0.09	−0.08	−0.10	−0.02	0.10	0.15	−0.02
Malar length, maximum (left)	−0.03	0.02	−0.84	−0.02	−0.01	−0.01	0.17	0.05	−0.08	−0.27	0.03	−0.07	0.01	0.14	0.08	0.01	0.08
Cheek height (left)	−0.04	−0.11	−0.10	−0.07	−0.08	0.08	0.00	−0.00	0.00	−0.87	−0.02	−0.03	0.01	−0.00	−0.05	0.10	0.06
Length of occipital condyle (left)	−0.11	−0.02	−0.06	0.03	0.01	0.06	0.02	0.15	−0.91	0.00	0.02	−0.05	−0.04	−0.02	0.05	0.01	0.00
Breadth of occipital condyle (left)	−0.04	0.00	−0.02	0.06	0.04	0.11	0.08	0.05	−0.05	−0.01	0.00	−0.03	−0.92	0.00	−0.02	0.03	0.05
Biasterionic breadth	−0.05	0.03	−0.07	−0.15	−0.15	0.10	−0.02	0.06	0.05	−0.02	0.03	−0.03	−0.01	0.86	0.03	−0.01	0.09
Frontal subtense	0.06	0.06	0.12	−0.76	0.25	−0.03	0.20	−0.24	0.03	0.06	−0.08	−0.18	0.12	−0.03	−0.11	−0.08	0.11
Frontal subtense fraction	−0.07	−0.18	−0.05	−0.55	−0.28	−0.04	−0.07	0.29	−0.02	−0.12	−0.02	0.13	0.09	0.08	0.50	0.06	−0.09
Parietal chord	0.03	−0.14	−0.15	−0.23	0.22	0.04	0.79	0.03	−0.04	−0.03	−0.00	0.04	−0.25	0.11	0.10	0.09	−0.09
Parietal subtense	−0.13	0.03	−0.16	−0.06	−0.18	−0.01	0.87	0.04	−0.01	−0.00	0.04	−0.00	0.07	−0.15	0.12	0.04	0.06
Occipital chord	−0.22	−0.01	−0.09	−0.07	0.24	0.18	−0.22	0.10	−0.30	0.15	0.04	0.14	−0.01	0.51	−0.14	0.15	−0.37
Mastoid breadth (left)	−0.58	0.04	−0.20	0.06	−0.12	0.33	0.03	−0.22	−0.27	−0.03	−0.10	0.05	−0.02	−0.10	−0.03	0.25	0.07
Mastoid length 2 (left)	−0.87	−0.02	−0.02	−0.09	0.06	0.04	0.08	0.02	−0.04	−0.02	0.05	−0.05	−0.04	0.12	−0.04	−0.05	0.08

[1] Data source: Droessler (1981). The sample size for correlation coefficients varies from 121 to 188.

Table 16. Craniofacial measurements suggested by t- and/or t'-tests as well as by PCAs and/or the varimax rotations to be significantly or relatively strongly affected by neurocranial deformation in ancient Peruvians.

Variable	Males		Females	
	t- and/or t'-tests	PCs and/or rotated factors[1]	t- and/or t'-tests	PCs and/or rotated factors[1]
Length	*	*		
Breadth	*			*
Cubic root of capacity	*			
Maximum circumference	*			
Minimum frontal diameter	*	*		
Breadth of orbit (R.)	*	*		
Height of orbit (R.)			*	*

[1] Strong association suggested by a PC or rotated factor which has the highest factor loading on the degree of deformation among the PCs and rotated factors and, simultaneously, a factor loading of more than 0.32 (about 10% of the total variance) in absolute value on the relevant craniofacial measurement.
* Affected by deformation.

Table 17. Craniofacial measurements suggested by t- and/or t'-tests as well as by PCAs and/or the varimax rotations to be significantly or relatively strongly affected by neurocranial deformation in American Natives from the North Pacific coast.

Variable	Males		Females	
	t- and/or t'-tests[1]	PCs and/or rotated factors[2]	t- and/or t'-tests[1]	PCs and/or rotated factors[2]
Length	*	*	*	*
Breadth	*	*	*	*
Height (ba-b)	*		*	
Median-sagittal parietal chord	*	*	*	*
Median-sagittal occipital chord	*		*	
Cranial base length (n-ba)	*		*	
Length of foramen magnum	*		*	
Bizygomatic breadth	*	*	*	*
Orbital height	*		*	
Nasal width	*		*	
Nasal height	*		*	

[1] Suggested in more than two of the six samples, i.e., Cowichan, Chinook, and Koskimo male and female samples.
[2] Strong association suggested by a PC or rotated factor which has the highest factor loading on the degree of deformation among the PCs and rotated factors and, simultaneously, a factor loading of more than 0.32 (about 10% of the total variance) in absolute value on the relevant craniofacial measurement.
* Affected by deformation.

compared with those based on all available variables.

The differences between the undeformed and deformed groups of Coobool Creek males were also examined using t- and t'-tests, as shown in Table 20. In Table 21, the variables commonly available in the Coobool Creek male sample and the three American Native samples are shown together with the information on their association with neurocranial deformation. It is evident that there are few variables which are not affected across all the samples analyzed here. Therefore, the respective sets of variables suggested in the analyses of the three American Native samples were separately examined to confirm whether they can be useful in estimating D^2 distances close to zero between the undefored and deformed groups of Coobool Creek or of the three American Native samples.

In Table 22, the results of significance tests of

Table 18. Craniofacial measurements suggested by *t*- and/or *t′*-tests as well as by PCAs and/or the varimax rotations to be significantly or relatively strongly affected by neurocranial deformation in American Natives from west-central Illinois.

Variable	Males		Females	
	t- and/or *t′*-tests	PCs and/or rotated factors[1]	*t*- and/or *t′*-tests	PCs and/or rotated factors[1]
Glabello-occipital length		*		*
Frontal chord		*		
Anterior interorbital breadth				*
Orbital breadth, mf (left)	*			*
Nasal breadth				*
Dacryal chord	*			*
Minimum breadth of nasals				*
Biangular breadth			*	*
Maximum condylar length (left)				*
Malar length, inferior (left)			*	
Malar length, maximum (left)	*			
Length occipital condyle (left)		*		
Breadth occ. condyle (left)		*		
Frontal subtense	*	*		*
Frontal subtense fraction			*	*
Parietal chord			*	
Parietal subtense	*		*	
Occipital chord		*		
Mastoid breadth (left)				*

[1] Strong association suggested by a PC or rotated factor which has the highest factor loading on the degree of deformation among the PCs and rotated factors and, simultaneously, a factor loading of more than 0.32 (about 10% of the total variance) in absolute value on the relevant craniofacial measurement.

* Affected by deformation.

D^2 distances between undeformed and deformed groups are shown for the respective sets of variables selected according to the results shown in Table 21. All of the resultant sets of variables show that the deformed and undeformed groups of Coobool Creek can be treated as the samples from the same population. In the case of American Natives, however, most of D^2 distances between undeformed and deformed groups are significantly different from zero at the 5% level or less.

Finally, using three sets of variables showing the highest probabilities for the null hypothesis of D^2 between the undeformed and deformed skull groups of Coobool Creek (Table 22), typicality probabilities to the Coobool Creek sample were estimated for Keilor and some other Australian Pleistocene fossils for which the same variables were available. The results are shown in Table 23.

Discussion

The purpose of this short article is to identify sets of craniofacial measurements that are minimally affected by neorocranial deformation and therefore may be most useful in testing the morphological relationship between populations regardless of whether, or not, the populations have the tradition of artificial neurocranial deformation. This attempt is conducted on the premise, as suggested by Weidenreich (1941), and as consistent with Bailit and Friedlaender's (1966) "metabolic balance" or "economic benefit" hypothesis, that the body is a totality in which all parts harmonize from the beginning of its organization and every essential alteration is accounted as a consequence of a change in the entire construction. If this is correct, it means, in our practical context, that a set of randomly selected craniofacial measurements effectively retain information

Table 19. D^2 distances between undeformed and deformed samples based on all available variables and on the variables relatively free of deformation.

Sample		Sex	No. of variables[1]	D^2	F	First d.f.	Second d.f.	Probability
Ancient Peruvians		M	26 (all)	10.36	7.04	26	75	0.000
			19 (*t*)	1.67	1.72	19	82	0.049
			21 (PCA)	5.01	4.50	21	80	0.000
		F	26 (all)	366.19*	155.86	26	43	0.000
			19 (*t*)	1.68	1.16	19	51	0.330
			21 (PCA)	1.69	1.00	21	48	0.485
North Pacific coast:	Cowichan	M	18 (all)	32404.1*	34418.9	18	91	0.000
			7 (*t*)	1.41	4.22	7	101	0.001
			14 (PCA)	14.56	20.76	14	95	0.000
	Chinook	M	18 (all)	31997.6*	29312.9	18	70	0.000
			7 (*t*)	0.34	0.89	7	78	0.520
			14 (PCA)	13.55	16.73	14	73	0.000
	Koskimo	M	18 (all)	117211.0*	137705.0	18	114	0.000
			7 (*t*)	1.57	5.06	7	123	0.000
			14 (PCA)	10.81	16.90	14	118	0.000
	Cowichan	F	18 (all)	61.18	23.58	18	27	0.000
			7 (*t*)	1.78	2.40	7	37	0.039
			14 (PCA)	34.26	18.74	14	30	0.000
	Chinook	F	18 (all)	64.85	24.20	18	26	0.000
			7 (*t*)	2.07	2.67	7	35	0.025
			14 (PCA)	59.06	30.55	14	28	0.000
	Koskimo	F	18 (all)	81.63	39.95	18	37	0.000
			7 (*t*)	4.74	7.28	7	45	0.000
			14 (PCA)	46.23	30.50	14	39	0.000
West-central Illinois		M	32 (all)	5610.9*	3648.1	32	104	0.000
			23 (*t*)	10.58	10.40	23	113	0.000
			17 (PCA)	2.29	3.30	17	122	0.000
		F	32 (all)	24143.5*	15714.0	32	131	0.000
			23 (*t*)	242.56*	234.16	23	139	0.000
			17 (PCA)	1.38	1.94	17	148	0.016

[1] 'all': all available variables; '*t*': variables suggested by *t*- and/or *t′*-tests to be relatively free of deformation; and 'PCA': variables suggested by PCAs and/or the varimax rotations to be relatively free of deformation.

* The variance/covariance matrix necessary for calculating D^2 was estimated from the reduced number of relevant PCs.

on the entire skull. Empirically, it seems desirable from a statistical viewpoint that the number of variables is seven or more (because, if the variables to be used are of all-or-none or 0-1 type and the number of variables is seven, the probability that any arbitrary two sets of seven variables are consistent by chance is 0.0078 or less than 0.01). In the present study, therefore, efforts were made to obtain as many sets of seven or more variables as possible.

Univariate comparisons between undeformed and deformed skull groups

As reported by previous authors, Tables 1 to 3 on *t*- and *t′*-tests show that many craniofacial measurements are affected by neurocranial deformation. Needless to say on cranial length and breadth, significant difference was found between undeformed and deformed skull groups in the following measurements: minimum frontal breadth, orbital breadth and height (Peruvians); basi-bregmatic height, parietal and occipital chords, cranial base length, foramen magnum length, orbital height, nasal breadth (North Pacific coast); orbital breadth, malar length, frontal subtense and subtense fraction, parietal chord and subtense (west-central Illinois), etc. Some of these are the same as those shown by Brown

Table 20. Significance tests for the differences in means between the undeformed and deformed skull groups of Australian Aboriginal males from the Coobool Creek site.[1]

Variable		Undeformed skulls		Deformed skulls		*t*-value	*t′*-value
		Mean	*n*	Mean	*n*		
V7	Bi-parietal	137.2	13	139.0	9	−1.01	−1.09
V8	Glabella-opisthocranion	194.8	13	196.7	9	−0.56	−0.61
V10	Basion-bregma	140.5	12	142.3	8	−0.68	−0.69
V11	Basion-nasion	105.4	12	103.8	8	1.18	1.32
V12	Basion-nasospinale	103.4	10	101.0	6	1.37	1.65
V13	Basion-prosthion	111.8	9	107.7	6	2.22*	2.51*
V17	Bi-asterion	112.6	13	111.7	9	0.39	0.42
V20	Nasion-bregma	119.5	13	122.9	9	−1.55	−1.50
V21	Frontal subtense height	26.1	13	20.4	9	5.61***	5.39***
V22	Nasion-subtense	55.2	13	52.0	9	1.51	1.43
V27	Minimum temporal lines frontal	95.7	13	94.0	9	0.48	0.44
V29	Bi-zygion	145.5	4	140.0	3	1.65	1.73
V30	Bi-zygomaxilare	101.4	7	102.1	7	−0.29	−0.29
V34	Opisthion-lambda	100.0	13	105.4	9	−2.06	−1.97
V46	Bregma-lambda	118.4	13	120.4	9	−0.77	−0.77
V47	Parietal subtense height	23.5	13	25.4	9	−1.46	−1.41
V62	Nasion-nasospinale	54.2	10	54.6	7	−0.24	−0.25
V63	Nasion-prosthion	74.3	9	75.9	7	−0.89	−0.87
V64	Nasospinale-prosthion	20.1	9	21.3	7	−0.62	−0.64
V65	Nasal breadth	29.8	11	28.9	8	1.43	1.39
V66	Orbital height	31.6	11	31.7	7	−0.06	−0.06
V67	Orbital breadth	44.3	11	43.0	8	1.41	1.55
V81	Alveolar length	65.7	9	63.8	8	1.55	1.53
V83	Alveolar breadth M2	73.1	9	71.9	7	0.66	0.73

[1] Data source: Brown (2001).
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed test.

(1981) in a similar comparison on Melanesians. In Brown's *t*-tests, the variables showing highly significant differences ($P<0.01$) are bi-parietal breadth (equivalent to cranial breadth in Melanesians, Australian Aborigines, etc.), basi-bregmatic height, basion-lambda, frontal chord, frontal subtense, occipital chord, parietal subtense, auriculare-basion, and orbital height.

From the present and previous univariate comparisons, it is clear that, while the craniofacial measurements significantly affected by deformation vary from population to population, as already pointed out by Rhode and Arriaza (2006), basi-bregmatic height, frontal subtense, parietal chord and subtense, and orbital height, in addition to cranial length and breadth, seem to be almost always affected by deformation.

PCAs on the associations of the degree of deformation and craniofacial measurements

PCA assumes approximate normality of the input space distribution, but good low dimensional projection of the data may still be possible if the data are not normally distributed. In this analysis, however, the purpose is not to know the exact extent of associations between the variables dealt with but to know some tendency of covariation of neurocranial deformation with craniofacial measurements. Therefore, the results (Tables 4 to 15) should be interpreted only from such a viewpoint.

Among the PCs and the rotated factors (Facs) from male and female Peruvians (Tables 4 to 7), the PCs or Facs with the highest factor loadings on the degree of deformation are Fac V in males and Fac IV in females. The male Fac V is relatively strongly associated with cranial length, minimum frontal breadth and orbital breadth, and

Table 21. Craniofacial linear measurements common to those of Coobool Creek.[1]

		t- and/or *t′*-test				PCs and/or rotated factors		
		Coobool Creek	Peru	N Pacific coast	WC Illinois	Peru	N Pacific coast	WC Illinois
V7	Bi-parietal	0	1	1		1	1	
V8	Glabella-opisthocranion	0	1	1	0	1	1	1
V10	Basion-bregma	0	0	1		0	0	
V11	Basion-nasion	0	0	1		0	0	
V12	Basion-nasospinale	0	0			0		
V13	Basion-prosthion	1	0	0		0	0	
V17	Bi-asterion	0			0			0
V20	Nasion-bregma	0		0	0		0	1
V21	Frontal subtense height	1			1			1
V22	Nasion-subtense	0			1			1
V27	Minimum temporal lines frontal	0	1		0	1		0
V29	Bi-zygion	0	0	1		0	1	
V30	Bi-zygomaxillare	0			0			0
V34	Opisthion-lambda	0		1	0		0	1
V46	Bregma-lambda	0		1	1		1	0
V47	Parietal subtense height	0			1			0
V62	Nasion-nasospinale	0	0	1	0	0	0	0
V63	Nasion-prosthion	0	0	0		0	0	
V64	Nasospinale-prosthion	0	0			0		
V65	Nasal breadth	0	0	1	0	0	0	1
V66	Orbital height	0	1	1	0	1	0	0
V67	Orbital breadth	0	1	0	1	1	0	1
V81	Alveolar length	0	0	0		0	0	
V83	Alveolar breadth M2	0	0	0		0	0	

[1] 0: not affected by deformation; 1: affected by deformation.

the female Fac IV is associated with cranial breadth and orbital height. These findings are consistent with those shown by the above univariate comparisons in Peruvians.

In the case of American Native males and females from North Pacific coast (Tables 8 to 11), both male and female data show that Fac II is relatively strongly associated with neurocranial deformation and, simultaneously, with cranial length and breadth, parietal chord, and bizygomatic breadth. This is nearly the same tendency (except for bizygomatic breadth) as those shown by Mizoguchi's (1991) PCAs of the between-group variance/covariance matrices obtained by the use of Takeuchi and Yanai's (1972) dummy variable method from the same male and female samples (Oetteking, 1930), and not inconsistent with the above univariate comparisons between the undeformed group and the Cowichan, Chinook and Koskimo tribes.

The data of American Natives from west-central Illinois contain information on four kinds of deformation: frontal, bifrontal, occipital, and lambdoid flattening. Tables 12 to 15 suggest that there are different tendencies between males and females in the way deformation influences craniofacial measurements. There are only two relatively strong associations common to both males and females. The first is the association between frontal flattening and frontal subtense suggested by Fac V of males (Table 13) and PC II of females (Table 14), and the other is the association between occipital flattening and cranial length indicated by Fac IV of males (Table 13) and PC II and Fac V of females (Tables 14 and 15). The results of these multivariate analyses are considerably different from those of the above univariate comparisons. This may be due partly to the fact of having pooled the individuals from different periods of about A.D. 600 to A.D. 1300 in the

Table 22. D^2 distances between undeformed and deformed male samples estimated using the variables suggested by t- and/or t'-tests and PCAs and/or the varimax rotations to be relatively free of deformation.[1]

Sample	D^2	F	First d.f.	Second d.f.	Probability
1) Nine variables suggested by both t/t'-tests and PCAs/rotations of ancient Peruvians					
Coobool Creek: Undeformed – Deformed	1.36	0.29	9	7	0.956
Ancient Peruvians: Undeformed – Deformed	2.71	6.54	9	92	0.000
2) Five variables suggested by t/t'-tests of North Pacific coast American Natives					
Coobool Creek: Undeformed – Deformed	1.92	1.28	5	12	0.335
Undeformed NPC[2] – Cowichan	0.87	3.84	5	108	0.003
– Chinook	0.13	0.49	5	81	0.784
– Koskimo	1.39	6.54	5	126	0.000
3) Eleven variables suggested by PCAs/rotations of North Pacific coast American Natives					
Coobool Creek: Undeformed – Deformed	4.13	0.72	11	7	0.702
Undeformed NPC[2] – Cowichan	3.72	7.02	11	100	0.000
– Chinook	6.47	10.59	11	76	0.000
– Koskimo	6.20	12.65	11	121	0.000
4) Nine variables suggested by t/t'-tests of west-central Illinois American Natives					
Coobool Creek: Undeformed – Deformed	3.51	1.04	9	10	0.472
West-central Illinois: Undeformed – Deformed	0.56	1.52	9	126	0.145
5) Seven variables suggested by PCAs/rotations of west-central Illinois American Natives					
Coobool Creek: Undeformed – Deformed	1.05	0.45	7	11	0.852
West-central Illinois: Undeformed – Deformed	1.14	4.15	7	131	0.000

[1] D^2 distances were estimated using the mean within-group variance/covariance matrices obtained from two Australian Aboriginal male samples, Murray Valley and Swanport. The mean within-group variance/covariance matrices are presented in Appendices 1, 3, 5, 7, and 9.

[2] NPC: American Natives from the North Pacific coast.

present study. Such a discrepancy between univariate and multivariate analyses is possible if the type of deformation, or any craniofacial dimensions, show distinctive chronologically demarcated patterns.

Craniofacial variables relatively free of neurocranial deformation

From the lists of variables significantly or relatively strongly affected by neurocranial deformation suggested through t- and/or t'-tests and PCAs and/or varimax rotations in the three samples (Tables 16 to 18), some sets of variables relatively free of neurocranial deformation (Table 21) were determined so that the undeformed and deformed male skull groups of Coobool Creek are classified as phylogenetically equivalent samples. The resultant sets of variables are as follows.

1) Nine variables suggested by both of the univariate and multivariate analyses of Peruvians: basi-bregmatic height (V10 in Brown, 2001), cranial base length (V11), basion-nasospinale (V12), nasal height (V62), upper facial height (V63), nasospinale-prosthion (V64), nasal breadth (V65), alveolar length (V81), and alveolar breadth (V83).
2) Five variables suggested by the univariate analyses of American Natives from North Pacific coast: frontal chord (V20), upper facial height (V63), orbital breadth (V67), alveolar length (V81), and alveolar breadth (V83).
3) Eleven variables suggested by the multivariate analyses of American Natives from North Pacific coast: basi-bregmatic height (V10), cranial base length (V11), frontal chord (V20), occipital chord (V34), nasal height (V62), upper facial height (V63), nasal breadth (V65), orbital height (V66), orbital breadth (V67), alveolar length (V81), and alveolar breadth (V83).
4) Nine variables suggested by the univariate analyses of American Natives from west-central Illinois: cranial length (V8), biasterionic

Table 23. Typicality probabilities of some Australian Pleistocene human fossils to the Coobool Creek male sample estimated using craniofacial measurements relatively free of deformation.

Individual specimen	D^2 distance	F-value	1st d.f.	2nd d.f.	Typ. prob.
Nine variables[1]:					
Cohuna	1.15	0.06	9	8	0.9998
Keilor	10.73	0.56	9	8	0.7953
Eleven variables[1]:					
Keilor	17.69	0.68	11	8	0.7300
Seven variables[2]:					
Cohuna	10.84	1.01	7	13	0.4677
Keilor	8.30	0.77	7	13	0.6207
Lake Nitchie	13.20	1.23	7	13	0.3547
Kow Swamp 5	11.92	1.11	7	13	0.4125

[1] The degree of freedom for the elements of the mean within-group varaince/covariance matrix varies from 67 to 74.

[2] The degree of freedom for the elements of the mean within-group varaince/covariance matrix varies from 65 to 74.

breadth (V17), frontal chord (V20), minimum frontal breadth (V27), middle facial breadth (V30), occipital chord (V34), nasal height (V62), nasal breadth (V65), and orbital height (V66).

5) Seven variables suggested by the multivariate analyses of American Natives from west-central Illinois: biasterionic breadth (V17), minimum frontal breadth (V27), middle facial breadth (V30), parietal chord (V46), parietal subtense (V47), nasal height (V62), and orbital height (V66).

The significance tests of D^2 distances between undeformed and deformed groups (Table 22) show that all the above sets of variables are effective in excluding the influence of deformation on distance analyses for the Coobool Creek sample. However, most of D^2 distances between the undeformed and deformed groups of original American Natives are significantly different from zero at the 5% level or less (Table 22), although they are far smaller than the corresponding D^2 distances based on all the available variables including those susceptible to deformation (Table 19). This result may be due not only to the larger sample sizes of American Natives than that of Coobool Creek but also, in part, to the greater degree of defomation in the native American samples than in Coobool Creek.

Typicality probabilities to the Coobool Creek population

Among the above-mentioned five sets of variables, the first, third, and fifth sets of variables showed relatively high probabilities of 0.702 to 0.956 for the null hypothesis of D^2 between the undeformed and deformed skull groups of Coobool Creek. Although these high probabilities seem due to the small sample size of Coobool Creek, the undeformed and deformed skulls were grouped into one sample, and typicality probabilities to the Coobool Creek sample were estimated for Keilor and some other Australian Pleistocene fossils to which the three sets of variables selected here were available.

As a result, it was found that Keilor had relatively high typicality probabilities of 0.62 to 0.80 in the three sets of variables (Table 23), meaning that we can treat Coobool Creek as the original population to which Keilor belongs.

The typicality probability of Cohuna to Coobool Creek was extremely close to 1.0 in the first set of variables (nine variables), but, in the fifth set (seven variables), 0.47. In this case, more examinations seem to be necessary.

Regarding Lake Nitchie and Kow Swamp 5, their typicality probabilities based on the fifth set of variables are lower than that of Cohuna. These should also be examined furthermore using other sets of variables in the future.

Future perspective

In the paleoanthropological field where we are obliged to use morphological information instead of DNA, it is very important to exclude the influence of artificial cranial deformation from the total complex of morphological characteristics. However, as discussed above, it is extremely difficult to find an ideal sets of variables free of the influence of deformation. Nevertheless, we will continue to make efforts at finding more effective sets of variables to clarify the affinities of the populations in question, as the scarcity of fossil evidence means that methods have to be found to utilize as much of the available information as possible.

In the present study, it was found that five sets of variables suggested to be relatively free of deformation by the analyses based on three relatively large samples were applicable to the Coobool Creek sample. As easily imagined, however, these dimensions can not necessarily be utilized for classifying other samples where different methods of deforming the shape of a child's head have been employed. But, in the three American Native samples examined here, both anteroposteriorly and conically deformed skulls as well as their variants are contained. For the present, therefore, if the variables significantly or relatively strongly affected by deformation shown in Tables 16 to 18 are excluded from the sets of variables to be used, it seems possible to say that the sets of remaining variables may be used to reasonably classify the relevant populations.

Summary and Conclusions

In order to exclude the influence of artificial neurocranial deformation from a set of craniofacial measurements, t- and t'-tests for the differences in means between undeformd and deformed skull groups and principal component analyses and varimax rotations for the associations of the degree of deformation with craniofacial measurements were conducted using three relatively large American Native samples. As a result, five sets of variables relatively free of deformation were obtained for the classification of the Australian Coobool Creek sample. Using such sets of variables, Mahalanobis' D^2 distances were estimated between the undeformed and deformed skull groups of Coobool Creek, and they were found not to be significantly different from zero. The typicality probabilities based on the three sets of variables showing the highest probabilities for the null hypothesis of D^2 showed that Keilor belongs to the Coobool Creek population at the typicality probability of 0.62 to 0.80. In this way, if the variables significantly or relatively strongly affected by deformation are excluded from the sets of variables to be used, the sets of remaining variables may be useful for the reasonable classification of the relevant populations.

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Appendix 1. Mean within-group variance/covariance matrix for the nine variables suggested by both univariate and multivariate analyses of Peruvians to be relatively free of neurocranial deformation.[1]

Variable[2]	V10	V11	V12	V62	V63	V64	V65	V81	V83
Basi-bregmatic height (V10)	19.420	5.313	1.697	−0.257	2.156	2.326	−0.880	0.354	1.288
Cranial base length (V11)	5.313	11.640	9.952	2.311	5.336	2.679	1.646	5.626	3.322
Basion-nasospinale (V12)	1.697	9.952	14.910	1.606	3.701	1.465	2.147	6.869	2.076
Nasal height (V62)	−0.257	2.311	1.606	6.982	7.462	0.280	0.695	1.455	2.928
Upper facial height (V63)	2.156	5.336	3.701	7.462	14.680	7.050	−0.272	4.247	4.503
Nasospinale-prosthion (V64)	2.326	2.679	1.465	0.280	7.050	7.299	−1.110	2.719	1.616
Nasal breadth (V65)	−0.880	1.646	2.147	0.695	−0.272	−1.110	3.472	2.273	2.403
Alveolar length (V81)	0.354	5.626	6.869	1.455	4.247	2.719	2.273	13.630	4.646
Alveolar breadth (V83)	1.288	3.322	2.076	2.928	4.503	1.616	2.403	4.646	10.690

[1] Obtained from two Australian Aboriginal male samples, Murray Valley and Swanport.
[2] Variable number is according to Brown (2001).

Appendix 2. Degrees of freedom for the elements of the mean within-group variance/covariance matrix shown in Appendix 1.[1]

Variable[2]	V10	V11	V12	V62	V63	V64	V65	V81	V83
Basi-bregmatic height (V10)	71	71	71	70	70	70	67	71	70
Cranial base length (V11)	71	71	71	70	70	70	67	71	70
Basion-nasospinale (V12)	71	71	71	70	70	70	67	71	70
Nasal height (V62)	70	70	70	73	72	72	69	73	72
Upper facial height (V63)	70	70	70	72	73	73	69	73	72
Nasospinale-prosthion (V64)	70	70	70	72	73	73	69	73	72
Nasal breadth (V65)	67	67	67	69	69	69	70	70	69
Alveolar length (V81)	71	71	71	73	73	73	70	74	73
Alveolar breadth (V83)	70	70	70	72	72	72	69	73	73

[1] Obtained from two Australian Aboriginal male samples, Murray Valley and Swanport.
[2] Variable number is according to Brown (2001).

Appendix 3. Mean within-group variance/covariance matrix for the five variables suggested by the univariate analyses of American Natives from North Pacific coast to be relatively free of neurocranial deformation.[1]

Variable[2]	V20	V63	V67	V81	V83
Frontal chord (V20)	15.550	2.139	0.891	2.889	1.681
Upper facial height (V63)	2.139	14.680	0.711	4.247	4.503
Orbital breadth (V67)	0.891	0.711	3.049	2.664	1.737
Alveolar length (V81)	2.889	4.247	2.664	13.630	4.646
Alveolar breadth (V83)	1.681	4.503	1.737	4.646	10.690

[1] Obtained from two Australian Aboriginal male samples, Murray Valley and Swanport.
[2] Variable number is according to Brown (2001).

Appendix 4. Degrees of freedom for the elements of the mean within-group variance/covariance matrix shown in Appendix 3.[1]

Variable[2]	V20	V63	V67	V81	V83
Frontal chord (V20)	74	73	70	74	73
Upper facial height (V63)	73	73	69	73	72
Orbital breadth (V67)	70	69	70	70	69
Alveolar length (V81)	74	73	70	74	73
Alveolar breadth (V83)	73	72	69	73	73

[1] Obtained from two Australian Aboriginal male samples, Murray Valley and Swanport.
[2] Variable number is according to Brown (2001).

Appendix 5. Mean within-group variance/covariance matrix for the eleven variables suggested by the multivariate analyses of American Natives from North Pacific coast to be relatively free of neurocranial deformation.[1]

Variable[2]	V10	V11	V20	V34	V62	V63	V65	V66	V67	V81	V83
Basi-bregmatic height (V10)	19.420	5.313	8.658	5.638	−0.257	2.156	−0.880	−0.627	−0.070	0.354	1.288
Cranial base length (V11)	5.313	11.640	4.466	2.027	2.311	5.336	1.646	0.843	1.891	5.626	3.322
Frontal chord (V20)	8.658	4.466	15.550	5.431	0.468	2.139	0.300	0.396	0.891	2.889	1.681
Occipital chord (V34)	5.638	2.027	5.431	14.490	0.202	2.504	−1.231	−1.748	0.081	3.376	1.614
Nasal height (V62)	−0.257	2.311	0.468	0.202	6.982	7.462	0.695	2.059	0.737	1.455	2.928
Upper facial height (V63)	2.156	5.336	2.139	2.504	7.462	14.680	−0.272	3.114	0.711	4.247	4.503
Nasal breadth (V65)	−0.880	1.646	0.300	−1.231	0.695	−0.272	3.472	0.734	0.750	2.273	2.403
Orbital height (V66)	−0.627	0.843	0.396	−1.748	2.059	3.114	0.734	5.959	1.135	0.103	0.810
Orbital breadth (V67)	−0.070	1.891	0.891	0.081	0.737	0.711	0.750	1.135	3.049	2.664	1.737
Alveolar length (V81)	0.354	5.626	2.889	3.376	1.455	4.247	2.273	0.103	2.664	13.630	4.646
Alveolar breadth (V83)	1.288	3.322	1.681	1.614	2.928	4.503	2.403	0.810	1.737	4.646	10.690

[1] Obtained from two Australian Aboriginal male samples, Murray Valley and Swanport.
[2] Variable number is according to Brown (2001).

Appendix 6. Degrees of freedom for the elements of the mean within-group variance/covariance matrix shown in Appendix 5.[1]

Variable[2]	V10	V11	V20	V34	V62	V63	V65	V66	V67	V81	V83
Basi-bregmatic height (V10)	71	71	71	67	70	70	67	71	67	71	70
Cranial base length (V11)	71	71	71	67	70	70	67	71	67	71	70
Frontal chord (V20)	71	71	74	69	73	73	70	74	70	74	73
Occipital chord (V34)	67	67	69	69	68	68	69	69	69	69	68
Nasal height (V62)	70	70	73	68	73	72	69	73	69	73	72
Upper facial height (V63)	70	70	73	68	72	73	69	73	69	73	72
Nasal breadth (V65)	67	67	70	69	69	69	70	70	70	70	69
Orbital height (V66)	71	71	74	69	73	73	70	74	70	74	73
Orbital breadth (V67)	67	67	70	69	69	69	70	70	70	70	69
Alveolar length (V81)	71	71	74	69	73	73	70	74	70	74	73
Alveolar breadth (V83)	70	70	73	68	72	72	69	73	69	73	73

[1] Obtained from two Australian Aboriginal male samples, Murray Valley and Swanport.
[2] Variable number is according to Brown (2001).

Appendix 7. Mean within-group variance/covariance matrix for the nine variables suggested by the univariate analyses of American Natives from west-central Illinois to be relatively free of neurocranial deformation.[1]

Variable[2]	V8	V17	V20	V27	V30	V34	V62	V65	V66
Cranial length (V8)	32.470	8.924	11.360	15.450	4.865	8.903	1.961	0.534	2.226
Biasterionic breadth (V17)	8.924	15.510	5.643	11.790	−0.759	4.132	−0.437	−1.042	1.261
Frontal chord (V20)	11.360	5.643	15.550	12.560	2.782	5.431	0.468	0.300	0.396
Minimum frontal breadth (V27)	15.450	11.790	12.560	73.640	−3.334	3.864	−7.299	−2.961	0.320
Middle facial breadth (V30)	4.865	−0.759	2.782	−3.334	16.430	1.663	1.503	2.925	1.555
Occipital chord (V34)	8.903	4.132	5.431	3.864	1.663	14.490	0.202	−1.231	−1.748
Nasal height (V62)	1.961	−0.437	0.468	−7.299	1.503	0.202	6.982	0.695	2.059
Nasal breadth (V65)	0.534	−1.042	0.300	−2.961	2.925	−1.231	0.695	3.472	0.734
Orbital height (V66)	2.226	1.261	0.396	0.320	1.555	−1.748	2.059	0.734	5.959

[1] Obtained from two Australian Aboriginal male samples, Murray Valley and Swanport.
[2] Variable number is according to Brown (2001).

Appendix 8. Degrees of freedom for the elements of the mean within-group variance/covariance matrix shown in Appendix 7.[1]

Variable[2]	V8	V17	V20	V27	V30	V34	V62	V65	V66
Cranial length (V8)	74	67	74	74	74	69	73	70	74
Biasterionic breadth (V17)	67	67	67	67	67	66	66	67	67
Frontal chord (V20)	74	67	74	74	74	69	73	70	74
Minimum frontal breadth (V27)	74	67	74	74	74	69	73	70	74
Middle facial breadth (V30)	74	67	74	74	74	69	73	70	74
Occipital chord (V34)	69	66	69	69	69	69	68	69	69
Nasal height (V62)	73	66	73	73	73	68	73	69	73
Nasal breadth (V65)	70	67	70	70	70	69	69	70	70
Orbital height (V66)	74	67	74	74	74	69	73	70	74

[1] Obtained from two Australian Aboriginal male samples, Murray Valley and Swanport.
[2] Variable number is according to Brown (2001).

Appendix 9. Mean within-group variance/covariance matrix for the seven variables suggested by the multivariate analyses of American Natives from west-central Illinois to be relatively free of neurocranial deformation.[1]

Variable[2]	V17	V27	V30	V46	V47	V62	V66
Biasterionic breadth (V17)	15.510	11.790	−0.759	5.418	2.138	−0.437	1.261
Minimum frontal breadth (V27)	11.790	73.640	−3.334	9.978	3.333	−7.299	0.320
Middle facial breadth (V30)	−0.759	−3.334	16.430	5.640	0.792	1.503	1.555
Parietal chord (V46)	5.418	9.978	5.640	26.910	7.965	1.531	1.750
Parietal subtense (V47)	2.138	3.333	0.792	7.965	5.387	1.197	1.300
Nasal height (V62)	−0.437	−7.299	1.503	1.531	1.197	6.982	2.059
Orbital height (V66)	1.261	0.320	1.555	1.750	1.300	2.059	5.959

[1] Obtained from two Australian Aboriginal male samples, Murray Valley and Swanport.
[2] Variable number is according to Brown (2001).

Appendix 10. Degrees of freedom for the elements of the mean within-group variance/covariance matrix shown in Appendix 9.[1]

Variable[2]	V17	V27	V30	V46	V47	V62	V66
Biasterionic breadth (V17)	67	67	67	67	65	66	67
Minimum frontal breadth (V27)	67	74	74	69	67	73	74
Middle facial breadth (V30)	67	74	74	69	67	73	74
Parietal chord (V46)	67	69	69	69	67	68	69
Parietal subtense (V47)	65	67	67	67	67	66	67
Nasal height (V62)	66	73	73	68	66	73	73
Orbital height (V66)	67	74	74	69	67	73	74

[1] Obtained from two Australian Aboriginal male samples, Murray Valley and Swanport.
[2] Variable number is according to Brown (2001).