

# Variation in the cranial base orientation and facial skeleton in dry skulls sampled from three major populations

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**SUMMARY** The aim of this study was to analyse the effects of cranial base orientation on the morphology of the craniofacial system in human populations. Three geographically distant populations from Europe (72), Africa (48) and Asia (24) were chosen. Five angular and two linear variables from the cranial base component and six angular and six linear variables from the facial component based on two reference lines of the vertical posterior maxillary and Frankfort horizontal planes were measured.

The European sample presented dolichofacial individuals with a larger face height and a smaller face depth derived from a raised cranial base and facial cranium orientation which tended to be similar to the Asian sample. The African sample presented brachyfacial individuals with a reduced face height and a larger face depth as a result of a lowered cranial base and facial cranium orientation. The Asian sample presented dolichofacial individuals with a larger face height and depth due to a raised cranial base and facial cranium orientation.

The findings of this study suggest that cranial base orientation and posterior cranial base length appear to be valid discriminating factors between different human populations.

## Introduction

Differences in craniofacial morphology between human populations have been established on dry skulls as well as on the living (Lundström and Lysell, 1953; Krzypow *et al.*, 1974; Argyropoulos *et al.*, 1989; Inoue *et al.*, 1992; Hanihara, 1993; Luther, 1993; Jantz, 2001). There is evidence that this variation in craniofacial morphology results from both epigenetic and phylogenetic factors, although the interplay between these two processes is still unclear.

The craniofacial complex is composed of three principal regions: the cranial vault, the cranial base and the facial cranium. The cranial base comprises several skeletal units and is characterized as not only supporting the brain but is also the connecting element between the brain and the functional organs of mastication, respiration, balance, sight, hearing, taste, olfaction and the cervical spine. The variation between populations in cranial base orientation and flexion derives from differences in natural head posture (NHP), evolutionary history and genetic origin (Solow and Tallgren, 1977; Cole, 1988; Lundström and Cooke, 1991; Ross and Henneberg, 1995; Grave *et al.*, 1999).

The naso-maxillary complex and the mandible comprise the greater part of the facial region, such that they support most of the functional organs in its region. Individual facial patterns have close relationships with neuromuscular activities (Tallgren, 1970; Ingervall and Thilander, 1974). For instance, in a group of patients

with impaired breathing, the morphological effects of anomalous biomechanics in the region of the facial skeleton are expressed as a longer face and a greater total mandibular length and more prominent antegonial notching (Cheng *et al.*, 1988). The orientation of the head is also closely related to craniofacial morphology as a result of head posture (Solow and Tallgren, 1977; Cole, 1988; Leitao and Nanda, 2000).

Enlow and Hans (1996) proposed that differences in craniofacial morphology among living populations may be due to variation in the orientation of the cranial base and the facial cranium as a whole. According to this model, spatial configuration of the basicranium produces, in turn, correlated changes in the configuration of the face, e.g. dolichofacial and brachyfacial patterns. Enlow (1990) used the vertical posterior maxillary (PM) plane as a natural anatomical and morphological boundary that separates the anterior and posterior face. The anterior face is composed of the anterior cranial fossa, the ethmo-maxillary complex and the corpus of the mandible, whereas the middle cranial fossa, post-maxillary compartment and the ramus constitute the posterior face. Enlow and Azuma (1975) stated that the PM plane retains the basic relationship between the series of counterparts in front of and behind it throughout the growth process, and is approximately perpendicular to the neutral axis of the orbit. This statement has recently been tested by McCarthy and Lieberman (2001), confirming the accuracy of the PM plane as a vertical line perpendicular to the orbital axis.

According to this evidence, the PM plane, used as a vertical reference line, is suitable for the study of structural differences of the craniofacial complex between populations. The aim of this study was to analyse the effects that cranial base orientation may produce on the morphology of the craniofacial system in distant human populations.

### Materials and methods

Three geographically distant populations were chosen for this study: European, African and Asian.

The European sample were from Christ Church Spitalfields, London, UK. The 72 skulls of documented sex, 36 females and 36 males, examined date from the 18th and 19th centuries and are presently housed at the Natural History Museum, London. They lived in east London, an area renowned as the centre of the London silk industry. They were a middle-class group, largely of high nutritional status and, by the standards of the day, lived in comfortable conditions (Cox and Scott, 1992; Molleson *et al.*, 1993).

The African sample comprised 48 skulls, 22 females and 26 males, of the 19th-century Ibo tribe (West Africa), presently housed at the Natural History Museum, London. The area where they lived was located on both sides of the River Niger, southern Nigeria. They were an agricultural people, farming yam, cassava and taro in tropical rain forests (Middleton and Rassam, 1995). The sexing of the skulls from Africa was determined by two of the authors (KK and AR).

The Asian sample comprised 24 skulls, eight females and 16 males, from the Koganei Collection of named Hokkaido Ainu skeletons (18th and 19th centuries) in the University Museum, University of Tokyo (Inoue, 1987). They were a northern aboriginal population in Japan and were a hunting and plant collecting people. No direct evidence of cultivation has been found (Roksandic *et al.*, 1988).

The skulls examined were selected on the basis of the following criteria: (1) no cranial deformity; (2) no deformity of the jaw bones or dental arches; (3) a clinically acceptable occlusion with a skeletal Class I jaw relationship. The teeth were replaced and secured in their sockets where necessary and the occlusions were checked to confirm that the repositioning was correct. The sample size was determined by the availability of suitable skulls in the collection.

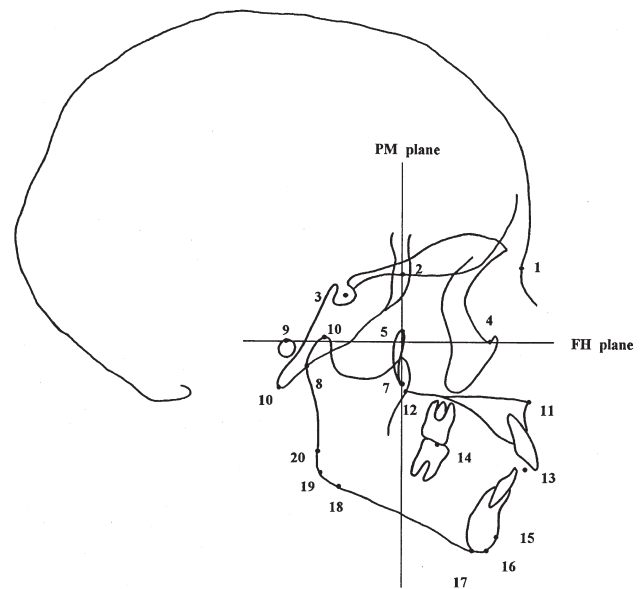
### Cephalograms

A portable X-ray machine (3002FTA, Andrex Radiation Products AS, Copenhagen, Denmark) with a cephalostat for dry skull material was used in the study. The film-focus distance and the distance from the mid-sagittal plane of the skull to the film were 150 and 15 cm,

respectively. No correction was made for enlargement of linear measurements. The lateral cephalograms of the European and African samples were taken at 80 kV, 3 mA and 60 seconds. The lateral cephalograms of the Asian sample used in this study came from a radiographic collection which had been taken using the same technique as the European and African samples (Inoue, 1987).

### Cephalometric analysis

Once the radiographs had been produced, tracings were carried out. In total, 20 cephalometric landmarks were marked directly on each traced film, and digitized using the PalaeoVision system, which consisted of a colour digital imaging system (Kontron ProgRes5012, Munich, Germany), of the Natural History Museum, London (Figure 1). The identified landmarks were then used to estimate angles and distances. The PM plane and the Frankfort horizontal (FH) plane were selected as baselines for analysis of differences in the cranial base and facial cranium components between samples. The PM plane was in accordance with the standard definition given by Enlow (1990). Angular and linear measurements were classified into two components: the cranial base and the face. Five angular and two linear variables from the cranial base component, and six angular



**Figure 1** Cephalometric landmarks. (1) N, nasion; (2) Se, sphenoidale; (3) S, sella turcica; (4) Or, orbitale; (5) PMs, superior point of the pterygo-maxillary fissure; (6) PMi, inferior point of the pterygo-maxillary fissure; (7) Co, condylion; (8) Ar, articulare; (9) Po, porion; (10) Ba, basion; (11) ANS, anterior nasal spine; (12) PNS, posterior nasal spine; (13) I, midpoint between the upper and lower incisal edges; (14) P, midpoint between the occlusal surface of the upper and lower first molars; (15) Pog, pogonion; (16) Gn, gnathion; (17) Me, menton; (18) inferior point of the gonial area; (19) Go, gonion; (20) posterior point of the gonial area.

and six linear variables from the facial component were measured (Table 1).

### Measurement error

The method error due to marking and digitizing the cephalometric landmarks was assessed after an interval of 2 weeks, using a second series of tracings of a selection of 10 films from each sample. The linear and angular method error variances were found to be less than 5 per cent. Mean, standard deviations, and ANOVA were used in the analysis of sample differences (Tables 2 and 3). Using the statistical package for social sciences (SPSS Inc., Chicago, USA), statistical results for each linear and angular measurement were obtained. The normal distribution of each measurement was established. ANOVA was used to identify the level of significance of any difference between the readings for each sample. A significance level of  $P < 0.05$  was used.

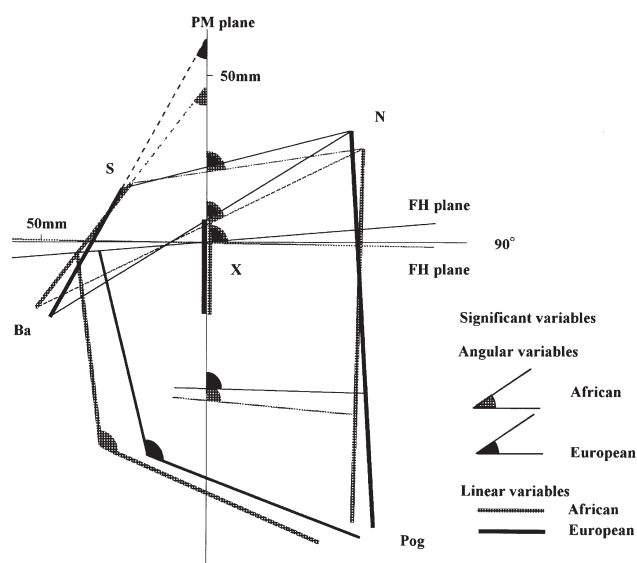
## Results

### Sample differences

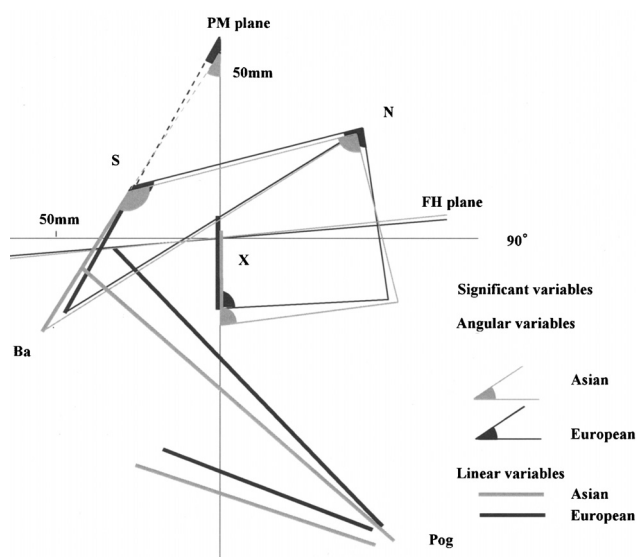
Schematic drawings of the statistically significant variables identified in Table 2 are given in Figures 2–4 which are based on the distances (mm) between the intersection (X) of the PM and FH planes and five lines of craniofacial measurements on the y axis shown in Table 3. They illustrate the linear and angular measurements that

**Table 1** Definition of angular and linear measurements.

Cranial base	
Angular measurements	
SN–SB	Posterior maxillary plane sella–nasion to sella–basion
PM–NB	Posterior maxillary plane to nasion–basion line
PM–FH	Posterior maxillary plane to Frankfort horizontal plane
PM–SB	Posterior maxillary plane to sella–basion
PM–SN	Posterior maxillary plane to sella–nasion
Linear measurements	
S–BaL	Sella–basion length
S–NL	Sella–nasion length
Facial skeleton	
Angular measurements	
PM–PI	Posterior maxillary plane to palatal plane
PM–Oc	Posterior maxillary plane to occlusal plane
PM–Md	Posterior maxillary plane to mandibular plane
NB–NA	Nasion–basion to nasion–anterior nasal spine
NB–NPog	Nasion–basion to nasion–pogonion
GoA	Gonial angle
Linear measurements	
MdL	Mandibular length
MdBL	Mandibular body length
RmH	Ramus height
MxL	Maxillary length
MxH	Maxillary height
N–PogL	Nasion–pogonion length



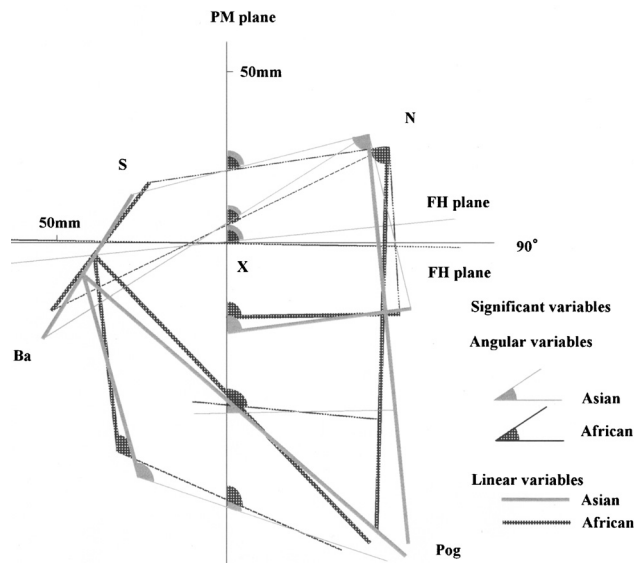
**Figure 2** Significant differences between African and European samples.



**Figure 3** Significant differences between European and Asian samples.

clarify the cranium and jaw configuration. The results are summarized below.

*European sample compared with the African sample (Figure 2, Table 2).* The cranial base angle (SN–SB) was similar in the two groups. The posterior cranial base length (S–Ba) was significantly smaller in the Europeans than in the Africans. A raised cranial base orientation with significantly decreased PM–NB, PM–FH, PM–SB and PM–SN was observed in the Europeans. The orientation of the occlusal plane (PM–Oc) was significantly smaller in the European than in the African group. However, even though these angles were lower



**Figure 4** Significant differences between African and Asian samples.

in the European group, facial orientation, as represented by the PM–Pl and PM–Md plane inclination, was not significantly different between these two samples. A larger face height with a significantly increased RmH, MxH and N–PogL was observed in the Europeans. The same was valid for MdbL and GoA.

*European sample compared with the Asian sample (Figure 3, Table 2).* SN–SB was significantly smaller in the Europeans than in the Asians. A raised and smaller posterior cranial base with significantly decreased PM–SB and smaller SB was observed in the European sample. The orientations of the Oc and Md planes were not significantly different. A smaller mid-face height with decreased PM–Pl and smaller MxH, a smaller face depth with decreased NB–NPog and smaller MdL and MdbL and mandibular retrognathism with decreased NB–NPog were observed in the European sample. Face height was not significantly different between these two groups.

*African sample compared with the Asian sample (Figure 4, Table 2).* SN–SB was similar in the two groups. S–Ba was significantly smaller in the Africans than in the Asian sample. A lowered cranial base orientation with significantly increased PM–NB, PM–FH, PM–SN and a lowered facial orientation with significantly increased PM–Pl, PM–Oc and PM–Md were observed in the Africans. A smaller face height with significantly decreased MdL, RmH, N–PogL and GoA, and a smaller middle and lower face depth with significantly decreased NB–NPog and smaller MxL and MdL were found in the African sample.

The findings can be interpreted as indicating that the Europeans were dolichofacial individuals with a larger face height and a smaller face depth derived from a

raised cranial base and facial cranium orientation tends to be similar to the Asian sample, whereas the African sample was characterized by a brachyfacial pattern with a reduced face height and a larger face depth derived from a lowered cranial base and facial cranium orientation. The Asian sample were dolichofacial individuals with a larger face height and depth derived from a raised cranial base and facial cranium orientation similar to the European sample.

## Discussion

### *Cranial base*

Previous work has demonstrated that the cranial base angle is similar within populations (Argyropoulos *et al.*, 1989; Varrel, 1990), but varies between populations (Anderson and Popovich, 1983). Argyropoulos *et al.* (1989), for instance, found a remarkable similarity in the cranial base angle between ancient Greek skulls (1800–1200 BC) and present-day Greek individuals. They suggested that the cranial base angle indicates a genetic homogeneity. The findings of the present study show that there was a significant difference between the cranial base angle of the European and Asian samples, while a considerable similarity was found between the European and African samples. However, it is insufficient to conclude that the population difference or similarity of the cranial base angle in this study reflects the degree of genetic homogeneity of the samples.

The correlation between sella–nasion orientation based on NHP and the facial profile from Caucasian and Chinese children has been described by Lundström and Cooke (1991). They reported that the sella–nasion line superimposed on sella and the true vertical was found to be inclined more forward and upward in Chinese than in Caucasian children. Solow *et al.* (1982) compared the head posture and craniofacial morphology of young adult Australian aboriginals and a Danish population. They found that NHP was lower and the posterior cranial base was shorter in the Australian aborigines. In the present study, the European and Asian samples had a raised cranial base orientation compared with the African sample. The Africans had a lowered cranial base orientation and a short posterior cranial base length compared with the Asians. The findings of this study suggest that cranial base orientation and posterior cranial base length appear to be valid major discriminating factors between different populations.

### *Facial skeleton*

According to Enlow and Hans (1996), the cranial base is the bridge between the neuro- and facial cranium upon which the face is constructed, so that variations in the cranial base are associated with corresponding variations in the form of the face. Kasai *et al.* (1993)

**Table 2** Cephalometric variables of the cranial base and facial skeleton.

	African sample ( <i>n</i> = 48)		European sample ( <i>n</i> = 72)		Asian sample ( <i>n</i> = 24)	
	Mean	SD	Mean	SD	Mean	SD
<b>Cranial base</b>						
Angular measurements (degrees)						
SN-SB	135.36	3.76	135.20	5.11	138.08	4.43
PM-NB	63.44	4.08	58.25	4.19	59.13	2.94
PM-FH	90.53	4.46	84.83	3.81	83.83	3.57
PM-SB	36.43	5.02	30.56	5.31	34.08	4.22
PM-SN	81.05	4.16	75.49	4.47	76.08	3.54
Linear measurements (mm)						
S-BaL	474.35	32.86	442.61	30.75	508.08	42.69
S-NL	715.64	37.99	705.13	42.04	720.58	36.43
<b>Facial skeleton</b>						
Angular measurements (degrees)						
PM-Pl	89.28	4.77	86.24	3.86	83.00	3.55
PM-Oc	95.18	6.90	90.83	6.17	88.68	5.34
PM-Md	111.96	7.97	110.71	6.24	107.71	5.81
NB-NA	68.81	3.54	67.63	3.70	71.38	3.13
NB-NPog	62.44	3.10	61.60	3.57	63.58	3.48
GoA	117.55	6.51	124.98	7.69	122.08	6.88
Linear measurements (mm)						
MdL	1189.21	67.62	1204.52	73.54	1272.88	60.11
MdBL	744.37	56.31	698.74	50.82	774.08	33.75
RmH	603.50	58.06	633.94	65.39	646.83	55.70
MxL	518.97	31.67	523.96	35.86	543.46	30.28
MxH	290.55	25.36	305.69	28.01	284.04	26.00
N-PogL	1141.00	92.30	1207.40	90.10	1218.42	72.63

\**P* < 0.05; \*\**P* < 0.01; \*\*\**P* < 0.001.

SD, standard deviation.

investigated craniofacial morphology in Japanese and Australian aboriginal populations living between 100 and 500 years ago. They reported that the Australian aboriginals were characterized as brachyfacial with a larger posterior and smaller anterior face height, with the Japanese tending to be more dolichofacial. In the present study, the European sample were dolichofacial with a raised cranial base and facial cranium orientation similar to the Asian individuals. The African sample were brachyfacial with a lowered cranial base and facial

cranium orientation. The Asian sample were dolichofacial with a raised cranial base and facial orientation similar to the European sample. The results of this study seem to confirm that the cranial base and facial skeleton are highly integrated. Thus, specific patterns of the facial skeleton are associated with the variation in the configuration of the cranial base orientation which shows integrated variation of the craniofacial complex as a whole. A lowered inclination of the cranial base is accompanied by a relatively short face orientated

**Table 3** Distances (mm) between X and five lines of craniofacial measurements on the y axis.

	African sample		European sample		Asian sample	
	Mean	SD	Mean	SD	Mean	SD
X to SN	21.11	1.87	22.60	2.29	21.65	2.35
X to NB	4.96	2.04	7.10	1.83	5.55	1.84
X to Pl	23.18	2.50	22.59	2.26	26.73	2.15
X to Oc	48.65	5.78	44.51	3.95	50.84	5.05
X to Md	77.44	8.03	71.60	6.51	78.93	6.47

X, intersection of the posterior maxillary and Frankfort horizontal planes.

SD, standard deviation.

downwards, while a raised inclination of the cranial base is accompanied by a relatively long face orientated upwards. This is particularly well illustrated in the comparison of the African and Asian samples. These results may be interpreted as a corroboration of Enlow's (1990) hypotheses regarding the analysis of the variation in the human facial skeleton. The findings from this study suggest that the orientation and length of the cranial base are major factors in producing differences in the craniofacial system of modern humans.

### Conclusions

The European sample were dolichofacial with a larger face height and a smaller face depth as a result of a raised cranial base and facial cranium orientation similar to the Asian sample. The Africans were brachyfacial with a reduced face height and a larger face depth derived from a lowered cranial base and facial cranium orientation. The Asian sample were dolichofacial with a larger face height and depth due to a raised cranial base and facial cranium orientation, which was similar to the European sample.

The findings of this study suggest that cranial base orientation and posterior cranial base length appear to be valid discriminating factors between different human populations.

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