



Variability in facial size and shape among North and East African human populations

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ABSTRACT

A 3D configuration of landmarks was selected on the craniofacial district to analyse the morphological variability within and among North and East African human populations. Multivariate analysis of data obtained from generalised Procrustes superimposition showed that the observed variability is relatively homogeneous and not polarised. A general vertical flattening/extension of the whole face with consequent widening/narrowing of the facial structure and forward/backward maxillary rotation corresponds to the main axis of variance, and this is probably related to the sub-Saharan morphological contribution. There are no significant size differences between populations. The overall allometric component involves mainly a vertical growth of the face. There are morphological differences between North and East African specimens related to nasal flattening and maxillary development in the latter group.

KEY WORDS: Modern human populations - Cranial variation - Facial morphology - North Africa.

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INTRODUCTION

Variability among modern human populations is rather limited when compared with that expressed by living apes (Kaessmann *et al.*, 2001; Noda *et al.*, 2001); the variation between groups is gradual and continuous, with distributions of the various characters, in terms of both phenotype and genotype, that largely overlap each other (Howells, 1973, 1989; Richardson, 1980; Cavalli-Sforza *et al.*, 1994; Relethford, 1994; Relethford & Harpending, 1994; Hanihara, 1996). Cranial morphology of North African populations, however, suggests the occurrence of different biological backgrounds (Keita, 1990), related to the complex geographical features and bio-cultural dynamics of this region. At the same time, early modern human settlements in North Africa represent a crucial context for the evolutionary origin and diffusion of *Homo sapiens* itself, with migration patterns that are far from being resolved (Hublin, 2002). At the same time, East Africa represents a populational link between North Africa, sub-Saharan regions and Asia (see Cavalli-Sforza *et al.*, 1994), with a determinant role within this biogeographical system.

From this perspective, facial morphology is considered a useful source of information about human variability (Howells, 1973, 1989, 1995) and is employed in forensic anthropology to localise some major differences between human groups (Gill & Rhine, 1990). The orbito-nasal districts were demonstrated to be especially sensitive in this respect (Gill, 1984).

In this paper, configurations of facial landmarks from North and East African crania are analysed using geometric morphometric methods. The aims are to characterise North African facial variability and localise distribution patterns in cranial morphology within and among modern human populations.

MATERIALS AND METHODS

A sample of 49 crania from different areas of East and North Africa (Table I) were selected from the collections preserved at the "G. Sergi" Museum of Anthropology of the "La Sapienza" Rome University. Only adult specimens in good conditions of preservation and completeness were considered.

TABLE I - Composition of the sample (n = 49).

Group	Provenience	Label	n
East Africans	Somalia, Ethiopia	EA	20
North Africans			
Mediterranean Africans	Tunisia, Lybia, Egypt	NAM	14
Canarians	Canary Islands	NAC	7
Saharan Libyans	Libyan desert	NAS	8

A bilateral configuration of 33 landmarks was used to represent the human facial morphology in some detail (Fig. 1), with special attention addressed to some recognised diagnostic features (Howells, 1973, 1989; Richardson, 1980; Gill, 1984; Krogman & Iscan, 1986; Gill & Rhine, 1990; Burris & Harris, 1998; Dean *et al.*, 1998). The landmarks were: glabella, nasion, maxillo-frontale, rhinion, inferior maxillo-nasale, alare, nasospinale, prosthion, alveolare I²/C, alveolare P⁴/M¹, inferior spheno-maxillare, zygo-maxillare, zygo-orbitale, dacryon, fronto-malare orbitale, fronto-malare temporale, superior and inferior temporo-malare, porion. 3D coordinates were collected using a Microscribe 3DX.

A bilateral configuration was preferred to keep the structural balance of the morphological system. Morphology is, in fact, better interpreted as the result of a biomechanical network between ipsilateral and contralateral components, functionally related by physical interactions (Moss & Young, 1960; Enlow, 1990).

Unfortunately, most of the specimens are represented by isolated crania, with obvious limitations for sex diagnosis, and the sample size is not sufficiently large to consider sexual dimorphism statistically. Therefore, sex differences will not be taken into account in this analysis.

Generalised Procrustes Analysis (GPA) was used to superimpose configurations through translation, rotation and scaling. Centroid size was used as size index, defined as the square root of the sum of squared distances of a set of landmarks from their centroid (Slice *et al.*, 1996). A Multivariate Analysis of Variance (MANOVA) was performed to test differences between groups.

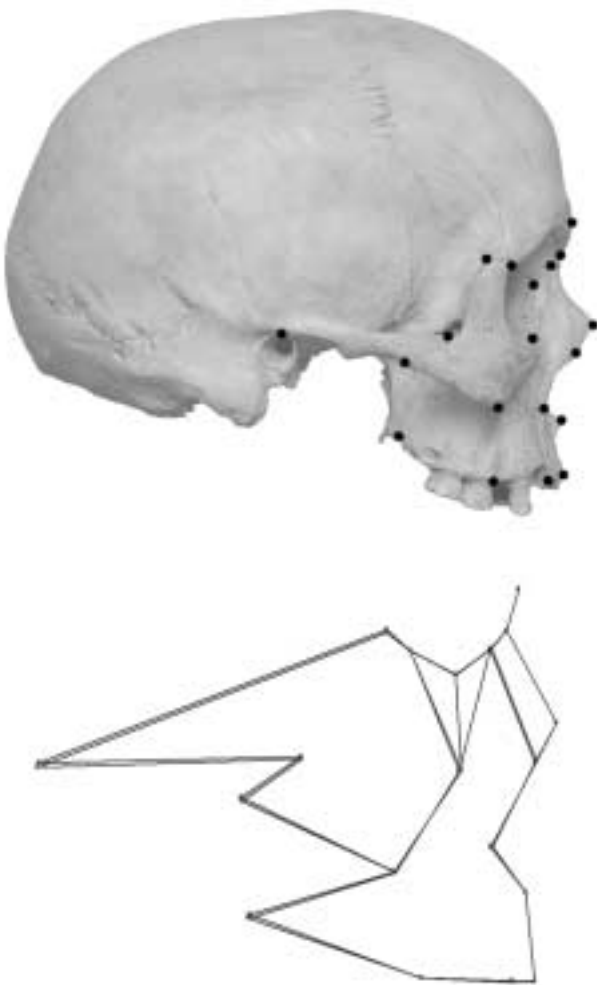


Fig. 1 - Landmark configuration in right lateral view, with the resulting facial "mask" (see text for the landmarks description).

Principal Component Analysis (PCA) based on GPA residuals was used to describe the overall variability, and a Discriminant Analysis (DA) was used to characterise the main differences between groups. GPA and MANOVA were performed by Morpheus *et al.* (Slice, 2000), while centroid size, PCA, and DA were computed by APS 2.3 (Penin, 2000). Univariate comparisons were performed by ANOVA and Kruskal-Wallis analysis, setting $\alpha = 0.05$.

RESULTS

The centroid size distributions indicate only a shift toward higher average values for the Canarians, some degree of skewness toward smaller values for the East Africans, and toward larger values for the Mediterranean group (Fig. 2). However, these differences in facial size are not statistically significant.

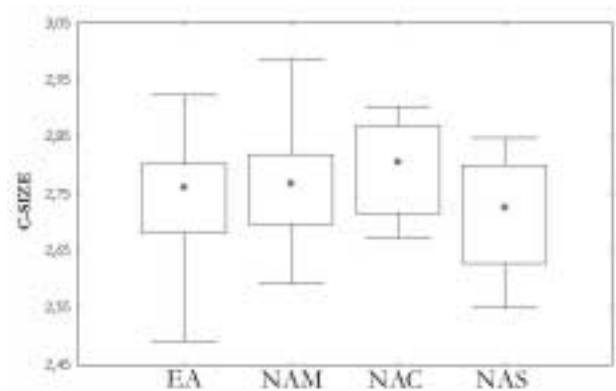


Fig. 2 - Centroid size variability within each group (median, interquartile, range); compare Table I for labels.

Considering the morphospace generated by the PCA, differences in facial shape show a non-polarised variability. Thus, the morphological variation is not mainly organised along a specific vector, but distributed among successive components, and the percentage of variability expressed by each axis (Fig. 3A) decreases gradually without any marked step from the first to the subsequent components. Such a homogeneous morphospace can be defined as "hyperspheroidal", as opposed to "hyperellipsoidal" in which the first axes account for a major part of the variability. The closer the eigenvalues, the less well defined the principal components will be, with a resulting instability of the coefficients and of the morphospace itself.

The first principal component accounts for 16.5% of the total variance. Towards one extreme (positive values, according to this analysis), faces become wider and lower (Fig. 4B). The nasal bones flatten and the upper face lowers. Also, the maxilla becomes vertically flattened, while the prognathism increases. The entire structure widens, and the nasal aperture becomes broader. In summary, the face shortens vertically and

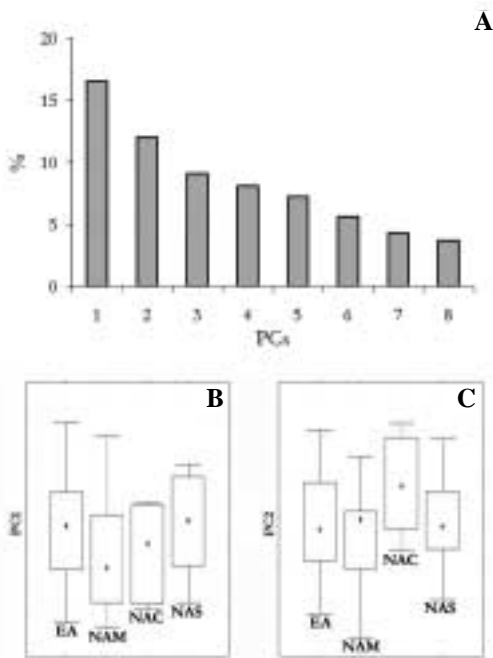


Fig. 3 - Percentage of variance expressed by the first eight principal components (A), and distribution (median, interquartile, range) of values for each human group along the PC1 (B) and PC2 (C) vectors.

this flattening leads to a relative lateral enlargement of the whole morphology and maxillary frontward rotation. The pattern toward the other extreme shows, of course, the opposite processes, with a general vertical stretching related to a lateral narrowing (Fig. 4A). The face becomes laterally flattened (including the nasal bones, the nasal aperture, the maxilla and the upper face) and developed vertically with increasing orthognathism. Differences between groups are not significant, although the East African sample shows a distribution slightly shifted toward higher positive values, while the NAM variability is skewed in the opposite direction (Fig. 3B).

Concerning the second principal component (12.0% of the variance), the shifting toward one direction involves a broadening of the skull (zygoma and biporionic breadth) with narrowing of the upper fraction of the nasal bones, and vertical flattening of the face (Fig. 5B). The structure shortens frontally, with a maxillary decrease and nasal flattening, pushing the face against the cranium. In the opposite direction, the skull becomes narrower, the upper nasal areas develop laterally, superiorly, and anteriorly, the maxilla grows and the entire structure develops vertically and anteriorly (Fig. 5A). The Canarians show a distribution slightly shifted toward higher positive values, but differences between groups are again not significant (Fig. 3C).

The first ten components were used in a multivariate regression on centroid size to test for allometry, and were found to have a significant relationship ($r = -0.69$,

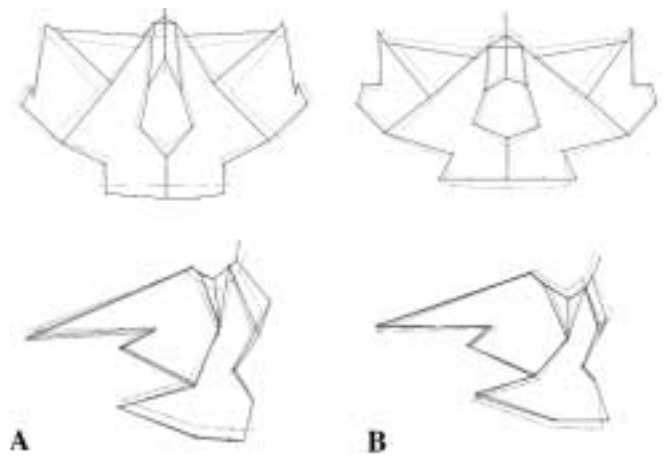


Fig. 4 - Morphological pattern related to the first principal component (16.5% of the total variance) between the two extremes, from conventional negative (A) to positive (B) values. Frontal (top) and right lateral (bottom) views; dotted lines represent the consensus configuration.

$P < 0.01$). The morphological transformation along the regression vector shows that as size increases the face develops vertically (Fig. 6). The maxilla enlarges downward, while the nasal bones grow dorsally and the interorbital structures broaden (in frontal view, not shown). Comparing the multivariate correlation coefficients, size seems to be correlated with different axes and not related to a specific principal component. The second principal component gives the greater contribution to the regression.

To test the main differences between East and North Africans, the NAM, NAC and NAS samples (cf. Table I) were pooled, and a discrimination test between North and East groups was computed by multiple regression on principal components (Penin, 2000). Considering the first three PCs, the discrimination is weak but significant ($r = 0.44$, $P < 0.02$). The discrimination vector is almost

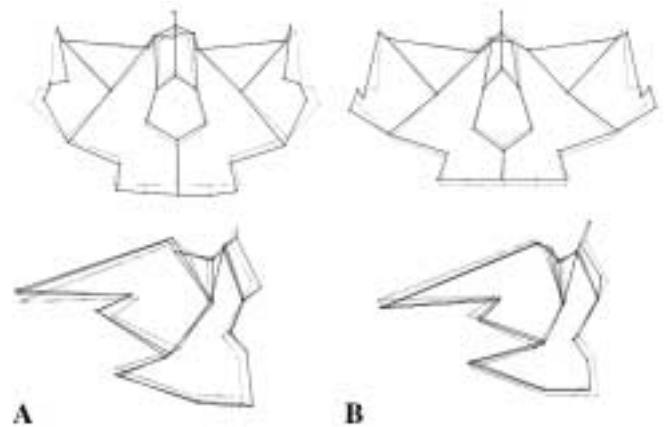


Fig. 5 - Morphological pattern related to the second principal component (12.0% of the total variance), from conventional negative (A) to positive (B) values. Frontal (top) and right lateral (bottom) views; the dotted line represents the consensus configuration.



Fig. 6 - Morphological pattern related to the regression of the first ten principal components onto centroid size, from small to large faces (right lateral view); dotted lines represent the consensus configuration.

totally related to the third component of the PCA (9.13% of the total variance): the correlation coefficient between these two vectors is 0.96, and the morphological changes observed along the two axes are extremely similar, except for some very small differences at the fronto-malar junction. Nevertheless, also the first PC axis of variability shows a certain amount of correlation with the discrimination function ($r = -0.36$, $P < 0.01$). In general, the East Africans show an upper and middle facial flattening, maxillary development, and a slight coronal broadening (Fig. 7A). In contrast, the North African pooled groups show an anterior development and mid-sagittal growth of the upper and middle face, a relative decrease of the maxilla, and a lateral narrowing of the structure (Fig. 7B). Considering the whole landmark data set, a MANOVA computed between these two groups is not significant but suggestive ($P = 0.08$). The comparison between the respective average shapes supports the pattern described by the discriminant vector. A MANOVA computed between all the four groups including the entire landmark data set is not significant. However, the limited number of specimens per group, compared to the large number of variables used in this analysis, must be considered.

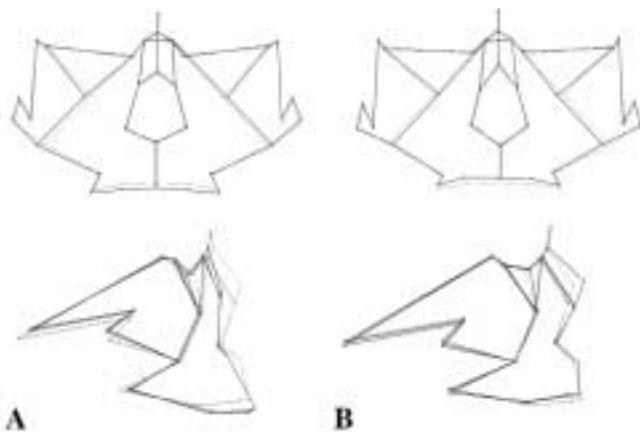


Fig. 7 - Morphological pattern related to the discriminant vector, from East African values (A) to North African values (B). Frontal (top) and right lateral (bottom) views; dotted lines represent the consensus configuration.

DISCUSSION

A limited variability has been recognised between modern human populations, both in morphology and genetics (e.g., Howells, 1973, 1989; Richardson, 1980; Cavalli-Sforza *et al.*, 1994; Relethford, 1994; Hanihara, 1996). Our sample represents a localised geographical region, and it may be assumed that variations between human groups in this restricted context are even less stressed. Considering the facial morphology within these North and East African populations, the variability is clearly not stretched along any dominant pattern. Thus, although some principal trends can be characterised, there are no determinant axes of variation, and differences are scattered into a rather homogeneous morphospace. Therefore, the direction and the degree of variation suggest low levels of morphological differentiations between and within these samples.

This multivariate analysis of the facial shape, however, allows us to:

1. characterise the overall variability and describe the main patterns of morphological variability, including structural relationships and allometric patterns;
2. localise the distribution of each sample along the shape vectors. Although there are no features or morphogenetic processes that can be used to describe univocally any specific group in the sample, the distribution of each population along some specific morphological vector can be indicative of some clines. These patterns will be further investigated with larger sample sizes to compute canonical variates and localise population-specific features.

Despite the observed “hyperspheroidal” organisation of the morphospace, the difference of variances expressed by the first two axes suggests a certain stability of the first PC, that is supposed to be independent of minor changes of the sample, or of the landmark configuration. This hypothesis was tested both by using different sub-samples and different configurations. The main features of this component of facial shape variation are also supported by a previous analysis based on a reduced facial configuration of 20 landmarks and a sample size of 135 adult individuals from the same African areas (Bruner *et al.*, 2002), where the results were less informative in many morphological details, but more definite with respect to general trends.

Along this morphological vector the face stretches vertically and becomes narrower, while in the opposite direction the entire structure flattens vertically becoming broader and protruding the maxilla. Interestingly, all the single features involved in this process are those generally used to describe African groups of sub-Saharan origin (Krogman & Iscan, 1986; Bass, 1987; Gill & Rhine, 1990): alveolar prognathism, wide pyriform aperture, flattened and large nasal bones, larger maxilla, larger and more squared orbits, large interorbital diameters, etc (Fig. 8A). The opposite pattern (orthognathism, narrow and protruded nasal bones, narrow nasal aperture,



Fig. 8 - Frontal view of crania from Central Africa (A) and North Africa (B), showing two morphotypes stressing the sub-Saharan and North-Saharan (Mediterranean) patterns. The sub-Saharan specimen shows a generalised vertical facial flattening, with consequent widening of the entire structure. This pattern involves interorbital and orbital enlargement, widening and flattening of the nasal bones and aperture, maxillary development and upper rotation. The North Africa cranium shows the opposite pattern.

small interorbital diameters, etc.) characterises European/North African populations (Fig. 8B). Therefore, this vector may represent a Mediterranean - sub-Saharan vector in which the two different morphologies grade into one another according to the group-specific composition. The more a sub-Saharan contribution is represented within a population, the more its variability will be shifted along this morphological vector. Because of the clinal nature of the human populational variability, this shifting may not actually be statistically significant in a given data set.

To test this hypothesis two skulls from Central Africa were included in the sample, and they both showed high PC1 values, supporting this observed tendency. Moreover, analysing specimens from a late prehistoric population of central Sahara, with composite facial features well recognisable in distinct specimens, those faces clearly showing sub-Saharan features were displaced toward comparable values for this component (Bruner *et al.*, 2002).

Clearly, this is an exploratory analysis and a larger sample size should be considered. However, two general inferences may be proposed:

1. The principal genetic and cranial differences described in the literature on a world-wide scale are detected between sub-Saharan populations versus other human groups (e.g., Howells, 1973, 1989; Vigilant *et al.*, 1991; Cavalli-Sforza *et al.*, 1994). According to these data based on the North and East African facial morphology, this first axis of variation could be recognisable even when a more localised geographical area is considered, within a limited morphological variability. It corresponds to an African “North-South cline”, independently of the source of this process, and it represents the principal axis of “regional” variability between African human groups.

2. The set of morphological features usually recognised to describe sub-Saharan or conversely Mediterranean/North African populations are not single and isolated characters but the result of a common morphogenetic pattern. The whole face undergoes a structural development that involves a general rearrangement of its components. In sub-Saharan populations, enlargement, widening and flattening of interorbital and nasal areas, prognathism and vertical shortening, are the result of a single process which can be described as a generalised vertical compression of the entire structure. Many morphological features should be therefore interpreted not necessarily as adaptations, genetic markers, or physiologic responses, but contextually as the structural constraints of the morpho-functional environment (cf. Thompson, 1942; Moss & Young, 1960; Enlow, 1990).

When all the North African groups (North-Central Africans, Canarians and Sahara Libyans) are pooled together, some differences characterising the East African sample are evidenced. This group shows mainly a marked flattening of the nasal bones, with an antero-inferior maxillary development and a slight widening of the whole face. According to the previous hypothesis, the East African morphology might be interpreted as an “elongated” sub-Saharan face, in which the sub-Saharan features do not match a vertical facial shortening. This perspective is in agreement with previous interpretations that consider the East African populations as a result of the genetic mixing of sub-Saharan and other foundations (Cavalli-Sforza *et al.*, 1994). The partial contribution of the first PC to the discrimination vector supports this hypothesis. However, the variability of the North and East groups along the discrimination axes, even in presence of statistically significant differences, appears to have considerable overlap (Fig. 9).

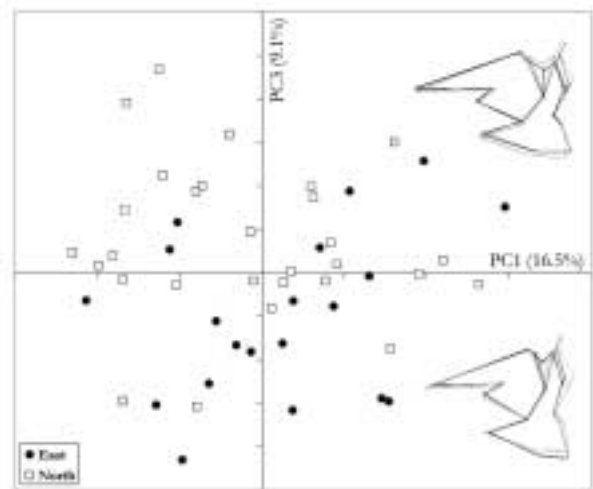


Fig. 9 - PC1 vs. PC3 values for North and East Africa groups. Shape configurations represent the morphological patterns along the PC1 positive values (sub-Saharan pattern) and the PC3 negative values (East African pattern); dotted lines represent the consensus configuration.

Size accounts for a certain percentage of the facial morphological variability. The main allometric pattern involves a downward maxillary development and the growth of the midsagittal upper facial areas as size increases. This allometric vector is partially related to the second PC, but generally it is not associated with any specific principal components and it is distributed into the PCA morphospace (thus, transversal to the main axes of variation). Nonetheless, there is no evidence of size differences between the four groups, and it may be assumed that the allometric process is shared by all the populations. A similar conclusion on size differences was already proposed on the basis of traditional morphometrics (Howells, 1973, 1989).

In summary, the first axis of variability has been related to a North-South morphological grade, the second to a size-related component, and the third to the specific differences between North and East African specimens.

Geometric morphometrics deals with phenetic affinities and differences. The final morphology of each individual and the related population variability is the expression of a dynamic system resulting from the integration of three different biological contributions: adaptations, physiology, and functional matrix. Adaptations concern genetically-based selected characters, affecting the populations' evolutionary fitness. Physiology accounts for a certain proportion of individual response to the inner and outer environments. Functional matrix refers to those biological networks between morphology, physiology, ecology, and genetics which involve a univocal response of the model to perturbations (allometry, polygeny, pleiotropy). The analysis of shape *per se* does not allow a fine resolution between these three components, but needs integration with other data. In this study, the clinal or populational differences and affinities may be the result of adaptations (i.e., to climate) as well as to unknown physiological factors. Considering the complementary information from the genetic background (Cavalli-Sforza *et al.*, 1994), the most parsimonious interpretation involves population distribution and movements as well as gene exchange.

Considering the small sample size and the limited geographical variability analysed in this paper, the facial morphology is confirmed to be a useful source of information when dealing with variability among modern human groups. Additionally, geometric morphometrics allows a rather complete synthesis of the structural system, characterising differences as well as suggesting processes. The analytical power of these techniques combines with a new perspective in animal and human biology, where the anatomical structures are interpreted as whole integrated systems, and marking a new era of morphological studies.

REFERENCES

- Bass W. M., 1987 - Human osteology. A laboratory and field manual. Missouri Archeological Society, Columbia.
- Bruner E., Ricci F., Manzi G., 2002 - Faces from the ancient Fezzan: a geometric morphometric approach. *In*: S. di Lernia & G. Manzi (eds), Sand, stones, and bones. The archaeology of death in the Wadi Tanezzuft Valley. AZA Monographs 3. All'Insegna del Giglio, Firenze, pp. 251-260.
- Burris B. G., Harris E. F., 1998 - Identification of race and sex from palate dimensions. *J. Forensic Sci.*, 43: 959-963.
- Cavalli-Sforza L. L., Menozzi P., Piazza A., 1994 - The history and geography of human genes. Princeton University Press, Princeton.
- Dean D., Bookstein F. L., Koneru S., Lee J. H., Kamath J., Cutting C. B., Hans M., Goldberg J., 1998 - Average African-American three-dimensional computed tomography skull images: the potential clinical importance of ethnicity and sex. *J. Craniofacial Surg.*, 9: 348-358.
- Enlow D. H., 1990 - Facial growth. WB Saunders Company, Philadelphia.
- Gill G. W., 1984 - A forensic test case for a new method of geographical race determination. *In*: T. A. Rathburn & J. E. Buikstra (eds), Human identification. C.C. Thomas, Springfield, pp. 329-339.
- Gill G. W., Rhine S., 1990 - Skeletal attribution of race. Maxwell Museum of Anthropology, Albuquerque.
- Hanihara T., 1996 - Comparison of craniofacial features of major human groups. *Am. J. Phys. Anthropol.*, 99: 389-412.
- Howells W. W., 1973 - Cranial variation in man. A study by multivariate analysis of patterns of difference among recent human populations. Peabody Museum of Archeology and Ethnology. Harvard University Press, Cambridge.
- Howells W. W., 1989 - Skull shapes and the map. Craniometric analyses in the dispersion of modern *Homo*. Peabody Museum of Archeology and Ethnology. Harvard University Press, Cambridge.
- Howells W. W., 1995 - Who's who in Skulls. Ethnic identification of crania from measurements. Peabody Museum of Archeology and Ethnology. Harvard University Press, Cambridge.
- Hublin J. J., 2002 - Northwestern African Middle Pleistocene hominids and their bearing on the emergence of *Homo sapiens*. *In*: L. Barham & K. Robson-Brown (eds), Human roots, Africa and Asia in the Middle Pleistocene. CHERUB, Bristol, pp. 99-121.
- Kaessmann H., Wiebe V., Weiss G., Paabo S., 2001 - Great ape DNA sequences reveal a reduced diversity and expansion in humans. *Nat. Genet.*, 27: 155-156.
- Keita S. O. Y., 1990 - Studies of ancient crania from Northern Africa. *Am. J. Phys. Anthropol.*, 83: 35-48.
- Krogman W. M., İçcan Y. M., 1986 - The Human skeleton in forensic medicine. C.C. Thomas, Springfield.
- Manzi G., Saracino B., Bruner E., Passarello P., 2000 - Geometric morphometric analysis of mid-sagittal cranial profiles in Neandertals, modern humans, and their ancestors. *Riv. Antropol.*, 78: 193-204.
- Moss M. L., Young R. W., 1960 - A functional approach to cranio-logy. *Am. J. Phys. Anthropol.*, 18: 281-292.
- Noda R., Kim G. C., Takenaka O., Ferrell R. E., Tanoue T., Hayasaka I., Ueda S., Ishida T., Saitou N., 2001 - Mitochondrial 16S rRNA sequence diversity of hominoids. *J. Hered.*, 92: 490-496.
- Penin X., 2000 - Applied Procrustes softwares 2.3. Available at <http://www.cpod.com/monoueb/aps>
- Relethford J. H., 1994 - Craniometric variation among human populations. *Am. J. Phys. Anthropol.*, 95: 53-62.
- Relethford J. H., Harpending H. C., 1994 - Craniometric variation, genetic theory, and modern human origins. *Am. J. Phys. Anthropol.*, 95: 249-270.
- Richardson E. R., 1980 - Racial differences in dimensional traits of the human face. *Angle Orthod.*, 50: 301-311.
- Slice D. E., 2000 - Morpheus et al. Department of Ecology and Evolution, State University of New York at Stony Brook, Stony Brook (NY). <http://life.bio.sunysb.edu/morpb/morpheus>.
- Slice D. E., Bookstein F. L., Marcus L. F., Rohlf F. J., 1996 - A glossary for geometric morphometrics. *In*: L. F. Marcus M. Corti, A. Loy, G. J. P. Naylor & D. E. Slice (eds), Advances in morphometrics. Plenum Press, New York, pp. 531-551.
- Thompson D'A. W., 1942 - On growth and form. Cambridge University Press, Cambridge.
- Vigilant L., Stoneking M., Harpending H., Hawkes H., Wilson A., 1991 - African populations and the evolution of human mitochondrial DNA. *Science*, 253: 1503-1507.