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MORPHOMETRIC STUDY OF FOSSIL MANDIBLES, NUMERICAL REPRESENTATION OF DENTAL ARCADES BY A BIOMETRIC METHOD

by

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1. INTRODUCTION

In this study the shape of the dental arcades in mandibles is numerically represented and is compared, using statistical means.

For this purpose a simple method was developed, which permits us to measure widths and lengths of fossils in a precise and reproducible way (ROTH, 1983). The measuring method will be explained in this paper.The procedure uses an optical aiming system and determines the Cartesian coordinates of 14 key points on the dental arcades of 58 mandibles of the collection of the Laboratoire d'Anthropologie in Marseille. This collection contains reproductions of most of the important human mandibles and is especially rich in *Homo erectus* and *Homo s. neanderthalensis*.

The data obtained have been statistically analyzed by computer. From the length and width values of dental points on the arcades numerous angles and angle combinations are constructed and compared in the following tables and figures.

The aim of this work is to compare the dental arcades of the mandibles, ranging from *Homo erectus* to the modern *Homo sapiens*, and to show the increasing slendering and flattening-out of the arcades. The attempt will be made to characterize the shape of the evolutionary groups and to describe the possible evolutionary continuity between European Middle Pleistocene hominids and Neanderthals.

2. MEASURING PROCEDURE AND MEASURING POINTS

The essential components of the measuring method are reproduced in two photographs (figure 1(a), (b)). The mandible is first positioned horizontally. The horizontal adjustment of the mandible can be made by embedding it in plasticine and by checking against a horizontal level. More convenient is the use of two triangles, a lower one which slides along the ruler and an upper one to which the mandible is fixed.

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By turning three screws, the upper triangle can be properly adjusted. The alveolar plan of Klaatsch is used as a horizontal reference and is defined by the points between the median incisors and between the second and third molars.

The whole instrument is placed on millimetre graph paper. It slides along a large fixed ruler, thus always moving parallel to its initial position. Two threads are arranged to cross the paper at right angles and the mandible is moved along until the measuring point is directly below the reticle.

The Cartesian coordinates of this point are read at the tip of the triangle using the millimetre lines of the graph paper. By using a magnifying glass, an accuracy of some two tenths of a millimetre can be obtained, certainly no worse than the accuracy of most fossil casts.

A comparison of the measuring rows resulted in a repeatability of $1\ \delta = 0{,}37$ mm or $1\ \delta = 0{,}3°$ to $1{,}2°$ (depending on whether these angles were formed from short or long section ratios). However, this error is negligible, compared to the mean variation of the measuring data within the evolutionary groups. Four small mirrors facilitate orthogonal aiming (avoidance of parallaxis error). In order to assure that the coordinates are read in parallel and perpendicular with the symmetrical axis of the mandible, the graph paper and the reticle are positioned in such a way that the distal tangent to the crowns of the second molars is parallel to the x-axis, as shown in the photograph (figure 1).

The measuring points are defined in figure 2(a) as the intersection of distal and vestibular tangents to the alveolar border of the tooth crown. The origin 0 of the Cartesian coordinate system is set between the median incisors and the frontal tangent of these teeth. All lengths are measured between the origin and distal tangents, all widths between vestibular tangents.

Technical note:

The boundaries of the alveolar tim of the molars and premolars are often hidden by the crowns and not clear when observed vertically from above. In these cases the measuring points of the lengths are determined distally on the lingual side of the teeth, and the measuring points of the widths take their bearings frontally to the fore and are determined vestibularly at the point set on the transition from the crown to the neck of the tooth.

These measuring points are virtual points, situated partly outside of the teeth. However, they are exactly defined, general points and can also be used in non-human teeth.

By putting them together the arc of the mandible can be reconstructed. It is common practice to take the ratio of some selected lengths and widths to form indices and to characterize the shape of an object by such indices. More imaginative is the use of angles (AMBROISE, 1972) which, mathematically speaking, are just trigonometric functions of these indices.

In the present work two different kinds of angles have been calculated:

— α angles are formed by the symmetrical axis of the arcade and a straight line through two measuring points. They signify the opening of the arcade with respect to the symmetrical axis.

— β angles are composed of two α angles and are formed by three measuring points. They indicate the curvature of the arcade at the central point of the angles. The definition of these α and β angles is shown in figure 2(b).

Altogether 28 α angles and 56 β angles can be calculated from the measured 14 lengths and widths which can be arranged in 23 angle series (ROTH, 1982, 1983, 1985) as shown in figure 4.

The analysis of the fossil mandibles has shown that the following angle series are the most useful to characterize and distinguish the various evolutionary groups of genus *Homo* : α - 0, α - I_2, α - P_2, showing the opening of the arcade at the points 0, I_2, P_2 with respect to the symmetrical axis, and β - $I_2 0$, β - CI_2 , β - $P_1 I_2$, β - $P_2 P_1$, showing the curvature of the arcade at I_2 , C, P_1 and P_2 .

3. COMPARISON OF THE EVOLUTIONARY GROUPS, RESULTS AND DISCUSSION

The method described above was used to compare the Neanderthals (HSN) with the Afro-Asiatic *Homo erectus* mandibles (PAS) and contemporaneous European Middle Pleistocene samples (AN) and with mandibles which, anatomically speaking, show modern characteristics (HSSR, HSSF, HS.PAL).

For this purpose 58 adult and adolescent arcades were measured with as complete as possible measuring points. The individuals were divided into evolutionary groups and are outlined in table 1. The first two columns show the group and their code. The third column refers to the individuals. The grouping of individuals in this paper is in keeping with usual classification used in human paleontology but is disputed in fossils e.g. Ehringsdorf 6 (STRINGER *et al.*, *in* Smith and Spencer, 1984), Tabun C2 (TRINKAUS, *ebenda,* 1984) which do not show clear morphological relations and datings. But the analyses for Tabun C2 have shown that the arcades of the early anatomically modern humans found in Palestine (HS.PAL), Skhul 5, Qafzeh 9 and Tabun C2 show a greater affinity to each other than to other modern *Homo sapiens*.

In order to obtain the greatest comparative group possible for the Upper Paleolithic period (HSSF), mandibles from the greatest variety of areas and geochronological age where brought together in this survey. In any follow-up investigations it would be of interest to complete the measuring sample and to make regional investigations into more precise chronological groupings.

Note : Comparisons of the angle-values have shown that the reconstructions of Grimaldi 6, Predmosti 3 and Subalyuk 1 have typically differing results. Grimaldi and Predmosti show α - 0 values which are too low and Subalyuk shows β - $P_2 P_1$ values which are too strongly curved.

In table 2, the mean values (x) and the standard deviations (S.D.) of the measured lengths and widths (figure 1(a)) for the groups analyzed in this study have been compiled. From these values, the various angles used in figure 4 were calculated and presented in table 3.

Figure 3 shows the "mean measuring points" of the arcades in the 6 evolutionary groups. What is striking is the tendency of the length dimensions to decrease in the course of evolution. This is why modern mandibles possess proportionally wider dental arcs.

It can also be seen that there is a definite difference between the Afro-Asiatic and the European version of *Homo erectus,* so that it seems justified to speak of two different subgroups. This difference, however, is markedly smaller between the two groups than between them and the Neanderthals who are, in general, shorter and proportionally larger.

Palestine mandibles are significant for their long jugal arcades.

These differences can be analyzed in more detail by looking at the angle series (table 3). The series of the α - 0 angles ($\alpha I_2 0$ to $\alpha M_3 0$) is presented in figure 4. This shows the opening of the arcade in relation to the point 0 and the sagittal medial axis of the mandible. The ordiante of this plot shows the values of the angles, which are plotted consecutively from frontal (left) to jugal (right).

With the help of the β-series: β - CI_2, β - P_1I_2 and β - P_2P_1 the curvature relationships of the different groups in the canine, first premolar and second premolar, are represented. Again, frontal angles are on the left hand side of the plots, jugal angles on the right hand side.

A quick glance shows that the curves of both Middle Pleistocene groups take on a similar process. Their α - 0 curves show the lowest values and characterize generally elongated curvatures. The difference between the two subgroups is mainly visible in the frontal and premolar region, where the Europeans are flatter.

Particularly strinking is the proportionally wider position of the second premolars. The European mandibles therefore also have very low curvature values in the $\beta - P_2P_1$ series. The Neanderthals are characterized by overall higher α - 0 values, particularly in the jugal area, and have a wider arcade.

A similar result is shown in the comparison of the series β - CI_2, β - P_1I_2, reflecting the general tendency that the Middle Pleistocene hominids are closer together. The Neanderthals have in general smaller angle values or a more curved arcade especially in the first premolar series. Their high value for the angle β - P_1CI_2 (β 22), on the contrary, is quite remarkable for this plot. This is a characteristic feature of the Neanderthals, arising from the fact that the curvature change from the frontal to the jugal part is less localized at the canine and includes the first premolar. This phenomenon is also seen in the α - 0 series, where the angles $\alpha C0$ and $\alpha P_1 0$ have nearly the same value.

In spite of the relatively large frontal width, no evidence of this feature is seen in the European Middle Pleistocene hominids (often referred to as Pre-Neanderthalians).

The Palestine specimens among modern specimens are characterized by a long, proportionally narrow curvature which, however, shows similar high α - 0 values in the frontal region which is, like with modern Europeans, rounded off and flattened out.

The frontal, flat shape, along with the elongated jugal arcade explains the lower curvature values in canine and first premolar. The bending curves of the three anatomically modern hominid samples show similarity in shape by a graph curve, running parallel. The graphs show that the curvatures in the centre of the semi-arcade and the related flattening-out of the frontal area are most pronounced in the youngest hominids.

4. CONCLUSION

A new morphometric method has been developed which permits the measurement of lengths and widths in a precise and reproducible way. By using this method the dental arcades of Neanderthals are analyzed and compared with two Middle Pleistocene hominid groups and three anatomically modern hominid samples.

It is found that the distinction between the Afro-Asiatic and the European Middle Pleistocene hominids is jutified. But the differences between the subgroups are smaller than the differences between them and the Neanderthals.

The Neanderthals show a typical flattened-out, rounded curve-shape which has nothing in common with the Skhul-Qafzeh sample or with the Upper Pleistocene sample and whose "unique facial topography" can be explained by "change of much of the infra-orbital region from the coronal orientation of the generalized face to a more sagittal orientation" (RAK, 1986).

Affinities between European Middle Pleistocene hominids and Neanderthals are nontheless apparent. The tenency towards flattening-out of the dental arcade in the anterior part in the first group, which is mentioned by several authors (e.g. STRINGER, HUBLIN, VANDERMEERSCH, 1984 *in* Smith and Spencer), is confirmed by the experimental results (α- 0 angles series) and points towards evolutionary transitions.

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TABLE 1

List of measured mandibles

Group	Code	Individuals	
Modern western European	HSSR	Mandibles from the Laboratoire d'Anthropologie, Marseille 1	
Upper Paleolithic Modern *Homo Sapiens*	HSSF	Hotu Cave 2	
		Gambles Cave 4	
		Kostenki 14 (Markina Gora)	
		Kow Swamp 5	
		Chancelade 1	
		Lac Mungo 3	
		Zhoukoudian UC.101	
		Wadjak 2	
		Predmosti 3	
		Pavlov 1	
		Grimaldi 6	
		Pinar, Carigüela 4	
		Cro Magnon 3	
		Combe Capelle 1	
Early modern *Homo Sapiens* from Palestine	HS.PAL	Skhul 5	
		Tabun C 2	
		Qafzeh 9	
Neanderthals	HSN	Hortus 4	
		Subalyuk 1	
		Tabun 1	
		Regourdou 1	
		Le Moustier 1	
		Ochoz 1	
		Mte Circeo 3, Mandib. B	
		La Naulette 1	
		Spy 1	
		Arcy 1	
		Arcy 2	
		Krapina G	
		Krapina H/58	
		Malarnaud 1	
		Amud 1	
European Middle and earlier Upper Pleistocene hominids	AN	Banolas 1	
		Ehringsdorf 6, Specimen F	
		Montmaurin 1	
		Atapuerca 1	
		Arago 2	
		Arago 13	* 1
		Mauer	
Afro-asiatic *Homo erectus*	PAS	Rabat 1	
		Temara 1	
		Zhoukoudian H1.12	
		Zhoukoudian G1.6, G1.7	* 2
		Atlanthrope, Ternifine 1	
		Atlanthrope, Ternifine 3	
		Sangiran 22, Mandib. F	

* 1 reconstruction of de Lumley
* 2 reconstruction of Weidenreich

TABLE 2

Mean values (x) and standard deviation (S.D.) of the lengths and widths for the groups compared in this work: afro-asiatic *Homo erectus* (PAS), European Middle Pleistocene hominids (AN), Neanderthals (HSN), early modern hominids from Palestine (HS.PAL), Upper Paleolithic hominids (HSSF), modern western Europeans (HSSR)

		LENGTHS (mm)							WIDTHS (mm)						
GROUP		$I_2 0$	CO	$P_1 0$	$P_2 0$	$M_1 0$	$M_2 0$	$M_3 0$	$I_2 I_2$	CC	$P_1 P_1$	$P_2 P_2$	$M_1 M_1$	$M_2 M_2$	$M_3 M_3$
HSSR	x	7,71	9,48	12,83	19,07	28,62	39,09	48,44	17,51	30,73	38,86	45,16	55,14	61,84	65,87
n = 12	S.D.	0,89	1,18	1,23	1,42	1,88	2,18	3,09	1,04	1,59	1,20	1,60	2,19	2,84	2,61
HSSF	x	7,5	10,55	14,73	20,96	31,32	41,93	52,66	19,67	33,20	41,79	48,70	57,56	63,82	67,46
n = 14	S.D.	1,09	1,73	1,75	2,20	2,71	3,16	3,97	1,58	1,62	2,60	2,22	2,56	3,25	2,51
HS.PAL	x	7,95	10,92	15,53	23,00	34,16	45,72	58,47	23,15	37,10	45,27	51,87	60,62	64,63	67,90
n = 3	S.D.	0,85	0,59	0,67	1,04	0,65	1,34	2,03	1,99	0,66	0,71	0,52	0,46	0,76	0,85
HSN	x	7,88	11,10	15,34	21,89	31,79	43,24	54,72	21,20	35,02	45,03	52,73	61,63	67,72	72,16
n = 15	S.D.	1,22	1,45	1,90	2,10	2,64	3,13	3,63	2,76	2,25	2,12	2,55	1,97	2,96	3,13
AN	x	7,81	11,84	17,52	24,19	35,36	47,21	58,92	22,40	36,03	45,61	53,80	61,86	67,17	71,54
n = 7	S.D.	1,20	1,64	2,03	2,93	3,62	4,72	5,28	1,68	2,86	2,32	2,58	3,60	2,72	3,34
PAS	x	9,40	13,59	19,97	27,70	39,34	51,71	64,26	21,73	35,75	45,33	53,31	62,36	67,85	72,68
n = 7	S.D.	1,35	1,86	2,83	3,05	3,18	4,17	5,89	2,58	3,12	2,71	3,52	3,95	5,78	6,38

TABLE 3

Mean values (x) and standard deviation (S.D.) of the α- and β- angle series for the various evolutionary groups

		α - 0 Serie (Degree)							β - CI_2 Serie (Degree)					
		α 1 α I_20	α 2 α CO	α 3 α P_10	α 4 α P_20	α 5 α M_10	α 6 α M_20	α 7 α M_30	β 22 β P_1CI_2	β 23 β P_2CI_2	β 24 β M_1CI_2	β 25 β M_2CI_2	β 26 βM_3CI_2
HSSR	x	47,90	59,06	56,61	49,86	43,97	38,56	34,27	154,07	142,49	137,72	133,02	130,21
	S.D.	2,61	3,28	2,90	2,24	2,53	2,43	2,21	13,86	11,06	9,27	9,04	7,98
HSSF	x	52,14	58,12	54,23	49,57	43,18	37,23	33,02	159,44	149,44	145,44	139,34	134,94
	S.D.	3,03	3,42	3,44	2,49	2,66	2,38	1,44	7,27	6,12	6,38	5,70	5,53
HS.PAL	x	55,54	59,52	55,55	48,45	41,59	35,27	30,16	155,06	145,01	140,38	135,13	131,49
	S.D.	5,10	1,19	1,17	1,40	0,53	1,11	1,13	6,17	6,29	5,00	5,97	6,05
HSN	x	52,82	57,73	55,88	50,48	44,27	38,20	33,63	165,14	155,54	148,24	142,36	139,85
	S.D.	2,76	2,69	2,33	1,89	2,40	2,39	2,22	10,43	7,44	6,32	6,03	5,16
AN	x	55,28	56,76	52,56	48,16	41,27	35,68	31,37	161,10	156,63	149,64	144,71	141,47
	S.D.	2,50	2,45	2,69	3,04	3,05	2,81	2,52	4,19	5,58	4,64	4,31	4,24
PAS	x	49,23	52,88	48,78	44,00	38,43	33,26	29,41	157,93	152,63	147,96	143,42	140,80
	S.D.	3,18	1,96	2,61	1,35	0,74	0,70	0,47	5,90	5,56	5,46	5,33	4,13

TABLE 3 (continued)

GROUP		β - P_1I_2 Serie (Degree)				β - P_2P_1 Serie (Degree)		
		β 27 β $P_2P_1I_2$	β 28 β $M_1P_1I_2$	β 29 β $M_2P_1I_2$	β 30 β $M_3P_1I_2$	β 47 β $M_1P_2P_1$	β 48 β $M_2P_2P_1$	β 49 β $M_3P_2P_1$
HSSR	x	144,93	143,53	139,48	136,08	180,72	175,86	172,99
	S.D.	9,83	7,13	7,44	6,39	6,58	7,54	8,63
HSSF	x	152,36	150,44	146,50	142,39	176,46	171,35	167,30
	S.D.	6,12	4,27	4,85	4,35	5,37	6,16	5,52
HS.PAL	x	148,49	147,01	142,41	139,38	177,65	171,88	168,87
	S.D.	4,20	3,43	4,67	4,48	3,72	3,06	2,06
HSN	x	153,05	148,61	143,98	141,04	174,18	170,24	166,50
	S.D.	6,89	4,45	4,66	3,81	5,83	4,46	4,82
AN	x	159,71	153,21	148,83	146,23	168,19	164,68	162,70
	S.D.	4,20	3,94	2,87	3,06	5,76	5,98	5,28
PAS	x	157,17	153,65	149,15	147,24	173,73	169,05	165,25
	S.D.	6,38	4,56	3,92	3,09	4,32	3,90	2,15

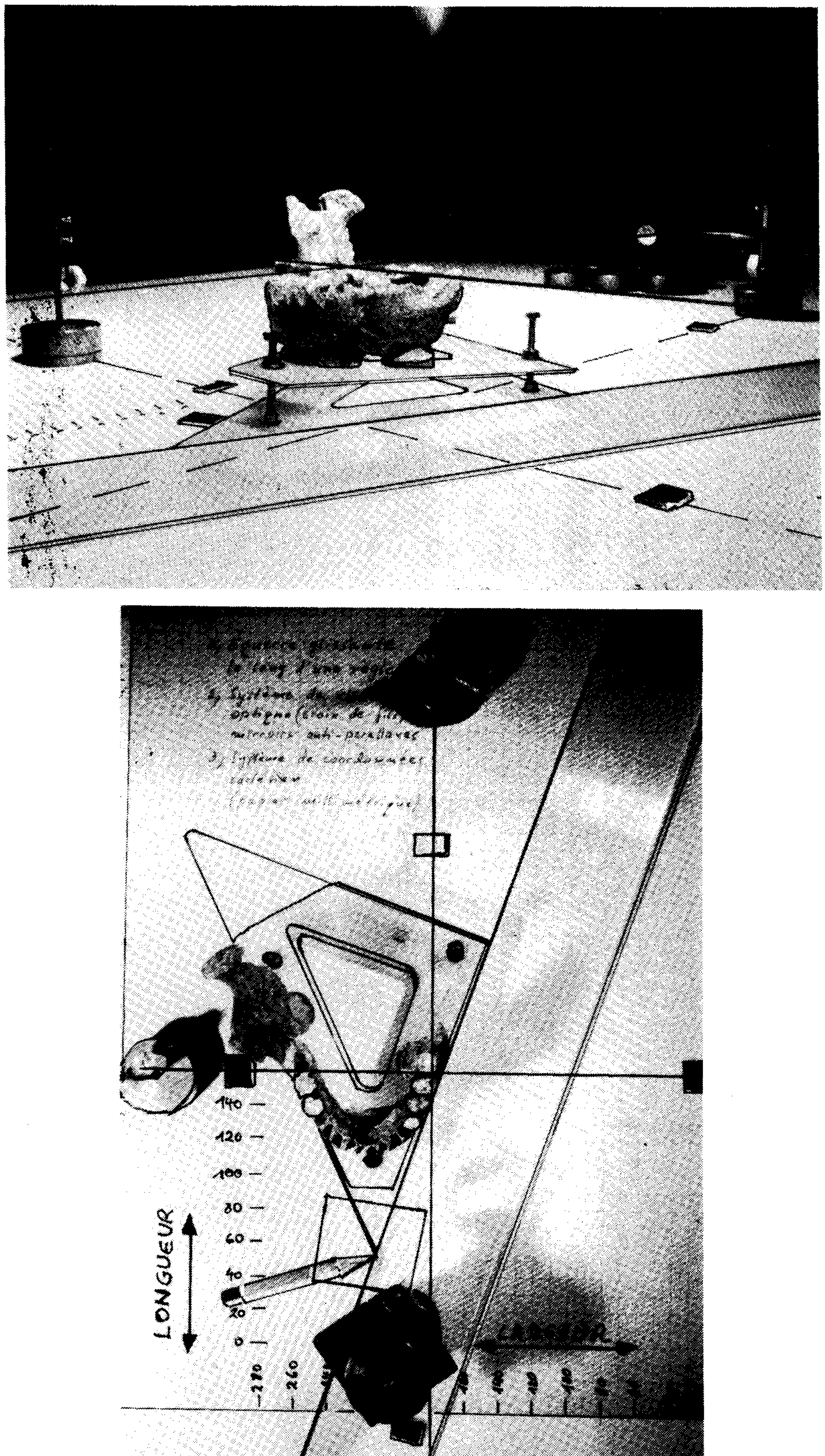

FIGURE 1 (a,b)

Measuring procedure

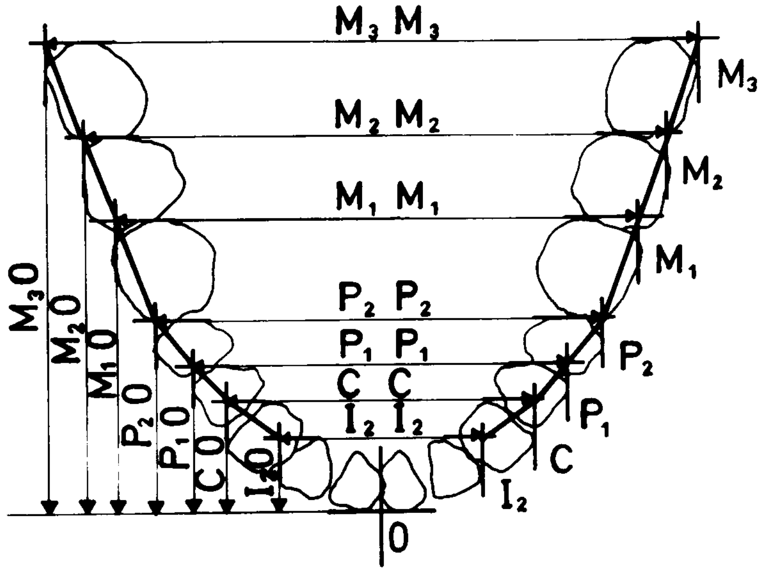

FIGURE 2 (a)

Definition of lengths and widths

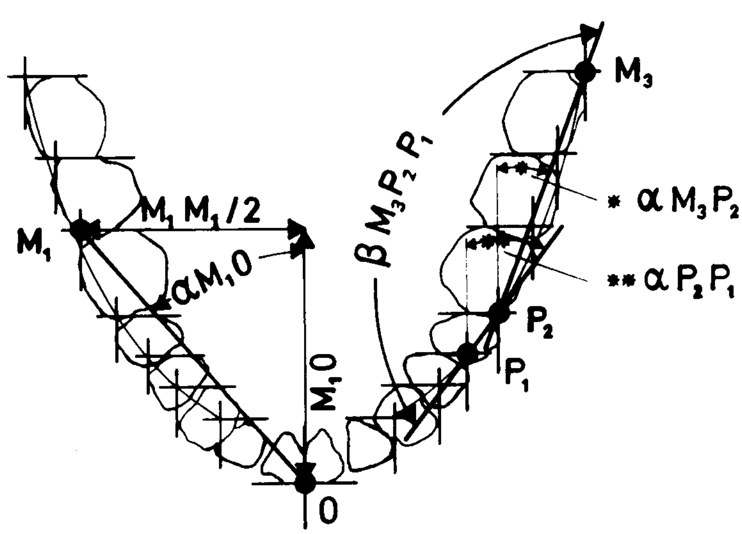

FIGURE 2 (b)

Definition of α - angles (opening of the arcade with respect to the symmetric axis) and β - angles (curvature of the arcade between 3 measuring points)

$$\alpha\ M_1 0 = \arctan\left(\frac{\frac{1}{2} M_1 M_1}{M_1 0}\right)$$

$$\beta\ M_3 P_2 P_1 = 180^\circ + \alpha\ M_3 P_2 - \alpha\ P_2 P_1$$

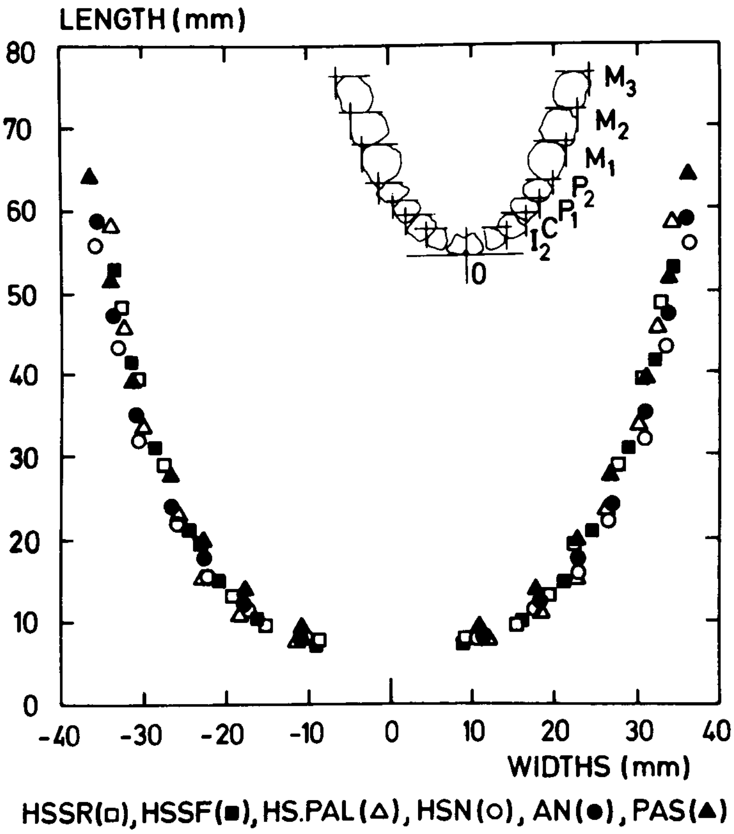

FIGURE 3

Measuring points constructed from the mean values of lengths and widths of the various evolutionary groups

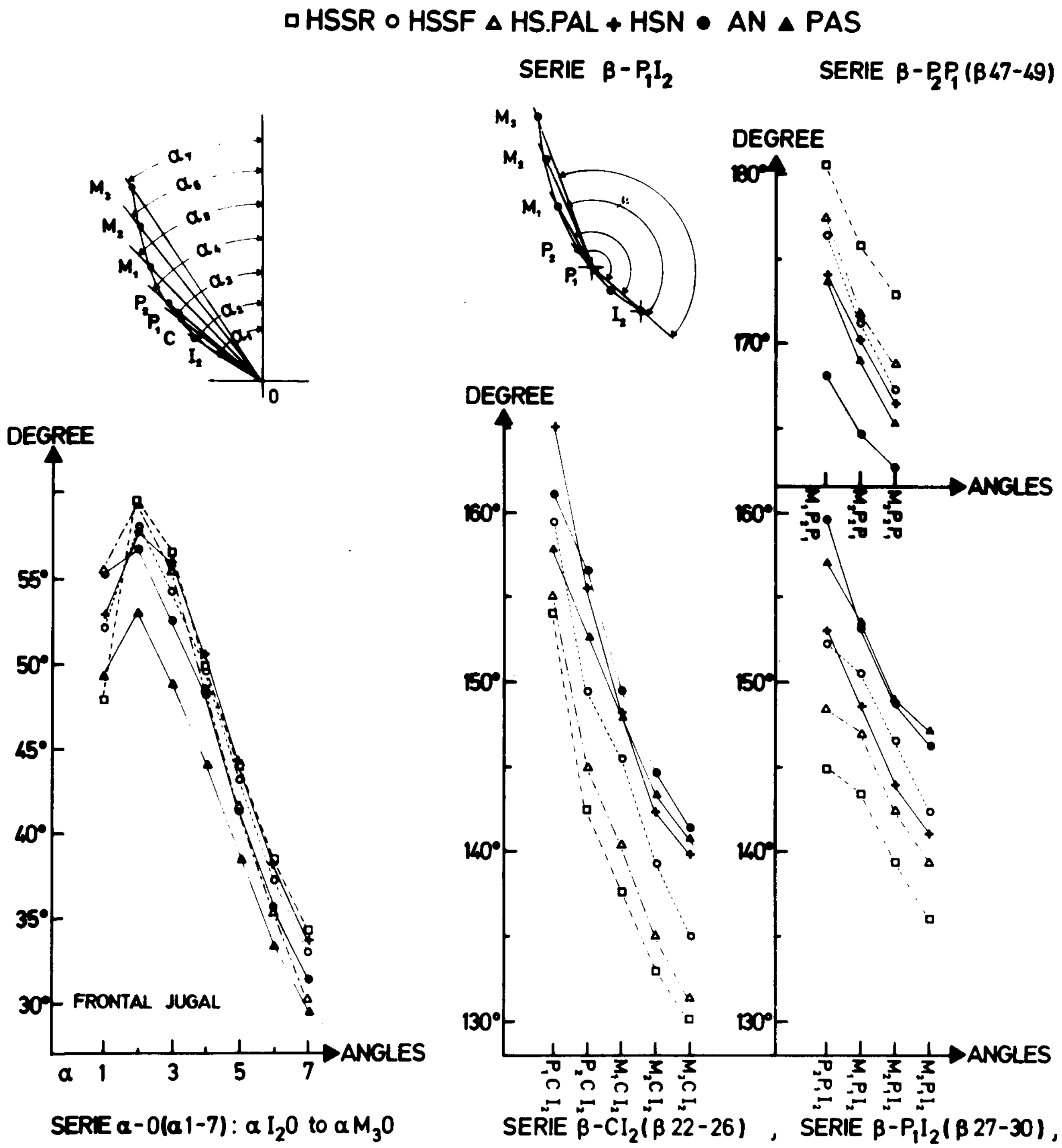

FIGURE 4

Comparison of Homo erectus (PAS▲), *European Middle Pleistocene homonids* (AN●), *Neanderthals* (HSN○), *Early modern hominids from Palestine* (HS.PALΔ), *Upper Paleolithic hominids* (HSSF■), *Modern European* (HSSR□)