Metric Description and Analysis of Cranial Contours

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Non-metric description of skulls in general and of artifically deformed skulls, in particular, is based mainly on subjective observation on the part of the investigator with no standard or objective criteria to serve as guidelines. A problem arising from such an approach is how to communicate information on skull curves to other scholars. This issue is not new and has been discussed by many anthropologists (cf. Kroeber 1940, Stewart 1950, and others).

Deformed skulls have ordinarily been described typologically; that is, a certain form is given a particular name, and another form will be given a different name. However, when there are intermediate degrees of deformation or deviations from the established typology, expressions like "slight deformation," "slight pressure, almost unnoticeable," or "cradle-board flattening" are coined (cf. Ewing 1950, Angel 1953, Saul 1972 and Bennett 1973).

The purpose of this paper is to propose a metric — that is, objective — method of describing and analyzing contours. Deformed skulls serve as the example in our demonstration.

Twelve skulls were chosen for the study. They were divided according to morphological criteria into three groups, each of which represents one kind of deformation. It is true that the classification was based on traditional (subjective) observation; however, in our sample there are no intermediate degrees of deformation nor typological deviations, since, in order to meet the particular needs of this study, only skulls with well-defined characteristics were chosen.

Group I: These four skulls present a clear example of what is called "tabular erect deformation" in Imbelloni and Dembo's 1938 classification (cited by Comas 1960) (Figure 2; Table 1: 1, 2, 3, 4).

Group II: This group consists of three skulls, which fit Imbelloni and Dembo's category "tabular oblique," in the above cited work (Figure 3; Table 1: 5, 6, 7).

Group III: This sample consists of five skulls and probably belongs to the "tabular oblique" category; however, it is different from Group II in that the occipital portion does not look deformed while the frontal section is quite oblique. Group III most likely represents Stewart's (1949, 1953) "fronto-vertico-occipital" category (Figure 4; Table 1: 8, 9, 10, 11, 12).

The cranial drawings are on an approximate scale of 1:1; each skull's shadow was cast on paper and the contours of the mid-sagittal plane were traced from glabella (G) to opisthion (O). The skull is oriented on the Frankfurt plane.

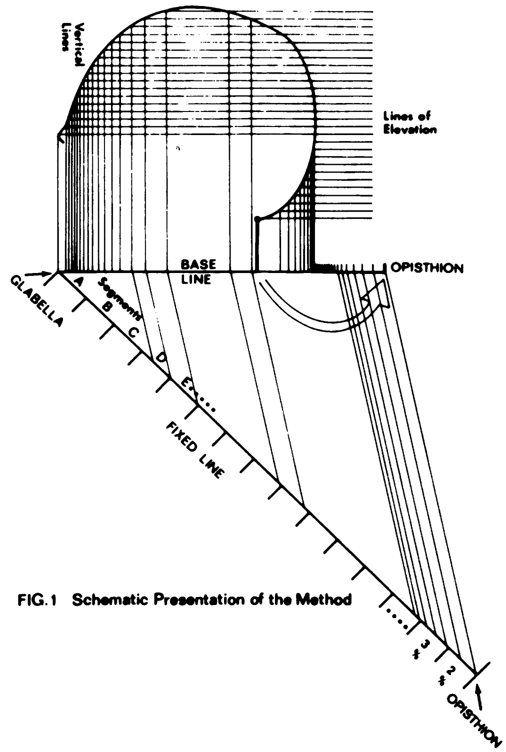

FIG. 1 Schematic Presentation of the Method

In this method the skull is viewed as a topographical object, such as a hill or a mountain. The lines of elevation are at horizontal intervals, which were fixed at .1 inch. Changes in the contour of the skull are reflected in the varying density of the vertical lines, as seen in Figure 1. These extend down to a horizontal axis, called the "base line", which is parallel to the Frankfurt plane. The steeper the curve of the skull, the denser the vertical lines will be.

Two problems present themselves at this point: A) The section of the contour between opisthion and the posterior-most point of the skull overlaps with the section between the latter point and the vertex (that is to say, the vertical intervals of the two sections fall on the same segment of the base line. B) The skull contours are not the same size, and, consequently, neither is the base line for each skull. Also, the size of the skull clearly affects the number of vertical lines represented on the base line.

Problem A) is solved by copying the segment of points covering the contour from the posterior-most point (not necessarily opisthocranion) to opisthion

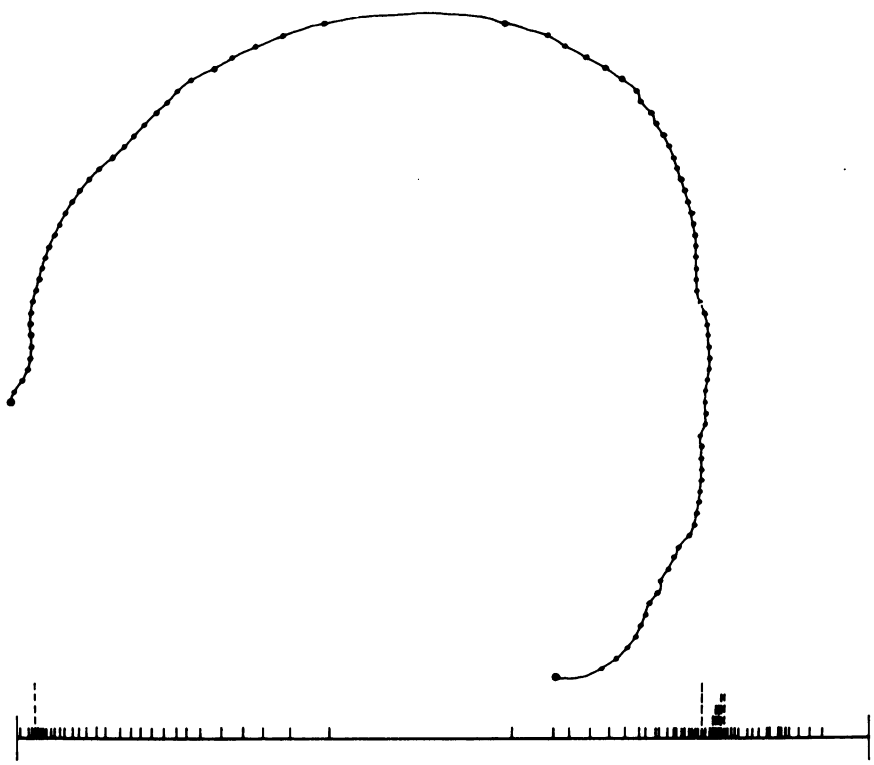

Fig. 2. The mid-sagittal contour and the base line of a skull representative of Group I.

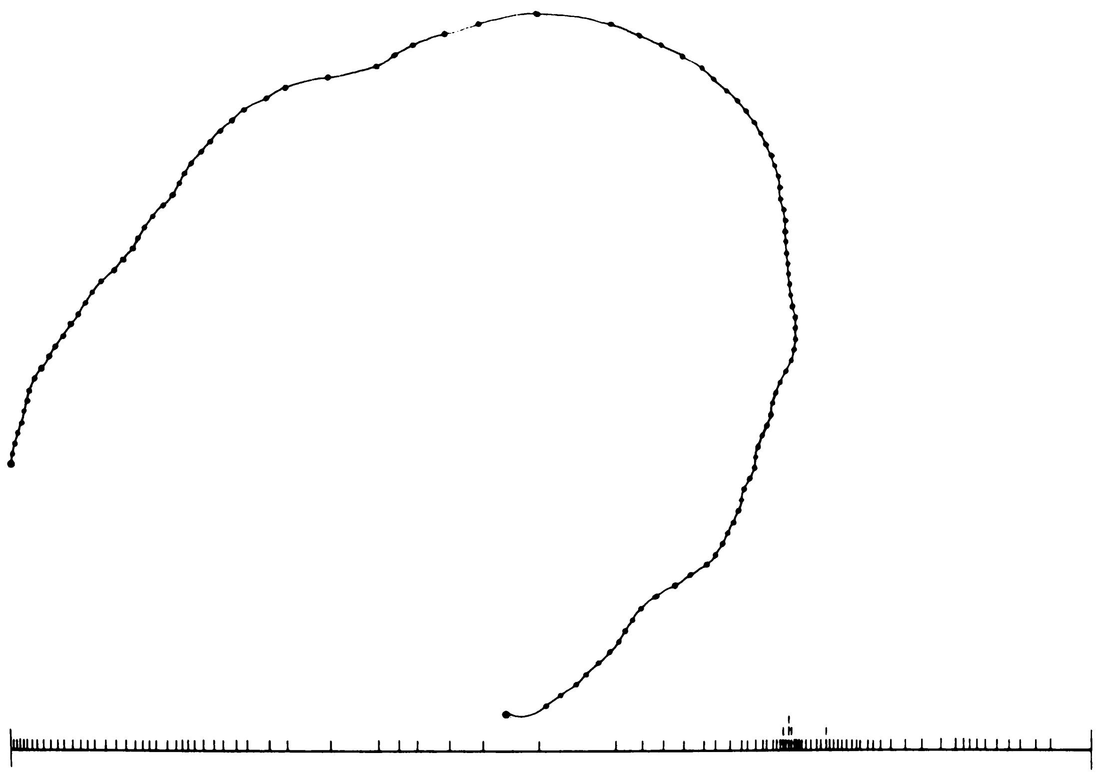

Fig. 3. The mid-sagittal contour and the base line of a skull representative of Group II.

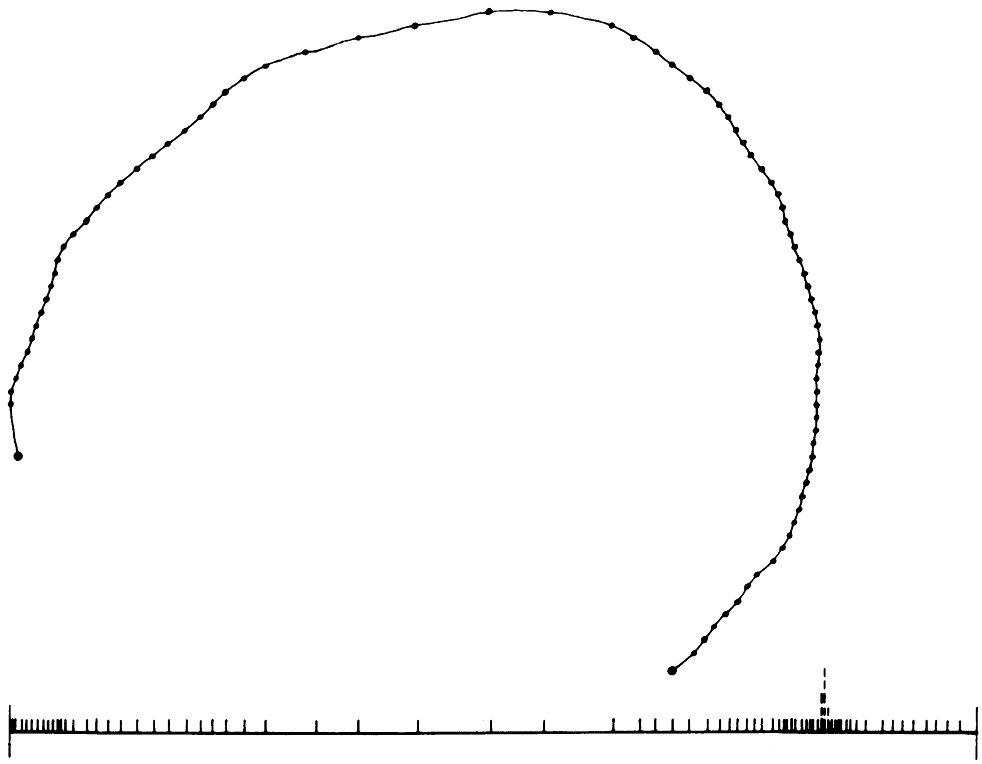

Fig. 4. The mid-sagittal contour and the base line of a skull representative of Group III.

onto the end of the base line, i.e. to the right of the segment containing the vertical intervals of the vertex to the posterior point (Figure 1). Problem B) is avoided by proportionally transferring the points on the base line, which indicate vertical intervals, to a "fixed" line, whose length is constant. By using the fixed line, we arrive at a standard scale. Another possible solution would be to trace the skull contours on the same scale initially and then to insert the lines of elevation at fixed horizontal intervals. The first alternative was chosen for its greater technical ease.

The fixed line has an arbitrarily determined length of ten inches. It is divided into twenty equal segments, each one-half inch long and labelled alphabetically. Segment A begins at glabella and segment T ends at opisthion. The number of vertical lines falling in each segment of the fixed line represents the slope of a particular portion of the skull's contour. The numbers of points on the fixed line vary due to skull size, i.e. a large skull will have more points on the line. To correct for this each segment will contain the percentage of the total number of points on the fixed line. With the conversion of these numbers to percentages, a standard procedure for expressing cranial contours in quantitative terms has been established. The numerical values obtained can be subjected to statistical analysis, and thus objective description and comparison of skull contours are possible.

One can determine, for example, the mean skull contour, standard deviation, and variance of a population and the section of the skull contour which contributes most to the group's heterogeneity. We can take advantage of multivariate techniques as demonstrated in Figure 5, where principal component analysis is used as a clustering method (see Temple 1968). The contours are seen to cluster into three well-defined groups corresponding to our typological classification.

The metric representation of the contour in each segment can be portrayed graphically for individual as well as population data. In Figure 6 we have superimposed three graphs referring to the following skulls, each of which is representative of one population:

Skull 3: Group I
Skull 5: Group II
Skull 12: Group III
(abbreviated, respectively, S3, S5, and S12.)

There are noticeable differences between the graphs. S3 begins with a high percentage of vertical lines in segment A which decreases significantly in B. This can be interpreted as a steep frontal line (A) and then a gradual leveling off of the skull contour towards the vertex (G through M). This trend is particularly visible in I, J, and K, where the contour is almost horizontal. A sharp up-turn in the graph, reaching a peak at Q, indicates that the occipital part of the skull is almost vertical. The down-turn at R represents a horizontal tendency which continues through T.

The graph of S5 has a much lower percentage in A than S3; the contour of the frontal part of the former, therefore, is far less steep than that of the latter. The decrease in percentage marking segment B (S5) is relatively small, which indicates that that section of the

Group	Skull	Segment:	A	B	C	D	E	F	G	H	I
I	1	V.L.	15	6	4	3	3	1	1	1	0
		%	16.3	6.5	4.3	3.2	3.2	1.1	1.1	1.1	0
	2	V.L.	12	5	4	3	1	2	1	1	1
		%	14	6	5	3.4	1.2	2.3	1.2	1.2	1.2
	3	V.L.	14	6	4	3	3	2	1	1	0
		%	15	6.4	4.3	3.2	3.2	2.1	1	1	0
	4	V.L.	16	4	4	2	2	1	1	2	1
		%	18	4.5	4.5	2.3	2.3	1.1	1.1	2.3	1.1
	Mean %:		15.8	5.8	4.5	3	2.5	1.6	1.1	1.4	.5
	S.D.:		1.5	.8	.3	.4	.8	.5	.07	.5	.6
II	5	V.L.	8	7	6	7	4	2	2	2	2
		%	8	7	6	7	4	2	2	2	2
	6	V.L.	11	7	6	7	3	2	1	2	2
		%	10.5	6.7	5.7	6.7	2.9	2	1	2	2
	7	V.L.	8	5	6	7	3	3	2	2	2
		%	8	5	6	7	3	3	2	2	2
	Mean %:		8.8	6.2	5.9	6.9	3.3	2.3	1.6	2	2
III	8	V.L.	11	7	5	4	4	2	1	1	2
		%	11.4	7.3	5.2	4.1	4.1	2.1	1	1	2.1
	9	V.L.	8	6	4	4	2	2	2	0	1
		%	10	7.6	5	5	2.5	2.5	2.5	0	1.3
	10	V.L.	9	7	6	4	3	1	1	1	1
		%	10	8	6.8	4.5	3.4	1.1	1.1	1.1	1.1
	11	V.L.	11	5	4	3	3	1	1	1	1
		%	13.5	6	4.8	3.6	3.6	1.2	1.2	1.2	1.2
	12	V.L.	9	8	5	4	2	3	1	2	1
		%	10	9	5.7	4.5	2.3	3.4	1.1	2.3	1.1
	Mean %		11	7.5	5.5	4.3	3.1	2	1.4	1.1	1.4
	S.D.:		1.5	1	.8	.5	.7	.9	.6	.8	.4

V.L. = Vertical lines
% = Percentage of vertical lines

Table 1: Summary of the absolute value of vertical lines in each segment, the percentage value, and the mean percentage for each segment of Groups I, II, and III and the standard deviation for Groups I and III.

J	K	L	M	N	O	P	Q	R	S	T
0	1	0	2	5	6	11	24	5	3	1
0	1.1	0	2.2	5.4	6.5	12	26	5.4	3.2	1.1
0	0	0	2	2	3	6	10	24	7	2
0	0	0	2.3	2.3	3.4	6.9	11.6	27.9	8.1	2.3
0	0	1	1	2	4	11	27	7	5	0
0	0	1	1	2.1	4.3	11.8	29	7.5	5.3	0
0	1	1	1	2	4	7	15	17	5	2
0	1.1	1.1	1.1	2.3	4.5	8	17	19	5.7	2.3
0	.5	.5	1.7	3	4.7	9.7	20.9	15	5.5	1.4
0	.5	.5	.6	1.3	1.1	2.2	6.9	9	1.7	.9
0	1	1	4	9	8	21	6	4	4	3
0	1	1	4	9	8	21	6	4	4	3
1	0	2	3	6	22	14	4	5	5	1
1	0	2	2.9	5.7	21	13	4	4.8	4.8	1
1	0	2	2	3	23	10	9	5	5	3
1	0	2	2	3	23	10	9	5	5	3
.6	.3	1.6	2.9	5.9	17.3	14.6	6.3	4.6	4.6	2.3
0	1	0	2	2	5	12	24	5	5	3
0	1	0	2.1	2.1	5.2	12.5	25	5.2	5.2	3.1
0	0	1	1	4	6	12	17	5	3	1
0	0	1.3	1.3	5	7.6	15	21.5	6.3	3.7	1.3
0	1	0	2	3	5	8	25	5	4	2
0	1.1	0	2.3	3.4	5.6	9	28	5.6	4.5	2.3
1	0	1	1	3	4	7	20	7	5	3
1.2	0	1.2	1.2	3.6	4.8	8.5	24.4	8.5	6	3.6
0	1	1	2	3	5	15	15	5	4	2
0	1.1	1.1	2.3	3.4	5.7	17	17	5.7	4.5	2.3
.2	.6	.7	1.8	3.5	5.7	12.4	23.1	6.2	4.8	2.5
.5	.5	.6	.5	1	1	3.7	4.1	1.3	.8	.8

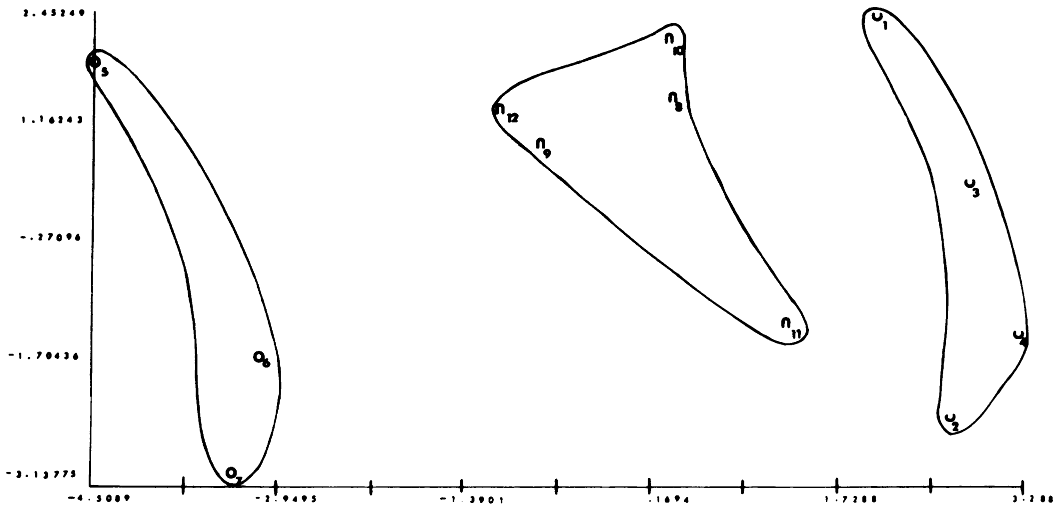

Fig. 5. The three groups of skulls clustered by means of first (horizontal axis) and second (vertical axis) principal components.

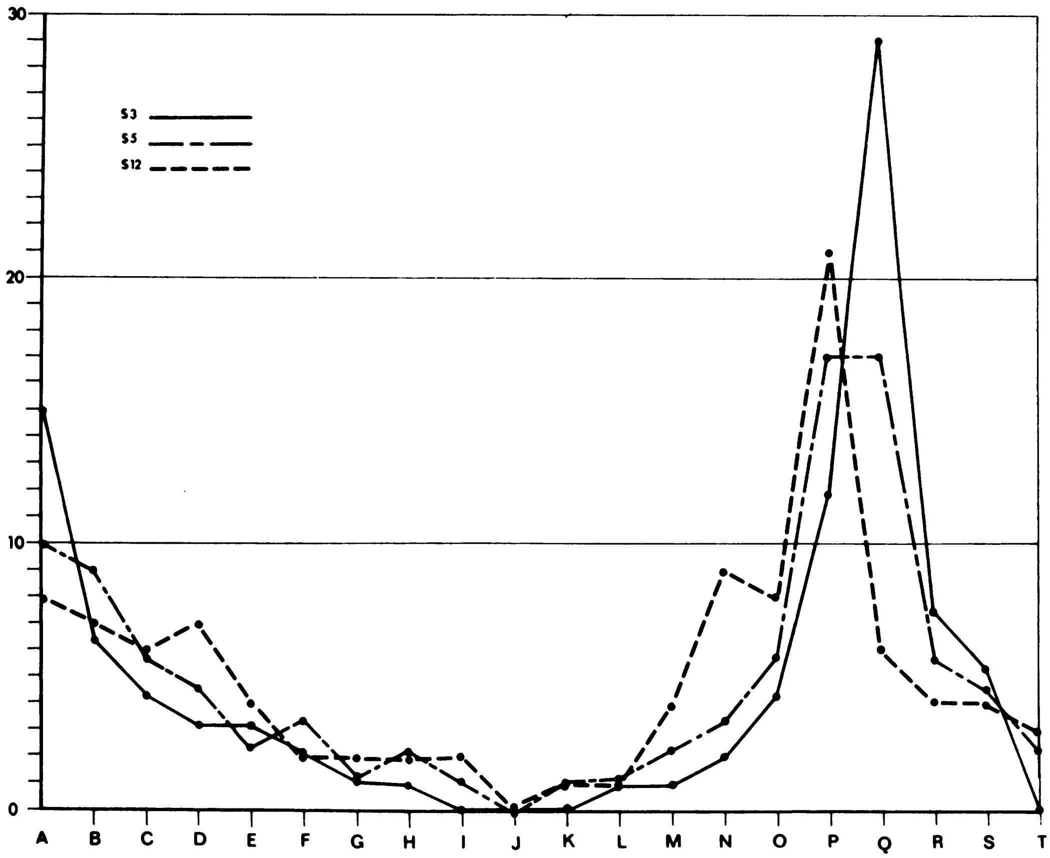

Fig. 6. A graphic representation of three cranial contours.

contour continues with only a slight change from that of A. The same tendency can be seen in segment C. In D there is an obvious difference between S3 and S5, whereas the former is leveling off (as reflected in a low percentage), the latter is still relatively steep (as seen in its larger percentage value). Only a small portion of the skull contour in the graph of S5 is horizontal — that in segment J, where the percentage is zero.

Segment A in the graph of S12 is similar to that of S5; the difference in the percentages (10 and 8, respectively) shows that S12 represents a slightly more vertical cranial contour at the frontal bone. The cranial contour levels off gradually, and in C, D, and E the graph indicates a more horizontal configuration than in S5. In the middle sections (G-L) the two graphs are very similar; that is, in both of them a small part of the vertex is completely flat (as is S3). The transition from O to P in S12 is sharp, but the peak is not high, indicating that the occipital portion is not vertical but slanted. P and Q have the same percentage values. The ends of the graphs of S5 and S12 are similar (segment T): the last part of the skull contour is not horizontal as in S3, but oblique.

At this point it should be emphasized that a horizontal portion of the graph does not necessarily signify a horizontal cranial contour, but, rather, a particular trend which continues in two adjacent parts of the contour, be they slanted or horizontal. Where the slope of any two or more adjacent sections of the skull is steep it will be seen as a high point in the graph (e.g. P and Q in S12), and where the skull contour is flatter in two or more contiguous parts, it will be expressed as a lower value in the graph (such as in I, J, and K in S3). We may further note that a peak's location on the horizontal axis is of particular importance; if the highest peak is found close to the right end, we know that the occipital portion of the skull rises sharply not far from the opisthion. A peak which occurs in the middle segments represents a large backward protrusion of the rear section of the skull.

Discussion and Conclusions

Visual observation remains a valuable tool in morphological analysis. Charles Oxnard justifiably states that:

> "The chief agent for studying shape in primates is the experience and creative human mind behind the human eye. This equipment, with its exquisite powers of recognition and discrimination, has provided the great bulk of what we know now about primate morphology."
>
> Oxnard (1973: 3)

On the other hand, the method which we have outlined may have a potential for obtaining and handling kinds of information that the traditional method could not. We have examined one contour only, the mid-sagittal, but a more detailed description and, consequently, a stronger basis for morphological comparison can be achieved through the further application of this method to sets of contours situated at equal intervals lateral to the mid-sagittal line. In addition, one can plot a number of different cranial measuring points, such as vertex, opisthocranion, lambda, and bregma, on the fixed line and examine their location on this line and the relationships among them. The method may also be valuable as an instrument for the comparison of fossil and prehistoric populations, since quite often only the braincase is found, and thus the morphology of its contour is an important source of information.

We should emphasize that the method presented above is in a most preliminary form and that many aspects are in need of refinement. For example, the proper balance must be found between the size of the segments on the fixed line and the size of the intervals between the lines of elevation; making the segments and the intervals smaller will increase the sensitivity of the method, should it be deemed necessary. Furthermore, it may be found preferable to place the skull on a line of orientation other than the Frankfurt plane, such as on the glabella-opisthion line or the glabella-inion line.

The somewhat involved technical procedure of this method seems to be a major detraction. However, we believe that this is outweighed by the greater degrees of precision and standardization that are afforded by a metric analysis.

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