Reprinted from AMERICAN JOURNAL OF PHYSICAL ANTHROPOLOGY Vol. 39, No. 1, July 1973 s The Wistar Institute Press 1973

Forty-five Northern Irish Families: A Cephalometric Radiographic Study

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KEY WORDS Genetics Family study • Skull • Radiographs Continuous variables.

ABSTRACT The individual bones that are identifiable from lateral skull radiographs have been analysed for the parents and growing children of 45 families. There were at least four children in each family and altogether there were 95 sons and 102 daughters. The youngest child was not less than seven years of age. Traced outlines were made of the bones and 24 linear and angular measurements were made; the raw data were transformed into scores to overcome differences due to age and sex. Analyses of variance of within and between families showed that for all the variables, the scores for persons in different families were significantly less similar, ($P < 0.001$), than scores to be found within families. Correlations were then computed for each variable between the mothers and fathers, the mothers and sons, the mothers and daughters, the fathers and sons, the fathers and daughters, brothers and sisters, paired brothers and paired sisters. It was found that there were no statistically significant correlations between the mothers and fathers, but for all the other combinations that were examined there were many correlations significant at a 0.1% and 1.0% level.

Children of the same family look like their parents and resemble each other in many different ways, but they are usually distinctly different from the children and parents of unrelated families as figures 1 and 2 clearly demonstrate (**omitted**). These photographs reveal many familial characteristics and suggest that genetic influences are very important factors; though the effects of similar environments within a given family cannot be dismissed, they are likely to be of secondary importance.

The similarities that are recognisable from these photographs or from observations of any family are those of head shape, hair pattern, likenesses around the eyes, the mouth or chin, and more obvious features like the shape of the nose or ears. These and many other aspects are the basis for the common observation that one child is more like his mother, his father or a mixture of both; but it is equally well known that the similarities that are recognisable one year have often disappeared by the next, when other likenesses may be recognisable. Rarely are the observers in total agreement as these observations are essentially subjective. Do the same kind of similarities known for so many of the superficial characteristics of the head also exist for the separate bones of the skull? Are they more under genetic than environmental influences?

Lateral cephalometric radiographs give a standardised view of all skulls and parts of most of the separate bones which comprise the cranial and facial skeleton are readily visible. These bones can be measured from the radiographs and the raw data used to determine the presence of statistically meaningful associations. In this way the hypothesis of greater similarities within families than between families for the shape and size of the different bones of the skull can be tested. If proven, then an analysis can be undertaken to show for which particular bones or parts of bones there are greater similarities between parents and their children, the brothers and sisters, paired brothers or paired sisters.

Statistically significant associations between

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the children and their parents or between each other should enable an assessment of growth trends and of the ultimate shape and size of the different structures of the cranio-facial complex.

The most important stimulus for this study was the technique employed by Kraus, Wise and Frei ('59) for studying triplets from tracings made from cephalo-metric radiographs. They extended the conventional analysis of linear and angular measurements by tracing outlines of parts of the bones, such as the lower border of the mandible, and showed that it was possible to obtain many concordant superimpositions for monovular triplets. Curtner ('53) had also employed the principle of superimposition of tracing bone outlines of families, and his illustrations of six families show very obvious similarities between the children and their parents.

An attempt was made in the early stages of this study to use a modified superimposition technique by comparing for some of the families the overall endocranial outline, that of the frontal and occipital bones and the mandibular outline. The results were encouraging and a preliminary report was published (Brown, '61). Although this approach was not objective enough to stand up to the severest critics, it laid the foundations for the method of analysis that was finally decided upon. As most of the individual bones of the skull were readily recognisable from the lateral cephalometric radiographs they could be examined separately. The frontal, parietal and occipital bones, and those comprising the cranial base, and the maxilla and the mandible were selected for study. The length and height of the cranium and the relationship of the mandible and maxilla to the cranial base were also examined.

Review of Literature

Only literature concerned mainly with the inheritance of several components of the skull is considered.

The reviews by Tobias ('55), Brash, McKeag and Scott ('56), Krogman and Sassouni ('57) and Krogman ('60) clearly indicate the importance of genetic influences in determining the major morphological characteristics that children inherit.

Fig. 1 **(omitted)** Family 30. Many similarities are apparent, and though the offspring resemble their parents (the top 2 photographs), in many different ways, they seem to resemble each other even more. The question this study attempts to answer is, are the same observations equally applicable to the underlying bony structures?

One of the first to recognise how cephalometric radiographs could be used to study inheritance was Wylie ('44), who measured different angles in 28 families with 37 children. His failure to find meaningful associations may have been due to his neglect of age differences and his choice of the linear and angular measurements used by orthodontists, which have uncertain biological validity.

One important aspect of the present study has been the establishment of strict criteria for the selection of variables to be measured; measurements made within individual bones or those representing brain size or relating the mandible and maxilla to the cranial base could be regarded as well defined biological units or relationships. Pearson and Davin ('24) specifically recommended that for anthropological purposes it would be wise never to take measurements on the skull which extended beyond the limits of a single bone. Horowitz ('63) noted that most cranio-facial diameters of clinical or anthropological interest tend to lump together a number of variable factors in a single dimension, and that measurements of a single bone would go a long way to minimise these unknown influences.

Skulls have been studied extensively in the past because skeletons usually are all that are left for the archaeologist to find, and only bones are readily discernible on radiographs; but bones themselves are only a record, albeit a permanent and measurable one, of periosteal development and activity.

Bones provide protection for the brain and the sense organs and give attachment to the muscles and the teeth. The several structures that have evolved as part of the individual bones are possibly under poly-genic control. Garn and his co-workers ('63) recognised that there were multiple influences and examined the inheritance of symphyseal size. Horowitz and Thompson ('64) outlined the regions of the lower jaw which vary independently, and Moss and Greenberg ('67) and Moss and Simon ('68) developed this principle of individual components for the maxilla and mandible and incorporated them into the system of functional matrices. Scott ('69) took the argument of the polygenic nature of skeletal structures and the environment in which they function one stage further, by suggesting that we need to study in greater depth the succession of the various stages in the development of each functional matrix.

Early recognition that twins were an important aid to the study of genetic and non-genetic influences was made by Galton in 1883. An early paper by Lundstrom on twins ('49) reported that there was less variation between identical than fraternal twins for the arch widths and lengths for both jaws and the palatal vault height. In a subsequent paper ('55) he demonstrated a rank order for several facial measurements from the least variable, between identical twins, to the most variable, that between unrelated population pairs. Horo-witz, Osborne and De George ('60), in a study of 56 like-sexed twins showed highly significant hereditary variations in the anterior cranial base, mandibular body length, the total face height and lower face height, and less variation in the upper face height.

In their study on triplets, Kraus, Wise and Frei ('59) examined the conventional type of facial polygon and found no greater similarities in lengths of lines or degrees of angles in monovular twins than in di-ovular twins; they questioned the validity of using diameters and angles for recognising the inheritance factor. Their examination of individual bones proved to be more meaningful. Studies such as these on measurements within bones likely to be under genetic control, influenced the selection of the variables chosen in this investigation.

Although researches into twins provided useful guidelines for the understanding of heredity, environmental influences may also be operating in varying degrees. In the extreme examples of cranial deformation in American Indian skulls. Moss ('58) pointed out that the deformation is brought

Fig. 2 **(omitted)** Family 31. As in figure 1 the offspring resemble each other more than they resemble their parents, (the top 2 photographs). They are all very strikingly different from members of family 30.

about by a redirection of the vectors of normal neurocranial growth. McNeill and Newton ('65) found similar artificial alter-ations among adult Pacific Northwest Indian crania.

The presence of wormian bones is thought by Bennett ('65) to represent secondary sutural characteristics brought about by stress and therefore not under direct genetic control. Gundara and Zivanovic's ('68) report that wormian bones were found only in the asymetrical skulls of the 297 East African skeletons they studied support this thesis. However, Hulse ('63) reports that there is a higher frequency of wormian bones among American Indians than among Europeans. This observation does not necessarily contra-dict the previous view, but it does alert one to the possibility of mistakenly identifying a special bony feature with special genetic significance, when in fact it may be more a consequence of environmental influences.

MATERIALS AND METHODS

All the sample was born in Ireland and was living at the time of the investigation in Northern Ireland. No attempt was made to restrict the selection of the sample from any one area or social class, both of which factors have a varying influence on skeletal development as reported by Cheese-man and Walby ('54), Acheson, Hewitt, Westropp and Maclntyre ('56), and Ache-son and Fowler ('64).

Each family comprised both parents and at least four children, none less than seven years of age. Among the 45 families were 31 with four children, 11 with five children and three with six children. Of these families, two had sons only and three had daughters only. Included among the families are four sets of dizygous twins. The mean ages, standard deviations and ranges for the mothers, fathers, sons and daughters are given in table 1.

Thirty of the families were identified from among those parents who brought their children to the Royal Victoria Hospital in Belfast for orthodontic treatment and who were willing to involve their families in the project. The cephalometric radiographs were taken before any treatment was begun. Another nine families were associated with the Queen's University

TABLE 1 *The mean ages, standard deviations and ranges of the parents and their children*

Group	n	Mean	Standard deviation	Range
Mothers	45	44.30	6.28	31.50-56.50
Fathers	45	47.98	7.83	33.75-73.75
Sons	95	14.49	5.68	7.00-32.75
Daughters	102	14.27	4.77	7.50-30.50

of Belfast and the remaining six families were from miscellaneous sources. Although a randomly selected sample would have added to the integrity of the investigation, it was not of itself an important prerequisite for testing the family hypothesis.

Among the 90 mothers and fathers, 56 were completely without teeth from one or both jaws. Because of this and the special relationship of the dentition to skeletal structures (Krogman, '48), none of the variables that were studied were related to the teeth.

All members of the sample were positioned in an Adam's cephalostat with the right side of their heads opposite the x-ray tube as described by Adams and Brown ('66), figure 3. The mid-sagittal plane of the subject's head was 152 cms from the x-ray source and 13 cms from the cassette, giving a constant enlargement of 8.5% for each subject. The unit was set at 100 kv and 10 Ma with an exposure time of 1/100 second for the adults and 1/150 second for the children. The radiographs were taken with the subject's teeth in centric occlusion, except of course for those parents who were without teeth. For these parents the radiographs were taken with the mandible in the rest position.

The variables

Attempts to utilise the technique of superimposition suggested by Kraus, Wise and Frei ('59) proved unreliable for comparing children of different ages with their parents. An approach largely combining the familiar procedures used by orthodontists and anthropologists was worked out to determine which variables should be examined. Before the analysis was begun on the cephalometric radiographs, the disarticulated bones of several skulls were radiographed in positions that would simulate as closely as possible their

location in a routine lateral cephalometric radiograph (figs. 4-11). From these views it was possible to determine unequivocally which lines and points of a bone were projected as apparent midplane shadows on the radiographic film, and made them much more readily recognisable. It became apparent from these disarticulated bone radiographs that the endocranial outline of the frontal, parietal and occipital bones could not be reliably identified.

The bones and features examined were:

(A) The Cranium: Frontal bone; parietal bone; occipital bone; cranial base; length and height.

(B) The Face: Maxilla and mandible.

(C) The relationship of the mandible and maxilla to the cranium.

For these bones and special features a series of measurements were made using a modification of constructions for the frontal and parietal bones suggested by Woo ('49) and Young ('56). Special points are defined as follows:

Nasion: N The mid-point of the suture between the frontal and two nasal bones.

Bregma: The exocranial intersection of the coronal and sagittal sutures.

Lambda: The exocranial intersection of the sagittal and lamboid sutures.

Basion: Ba The lowest point on the external surface of the anterior margin of the foramen magnum in its mid-sagittal plane.

Sella: S The mid-point of the sella turcica.

Keith and Campion ('22) and Scott ('56) reported that during growth the suture between the frontal bone and the inter-nasal suture, that locates nasion, may move slightly upward on the frontal bone. Sella too, according to Acheson and Archer ('59) is not fixed in its outline until after a child has passed its pre-adolescent growth spurt.

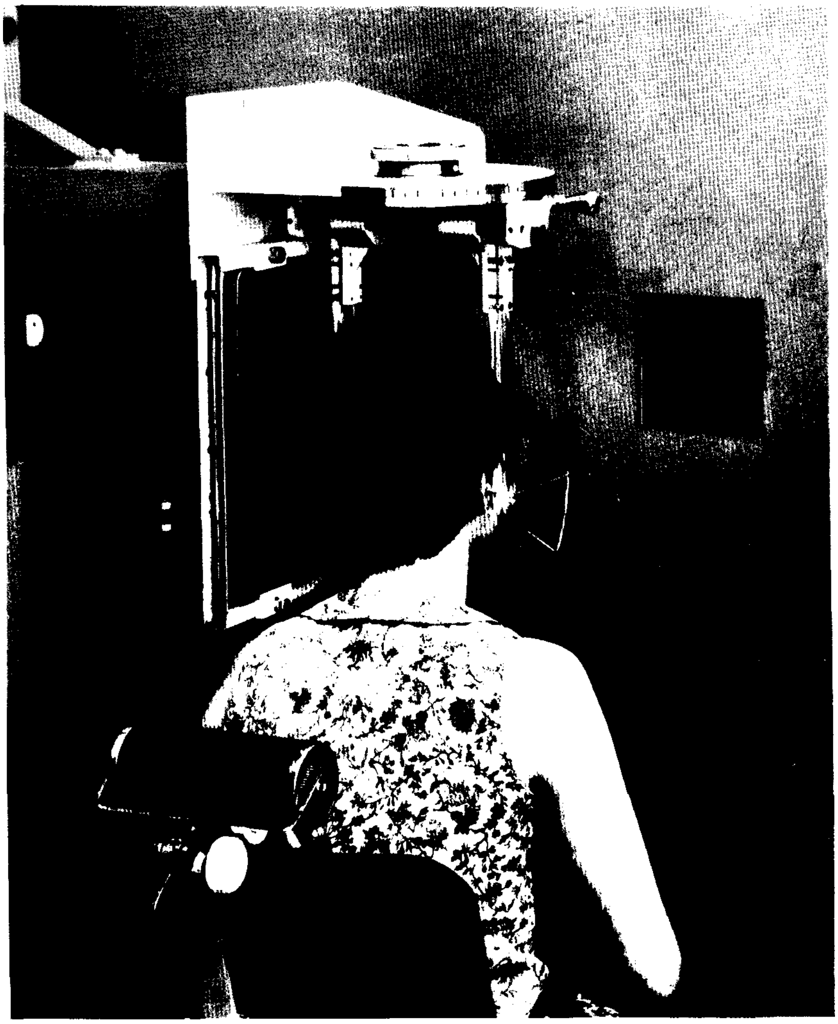


Fig. 3 An Adams' Cephalostat. The ear posts are adjustable to position the subject's head at a constant midline distance from the cassette holding the x-ray film, and so assure a constant enlargement for all subjects. The x-ray source is positioned at right angles to the cassette at a distance of 165 cms.

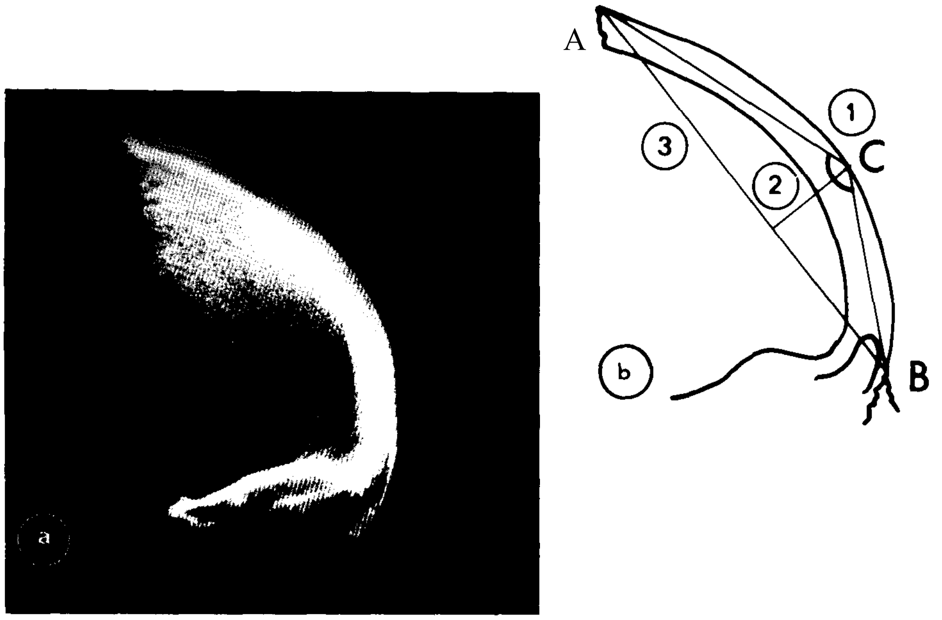
For each bone and feature, the outlines were traced separately. Appropriate outlines were drawn for the cranial base, and for the length and height of the cranium (figs. 4—11). Because the figures are of disarticulated bones, terms like bregma and lambda were not used, and to identify the several points, letters A, B, C and D have been used. Wherever there were two outlines, like the lower borders of the mandible, a mid-point was located.

All the tracings were made using an x-ray viewer in the same optimal conditions of complete darkness.

(A) *The cranium The frontal bone;* Figure 4

(1) Frontal angle: the angle at the intersection of chords (AC), (CB), drawn from nasion (B) and bregma (A) to the point of maximum curvature C.

(2) Frontal subtenuse: the maximum perpendicular distance from the frontal chord (AB) to the frontal curvature.



Figs.. 4a-b The frontal bone: (Variables 1, 2, 3)..Fig. 4a The lateral radiograph demonstrates how difficult it would be to follow the endo-cranial outline. The suture line with the nasal bone is not apparent on the radiograph.Fig. 4b The outline and construction lines used. The frontal chord A-C-B *(1);* the frontal subtenuse (2); the frontal chord A-B (3).

(3) Frontal chord: the straight line distance from nasion B to bregma A.

The outline represents a true mid-sagittal plane shadow of the squamous plate. On to this were constructed the chord, subtenuse and angle of curvature.

The parietal bone: Figure 5

(4) Parietal angle: the angle at the intersection of chords (AC), (CB), drawn from bregma (B) and lambda (A) to the point of maximum curvature.

(5) Parietal subtenuse: the maximum perpendicular distance from the parietal chord (AB) to the parietal curvature.

(6) Parietal chord: the straight line distance from bregma (B) to lambda (A).

The occipital bone: Figure 6

(7) Occipital angle: the angle at the intersection of chords (AC), (CB) drawn from lambda (A) and basion (B) to the point of maximum curvature.

(8) Occipital subtenuse: the maximum perpendicular distance from the occipital chord (AB) to the occipital curvature.

(9) Occipital chord: the straight line distance from lambda (A) to basion (B).

Basion was located on the outlined anterior edge of the foramen magnum, as neither the anterior edge of the occipital bone nor the posterior edge of the foramen could be routinely detected.

The cranial base: Figure 7

(10) Cranial Base, S-N: the line between (S) the centre of sella turcica to nasion (N).

(11) Cranial base, S-Ba: the line between sella (S) and basion (Ba).

(12) Cranial base angle: the angle formed by the arms (NS), (BaS).

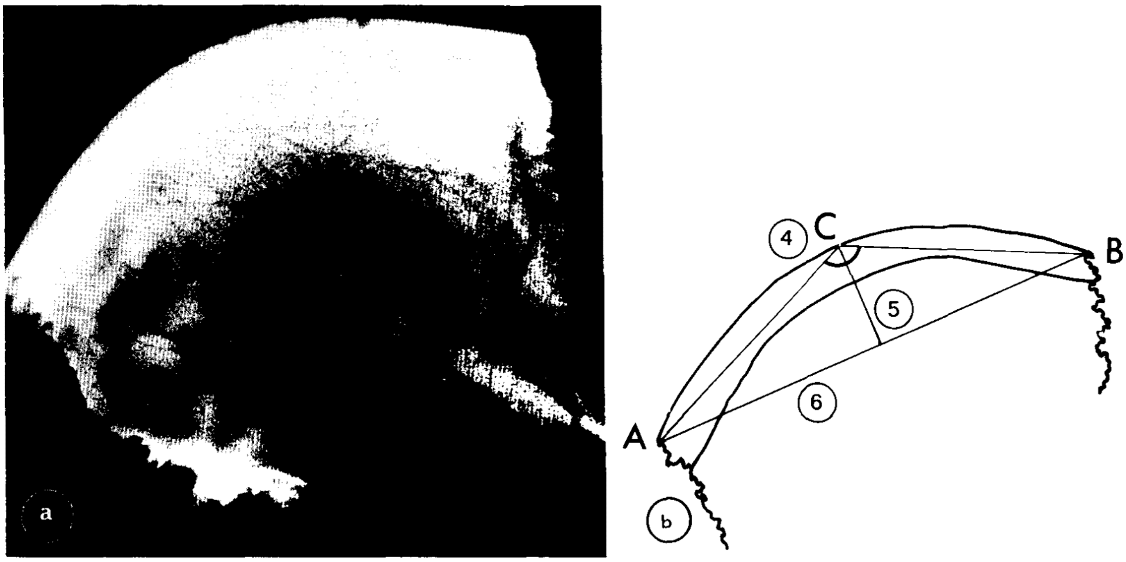
The anterior cranial base was included to complete the cranial outline, and because this familiar landmark completes its growth at about age seven (Scott, '56).

The length and height: Figure 8

(13) Cranial length: the maximum anterior-posterior length of the exocranial outline.

(14) Cranial height: the maximum height from basion to the exocranial outline of the parietal bone.

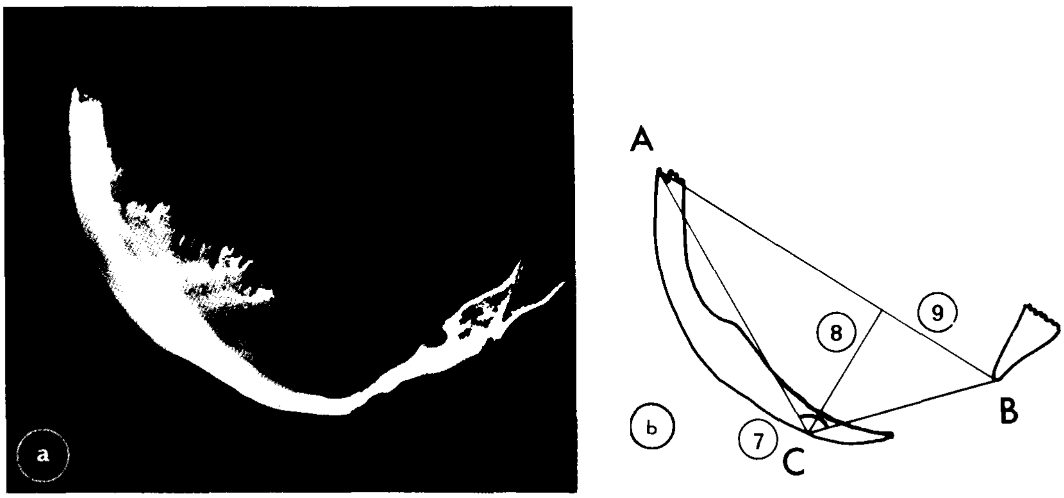
Choosing total length and total height of the cranium may appear to contradict the principle of analysis of single discrete biological units, much emphasised as an essential basis of this study. However, in a lateral radiograph the length and height reflect in large part the size of the brain,



Figs. 5a—b The parietal bone: (Variables 4, 5, 6).

Fig. 5a The lateral radiograph. The fuzzy outline of the superior surface corresponds to the interdigitations of the sagittal suture.

Fig. 5b The outline and construction lines used. The parietal angle A-C-B (4); the parietal subtenuse (5); the parietal chord A-B (6).



Figs. 6a-b The occipital bone: (Variables 7, 8, 9).

Fig. 6a The lateral radiograph reveals very clearly the position ofbasion. Fig. 6b The outline and construction lines used. The occipital angle A-C-B (7); the occipital subtenuse (8); the occipital chord A-B (9).

a biological unit whose size is reflected by these measurements. As these measurements include the thickness of the cranial bones since the endocranial outline could not be consistently identified, they are not exact descriptions of brain size. The small additional measurement, however, does not seriously influence the results.

To measure the cranial length in a consistent manner the line SN was drawn and extended forwards beyond N and back-

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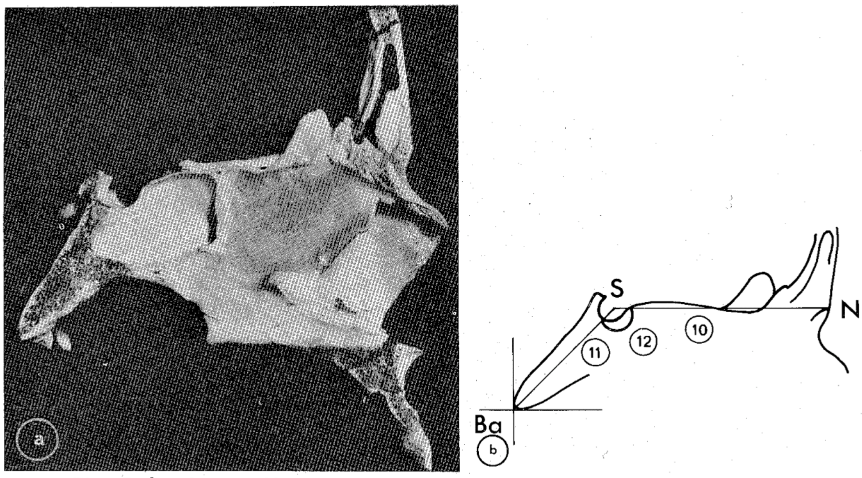


Figs. 7a–b The cranial base: (Variables 10, 11, 12).
Fig. 7a Shows the medial aspect of a half section through a skull and identifies what is commonly called the cranial base.
Fig. 7b The construction lines that were used. The line between sella and nasion S-N (10); the line between sella and basion S-Ba which crosses the junction between the sphenoid and occipital bones (11); the cranial base angle Ba-S-N (12).

wards beyond the occipital exocranial outline. Tangents from the exocranial outlines of the occipital and frontal bones were dropped perpendicular to the extended line to cut it at A and B respectively. The distance between A and B was recorded as cranial length.

To determine the height, a line was drawn perpendicular to the extended S-N line to pass as a tangent to basion and through the parietal outline. Tangents from basion and from the parietal outline were dropped perpendicular to this line to cut it at C and D respectively. The distance between C and D was recorded as the cranial height.

(B) The face
The maxilla: Figure 9

(15) Maxilla length: the distance between the posterior wall of the maxillary antrum (A) and the point of greatest concavity on the anterior nasal aperture (B). To establish the length, tangents were dropped perpendicular to a base line drawn horizontally through the hard palate, midway between the roof of the mouth and the floor of the nose.
(16) Maxilla orbital height: the perpendicular distance between the horizontal plane through the palate to the lowest point of the anterior orbital outline.
(17) Maxilla nasal height: the perpendicular distance between the horizontal plane and nasion.

The maxilla was outlined by the hard palate, the posterior aspect of the antrum, the anterior lateral edge of the nasal aperture, part of the lower border of the orbit and the junction of the maxilla with the nasal bones. In fact the junction between the nasal and frontal bones, nasion, was taken to represent this last point, because of the ease with which it could be identified. Unlike the cranial bones the outlines of the maxilla are midline projections of laterally located features. The posterior and anterior borders of the maxilla are more than a centimetre away from the midline and the lower borders of the orbits may be anything up to three or more centimetres. As there are nearly always the shadows of the left and the right maxillae, an average of the distance between the two outlines was taken. The two shadows are not visible in the illustration because only a single bone was radiographed.

Mandible: Figure 10

(18) Mandible beta angle: the angle formed between the arms of the mandibu-lar plane, drawn as a tangent from the lowermost aspect of the symphysis to the point of maximum curvature along the lower border of the mandible, and the line representing the length of the mandible (AB).

(19) Mandible gonial angle: the angle formed by the arms of the mandibular plane and the tangent drawn to the posterior aspect of the ascending ramus.

(20) Mandible length: The maximum distance between the symphysis and the outline of the condylar head.

(21) Mandible height: the maximum distance between the mandibular plane and the condylar head outline described by a line parallel to the tangent to the posterior aspect of the ascending ramus.

The anterior aspect of the mandible represented by the symphysis is a mid-plane outline, but as the bodies and rami diverge, a left and right shadow become a nearly constant feature.

(C) The relationship of the mandible and maxilla to the cranium:

Figure 11

(22) Basion to mandible: the distance from basion to the most convex point on the posterior outline of the condylar head.

(23) Mandible to sella: the distance from the most convex point on the posterior out-line of the condylar head to the perpen-dicular line dropped from sella (S).

(24) Sella to maxilla: the distance from the perpendicular dropped from sella (S) to the most posterior aspect of the maxillary antrum.

The line S-N was drawn and extended so that tangents perpendicular to the extended S-N line could be drawn from the outlines of the anterior edge of foramen magnum, the posterior condylar head of the mandible, and the posterior outline of the maxillary antrum. The distances along the extended S-N line between intersections of the tangents were measured to give the desired relationship of the mandible and maxilla to the cranial base.

Figure 12 shows all the variables that were measured and analysed.

Double determinations

Because some of the dimensions were unfamiliar and because of the known dif-ficulties of reproduceability (Bjork, '47; Richardson, '66), repeat tracings and mea-surements of the 24 variables were made for 30% of the sample. The 86 cases were randomly selected and the measurements from the separate tracings were paired and analyzed by the "t" test.

Among the 24 variables, the cranial length and maxilla orbital height were significantly different between the two tracings at a 0.1% level and the maxillary nasal height, mandible length and basion to mandible at a 1.0% level, table 2.

Statistical method

The early family studies of Dockrell ('59) and Sarnas ('59) employed a scoring tech-nique to overcome the problem of comparing children of varying ages and different sex. In order to compare the individual bones and features of the skulls of growing children and their parents in our study, we transformed the raw data of linear and angular measurements into scores, so that differences due to age and sex could be discounted. An analysis of variance was then calculated to determine whether families resembled each other more than members of another family. When greater likenesses within the families were shown to exist, correlations between parents and their children and between brothers and sisters, paired brothers and paired sisters were calculated. To obtain the scores, the measurements were plotted on the y axis against age on the x axis separately by sex. For most of the variables growth was completed between 17 and 19 years of age as illustrated for sons and daughters (figs. 13a,b, 14a,b).

For some of the variables, the frontal subtenuse, the parietal chord and sub-tenuse, the occipital and cranial base angles and the distance of the mandible to basion, there was little change of size with age. The gonial angle graph was quite different in its form and actually showed a decrease in size with age (figs. 15a,b).

Figs. 8a—b The length and height of the cranium: (Variables 13, 14).

Fig. 8a A lateral cephalometric radiograph of a dry skull. Though measurements from points on the endocranial outlines would have been a truer representation of the brain size, their exact location could not be made and so measurements had to be made on the exocra-nial outline.

On the basis of the differences for age and sex that have already been noted and from an examination of the graphs, it was decided to divide the sample into four classes: males seven to 17 years, males 17 and over, females 7 to 17 years and females 17 and over.

For each of these classes and for all the variables, the mean measurement, standard deviation, correlation and its level of significance were obtained; and also a linear regression and standard deviation of deviation about the regression of sub-tenuse on age were calculated. All the calculations were processed by a computer.

To convert the raw data into scores so that differences due to age and sex could be discounted the following formula was used:

$$y = \frac{(x - [c + ba])}{s}$$

where y = score, x = observed value, a = age, b = regression coefficient, c = regres-sion constant and s = standard deviation about the regression line.

Once the scores were obtained, it was possible to calculate an analysis of variance between and within family differences to show for which variables the members of a family more resembled each other than members of another family.

The last procedure was to determine if there were any significant correlations between the scores of the mothers and

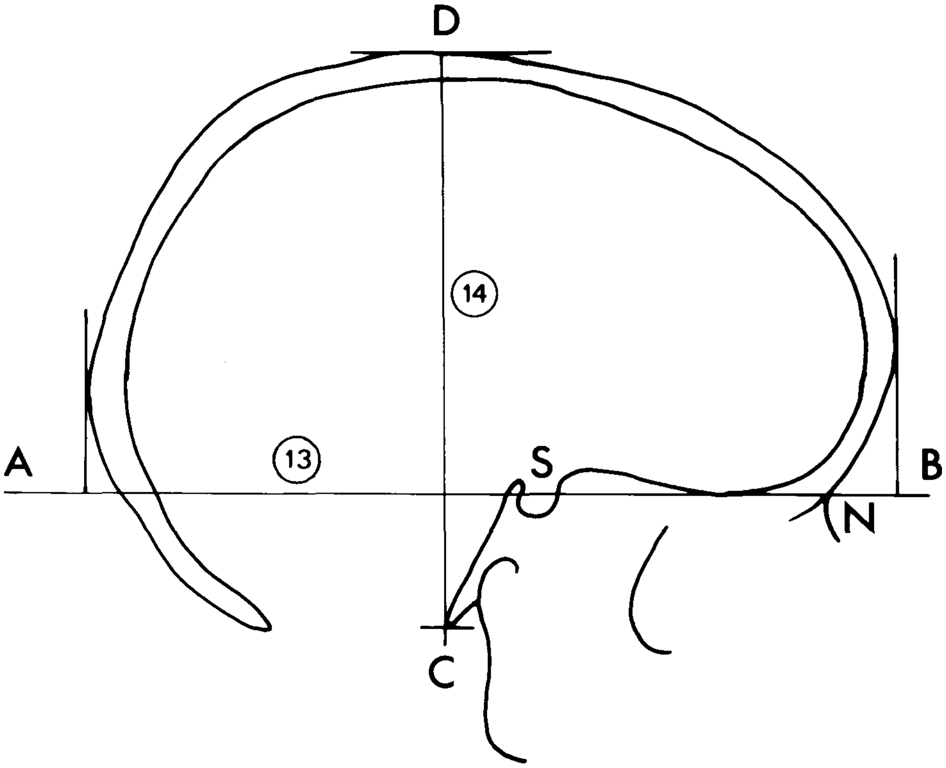
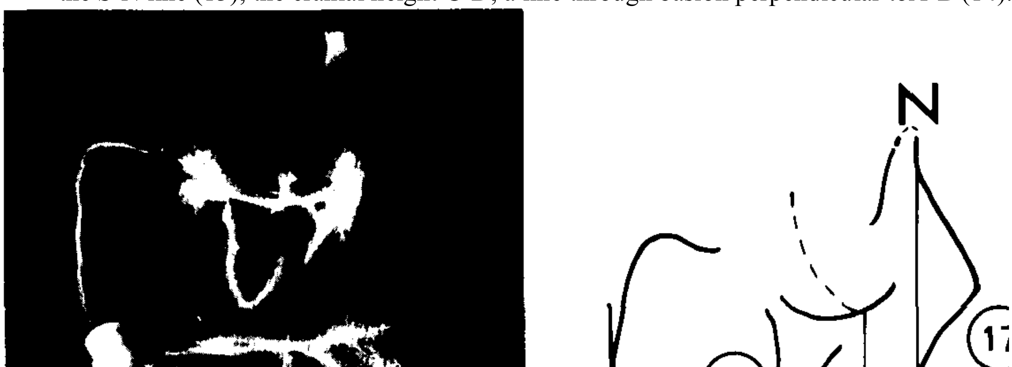


Fig. 8b The outline and construction lines used. The cranial length A-R which is an extension of the S-N line (13); the cranial height C-D, a line through basion perpendicular toA-B (14).



Figs. 9a-b The maxilla: (Variables 15, 16, 17).

Fig. 9a A radiograph of a single maxilla, showing clearly the posterior border of the maxilla.

Fig. 9b The outline and construction lines used. The length A-B (15); the orbital height (16). The perpendicular line is shown in the position it would be drawn on a cephalometric radiograph. The zygomatic outline has been dotted in; the nasal height (17).

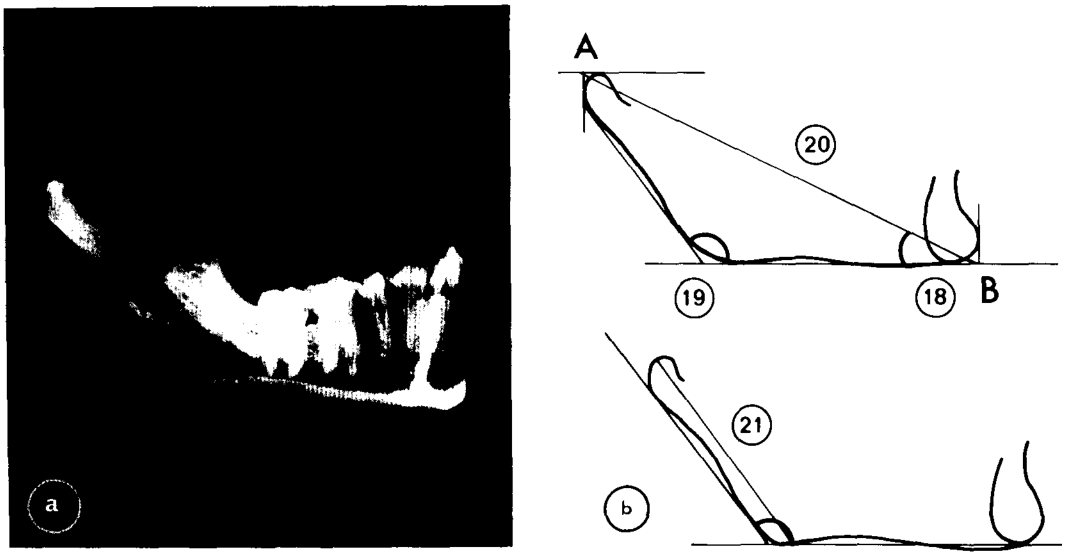


Fig 10a-b The mandible (variables 18, 19, 20, 21).

Fig. 10a The lateral radiograph.

Fig. lOb The outline and construction lines. For simplicity only single outlines have been drawn. The beta angle (18); the gonial angle (19); the length (20); the height (21).

fathers, parents and their children, brothers and sisters, paired brothers and paired sisters.

Correlations were calculated between mothers and fathers to make sure that for all the variables none was significant. For the correlations between parents and their children each child's score was correlated with his mother's and father's score. For brothers and sisters correlations were worked out for all the possible 172 brother and sister pairs; a random brother and sister pairs correlation test was carried out with a total of 41 pairs to enable comparisons to be made of the results from the 36 random brother pairs and the 41 random sister pairs.

Findings

The analysis of variance between and within families

For each of the 24 variables for the 287 members of the 45 families the F values are all significant at a 0.1% level, table 3. These results amply confirm the hypothesis that for these variables, members of each of these Northern Irish families are more similar to each other, than they are to members of another family.

Though it is not possible to define the meaning of the differences of one F value from another when they are all significant at a 0.1% level, the values for the variables for the frontal bone (1), (2) and (3), the cranial length (13) and height (14) are among the highest, while the occipital subtenuse (8) and angle (7), the cranial base angle (12) and the mandible height (21) are among the lowest.

The correlations

Correlations were carried out to find associations between the different family groups. The significant correlations found between the children and their parents, between brothers and sisters or between paired brothers and paired sisters are the most important part of this study for they are very likely to imply hereditary factors which families may have in common.

No significant correlations existed for any of the 24 variables between mothers and fathers.

The tables, 4—8, showing the correlations for mothers and fathers and their children and multiple brothers and sisters only record correlations significant at a 0.1% and 1.0% level, while the tables, 9—11, showing the correlations for the random brothers and sisters, and paired brothers and sisters, show correlations significant at a 5.0% level as well. This has been done because there are fewer random brothers and sisters and the correlations significant at the 5.0% level appeared to be of importance in understanding the results.

Mothers and daughters: Table 4 and figure 16

The three variables of the frontal bone (1, 2, 3) and a variable from each of the other components of the cranial outline are significant at a 0.1% level, whereas the variables associated with the face are significant at a 1.0% level.

Mothers and sons: Table 5 and figure 17

There are half the number of significant correlations at a 0.1% level than between the mothers and daughters and three of these are related to the face (15, 18, 19). Those at a 1.0% level are concerned with variables relating the mandible and maxilla to the cranial base (23, 24) and with the overall length and height of the cranium (13, 14) and the parietal chord (6).

Fathers and sons; Table 6 and figure 17

The pattern of significant correlations at a 0.1% level is markedly different from that of mothers and daughters, only the frontal angle (1) and subtenuse (2) being the same. The correlations significant at a 1.0% level are all concerned with cranial variables and again contrast with the pattern for the mothers and daughters.

Fathers and daughters: Table 7 and figure 16

Three of the variables (1, 2, 14) are at the same 0.1% level of significance with the mothers and daughters. Again there are many fewer correlations between children and parents of opposite sex.

The brothers and sisters, n= 172:
Tables 8 and 9

The correlations for the variables between the brothers and sisters have been calculated with two different sample sizes. One sample with 172 pairs, representing the maximum number of paired combinations that could be obtained with 95 brothers and 102 sisters will be described first. The second sample size of 41 pairs is the total possible number of random pairs of the brothers and sisters on the basis of one pair from each family that had a pair.

The correlations for 172 pairs have been calculated to compare the findings with those of the correlations that have been described for parents and their children. There are 17 correlations at a 0.1% level and two at a 1.0% level. The five variables which do not correlate are two for the parietal bone, the angle (4) and the subtenuse (5), the cranial base S-Ba (11), the mandible beta angle (18) and the relationship of the mandible to the cranial base (22).

All four variables (7), (8), (20) and (21) which did not correlate between the parents and their children, do correlate significantly between the brothers and sisters.

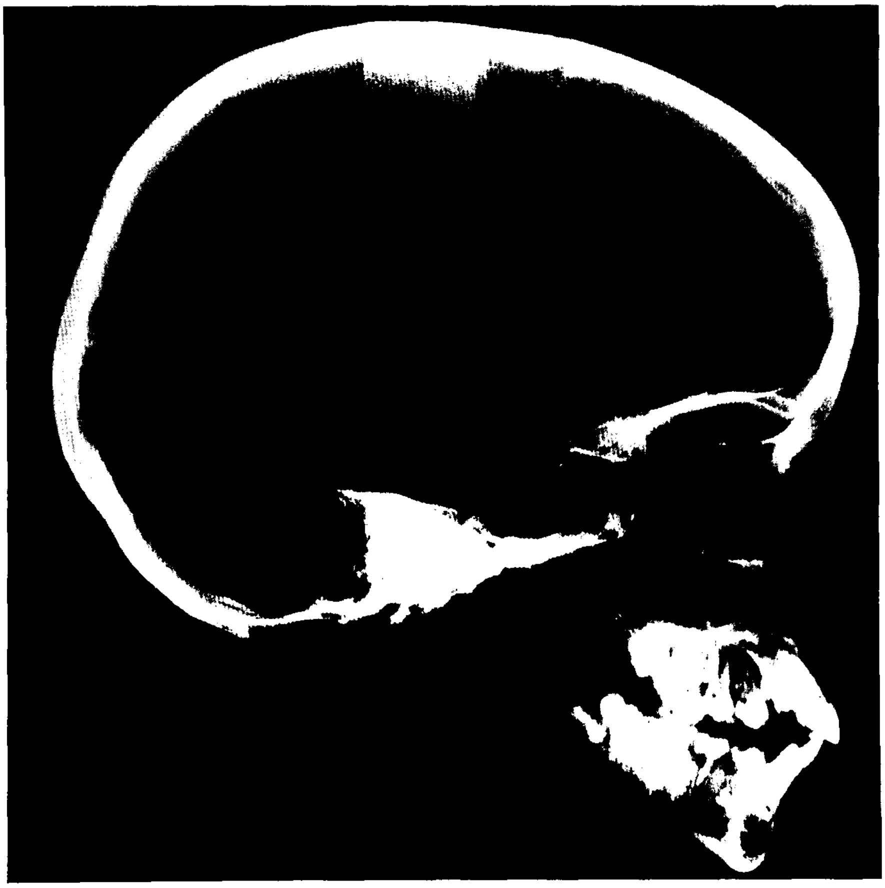
All the variables for the maxilla (15), (16) and (17) and three of the variables for the mandible (19), (20) and (21), correlate at a 0.1% level, as do the two that relate the mandible and maxilla to the cranial base (23) and (24). The two less significant correlations are related to the cranial outline, the occipital and cranial base angles, (7) and (12).

For the randomly paired brothers and sisters there are far fewer significant correlations at a 0.1% and a 1.0% level hence those significant at a 5.0% level have been included. Of the five variables significant at a 0.1% and 1.0% level only the mandible length (20) of the facial measurements correlates; the others are related to the frontal bone (2) and (3), the .parietal bone (6) and the cranial height (14). There are six variables significant at a 5.0% level and of these the variables (23) and (24) relating the mandible and maxilla to the cranial base should be noted, table 9.

To complete this family study correlations were calculated for randomly paired brothers and randomly paired sisters.

Random paired brothers, n = 36: Table 10

As with the reduced numbers of the pairs of brothers and sisters, there are fewer correlations at a 0.1% and 1.0% level of significance with only the gonial angle (19) significant at a 0.1% level. Of the eight variables significant at a 1.0% level, none are within the maxilla, but variable 24 relating the maxilla to the cranial base is. Even at a 5.0% level none



Figs. lla-b The relationship of the maxilla and mandible to the cranial base: (Variables 22, 23, 24).
Fig. 11 a A lateral cephalometric radiograph of a dry skull.

of the variables related to the cranial base (10), (11) and (12) is significant.

Random paired sisters, n = 41: Table 11

Only the occipital chord correlates at a 0.1% level. At a 1.0% level only the variable relating the mandible to the cranial base (23) outside the cranium is significant. The only variable of the maxilla significant at a 5.0% level is that relating it to the cranial base. The two angles of the mandible (18) and (19) are significant at this level too.

DISCUSSION

This analysis of 24 variables of the individual bones and selected features of the skull, for 45 families comprising 287 subjects, confirms specifically and objectively the hypothesis that individual members of a family are more like each other than members of other families.

The several stages through which the conclusions have been reached are from the selection of the sample; the identification of the bones and features of the skull which could be measured; the conversion of the measurements into scores which would allow subjects of different ages and sex to be compared; the calculation of analyses of variance within and between families to test in the first instance the hypothesis; and lastly, by identification of statistically significant associations, the demonstration of the way parents and children, brothers and sisters, paired brothers and paired sisters, may be, for the 24 variables, related to each other.

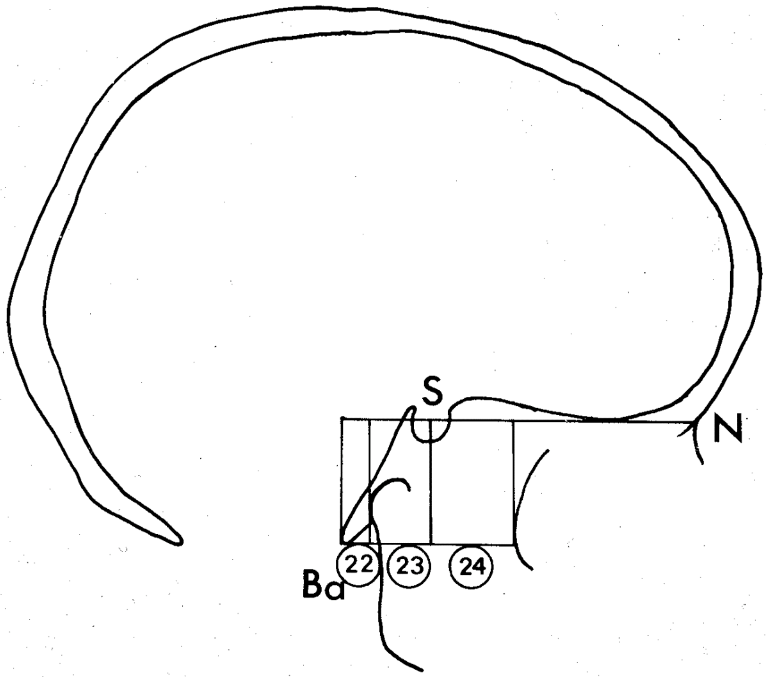


Fig. 11b The outline and structure lines. The distance of the posterior border of the condylar head of the mandible from the anterior border of the foramen magnum at basion Ba (22); the distance of the posterior border of the condylar head to a perpendicular dropped from sella S (23); the distance of the posterior border of the maxilla to the perpendicular dropped from sella S (24).

In one or two of the families the mothers and fathers looked very similar in full face or profile photographs. Despite the popular quote and some evidence, Pearson and Lee ('03), that like-appearance people marry each other, there were no significant correlations for any of the variables between the mothers and fathers of this sample.

All the families lived in separate accommodation and and were not at the time thought to be closely related; and though cousin marriages are not uncommon in Ireland, no special precaution was taken to exclude the possibility of such marriages. Benoist's ('64) analysis of 103 males who lived as part of a genetic "isolate" helps to put into perspective the possible influence of cousin marriages. He found that despite a very rigid endogamy, the variability from one individual to another for the classical anthropometric dimension remained of the same order of magnitude as much larger and less consanguinous populations.

Similarities present in profile views of fam.ily members in this study were often not present in full-face. Analysis of antero-posterior cephalometric radiographs should thus reveal some important dissimilarities.

The need to transpose the data to enable comparisons of growing children with their parents and each other has proved a satisfactory technique, but it is still possible that the similarities found for the children of this sample may not be found if the children are examined again when they are older.

The problem of change of size or shape with age is of special importance. Although these variations with age could represent overall change in shape of a particular bone or feature, it seems more likely on the basis of the findings of Kraus, Wise and Frei ('59) that these changes are related to the adjustments of bones to each

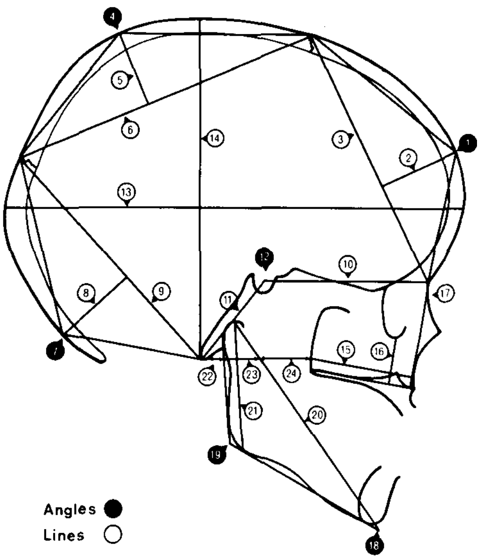


Fig. 12 The variables. All aspects of the cranium that can be clearly seen in a lateral cephalo-metric radiograph are represented by variables

(I) to (14). The maxilla is represented by variables (15) to (17), and the mandible by variables (18) to (21). The relationship of the mandible and maxilla to the cranial base is represented by variables (22) to (24). In all the subsequent figures of the skull the variable numbers have been located in the same positions as in this figure. (1) Frontal angle, (2) Frontal subtenuse, (3) Frontal chord, (4) Parietal angle, (5) Parietal subtenuse, (6) Parietal chord, (7) Occipital angle, (8) Occipital subtenuse, (9) Occipital chord, (10) Cranial base S-N,

(II) Cranial base S-Ba, (12) Cranial base angle, (13) Cranial length, (14) Cranial height, (15) Maxilla length, (16) Maxilla orbital height, (17) Maxilla nasal height, (18) Mandible beta angle, (19) Mandible gonial angle, (20) Mandible length, (21) Mandible height, (22) Basion to mandible, (23) Mandible to sella, (24) Sella to maxilla.

other to enable them to adapt to a complex of influences.

The extent to which changes in the relationship of one bone to another influence the final shape of a particular bone of the skull is not clear.

Choice of variables

The variables chosen for analysis had to be relevant to everyday questions asked about the skull, representative of all aspects of the skull, readily reproduceable, and least likely to be affected by environmental influences.

Woo's ('49) findings of a rank order for the frontal curvature angle measured on the skulls of different racial groups suggested that analysis of other individual bones would give positive results.

The fact that some of the outlines of the bones on the radiographs, such as the frontal, parietal and occipital, were mid-plane outlines, whereas the maxilla and mandible have features located laterally, does not appear to have markedly influenced the number of the correlations between parents and their children or between the brothers and sisters. There is no discernible pattern to suggest that this variation in bone position is an important difference.

Moss and his co-workers have been among the most active propounders of the multiple functions of bone; Moss and Salentijn ('69b) recently wrote that since all cranial bones are biomechanically implicated in a multiplicity of functions, they all consist of several skeletal units. In an-

TABLE 2 Variabies with significant differences between first and second tracing

Significance level	Variables	t[1]
%		
0.1	13 Cranial length	-4.1163
	16 Maxilla orbital height	- 3.8623
1.0	17 Maxillary nasal height	-3.1203
	20 Mandible length	-3.0156
	22 Basion to mandible	-2.6575
5.0	11 Cranial base S-Ba	2.3724
	18 Mandible beta angle	2.3015

[1] Student t test.

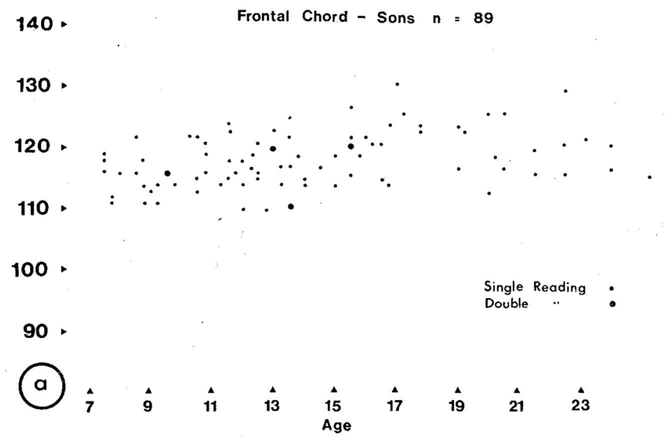


Fig. 13a The frontal chord for sons. The relationship between length and age appears to level off around 17 years of age. Of the sons six were too old to show on the scale.

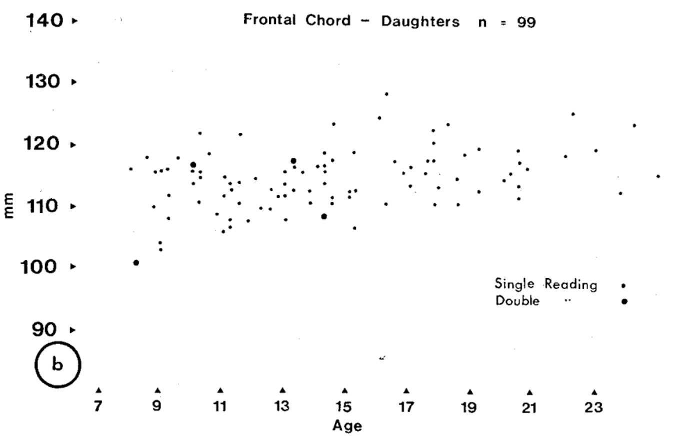


Fig. 13b The frontal chord for daughters. The relationship between length and age shows that the shortest length is 10 mm less than that of the sons, but levelling occurs around 17 years. Of the 105 daughters, six were too old to include on the scale.

other paper ('69a) they define skeletal units as composed variably of bone, cartilage, or tendinous tissues; when such a "bone" consists of a number of skeletal units, they are microskeletal units.

For each of the bones studied in this investigation, there are easily identifiable microskeletal units. A major contribution to the morphology of the bones would be an understanding of the part played by the muscles in gaining their attachment. This seems to be borne out with the complete absence of significant correlations between parents and children for the variables related to the mandible (20) and (21). Where the construction of a variable has traversed several bones as in the cranial base (11) and (12) there is only one significant correlation. The situation between the random brothers and sisters,

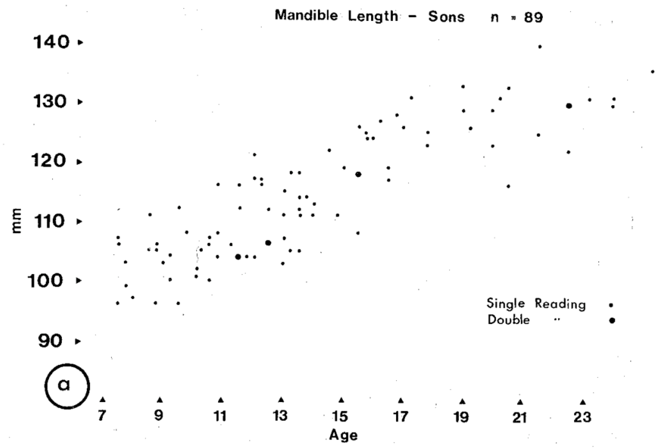


Fig. 14a The mandible length for sons. The relationship between length and age shows one of the largest increases of all the variables. In this data the mandible appears to slow down its growth at around 17 years. Of the sons six were too old to include on the scale.

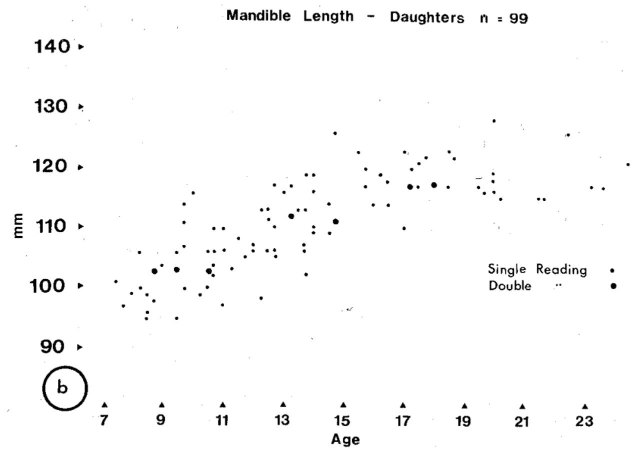


Fig. 14b The mandible length for daughters. The maximum length is smaller for the daughters than for the sons. Of the daughters six were too old to be included on the scale.

paired brothers and paired sisters, is not very different. There are only significant correlations at a 1.0% level and none higher for the mandible length (20) and height (21) for brothers and sisters and paired brothers respectively.

The low number of correlations related to the length of the mandible is explainable from many points of view. The mandible length (20) has included the outline of the chin, or symphysis, which Garn, Lewis and Vicinus ('63), described as an example of an anatomically simple and developmentally independent growth entity, uncomplicated by evolutionary changes and largely free from dimensions susceptible to environmental modification. This identifies the symphysis in Moss's terms

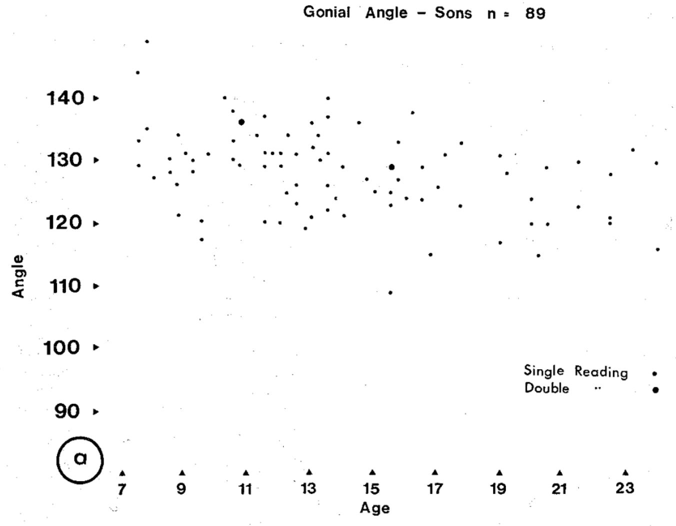


Fig. 15a The gonial angle for the sons. The relationship between the angle and age appears to show a definite decrease in the size of the angle with age. Of the sons six were too old to be included on the scale.

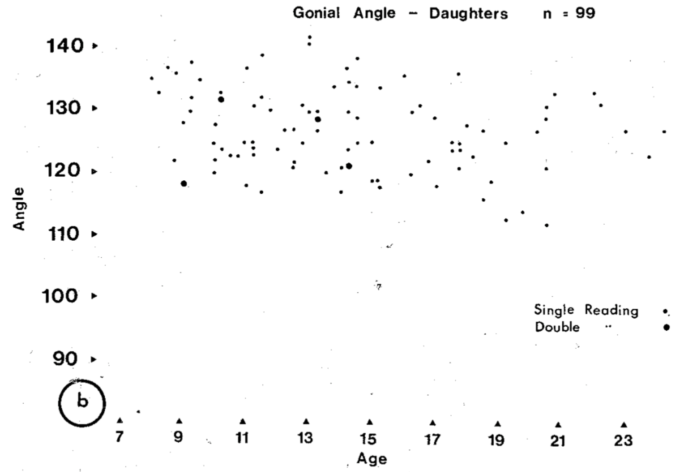


Fig. 15b The gonial angle for the daughters. As for the sons there appears to be a decrease in the size of the angle with age. Of the daughters six were too old to be included on the scale.

as a microskeletal unit which should perhaps be excluded from the mandible length. Berger ('69) confirmed the view that the chin is isolated from the total complex of the mandible. The mandible needs further detailed study to elucidate the interaction between its genetic and environmental background. Conversely, where the microskeletal units are not associated with powerful muscles, more variables significantly correlate between parents and their children, as for instance

TABLE 3

The analysis of variance between and within 45 families for the 24 variables of the skull. n = 287

	Variables	F Values [1]
(a) The frontal bone	1 Frontal angle	4.9905
	2 Frontal subtenuse	6.0006
	3 Frontal chord	4.1302
(b) The parietal bone	4 Parietal angle	2.9042
	5 Parietal subtenuse	3.0344
	6 Parietal chord	3.9156
(c) The occipital bone	7 Occipital angle	2.3871
	8 Occipital subtenuse	2.5569
	9 Occipital chord	3.4052
(d) The cranial base	10 Cranial base S-N	2.9504
	11 Cranial base S-Ba	2.8886
	12 Cranial base angle	2.5519
(e) The cranium	13 Cranial length	4.3416
	14 Cranial height	5.7258
(f) The maxilla	15 Maxilla length	3.8871
	16 Maxilla orbital height	2.8351
	17 Maxilla nasal height	3.5738
(g) The mandible	18 Mandible beta angle	3.6467
	19 Mandible gonial angle	3.7227
	20 Mandible length	2.9884
	21 Mandible height	2.3170
(h) The cranial base mandible and maxilla	22 Basion to mandible	2.4410
	23 Mandible to sella	4.0936
	24 Sella to maxilla	3.1919

[1] All the F values were significant at a 0.1% level.

TABLE 4

The correlations significant at a 0.1% and 1.0% level for mothers and daughters. n = 102

Significance level %	Variables	r
0.1	1 Frontal angle	0.3998
	2 Frontal subtenuse	0.4995
	3 Frontal chord	0.4508
	6 Parietal chord	0.3706
	9 Occipital chord	0.3508
	10 Cranial base S-N	0.3367
	13 Cranial length	0.4548
	14 Cranial height	0.4785
1.0	15 Maxilla length	0.3139
	18 Mandible beta angle	0.3029
	19 Mandible gonial angle	0.2952
	23 Mandible to sella	0.2737
	24 Sella to maxilla	0.2883

the frontal bone (1) and (2), cranial height (14), maxilla length (15), although the mandible beta angle (18) has three significant correlations between the parents and children, as also do variables (23) and (24) which relate the mandible and maxilla to the cranial base.

Bones that have cartilage precursors are thought to be more stable than bones that form in membrane as recorded by Scott and Dixon ('65). The only features which are preformed in cartilage are the cranial base S-N (10) and S-Ba (11). Variable S-N (10) does significantly correlate between mothers and daughters and fathers and sons, whereas variable S-Ba (11) correlates only between fathers and sons (tables 4 and 6). Between the random brothers and sisters, paired brothers and paired sisters there is only one weak correlation, tables

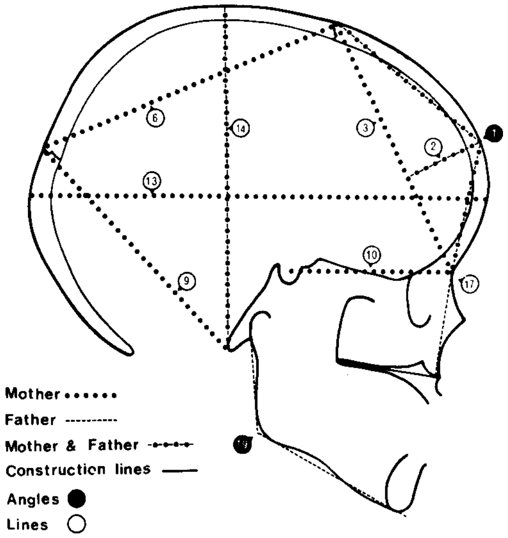


Fig. 16 The genetic sources of variables for daughters, n = 102 with correlations significant at a 0.1% level. The lines and angles illustrated show those with significant correlations of the daughters with their father or mother, or both. In contrast to the sons, the maxilla nasal height (17) and the gonial angle (19) are the only variables of the face that correlate at this level; most of the correlations are related to the cranium and are correlations with the mothers.

9, 10 and 11. These findings suggest that though the cranial base may be stable, it is nevertheless comprised of a complex of bones which would appear to be under multiple gene control.

The validity of choosing two all-embracing measurements with which to describe the cranium size (13) and (14), and thus the brain size is justified from Mednick's and Washburn's work ('56) and is confirmed in part by the number of significant

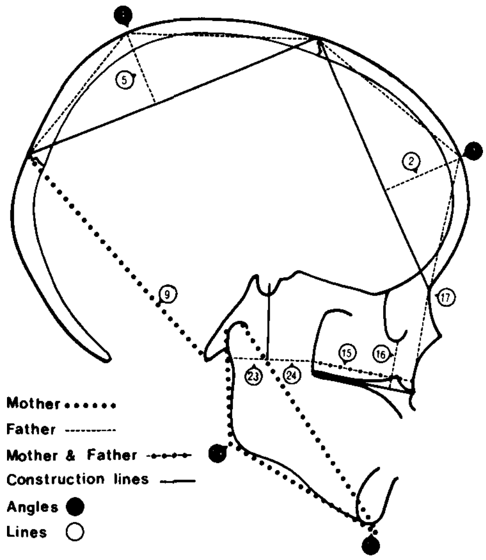


Fig. 17 The genetic source of variables for sons, n = 95, with correlations significant at a 0.1% level. The lines and angles illustrated show those with significant correlations of the sons with their father or mother, or both. Except for the cranial base, there is at least one correlation for each of the components analysed. Variable (15), the maxilla length correlates with both parents. Variables (23) and (24) that relate the mandible and maxilla to the cranial base are significantly correlated with the fathers, but at a 1.0% significance level they correlate with the mothers. As might be expected most of the correlations are with the fathers.

correlations found in this study. More were found for the cranial height (14) than the cranial length (13); the exocranial outline for the length reflects the additional complications of the enlargement, especially in males, of the frontal sinuses and the larger muscle attachments on the occipital

TABLE 5

The correlations significant at a 0.1% and 1.0% level for mothers and sons. n = 95

Significance level	Variables	r
%		
	9 Occipital chord	0.3726
0.1	15 Maxilla length	0.3641
	18 Mandible beta angle	0.3674
	19 Mandible gonial angle	0.4365
	6 Parietal chord	0.2701
	13 Cranial length	0.3077
1.0	14 Cranial height	0.3274
	23 Mandible to sella	0.3319
	24 Sella to maxilla	0.2707

TABLE 6

The correlations significant at a 0.1% and a 1.0% level for fathers and sons. n = 95

Significance level	Variables	r
%		
0.1	1 Frontal angle	0.4252
	2 Frontal subtenuse	0.4225
	4 Parietal angle	0.3342
	5 Parietal subtenuse	0.3746
	15 Maxilla length	0.3469
	16 Maxilla orbital height	0.4629
	17 Maxilla nasal height	0.4441
	23 Mandible to sella	0.4156
	24 Sella to maxilla	0.4131
1.0	6 Parietal chord	0.3270
	10 Cranial base S-N	0.3035
	11 Cranial base S-Ba	0.2748
	12 Cranial base angle	0.3149
	14 Cranial height	0.2893

TABLE 7

The correlations significant at a 0.1% and a 1.0% level for fathers and daughters. n = 102

Significance level	Variables	r
%		
0.1	1 Frontal angle	0.3585
	2 Frontal subtenuse	0.4744
	14 Cranial height	0.4816
	17 Maxilla nasal height	0.3343
	19 Mandible gonial angle	0.3489
1.0	5 Parietal subtenuse	0.2634
	15 Maxilla length	0.3169
	18 Mandible beta angle	0.3163
	22 Basion to mandible	0.2711

TABLE 8

The correlations significant to a 0.1% and 1.0% level for the brothers and sisters. n = 172

Significance level	Variables	r
%		
0.1	1 Frontal angle	0.4823
	2 Frontal subtenuse	0.5205
	3 Frontal chord	0.4080
	6 Parietal chord	0.3076
	8 Occipital subtenuse	0.3451
	9 Occipital chord	0.2971
	10 Cranial base S-N	0.3336
	13 Cranial length	0.3357
	14 Cranial height	0.4705
	15 Maxilla length	0.3470
	16 Maxilla orbital height	0.2945
	17 Maxilla nasal height	0.2740
	19 Mandible gonial angle	0.2780
	20 Mandible length	0.3913
	21 Mandible height	0.2725
	23 Mandible to sella	0.3596
	24 Sella to maxilla	0.2539
1.0	7 Occipital angle	0.2406
	12 Cranial base angle	0.2349

TABLE 9

The correlations significant at a 0.1%, 1.0% and 5.0% level for random brothers and sisters. n = 41

Significance level	Variables	r
%		
0.1	6 Parietal chord	0.5106
	14 Cranial height	0.5775
	2 Frontal subtenuse	0.4600
1.0	3 Frontal chord	0.4347
	20 Mandible length	0.4225
	5 Parietal subtenuse	0.3545
	13 Cranial length	0.3498
5.0	17 Maxilla nasal height	0.3393
	19 Mandible gonial angle	0.3557
	23 Mandible to sella	0.3846
	24 Sella to maxilla	0.3162

TABLE 10

The correlations significant at a 0.1%, 1.0% and 5.0% level for random paired brothers. n = 36

Significance level	Variables	r
%		
0.1	19 Mandible gonial angle	0.5520
	1 Frontal angle	0.4770
	5 Parietal subtenuse	0.4454
	6 Parietal chord	0.4916
1.0	13 Cranial length	0.4368
	18 Mandible beta angle	0.4857
	21 Mandible height	0.4791
	23 Mandible to sella	0.4607
	24 Sella to maxilla	0.4657
	2 Frontal subtenuse	0.3844
	4 Parietal angle	0.3573
5.0	8 Occipital subtenuse	0.3805
	14 Cranial height	0.3690
	16 Maxilla orbital height	0.3397
	20 Mandible length	0.3607

bone. These factors could easily explain why correlations for cranial length (13) are found only between mothers and their sons and daughters, and none for the fathers.

Family studies

Although twin studies such as those of Lundström ('55), Kraus, Wise and Frei ('59) and Horowitz, Osborne and De George ('60) have been used to measure heredity versus environment, they represent a special type of sample and can only hint at what complete family studies may reveal.

Stein, Kelley and Wood ('56) examined cephalometric radiographs of brothers and sisters and found that they were a valuable method for analysing craniofacial similarities, which is confirmed by this investigation.

Kraus, Wise and Frei ('59) suggested that there were different functions for the body and ascending ramus of the mandible, and this may explain why in this study mandible length (20) and height (21) have no significant correlations between parents and their children, though there is one between the brothers and sisters and two between the paired brothers. Horowitz, Osborne and De George ('60), employing a different measurement for mandible length, found a high component of

TABLE 11

The correlations significant at a 0.1%, 1.0% and *5.0%* level for random paired sisters, n =41

level	Variables	r
0.1%	9 Occipital chord	0.5264
1.0%	1 Frontal angle	0.4045
1.0%	6 Parietal chord	0.4214
1.0%	13 Cranial length	0.4847
1.0%	14 Cranial height	0.4078
1.0%	23 Mandible to sella	0.4734
5.0%	2 Frontal subtenuse	0.3345
5.0%	7 Occipital angle	0.3449
5.0%	8 Occipital subtenuse	0.3375
5.0%	10 Cranial base S-N	0.3899
5.0%	18 Mandible beta angle	0.3614
5.0%	19 Mandible gonial angle	0.3975
5.0%	24 Sella to maxilla	0.3359

genetic variability in their measurement. By studying individual bones and not the usual angular or polygon constructions and so obtaining so many significant correlations, it is easy to forget that there is very great variability in cranio-facial outline.

Another conclusion which may be drawn from this study is that whatever methods explain the mechanisms by which the skull grows, all of them are part of a master plan mediated through biochemical processes, monitored by the genes.

The family correlations

Significant correlations existed between parents and their children for the cranial height (14) and maxilla length (15) for all the possible combinations of parents and children, tables 4, 5, 6 and 7. It is tempting to suggest this may be because these two variables are among those most isolated from the polygenic influences associated with muscle attachments, but for the random brother and sister correlations there were no significant correlations for maxilla length (15), table 9.

Two variables, the occipital chord (9) and cranial length (13) correlate significantly only between the mothers and their sons or daughters. Both these measurements are related to bones where there are important accessory sexual characteristics as the attachment processes for the neck muscles and supra-orbital ridges of the frontal bone. However, though there is one strong correlation between paired sisters for variable (9), all the brother and sister pairs correlate for variable (13).

Only the cranial base S-N (10) significantly correlates between the mothers and daughters and fathers and sons; it is the only one which can suggest a sex link. The S-N line is composed of several bones which have a different time cycle for their growth and its inheritable component is difficult to interpret. Significant correlations between the fathers and sons for the parietal angle (4), cranial base S-Ba (11), cranial base angle (12) and maxilla orbital height (16), suggest a sex link transmission. It is of special note that all three cranial variables seem to be sex linked. Of all the possible brother and sister correlations only paired brothers correlate significantly for the parietal angle (4).

In comparing the two sets of correlations carried out with brothers and sisters, n = 172, and random brothers and sisters, n=41, it was thought that if there were no correlation for the sample of 172 there would be none for the sample of 41. This was not so for three of the variables: variable (4) has a weak correlation between paired sisters, variable (5) between brother and sister and paired brothers, variable (18) between paired brothers and paired sisters.

The significance to anthropology

Ashley Montagu wrote ('60), "Physical anthropology makes use of every method which is capable of throwing light upon the significant likenesses and differences existing between individuals and man." The techniques employed in this study which are only the extension and combination of many earlier workers, may be usefully employed to further the studies of man. Montagu was critical of the anthropometric approach. "The accumulated evidence from many different sources," he wrote, "has shown that the head is subject to change through environmental influences, and that there are great differences in intra-group variability in all measurements and indices among the ethnic groups of mankind, that closely related groups and individuals frequently exhibit considerable differences in cranial measurements and indices, while more distantly related groups and individuals exhibit striking likenesses."

A similar view is expressed by Coon ('63) who recommends research into blood groups, haemoglobins and other biochemical features. Nevertheless, the early studies are not without interest. Cameron ('26a,b, '29) from an examination of the cranial bases of skulls of different racial groups, concluded that the main angle of cranial flexion was larger in the American Negro than the American White, while the nasion-pituitary length is larger in the White races as compared with the Negro. Woo ('49), whose method for analysing the frontal bone influenced the choice of technique employed in this study, found a rank order for the frontal angle;

the highest was among the American Whites and the smallest among American Indians.

From the findings of this study it is apparent that unless variables for measurement are defined to reduce the number of genes that are being expressed, the chances of obtaining significant associations are greatly reduced. Physical anthropologists have measured thoroughly and completely all they could in their living subjects and even more in their dry skull selections, but it must be questioned whether or not they paid enough attention to the basic principles of inheritance and the fundamental concepts of sampling techniques.

As this study is concerned with families, the techniques of analysis employed may answer the archaeologists' questions on the identification of family units or small interbreeding communities, among the skeletal remains found in burial chambers or other isolated groups of burial (Broth-well, '65).

CONCLUSIONS

1. For all the 24 variables related to the bones of the skull greater similarities exist within the families than between the families.

2. Children derive their similarities from both parents, but there are more similarities between parents and children of the same sex.

3. When correlations were derived from the maximum number of brother sister pairings, (n=172), there were 17 out of the 24 variables which correlated significantly at a 0.1% level. When correlations were derived for random brothers and sisters, (n=41), there were only two variables which correlated significantly at a 0.1 % level, tables 8 and 9.

4. Paired brothers, (n = 36), and paired sisters, (n==41) only have one variable each which correlates significantly at a 0.1% level, but many more which correlate at a 1.0% and 5.0% level, tables 10 and 11.

5. The above findings suggest that further investigations into the prediction of growth and size may not only be determined from a comparison of children with their parents, but also by comparisons with each other.

6. Traditional anthropometric techniques could be reviewed and an attempt made to utilise cephalometric radiographs and the variables described or similar ones, to evaluate evolving bony characteristics.

7. In the same way as these techniques have been employed for the living, they could be used for an analysis of grouped skeletal material, and thus useful in archaeological research.

8. Because it is possible to obtain very good radiographs from fossil material, it is thought that where the fossilised material has not been distorted by crushing, it could be analysed by the methods herein described.

9. The positive results that have been obtained from an examination of a very

few variables for each bone suggest that a more detailed analysis of individual bones in terms of micro skeletal units would be very valuable.

ACKNOWLEDGMENTS

The author is indebted to Mr. H. G. Lovell, Lecturer in Mathematical Statistics and Operational Research at University College, Cardiff, for his invaluable assistance in advising and carrying out the statistical analysis: to Professor J. J. Pritchard and the late Professor J. H. Scott of the Queen's University, Belfast, for their critical review of the study as it was in progress and finally to the staff of the Dental Illustration Unit of the Welsh National School of Medicine, Cardiff.

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