Quantitative evaluation of correlation of skull morphology in families in an attempt to predict growth change

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SUMMARY The purpose of the present study was to obtain quantitative values for human skull structures in a cross-sectional analysis of offspring and their parents. The offspring were classified into three groups according to age. For each of 11 maxillo–facial and nine dento–alveolar structural angular measurements, the mean and SD were calculated for each set of paternal, maternal, midparent and offspring. The standard deviation unit (SDU) values were calculated from the disparity between the measured value in a given individual, i.e. father, mother, midparent, offspring, and their corresponding group mean value. Three disparity values (D.v.), expressed by the difference between the SDU values in each pair (father–offspring, mother–offspring and midparent–offspring), were developed to evaluate the degree of familial resemblance for each of 20 morphometric measurements, and the differences among these values in three age groups were then investigated. The similarity ratio (S.r.), expressing the degree of correlation to the father and mother, was derived by processing the D.v. The relationship between the maxillo–facial S.r. and the dento–alveolar S.r. was analysed in each age group.

There were significant differences between the D.v. in families and those in unrelated control groups. Consistency between the S.r. for maxillo–facial and that for dento–alveolar measurements was found in the older age groups. It is concluded that individual growth of skull morphology might be more predictable using the present method.

Introduction

A variety of methods have been proposed for the evaluation of morphological correlation in families and for the prediction of craniofacial growth. Moorrees and Lebret (1962) utilized a version of the coordinate system mesh diagram for analysis of facial resemblance, with which differences between the face tracing for the offspring and those of their parents are displayed visually by distorting the rectilinear mesh diagram. This method is suitable for the graphical study of skull morphology but provides no quantitative values for the proportional relationship of the facial parts to each other. Sneath (1967) introduced a calculation technique employing a standardized coordinate system transformation grid in order to compare the skull shapes of closely related species. The method of calculation is based on analysis of variances. Each diagram is adjusted to a fixed standardized size, and the overall correlation

evaluated. The degree of disparity is then expressed by a numerical value. Correlation is evaluated using the indicator value. Sneath estimated the correlation of skull morphology by the coordinates of cephalometric points. However, these points have characteristic error distributions on the x and y axes of the coordinate system (Nakasima *et al.*, 1980), and the effect was found to be due to the error distribution for each point rather than the angular measurements ordinarily used in anthropology and orthodontics.

Johnston (1968) evaluated the utility of cephalograms for growth prediction using stepwise multiple regression. The relationship of maxillo–mandibular measurements (dependent variables) to cranio–facial structural measurements (independent variables) was evaluated together with the predictive value of each sample measurement for the growth and morphology of the relevant structure 5 years later. However, in studies of skull morphology, which

may be strongly influenced by genetic factors, information regarding the skull morphology in families (parents, twins, and siblings) should also be considered in the prediction of future growth. Nakata *et al.* (1973) conducted a study of families with twins using a multiple regression equation. A strong genetic influence was found, and the predictive value of each of eight cephalometric measurements in the offspring was increased when the values for these eight cephalometric measurements and the stature of the parents were included in the calculation together with the offspring's age and sex. The study showed that the heritability estimate in the offspring–midparent group ranged between 37 and 74 per cent in cephalometric measurements and stature. Nakasima and Ichinose (1986) carried out an investigation to determine whether parental cephalometric variables could be used to enhance the prediction of skull structural parameters in their offspring. In this study, the averages of heritabilities of all variables were approximately 54 per cent for maxillo–facial and 49 per cent for dento–alveolar traits. They also proposed that the validity of the multivariate approach to cephalometric prediction in a given individual would be increased by the inclusion of measurements of the morphological features of the individual's family in addition to those for the individual. The midparent value (the mean value for paternal and maternal measurements) was adopted.

It is difficult to predict individual growth change based on group growth measurements, and it is impossible to predict individual growth based on the average growth value. Furthermore, children in the same family do not always show the same growth pattern. Information regarding the degree of correlation of morphological parameters in both parents with those in the offspring as well as that regarding the separate pattern of change of this relationship during the growth process in the maxillo–facial and dento–alveolar structures would be useful in enhancing the accuracy of prediction of maturational change. The growth pattern of the maxillo–facial structures may be an indication of that of the dento–alveolar structures, because growth in the former precedes that in the latter, which is relatively easily controlled by orthodontic treatment.

There is great interest regarding the influence in families of hereditary factors on the morphology of the skull and maxillo–facial and dento–alveolar structures. Therefore, the authors attempted to elucidate the contribution of genetic factors to these morphologies at various ages by comparing quantitative values for human skull morphology in offspring with those in both parents. We then attempted to examine a method of individual growth prediction from a clinical standpoint.

Subjects and methods

Samples

All material was randomly selected from the files of patients seen for consultation regarding their occlusion at the Orthodontic Clinic of Kyushu University Dental Hospital, Japan, and their parents. Radiographs of the parents were taken to clarify the correlation of skull morphology in families and to examine the role of heredity in influencing malocclusion. Adequate explanation on the procedures and the purpose of the study was given to the parents and cephalograms were only obtained for those who agreed to being radiographed. The patients presented with malocclusions, some of which were comparatively serious cases, while others had nearly normal occlusions. In all, data for 985 families were used in this study. The patients were classified into three groups according to age: Group I (6–9 years) included 197 boys and 317 girls (514 patients); Group II (10–13 years) consisted of 122 boys and 222 girls (344 patients); and Group III (14–17 years) contained 37 boys and 90 girls (127 patients). The age distributions (mean and SD) of the patients and their fathers and mothers are shown in Table 1. For each cephalometric measurement, father–offspring, mother–offspring, and midparent–offspring, comparisons were made. The control group for each parent–offspring comparison consisted of adults and children randomly selected from different families and paired without repetition. The sampling was conducted every 4 years to obtain a sufficient number of familial pairs for conventional statistical analysis.

Cephalometric measurements

A lateral roentgenographic cephalogram was obtained for each subject and traced on acetate paper by the same investigator. Figure 1 shows

Table 1 Age distributions of the patients in each group and their fathers and mothers.

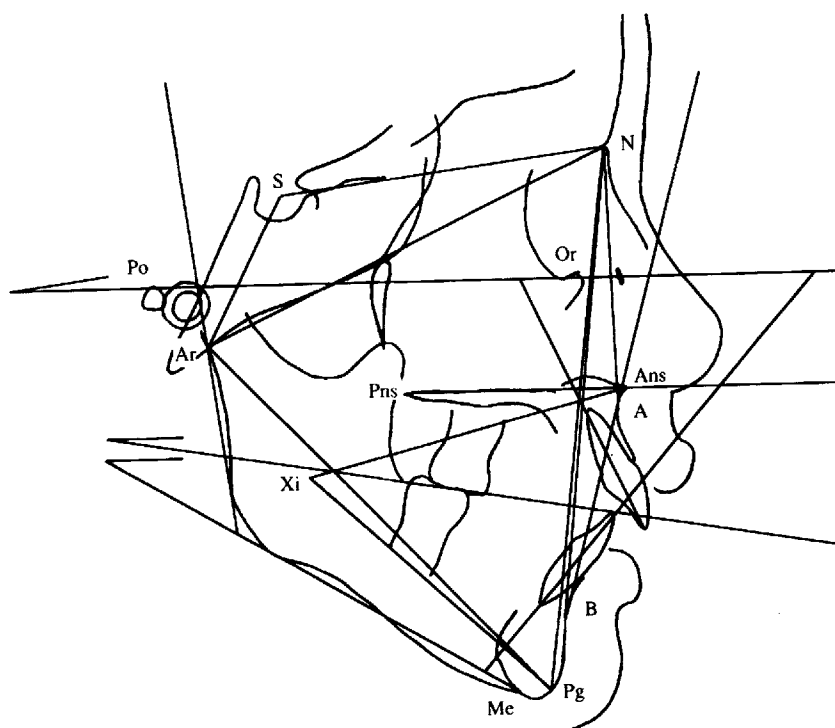| Group	Group I (6–9 years) Age (years)	n	Group II (10–13 years) Age (years)	n	Group III (14–17 years) Age (years)	n
Father	38.7 ± 7.4	514	41.5 ± 4.9	344	46.1 ± 4.6	127
Mother	35.4 ± 7.2	514	38.1 ± 4.9	344	42.4 ± 4.1	127
Offspring	7.9 ± 1.0	514	11.3 ± 1.1	344	15.1 ± 1.0	127
Boys	7.8 ± 1.0	197	11.3 ± 1.1	122	15.1 ± 1.0	37
Girls	7.9 ± 1.0	317	11.3 ± 1.1	222	15.1 ± 1.0	90

Mean ± SD

Figure 1 *Maxillo–facial angles.* 1. SNA, 2. SNB, 3. Facial opening–Angle between N-Ar line and Ar-P Line, 4. NSAr, 5. SN to FH-Angle between S-N line and Frankfort horizontal place (Po–Or), 6. Facial plane angle, 7. Lower face height (Rickets *et al.*, 1972)-Angle between Ans-Xl and Xi-P line (Xi point: the geographic centre of ramus, selected by geometric bisecting of the height and width of the ramus), 8. Ramus plane angle, 9. Mandibular place angle, 10. A-B plane angle, 11. Gonial angle.
Deto-alveolar angles. 1. Upper incisor angle to FH (Ul to FH), 2. Upper incisor angle to Palatal plane (Ul to Palatal plane), 3. Upper incisor angle to Occlusal plane (Ul to Occlusal plane)-Occlusal plane (formed by a line projecting from the lower incisor edge to one-half of the cusp overlap at the first molars), 4. Occlusal plane angle, 5. Interincisor angle, 6. Lower incisor angle to FH (Ll to FH), 7. Lower incisor angle to Palatal plane (Ll to palatal plane), 8. Lower incisor angle ro Mandibular plane (Ll to Mandibular plane), 9. Lower incisor angle to Occlusal plane (Ll to occlusal plane).

the main points that were employed for cephalometric measurements (in total there were 19 landmark points). The landmarks on each tracing were converted to coordinates with a coordinate-value-reading computer (model 109–130; Sanyo Denki Co. Ltd., Osaka, Japan). The 11 maxillo–facial structural angles and nine dento–alveolar structural angles illustrated in Figure 1 were selected to provide a thorough cephalometric description of the skull structure

and were calculated using the coordinates for the anthropological landmarks.

Disparity value

In order to quantitatively evaluate the overall correlation between each cephalometric angular measurement in the offspring and that in each parent, a correlation indicator was developed. For each cephalometric angular measurement, the mean and standard deviation was calculated for each set of paternal, maternal, midparent and offspring values. In the offspring, the mean value was obtained for each of the three different age groups. The disparity between the measured value in a given individual and the corresponding group mean value was expressed as a standard deviation unit (SDU) with positive or negative values. The SDU for each offspring was compared with that for the individual's father and mother and the midparent value, and the absolute value of the difference between the SDU values in each pair was defined as the 'disparity value' (D.v.) for the father–offspring, mother–offspring and midparent–offspring value pairs. Figure 2 illustrates a specific application of the method in obtaining the D.v. for the SNA angle dimension in a 17-year-old girl and her parents. The measured

value (and its distance from the mean) for the offspring, father, mother and midparent values was 86.05° (+1.38 SDU), 80.98° (−0.21 SDU), 86.74° (+1.51 SDU) and 83.86° (+0.65 SDU) respectively. As can be seen, in the measured value of the SNA angle, the offspring and her mother had almost the same relationship to the respective means, while that in her father was very close to but below the mean paternal value. The D.v. is shown graphically as the distance between the respective pairs of arrows in Figure 2. The father–offspring D.v. is 1.59 (SDU) and the mother–offspring D.v. is 0.13 (SDU). The D.v. presented the difference between the SDU values in each pair. The smaller the value was, the stronger the correlation between pairs. In this family the SNA angle in the offspring is more similar to that in the mother than the father. To quantify the degree of correlation of skeletal and dental patterns among individuals in the same family, the mean of the D.v. for each of the 11 maxillo–facial angles was evaluated and nine dento–alveolar angles and statistically compared with those in the control group.

To evaluate the D.v. as an indicator of genetic correlation, the relationship between the D.v. and heritability (h^2), the regression coefficient for offspring and midparent values was studied
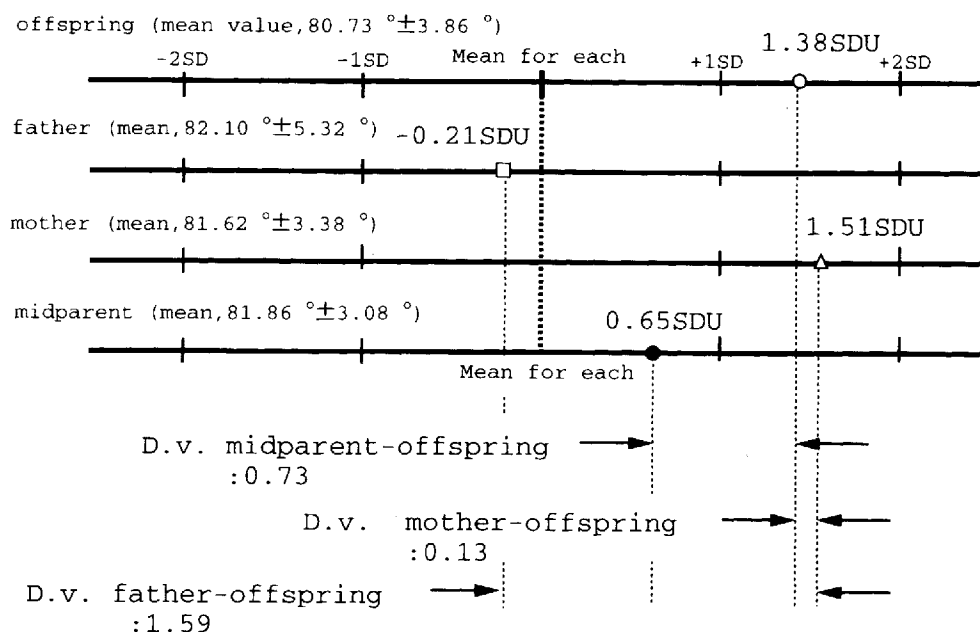

Figure 2 Example of calculation of Disparity value (D.v.) for SNA angle in case No. 4189.

using simple linear correlation for 35 measurements, which consisted of the 20 cephalometric measurements described above and 9 additional maxillo–facial (U–N, U–Gn, N–Me, U–Go, N–Ba, Ans–Pns, Ar–Go, Go–Me, and Xi–Pg U: the lowest point of the hypophyseal fossa) and six dento–alveolar (overbite, overjet, Ul–NPg, Ll–NPg, Ul–APg, and Ll–APg) linear measurements.

Heritability (h^2) in the narrow sense is defined as the ratio of the additive genetic variance (σ_A^2) to the phenotype variance (σ_P^2) and, in practice, it is taken as the regression coefficient of the offspring and midparent (the mean for both parents) values. Heritability is defined by the formula:

$$h^2 = (\sigma_A^2)/(\sigma_P^2) = COV_{O\bar{P}}/V_{\bar{P}},$$

where $COV_{O\bar{P}}$ is the covariance for the offspring and midparent values, and $V_{\bar{P}}$ is the midparent phenotypic variance (Falconer, 1989).

Similarity ratio of offspring to father and mother (S.r.)

In order to assess the (relative) degree of correlation of the values in each offspring to those of the two parents, the similarity ratio (S.r.) was calculated using the following formula:

$$S.r. = (D.v._{father-offspring} - D.v._{mother-offspring})/$$
$$(D.v._{father-offspring} + D.v._{mother-offspring})$$

When the $D.v._{father-offspring}$ is higher than the $D.v._{mother-offspring}$, the S.r. is positive, indicating the relatively stronger relationship between the values in the offspring and the mother. Conversely, a negative S.r. indicates a relatively stronger relationship between the values in the offspring and the father. The relationships between the S.r. for the maxillo–facial and dento–alveolar values were analysed using simple linear correlation, and the changes in their relationships during the growth process were studied.

Preliminary analysis revealed that there was no effect of sex of the offspring on the D.v. for any measurement except one, the inter-incisal angle in the 14–17-year-old group. Therefore, no statistical comparison of boys and girls was conducted.

Statistical analysis

Conventional statistical methods were used for the calculation of the mean, SE and SD, *t*-test

and simple linear correlation analysis (Snedecor and Cochran, 1980).

Results

Error of the method

The error of the method was evaluated by measuring the same cephalogram 30 times by the same tracer and calculating coefficients of variation for the values of each 11 maxillo–facial and nine dento–alveolar structural angles to estimate the accuracy of the method. Consequently, the mean of the error, expressed by the coefficient of variation, was 2.51 per cent with the range being 0.59–9.78 per cent.

Relationship between disparity value (D.v.) and heritability

The D.v. for each of the 11 maxillo–facial and nine dento–alveolar measurements, for which highly significant midparent-offspring correlation ranging from $P < 0.01$ to $P < 0.001$ were observed (Table 2), was strongly correlated with h^2 in all midparent–offspring age groups as follows: in group I (6–9 years), $r = -0.76$; in group II (10–13 years), $r = -0.72$; and in group III (14–17 years), $r = -0.63$. All groups were correlated at $P < 0.001$. Therefore, it is considered that the method used is appropriate for evaluating genetic correlation.

Comparison of disparity value (D.v.) in the family and control groups

Table 3 (a and b) shows the mean and SE of the D.v. for each maxillo–facial and dento–alveolar measurement and the significance of difference between the D.v. in the family groups and that in the control groups. Significant differences between these groups were noted for almost all maxillo–facial measurements in all age groups, and such differences were particularly obvious for midparent-offspring D.v. A similar pattern was also observed for the D.v. for dento–alveolar measurements. In all age groups, however, the significance of difference for the D.v. of the dento–alveolar measurements was less marked than that for the maxillo–facial measurements. The D.v. for dento–alveolar involving the lower incisor (Li) axis were slightly higher than those involving the upper incisor (Ui) axis. There was a high significance of difference between the mean of the D.v. for each of the 11 maxillo–facial and nine

Table 2 Correlation coefficients for midparent and offspring measured cephalometric values.

Group	Group I (6–9 years; $n = 514$)	Group II (10–13 years; $n = 344$)	Group III (14–17 years; $n = 127$)
Maxillo–facial structure			
SNA	0.28**	0.40***	0.28**
SNB	0.32**	0.4***	0.28**
Facial opening angle	0.44***	0.47***	0.31**
NSAr	0.32**	0.44***	0.54***
SN to FH angle	0.32**	0.0***	0.40***
Facial plane angle	0.34***	0.44***	0.42***
Lower face height	0.41***	0.42***	0.47***
Ramus plane angle	0.35***	0.37***	0.41***
Mandibular plane angle	0.33***	0.45***	0.44***
A–B plane angle	0.32**	0.43***	0.48***
Gonial angle	0.33***	0.36***	0.47***
Dento–alveolar structures			
U1 to FH	0.19**	0.27**	0.27**
U1 to palatal plane	0.15**	0.22**	0.28**
U1 to occlusal plane	0.13**	0.18**	0.26**
Occlusal plane angle	0.24**	0.35***	0.27**
Interincisor angle	0.26**	0.31**	0.35***
L1 to FH	0.36***	0.43***	0.44***
L1 to palatal plane	0.35***	0.43***	0.38***
L1 to mandibular plane	0.37***	0.40***	0.44***
L1 to occlusal plane	0.34***	0.42***	0.43***

**$P < 0.01$; ***$P < 0.001$.

Table 3a Maxillo–facial measurements: midparent–offspring disparity values. Data in parentheses indicate disparity value for control group compared with the corresponding value in the control group.

Group	Group I Mean ± SE	Group II Mean ± SE	Group III Mean ± SE
SNA	0.83 ± 0.03**	0.77 ± 0.03***	0.81 ± 0.06
	(0.95 ± 0.03)	(0.99 ± 0.04)	(0.94 ± 0.06)
SNB	0.81 ± 0.03***	0.76 ± 0.03***	0.79 ± 0.06
	(0.97 ± 0.03)	(0.98 ± 0.04)	(0.92 ± 0.07)
Facial opening angle	0.76 ± 0.03***	0.74 ± 0.03***	0.81 ± 0.06
	(0.98 ± 0.03)	(1.00 ± 0.04)	(0.96 ± 0.08)
NSAr	0.81 ± 0.03***	0.74 ± 0.03***	0.68 ± 0.05***
	(0.96 ± 0.03)	(1.01 ± 0.04)	(0.97 ± 0.07)
SN to FH	0.82 ± 0.03***	0.78 ± 0.03***	0.73 ± 0.06*
	(1.00 ± 0.03)	(0.95 ± 0.04)	(0.94 ± 0.07)
Facial plane angle	0.79 ± 0.03***	0.76 ± 0.03***	0.78 ± 0.05**
	(1.01 ± 0.03)	(0.97 ± 0.04)	(1.00 ± 0.07)
Lower face height	0.77 ± 0.03***	0.75 ± 0.03***	0.71 ± 0.06**
	(0.98 ± 0.03)	(0.99 ± 0.04)	(0.95 ± 0.07)
Ramus plane angle	0.80 ± 0.03***	0.78 ± 0.03***	0.80 ± 0.06*
	(1.00 ± 0.03)	(0.95 ± 0.04)	(0.98 ± 0.07)
Mandibular plane angle	0.81 ± 0.03***	0.74 ± 0.03***	0.76 ± 0.05***
	(0.98 ± 0.03)	(0.94 ± 0.04)	(1.05 ± 0.07)
A–B plane angle	0.82 ± 0.03**	0.77 ± 0.03**	0.75 ± 0.05**
	(1.01 ± 0.03)	(0.98 ± 0.04)	(1.02 ± 0.07)
Gonial angle	0.82 ± 0.03***	0.80 ± 0.03***	0.74 ± 0.05**
	(0.99 ± 0.03)	(0.96 ± 0.04)	(0.96 ± 0.07)
Total	0.81 ± 0.01***	0.76 ± 0.02***	0.758 ± 0.03***
	(0.98 ± 0.02)	(0.97 ± 0.02)	(0.971 ± 0.04)

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

Table 3b Dento–alveolar measurements: midparent–offspring disparity values.

Group	Group I Mean ± SE	Group II Mean ± SE	Group III Mean ± SE
U1 to FH	0.88 ± 0.03*	0.82 ± 0.04**	0.86 ± 0.06*
	(0.98 ± 0.03)	(0.98 ± 0.04)	(1.02 ± 0.07)
U1 to palatal plane	0.89 ± 0.03*	0.85 ± 0.04**	0.83 ± 0.06
	(0.97 ± 0.03)	(0.98 ± 0.04)	(0.95 ± 0.07)
U1 to occlusal plane	0.85 ± 0.04*	0.89 ± 0.04*	0.86 ± 0.06
	(0.94 ± 0.04)	(0.99 ± 0.04)	(0.96 ± 0.07)
Occlusal plane angle	0.84 ± 0.03*	0.81 ± 0.03**	0.82 ± 0.06*
	(0.93 ± 0.03)	(0.94 ± 0.04)	(1.00 ± 0.06)
Interincisor angle	0.84 ± 0.03***	0.82 ± 0.03***	0.80 ± 0.05*
	(0.99 ± 0.03)	(1.00 ± 0.04)	(0.98 ± 0.07)
L1 to FH	0.80 ± 0.03***	0.77 ± 0.03***	0.74 ± 0.05***
	(0.98 ± 0.03)	(0.95 ± 0.04)	(1.06 ± 0.07)
L1 to palatal plane	0.80 ± 0.03***	0.76 ± 0.03***	0.78 ± 0.05***
	(0.97 ± 0.03)	(0.93 ± 0.04)	(1.07 ± 0.07)
L1 to mandibular plane	0.79 ± 0.03***	0.78 ± 0.03***	0.74 ± 0.05***
	(1.01 ± 0.03)	(0.95 ± 0.04)	(1.07 ± 0.07)
L1 to occlusal plane	0.78 ± 0.03***	0.76 ± 0.03***	0.75 ± 0.05***
	(0.99 ± 0.03)	(0.97 ± 0.04)	(1.03 ± 0.07)
Total	0.83 ± 0.02***	0.81 ± 0.02***	0.80 ± 0.03***
	(0.97 ± 0.02)	(0.97 ± 0.02)	(1.01 ± 0.04)

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

dento–alveolar measurements in the family groups and those in the control groups ($P < 0.01 - P < 0.001$). There was no significant difference between the father–offspring D.v. and the corresponding mother–offspring D.v. at any age group.

Comparison of similarity ratios (S.r.) between maxillo-facial and dento-alveolar structures

No change with age was observed for the S.r. of overall maxillo–facial and dento–alveolar measurements. Simple linear correlation analyses of the relationship between the maxillo–facial S.r. and the dento–alveolar S.r. in each age group revealed no significant correlation in the 6–9-year-old group, but a significant correlation ($P < 0.05$) in both the 10–13 and 14–17-year-old groups (10–13 years, $r = 0.137$; 14–17 years, $r = 0.192$, $P < 0.05$). The increase in the value of the correlation coefficient was associated with growth.

Discussion

In this study a large sample consisting of 985 families was randomly selected from among children and their parents. In order to adjust for any sample bias, the values of the 11 max-

illo–facial and nine dento–alveolar cephalometric measurements were compared with the standard values in normal Japanese individuals reported by Sakamoto (1959). This preliminary analysis revealed that the measured values for the maxillo–facial structures were almost the same as the reported normal values, while those for the dento–alveolar structures were slightly different. This difference was thought to be due to malocclusion and related problems. However, all of the skull structural measurements have been found in a previous study by Ichinose *et al.* (1993) to be highly genetically associated. Thus, it is believed that the correlation observed in the present measured variables is due to genetic factors.

It is fundamentally difficult to quantify a correlation between two subjects; although correlation of the measured values in two given subjects may not be due to chance when the group shows a wide range of values, it may be due to chance in a group with a narrow range of values. Therefore, the degree of scatter of the measured values in a population must be taken into consideration when evaluating the degree of correlation between the values in two subjects. Since the present D.v. was developed as an indicator which takes into consideration the scatter of the measured values, it is reason-

able to speculate that the D.v. may be related to heritability.

The stronger correlation in families for max-illo–facial structures compared with that for dento–alveolar structures is consistent with the findings reported by other researchers (Nakasima *et al.*, 1982; Ichinose *et al.*, 1993). The stronger relationship for the maxillo–facial structures suggests that incisor inclination as well as molar position are highly influenced by such factors as the environment force of mastic-atory muscles, and tongue pressure. This specu-lation is also in part supported by the finding that masticatory functions affect the morpho-genesis of the dento–facial complex throughout growth and development in childhood (Moore, 1965; Kiliaridis *et al.*, 1985).

Theoretically, the expected distance (expected Disparity value) for control groups can be calcu-lated as follows. The measurements of randomly chosen offspring (children) and unrelated parents (adults) are denoted by x and y respectively, and it is assumed that each variable shows normal distribution. The measurements in the control groups are sampled randomly from individuals in different families, as in the present study, and x and y are independent variables whose distributions are the standard normal, that is,

with mean $\mu = 0$ and standard deviation $\sigma = 1$ (Johnson and Kotz, 1976). Using the expected distance $|x-y|^{(\text{see appendix})}$, as a criterion, the simil-arity index (S.i.) expressing the degree of correla-tion in families can be also derived as follows:

Similarity index

$$= (\text{expected D.v.} - \text{measured D.v.})/$$

expected D.v.

where the S.i. ranges from 0–1 and S.i. increases with the degree of relationship of the pairs. In Fig. 3, the change of S.i. with age is shown graphically. The degree of correlation in families is observed to have a tendency to increase with the growth process.

As in a large number of investigations of correlation in families, the utility of employing the parental morphology data in assessing the future morphology in the child was considered. Hunter *et al.* (1970) reported that, although regression equations based on the significant variables for both parents provided more accur-ate results than those based only on those for a single parent, the most significant variable in predicting a measurement in the offspring was the corresponding measurement in one of the parents (father or mother). Accordingly, the
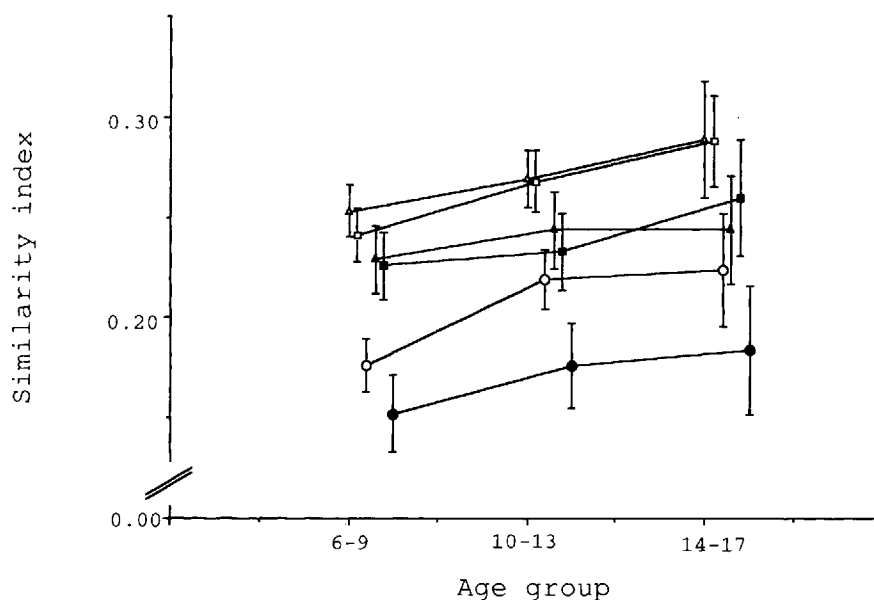

Figure 3 Change of similarity index with age (mean, S.E.). —△—: father-offspring (maxillo-facial), —□—: mother-offspring (maxillo-facial), —○—: midparent-offspring (maxillo-facial), —▲—: father-offspring (dento-alveolar), —■—: mother-offspring (dento-alveolar), —●—: midparent-offspring (dento-alveolar).

midparent value does not appear to be sufficient to increase the accuracy of prediction of the future morphology of the offspring, because there is a possibility that the offspring may become more similar to either the father or mother. Conversely, the correlation value would be calculated based on the extent to which each parent is similar to the offspring.

In the present study, the consistency of the S.r. of the maxillo–facial and dento–alveolar structures tended to increase with age. The calculation of parental measurements and the D.v. and S.r. for patients seen at the pre-puberty stage may enhance the accuracy of prediction of individual growth.

Hunter *et al.* (1970) found that the father–offspring relationship was stronger than mother–offspring for linear measurements of the skull. Stein *et al.* (1956) obtained similar results for several angular measurements. Nonaka *et al.* (1988) studied the longitudinal growth of rats and reported a maternal contribution to the cranio–facial complex at the early growth stage which declined rapidly thereafter. The present study revealed a somewhat stronger father–offspring relationship, but there was no significant difference between the father–offspring D.v. and the mother–offspring value. Thus, the present study provides no confirmation of the previous studies.

Figure 4 shows an example of clinical application of the present morphological study in a 17-year-old female patient. This chart displays graphically the differences from the mean values of angular measurements in the form of standard deviation units for each paternal, maternal and offspring group. The value for this offspring was very close to the value in the mother when expressed as differences from the mean. The D.v. and S.i. indicated a considerably higher relationship of values in this offspring with those in her mother compared with those in her father, and neither the maxillo–facial nor dento–alveolar father-offspring D.v. and S.i. showed strong relationship. Furthermore, the positive value of the maxillo–facial S.r. (0.544) as well as that for the dento–alveolar S.r. (0.300) indicated the greater correlation to the maternal traits. Consistency of the S.r. of both structures was recognized as well.

Using the present D.v. or S.i., the degree of correlation in families can be quantified indi-
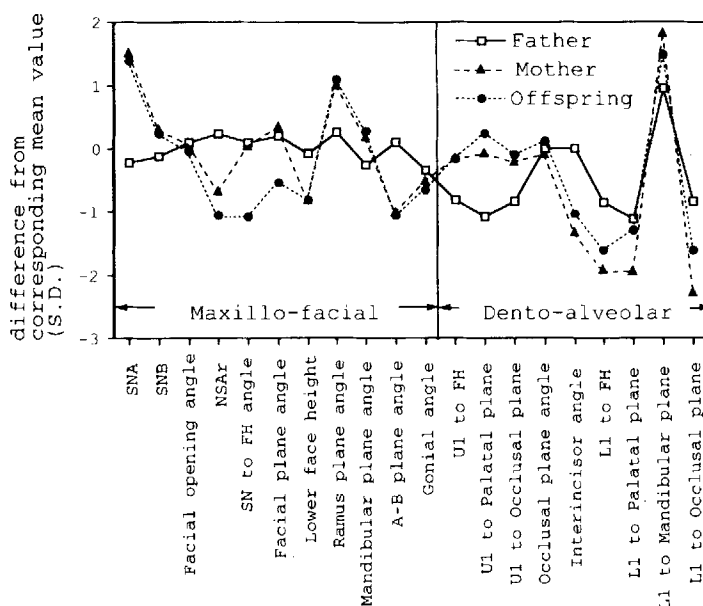

Figure 4 Disparity value (D.v.), Similarity index (S.i) and Similarity ratio (S.r.) for maxillo-facial and dento-alveolar structures in Case No. 4189.
maxillo–facial: father–offspring D.v.: 0.80, S.i.: 0.38, mother-offspring D.v.: 0.28, S.i.: 0.79, S.r.: 0.54.
dento–alveolar: father–offspring D.v.: 0.68, S.i.: 0.48, mother offspring D.v.: 0.33, S.i.: 0.75, S.r.: 0.30.

vidually in terms of a single parameter for the overall skull structure or for parts thereof. Moreover, the S.r. can be used to estimate the relative degree of correlation to each parent and to investigate the change during growth in each subject. As the offspring matures, each correlation of skull morphology in families and consistency between maxillo–facial and dento–alveolar measurements had an upward tendency. Therefore, these indicators may be appropriate for clinical diagnosis, individual growth prediction and treatment, but longitudinal studies are required to understand the details about the effect of genetic influences on skull morphology.

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Appendix

The joint density function, $f(x, y)$, is

$$f(x, y) = 1/2\pi e^{-(x^2 + y^2)/2}.$$

Therefore, the expected distance, $|x-y|$, can be expressed as

$$E(|x-y|) = 1/2\pi \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} |x-y| e^{-(x^2+y^2)/2}\, dx dy.$$

After some calculations, $E(|x-y|) = 2/\sqrt{\pi} \approx 1.288$ is obtained for the expected distance for single parent and offspring for control groups.

The midparent-offspring expected distance is then considered; in this case, the distance is $|x-(y+z)/2|$, where y and z are two randomly chosen measurements for the parent and x is the same as that given above. Note that y and z are independent in this case.

In the same way as above:

$$E(|x-(y+z)/2|)$$

$$= 1/\sqrt{2\pi^3} \int\limits_{-\infty}^{\infty} \int\limits_{-\infty}^{\infty} \int\limits_{-\infty}^{\infty} |x-(y+z)/2e^{-(x^2+y^2+z^2)/2} \,\mathrm{d}x\mathrm{d}y\mathrm{d}z$$

and

$$E(|x-(y+z)/2|)=6/\sqrt{2\pi}\approx 0.977$$

is obtained for the control pair of midparent–offspring expected distance.