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Relationship between cranial base structure and maxillofacial components in children aged 3–5 years

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SUMMARY The aim of this study was to clarify the inter-relationships between cranial base angle, the morphological variations of maxillofacial components, and growth of the anterior cranial base length. One hundred and twenty-two Japanese children aged 3–5 years with normal occlusion in the primary dentition were included in this investigation. To analyse the relationship between cranial base structure and maxillofacial components, the subjects were divided into three groups according to facial type (prognathic, orthognathic, or retrognathic) assessed by the magnitude of their NSAr angle (as cranial base angle). These categorized cephalometric profiles suggested that the antero-posterior location of the maxillofacial components corresponded to the NSAr angle.

Factor analysis of cephalometric variables showed that the variation of maxillofacial components from the S–N line was strongly related to the cranial base angle. This normal range of morphological variation was distinguished from that of growth by the factor loadings.

From these results, theoretical models of cephalometric profiles with normal occlusion were computed by linear regression analysis. Using the models, a standard profile related to an arbitrary cranial base angle was obtained for children with normal occlusion, aged 3–5 years.

Introduction

The wide range of variation in both size and relationship of the craniofacial complex is generally accepted. This knowledge has consistently shown that there are large variations in each population evaluated. Therefore, many attempts have been made to describe the range of normal variation of the human face. Based on significant correlations among some cephalometric variables, Hasund *et al*. (1974) devised a diagram of the skeletal pattern on an individualized basis, using floating norms. Järvinen (1984) found, by linear regression analysis, that approximately 24 per cent of the variation of the SNA angle could be explained by the variation of the NSAr angle. Segner (1989) proposed that the skeletal disharmony of a patient could be analysed by standards derived from the individual facial type (floating norms), rather than by relating individual cephalometric values to population means.

Schudy (1963, 1964) used the SN–MP angle to divide his sample into three groups (average, retrognathic, and prognathic), and concluded that the different facial types should be taken into consideration in treatment planning. Enlow *et al*. (1971) and Enlow and McNamara (1973) stated that the cranial floor is the foundation on which the human face develops, and demonstrated that the dimension of the middle cranial fossa considerably influences the relationship between the nasomaxillary complex and the mandible. Anderson and Popovich (1983) and Lavelle (1979) reported that subjects with an open cranial base angle showed a tendency to have an Angle Class II molar relationship. In longitudinal studies, Bishara and Jakobsen (1985) and Bishara *et al*. (1997) indicated that there were some significant differences in the craniofacial growth patterns between subjects with different facial types from the deciduous to the permanent dentition.

According to the above literature, it is clear that the cranial base structure influences maxillofacial morphology and its growth. Tollaro *et al.* (1996) recommended, in early childhood, the use of cephalometric floating norms in the primary dentition period for early diagnosis and treatment planning. However, there are few morphological models by which the harmonized inter-relationship shown in floating norms and the growth of the subjects can be explained simultaneously.

In the present study, the relationships between the cranial base angle, the morphological variations of maxillofacial components, and growth by multivariate analysis were investigated. From the results, theoretical models of cephalometric profiles with harmonized relationships between the maxillofacial components and the cranial base structure were devised.

Materials and methods

The cephalometric variables of 122 children (63 males and 59 females) were obtained from the data of the Japanese Society of Pediatric Dentistry (1995). The mean age of the subjects was 4.48 years (range 3.0 to less than 6.0 years) and all had normal occlusion in the primary dentition. Essential conditions of the subjects were as follows:

1. No dental caries or hypoplasia.
2. No abnormal teeth.
3. No severe attrition of teeth.
4. Little torsion of teeth (within ±15 degrees).
5. Normal shape and symmetry of the dental arches.
6. Little midline shift (within 1 mm).
7. Normal overbite and overjet.

The co-ordinates (*X*, *Y*) of 16 cephalometric landmarks (Figure 1) were used and fed into a computer. The S–N line was defined as the *X* axis, and the *Y* axis was perpendicular to the *X* axis. Hence, the intersection of both axes was the sella turcica (S). The NSAr was used as the cranial base angle instead of NSBa, as the original data did not include the co-ordinates of the point basion. The mean values of the angular and linear measurements used in this study are shown in Table 1. A drawing programme was

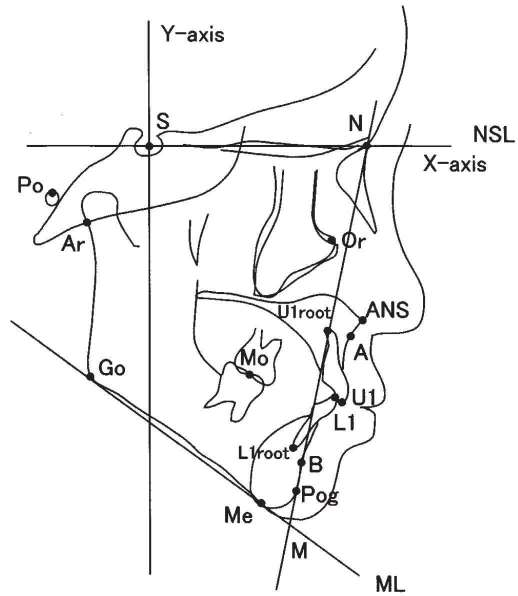

Figure 1 Cephalometric landmarks and lines. In this study, all profiles were orientated horizontally on the S–N line to clarify the relationship between cranial base and maxillofacial components. The S–N line was defined as the *X* axis, with the *Y* axis perpendicular to the *X* axis. The intersection of both axes was the sella turcica (S). The following cephalometric landmarks and lines were used in the study. N, nasion; Or, orbitale; Po, porion; ANS, anterior nasal spine; A, Point A; U1, upper central incisor tip; U1root, upper central incisor apex; L1, lower central incisor tip; L1root, lower central incisor apex; B, Point B; Pog, pogonion; M, junction of the facial and mandibular lines; Me, menton; Go, gonion; Ar, articulare; Mo, upper first molar; NSL, sella–nasion line; ML, mandibular line.

Table 1 Mean values of the cephalometric measurements.

Age (years)		3	4	5
NSAr	degrees	126.24	124.48	125.39
SNA		79.56	81.90	80.99
SNB		75.41	77.17	76.73
FH–NSL		8.35	8.09	8.31
NSL–ML		38.67	35.92	37.16
U1–NSL		88.65	89.44	89.86
ANB		4.14	4.74	4.25
L1 to mandibular line		86.73	88.25	86.27
Inter-incisal angle		145.92	146.38	145.86
Gonial angle		130.82	127.00	127.80
N–S	mm	60.94	62.43	63.54
N–M		100.53	103.02	106.23
S–M		102.28	106.37	109.13

produced in order to superimpose the profiles of the original data and to compute the mean profiles of the subjects.

Factor analysis (Takagi, 1991) was performed to determine the inter-relationship among the cephalometric variables. Factor analysis is a set of statistical methods for analysing the correlations among several variables in order to estimate the number of fundamental dimensions that underlie the observed data, and to describe and measure those dimensions. The result of factor analysis is shown as a matrix of factor loadings, and characteristics of factors are indicated by variables clustering on the various factors.

To clarify the meaning of the factors in the present factor analysis, the 14 variables analysed were grouped as follows:

1. NSAr, SNA, SNB, FH to NSL, NSL–ML and U1–NSL as angular measurements of which the datum line was the S–N line.
2. L1 to mandibular line, inter-incisal, ANB and gonial angle as other angular measurements of which the datum line was not the S–N line.
3. N–S, N–M and S–M as linear measurements.
4. The age of the subjects as an index of growth.

The factors having an eigenvalue larger than 2.0 were judged to be statistically significant, and the items having absolute magnitudes of factor loading equal to or larger than 0.50 were regarded as being significant.

Results

The skeletal profiles of all 122 subjects were divided into three groups: 22 prognathic (the NSAr angle was smaller than 121.02 degrees; mean ± 1 SD), 76 orthognathic (between 121.02 and 129.50 degrees), and 24 retrognathic (larger than 129.50 degrees; mean ± 1 SD). Figure 2 shows the mean profiles of these three groups. Dashed, dotted, and solid lines represent prognathic faces with an NSAr angle of 119.24 degrees, orthognathic faces with 125.06 degrees and retrognathic faces with 131.40 degrees, respectively. Although these superimposed profiles showed that the maxillofacial components of the three categorized profiles had different flexures from the cranial base, it was noted that both the shape and size of the maxillofacial components resembled each other.

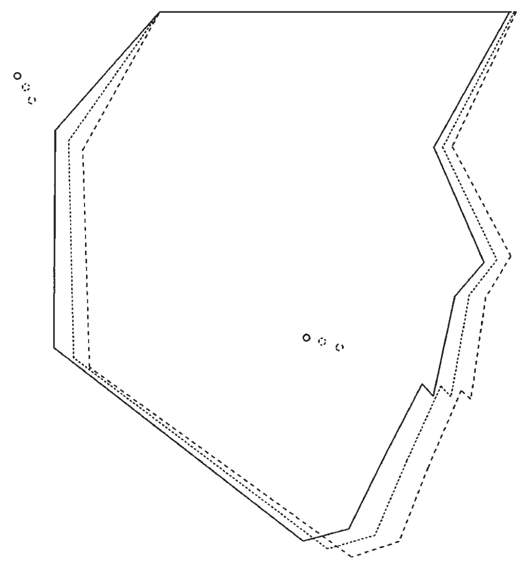

Figure 2 Mean profiles of three facial types. Dashed, dotted, and solid lines represent prognathic faces with an NSAr angle of 119.24 degrees, orthognathic faces with 125.06 degrees, and retrognathic faces with 131.40 degrees, respectively. The flexures of the maxillofacial components were different, but the shapes of the three profiles resembled each other.

The mean profiles, divided into three age groups as follows: 3 (dashed line), 4 (dotted line), and 5 years (solid line), are illustrated in Figure 3. These three groups comprised the 3 year group with 35 subjects aged 3.0 to less than 4.0 years, the 4 year group with 50 subjects aged 4.0 to less than 5.0 years, and the 5 year group with 37 subjects aged 5.0 to less than 6.0 years. These conventional mean profiles suggest that the size of the maxillofacial components and the cranial base length increased with age.

The results of the factor analysis to determine the relationship among cephalometric variables are shown in Table 2. The proportion of the first factor variance was 21.47 per cent, the second 18.09 per cent, the third 15.51 per cent, and the fourth 13.29 per cent. The cumulative proportion of variance was 68.36 per cent from the first to the fourth factor.

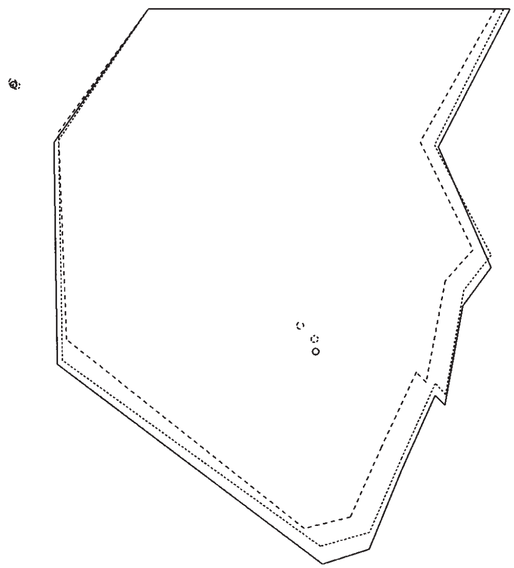

Figure 3 Mean profiles of the three age groups. Dashed, dotted, and solid lines represent the profiles of the 3, 4, and 5 year groups, respectively. The craniofacial growth of the subjects is illustrated and growth direction of the maxillofacial components from the cranial base could be visualized.

Table 2 Results of the factor analysis.

Item	Factor 1	Factor 2	Factor 3	Factor 4
Age	–0.10	0.54	0.04	0.16
NSAr	0.67	–0.14	0.02	0.04
SNA	–0.82	0.14	0.24	0.15
SNB	–0.97	0.07	–0.01	0.14
FH–NSL	0.64	0.04	0.00	–0.06
NSL–ML	0.30	0.13	0.04	–0.88
U1–NSL	–0.50	–0.08	0.58	–0.10
ANB	0.07	0.14	0.45	0.06
L1 to mandibular line	0.06	–0.12	0.85	0.33
Inter-incisal angle	0.12	0.03	–0.92	0.27
Gonial angle	–0.03	0.06	0.01	–0.86
N–S	0.13	0.69	0.03	0.13
N–M	0.07	0.92	–0.07	–0.23
S–M	–0.38	0.90	–0.08	–0.05
Eigenvalue	3.01	2.53	2.17	1.86
Proportion of variance (%)	21.47	18.09	15.51	13.29
Cumulative proportion of variance (%)	21.47	39.57	55.08	68.36

In the first factor, the absolute factor loading of SNA, SNB, FH–NSL, U1–NSL, and NSAr was equal to or more than 0.50. The values of SNA, SNB, and U1–NSL were negative but that of NSAr was positive. These findings indicate that the values of SNA, SNB, and U1–NSL were inversely related to the NSAr angle. In the second factor, the values of age, N–S, N–M, and S–M were positive and more than 0.50. In contrast, the absolute values of all angular measurements were less than 0.50. These findings indicate that the lengths of N–S, N–M, and S–M increased proportionally with the age of the subjects and not with angular measurements. In the third factor, the absolute values of L1 to the mandibular line, inter-incisal angle, and U1–NSL were more than 0.50, and in the fourth, the eigenvalue was 1.86, the values of gonial angle and NSL–ML were less than –0.80.

Discussion

Hasund *et al*. (1974), Anderson and Popovich (1983), Järvinen (1984), and Segner (1989) found that there are highly complex relationships between the cranial base and maxillofacial components. In the present study, the variations of the profiles were categorized into three groups by the magnitude of the NSAr angle and the mean profiles of these three groups are shown in Figure 2. The results indicate that there is a certain relationship between the NSAr angle and the variation of the flexure of maxillofacial components from the cranial base. The maxillofacial components of the subjects have different flexures from the cranial base, and these flexures are related to the NSAr angle. According to these findings, a child with normal occlusion, whether the facial type is prognathic, orthognathic, or retrognathic, has individually harmonized cephalometric variables depending upon the flexure (e.g. a child with large NSAr angle may have a reduction in size of SNA, SNB angle, etc.). In other words, whatever the profile category, children with normal occlusion will show a similar facial line.

Table 2 shows the matrix of factor loadings as a result of the factor analysis. The cumulative proportion of variance was 68.36 per cent, which means that the variations of the cephalometric variables can be attributed to these four factors with the remaining 31.64 per cent unexplained. Consequently, the present analysis seems to approximately represent the morphological relationship between cephalometric variables of children with normal occlusion, aged 3–5 years.

As to the factor loadings, for the first factor, the variable clusters indicated that the values of SNA, SNB, and U1–SN decreased when the value of NSAr angle increased. On the other hand, the values of FH–SN and SN–ML increased as NSAr angle increased. Therefore, this factor was concerned with the antero-posterior location of the maxillofacial components corresponding to the NSAr angle. These findings could serve to confirm the morphological variations of the three mean profiles in Figure 2.

For the second factor the loadings suggest that N–S, N–M, S–M, and age were in proportion to each other, and the angular measurements had slight relevance to the age. This finding indicates that facial depth and height increase with age. Therefore, the second factor seems to describe the craniofacial growth of 3–5-year-old subjects. The three mean profiles in Figure 3 show that facial depth and height expand without altering to a great extent the size of the NSAr angle and the shape of the facial line.

Kasai *et al.* (1995) described the characteristics of these factors using multivariate analysis in their study. They suggested that the first factor was concerned with horizontal growth and the second described the differences in the horizontal position of maxilla and mandible, although the subjects in their study were much older than those in the present investigation. For the first and the second factor loadings of age, there was a stronger correlation with linear cephalometric measurements than with angular measurements among 3–5-year-olds.

The third factor indicates the relationship between inclination of the upper and lower incisors. The fourth factor, even if the eigenvalue was slightly smaller than 2.0, shows a certain relationship between gonial angle and NSL–ML. These variables are in proportion to each other. This morphological variation of profiles was also shown by Kasai *et al.* (1995).

The results of other multivariate analyses on craniofacial variations (Cleall *et al.*, 1979; Saito, 1989) indicate that the variations are divided into vertical and antero-posterior factors. The variable clusters of their factors are in agreement with those of the first and the second factors of the present analysis, although subjects aged 3–5 years were excluded from their investigations.

In previous longitudinal studies, Brodie (1955) reported that the cranial base angle changed with growth in 18 out of 30 cases. Contrary to this, Anderson and Popovich (1983), Lavelle (1979), and Cleall *et al.* (1979) suggested that cranial base angle changed little during life. In either case, Järvinen (1984) claimed that the SNA angle alone was an unreliable predictor of the antero-posterior location of the maxillary apical base because of its close relationship with the cranial base angle. The results of the present study, only examining early childhood, revealed that flexure of the maxillofacial components from the cranial base was associated with the NSAr angle but not with age.

In Figure 4, a theoretical model of profiles with a NSAr angle of 105, 115, 125, 135, and 145 degrees is illustrated. These profiles were

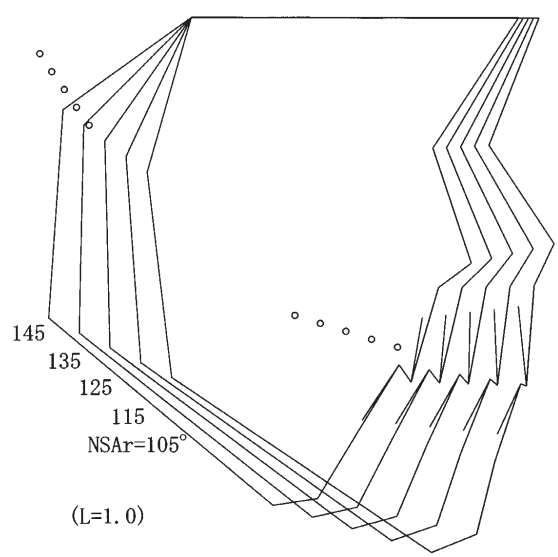

Figure 4 Theoretical profiles with a NSAr angle of 105, 115, 125, 135, and 145 degrees. These models illustrate use of the co-ordinates derived from the equations in the Appendix. Variable *L* in the equations indicates the size ratio of the maxillofacial components.

calculated by linear regression analysis of the co-ordinates of the cephalometric landmarks (see Appendix). Since the relationship between the cranial base angle and flexure of the maxillofacial component from the cranial base is distinguished from growth, another variable is needed to express growth. The co-ordinates are represented by the functions of NSAr, but the variable L to express the growth was independent from NSAr.

The profiles in Figure 4 were calculated only from the discontinuous values of the NSAr angle (105, 115, 125, 135, and 145 degrees). In these models, the variable L was substituted for 1.0 without calculation from the S–N length. These models indicate that the size of the NSAr angle increased 10 degrees with an increment of approximately 1 mm in S–N length. This two-parameter morphological modification strongly supports the first and second factors in the present factor analysis, although the age of the patients will be limited in the range of 3–5 years.

Conclusions

1. Relationships among the cephalometric variables were interpreted by factor analysis. The first factor was concerned with the flexure of the maxillofacial component from the cranial base related to the size of the cranial base angle, the second skeletal growth, and the third links the inclination of upper and lower incisors.
2. The weighting of the first factor could be confirmed by the normal range of morphological variations in the mean profiles categorized according to the cranial base angle.
3. The relationship seen in the second factor was supported by the mean profiles of the three age groups (3, 4, and 5 years old). They were similar in shape although the size of each profile enlarged with age.
4. Based on the results, theoretical models of profiles with normal occlusion, which simultaneously simulated the flexure of the maxillofacial components from the cranial base and growth among 3–5-year-old, were calculated by regression analysis.

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Appendix

Linear regression analysis for profile determination

$X_N = L \times (-0.0965 \times \text{NSAr} + 74.43)$ $R = -0.14$
$Y_N = 0$
$X_{Or} = L \times (-0.26 \times \text{NSAr} + 82.41)$ $R = -0.38$
$Y_{Or} = L \times (0.016 \times \text{NSAr} + 22.33)$ $R = 0.03$
$X_{ANS} = L \times (-0.38 \times \text{NSAr} + 107.37)$ $R = -0.48$
$Y_{ANS} = L \times (0.092 \times \text{NSAr} + 32.22)$ $R = 0.16$
$X_A = L \times (-0.44 \times \text{NSAr} + 109.91)$ $R = -0.53$
$Y_A = L \times (0.0095 \times \text{NSAr} + 48.73)$ $R = 0.01$
$X_{U1} = L \times (-0.54 \times \text{NSAr} + 118.08)$ $R = -0.55$
$Y_{U1} = L \times (-0.018 \times \text{NSAr} + 70.21)$ $R = -0.02$
$X_{L1} = L \times (-0.57 \times \text{NSAr} + 120.20)$ $R = -0.58$
$Y_{L1} = L \times (-0.088 \times \text{NSAr} + 77.06)$ $R = -0.10$
$X_B = L \times (-0.626 \times \text{NSAr} + 121.75)$ $R = -0.61$
$Y_B = L \times (-0.15 \times \text{NSAr} + 98.16)$ $R = -0.15$
$X_{POG} = L \times (-0.74 \times \text{NSAr} + 130.16)$ $R = -0.61$
$Y_{POG} = L \times (-0.17 \times \text{NSAr} + 113.10)$ $R = -0.15$
$X_{Me} = L \times (-0.73 \times \text{NSAr} + 121.40)$ $R = -0.60$
$Y_{Me} = L \times (-0.22 \times \text{NSAr} + 122.07)$ $R = -0.18$
$X_{Go} = L \times (-0.57 \times \text{NSAr} + 56.24)$ $R = -0.64$
$Y_{Go} = L \times (-0.27 \times \text{NSAr} + 95.49)$ $R = -0.26$
$X_{Ar} = L \times (-0.39 \times \text{NSAr} + 32.84)$ $R = -0.76$
$Y_{Ar} = L \times (-0.29 \times \text{NSAr} + 58.74)$ $R = -0.51$
$X_{Mo} = L \times (-0.48 \times \text{NSAr} + 88.08)$ $R = -0.62$
$Y_{Mo} = L \times (-0.15 \times \text{NSAr} + 76.47)$ $R = -0.18$
$X_{Po} = L \times (-0.23 \times \text{NSAr} + 5.23)$ $R = -0.39$
$Y_{Po} = L \times (-0.33 \times \text{NSAr} + 54.81)$ $R = -0.58$
$(X_S = 0, Y_S = 0)$

$*L = \text{S–N length}/(-0.0965 \times \text{NSAr} + 74.43)$

NSAr, NSAr angle (degrees);

R, correlation coefficient.

The standard size of S–N length in the theoretical profiles should be adjusted to the patient's actual size by the variable L. If these equations are used clinically, it will be necessary to calculate the value of the variable L from the patient's NSAr angle and S–N length by the asterisked equation in each case.