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Morphological relationship between the cranial base and dentofacial complex obtained by reconstructive computer tomographic images

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SUMMARY The aims of this study were to investigate the relationships between the cranial base, including the glenoid fossa and maxillofacial morphology, obtained by three-dimensional (3D) computed tomography (CT). The specimens were 45 Skeletal I and Skeletal II dry skulls of modern Japanese males without marked crowding, anterior crossbite, or maxillofacial asymmetry, which had been preserved in the Tokyo University Museum.

To examine the differences in the cranial base and maxilla between two groups classified by the median value of N line–A [N defined as a perpendicular line to Frankfort horizontal (FH) through point N, and N line–A as the distance between N and point A]. The specimens with an N–A line less than 1.5 mm were classified as the small group, and those with an N line–A more than 1.5 mm as the large group.

Correlation coefficients showed that S–SE was positively related to N–Ba, S–N, S–Ba, and ∠FH to S–Ba, and negatively related to SE–N. Ba–X, Ba–Y and Gf–X showed positive correlation with S–Ba and ∠FH to S–Ba. For the small group S–SE was longer, ∠FH to S–Ba was larger, and Ba–X, Gf–X, A–X, ANS–X, and PNS–X located more posterior and in addition more inferior in ANS–Y. The evidence suggests that S–SE, which is a main component factor of the anterior cranial base, and the antero-posterior position of glenoid fossa, is related to the position of the maxilla. The length and inclination of the posterior cranial base, which is related to Ba, influenced the position of the glenoid fossa.

Introduction

It is generally accepted that growth of the cranial base influences maxillofacial growth. Since the length and angle of the cranial base are larger in the order of Class III < Class I < Class II (James, 1963; Hopkins *et al*., 1968), and ArSN angle in Class II is larger than that in Class III subjects (Järvinen, 1984), the morphology of the cranial base has received attention regarding the morphogenesis and growth of the maxillo-mandibular complex. With regard to the relationship between maxillofacial morphology and the cranial base, it has been considered that the maxilla is related to the anterior cranial base, and the mandible to the posterior cranial base (Kasai *et al*., 1995).

Angle's classification, SNA, SNB, and ANB, have been used for evaluating the maxillo-mandibular positional relationship in clinical orthodontics. However, in recent studies, to assess skeletal discrepancies, angular indicators gave erroneous findings on the maxilla and mandibular antero-posterior jaw position. Furthermore, evaluation of the maxillo-mandibular bone depends on the specimens or reference line used (Rothstein, 1971; Rosenblum, 1995). Because these variables do not reflect the morphology and size of the maxillo-mandibular bones, they are not appropriate for evaluating over- and hypo-growth of the maxilla. For example, in patients with a large mandible, the ANB angle is not always small. In steep mandibular subjects, even if the mandible is large, point B in some case retrudes due to the increase of the mandibular plane, and ANB is within the normal range. Furthermore, in subjects in which the glenoid fossa is located anteriorly, even if the size of the mandible is the same, Pog or point B is not always in the anterior position. Therefore, maxillo-mandibular morphological characteristics are complicated, and the relationships between the cranial base and malocclusion cannot readily be determined. In this study, to evaluate the maxilla connected to the anterior cranial base, morphological characteristics of the cranial base were classified, and these factors and relationships with the size and morphology of the maxilla were investigated.

As the glenoid fossa, Basion, and sphenoethmoidal suture (SE) are not clearly visualized by conventional lateral roentgenographic cephalograms, three-dimensional (3D) detailed measurements were required. These positions were clearly visualized by using computed tomography (CT) to clinically compare over- and hypo-growth of the maxilla. Specimens were classified into two groups by the distance between Point A and nasion perpendicular (N–A) (McNamara, 1981), and the relationships between the cranial base and maxillofacial morphology were evaluated.

Materials and methods

The specimens were 45 Skeletal I and Skeletal II dry skulls of modern Japanese males (range 19–57 years of age) without marked crowding, anterior crossbite, or maxillofacial asymmetry, which had been preserved in the Tokyo University Museum.

Because CT images of the suture areas in dry skulls are unclear, lead balls (ϕ 0.5 mm) were placed on the suture areas, which were used as the measuring points. The dry skulls were then fixed to a stand with FH as the reference plane, and a single-scan mid-sagittal sectional CT was then taken under the following conditions: 120 kV tube voltage, 50 mA tube current, 3 mm slice thickness, and 3 mm/s movement of the bed using a CT apparatus (X lead, TCT-X series, Toshiba Medical Co., Tokyo, Japan) (Figures 1 and 2).

Zooming reconstruction of the data obtained was performed on the CT apparatus (magnification 1.88, reconstruction function FC10), and the data were transferred to a computer (Pegasus Viewer work station 4.0, Amin Co., Japan), and 3D reconstruction was performed (Figure 3).

To determine the measuring accuracy of the CT and workstation, a $45 \times 45 \times 60$ mm^3 plaster block was placed parallel to the floor using a level vial. The CT was taken and transferred to a workstation under the same conditions and statistical differences between the measurements and the measured values were tested. To assess the significance of the error involved, a series of 10 specimens were re-assessed 1 week after the initial measurements were carried out.

All the measurement points were shown as a co-ordinate, with point S as the reference point (Coben, 1955) (Figure 3). The *X*-axis was defined as a line parallel to the FH plane passing point S. The anterior area to point S was set to (+), and the posterior area to point S to (–). *Y*-axis, a line perpendicular to the *X*-axis passing point S, and the superior area to point S was set to (+), and the inferior area to point S to (–). *Z*-axis, a line perpendicular to the *X*- and *Y*-axes passing point S, and the right side of point S was set to (+), and the left side of point S to (–).

All measurements were performed using multiplanar reconstruction (MPR) images on the workstation under the conditions of window level 250 and window width 2500 (Matteson *et al.*, 1989), and were recorded by one observer. The points and measurement variables are shown in Figures 4–6.

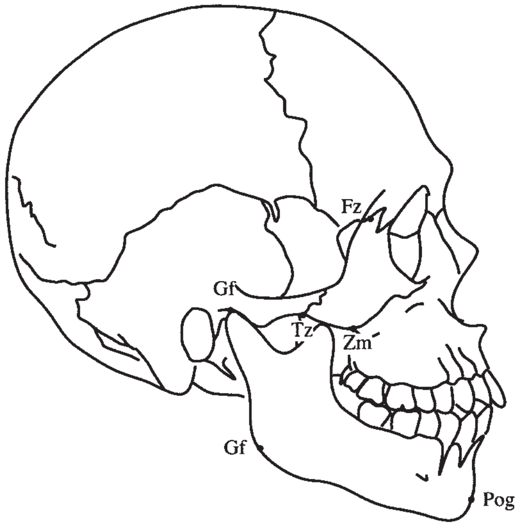

Figure 1 Definitions of craniometric variables. Fz, frontozygomatic suture; Tz, temporozygomatic suture; Gf, glenoid fossa; Pog, pogonion; Go, gonion; Zm, zygomatico-maxillary suture.

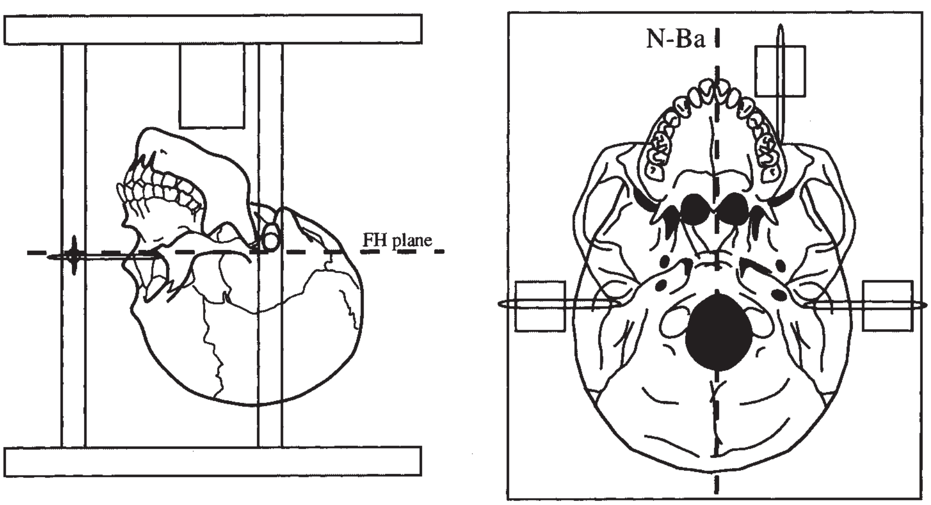

Figure 2 Placement of the dry skull. The dry skull was positioned parallel to Frankfort horizontal and computed tomographic images were taken in the sagittal plane through point N and Ba.

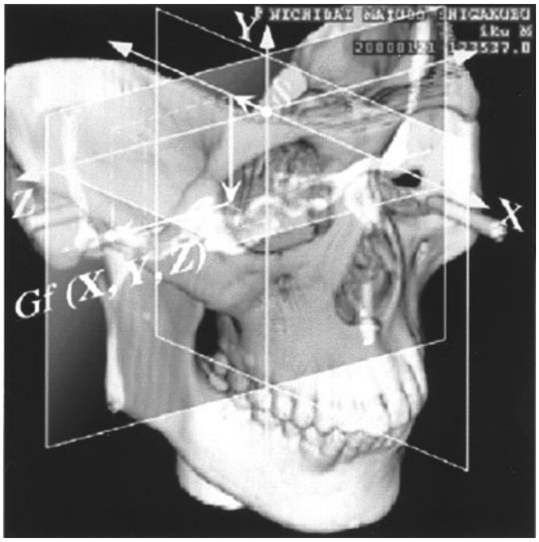

Figure 3 Three-dimensional reconstructed image of a dry skull. Point S was defined as the origin and each reference point was measured as the co-ordinate.

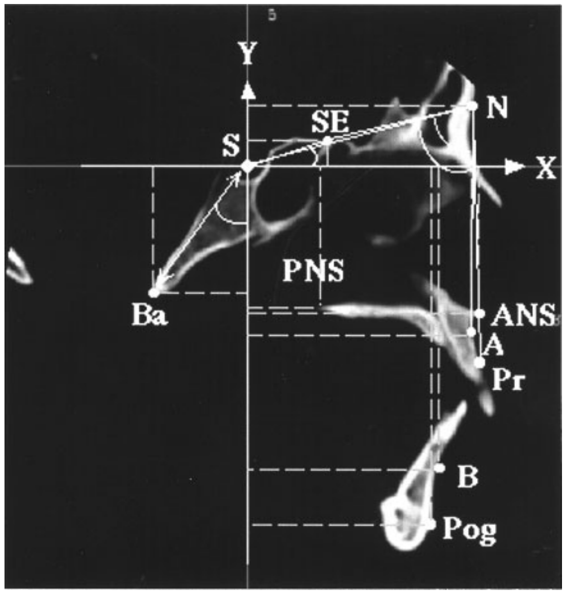

Figure 4 Definitions of CT variables in the mid-sagittal plane. S, sella; N, nasion; SE, sphenoethmoidal suture; Ba, basion; A, point A; ANS, anterior nasal spine; PNS, posterior nasal spine; B, point B; Pog, pogonion.

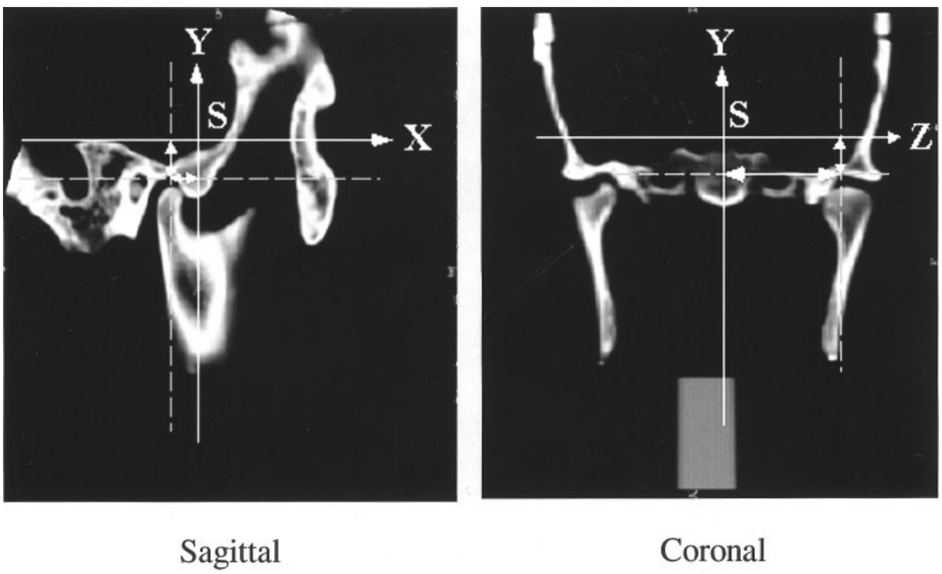

Figure 5 Co-ordinate measurements of the glenoid fossa.

Using the data obtained by the above methods, N–A line (N line defined as the perpendicular line to FH that goes through point N, and N–A line the distance between N line and point A) was measured, and the specimens were classified into two groups, according to the median value of N–A line. Subjects with an N line–A less than 1.5 mm were classified as the small group (n = 23), and those with an N–A line more than 1.5 mm as the large group (n = 22).

Results

The mean error for the plaster block was –0.005 mm (–0.008 per cent) for the X-axis, –0.075 mm (–0.16 per cent) for the Y-axis, and –0.13 mm (–0.07 per cent) for the Z-axis. Error variance (percentage) to total variance in repeated tests was 0.08–0.43 per cent, showing small values. No significant differences were observed. Dimensional accuracy of the 3D CT images was high, and it has been suggested that this system is useful for

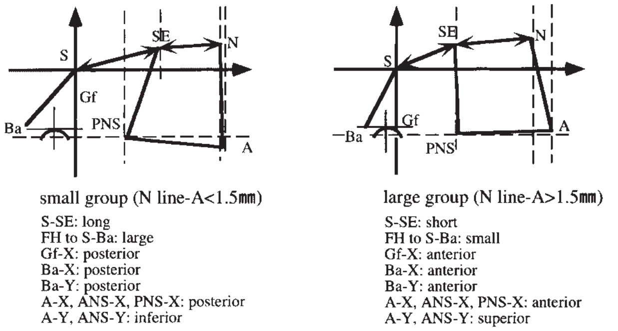

Figure 6 Morphological characteristics in the small and large groups.

analysing the morphology of the maxillofacial region (Matteson *et al*., 1989; Olcott *et al*., 1997).

The results of principal component analysis (PCA) of the measurement variables of the cranial base are shown in Table 1. Z1 indicates Fz breadth, Tz breadth, and Gf breadth, with 31.82 per cent proportion. Factors of the width of the face, Z2, were ∠N–S–Ba and ∠FH to S–Ba, with 23.98 per cent proportion. Factors of the degree of angulation of the cranial base, Z3, were S–SE and SE–N, with 16.50 per cent proportion, which were factors of the position of SE, and Z4 were S–N and N–Ba, with 12.33 per cent proportion, which were factors of the length of the cranial base.

Positive correlation coefficients were observed between S–SE and N–Ba or S–N, and negative correlations between S–SE and SE–N. Gf–X and Gf–Y, which were the horizontal and vertical positions of the glenoid fossa, showed positive correlations with Ba–X and Ba–Y, which were the horizontal and vertical positions of Ba. With regard to the relationship between the horizontal and vertical positions of glenoid fossa and the cranial base angle, a positive correlation was observed between Gf–X and FH to S–Ba, and a negative correlation between Gf–Y and ∠SN–FH (Table 2).

Table 3 shows the correlation coefficients between the co-ordinates of the maxilla and measurement variables of the cranial base. Positive correlations were observed between A–X, ANS–X, or PNS–X, which showed the antero-posterior relationship of the maxilla, and N–X, N–Ba, S–N, and S–SE. Negative correlations were found for A–Y, ANS–Y, or PNS–Y, which showed the vertical position of the maxilla, and ∠SN–FH. Negative correlations were observed between PNS–X, which is the posterior border of the maxilla, and ∠FH to S–Ba, Ba–X, or Gf–X.

With regard to the positional relationship between the mandible and glenoid fossa or Ba, there were negative correlations between Gf–X, which showed the

Table 1 Principal component analysis of cranial base (after varimax rotation).

	Z1	Z2	Z3	Z4
N–Ba	0.23	0.23	–0.11	–0.90
S–N	0.11	0.12	–0.01	–0.87
N–SE	–0.02	–0.01	0.96	–0.09
S–SE	0.08	0.07	–0.87	–0.41
S–Ba	0.25	–0.42	–0.30	–0.44
Fz breadth	0.58	–0.09	–0.36	–0.48
Tz breadth	0.89	0.05	–0.08	–0.34
Gf breadth	0.95	–0.06	0.03	0.00
∠N–S–Ba	–0.12	0.93	0.06	–0.28
∠SN–FH	–0.29	0.57	0.42	–0.41
∠FH to S–Ba	0.26	0.80	–0.34	0.03
Eigenvalue	3.77	2.48	1.67	1.22
Contribution %	34.31	22.53	15.18	11.11
Cum. percentage %	34.31	56.85	72.03	83.14

Table 2 Correlation coefficients for the cranial base.

	S–N	SE–N	S–SE	S–Ba	∠NS–S–Ba	∠SN–FH	∠FH to S–Ba	N–X(+)	N–Y(+)	Ba–X(–)	Ba–Y(–)	GfXAve.(–)
SE–N	0.04											
S–SE	0.57**	–0.82**										
S–Ba	0.19	–0.23	0.30*									
∠NS–S–Ba	0.04	0.09	0.00	–0.24								
∠SN–FH	0.08	0.30*	–0.20	–0.31*	0.67**							
∠FH to S–Ba	0.16	–0.24	0.30*	0.01*	0.63**	–0.04						
N–X(+)	0.94**	–0.05	0.61**	0.21	–0.04	–0.03	0.17					
N–Y(+)	0.26	0.22	–0.06	–0.26	0.46**	0.85**	0.15	0.15				
Ba–X(–)	–0.10	0.16	–0.25	–0.42**	–0.51**	0.05	–0.73**	–0.10	0.13			
Ba–Y(–)	–0.27	0.11	–0.23	–0.60**	0.58**	0.26	0.46**	–0.24	0.02	–0.33*		
Gf–XAve.(–)	0.00	–0.08	0.04	–0.35*	–0.37**	–0.02	–0.47**	–0.01	0.09	0.64**	–0.17	
Gf–YAve.(–)	–0.28	0.06	–0.22	–0.24	0.19	0.34**	–0.09	–0.24	0.31	0.04	0.34*	0.21

Ave., Mean values of left and right side.
(+), Vector which shows anterior area or superior area to point S.
(–), Vector which shows posterior area or inferior area to point S.
$^*P < 0.05$, $^{**}P < 0.01$.

Table 3 Correlation coefficients between co-ordinates of the maxilla and cranial base variables.

	A–X(+)	A–Y(–)	ANS–X(+)	ANS–Y(–)	PNS–X(+)	PNS–Y(–)
N–Ba	0.48**	0.14	0.56**	0.17	0.35**	0.03
S–N	0.58**	0.17	0.61**	0.14	0.46**	0.00
SE–N	–0.03	0.15	–0.02	0.15	–0.04	0.06
S–SE	0.36*	–0.04	0.39**	–0.06	0.30*	–0.05
S–Ba	0.22	–0.35*	0.10	–0.32*	–0.12	–0.39**
∠NS–S–Ba	–0.03	0.28	–0.01	0.36**	–0.05	0.53**
∠SN–FH	0.11	0.52**	0.11	0.54**	0.24	0.48**
∠FH to S–Ba	–0.20	0.00	0.05	0.09	–0.37**	0.21
Gf breadth	–0.04	–0.13	0.18	–0.11	0.13	–0.31*
FZ breadth	0.28	–0.12	0.38**	–0.09	0.21	–0.30*
TZ breadth	0.21	0.02	0.47**	0.06	0.30*	–0.26
N–X(+)	0.50**	0.07	0.55**	0.05	0.39**	–0.03
N–Y(–)	0.12	0.69**	0.36*	0.71**	0.47**	0.47**
Ba–X(–)	0.04	0.35*	0.23	0.28	0.53**	–0.01
Ba–Y(–)	–0.36*	–0.07	–0.49**	–0.03	–0.48**	0.38**
Gf–XAve.(–)	0.15	0.41**	0.18	0.34*	0.47**	0.23
Gf–YAve.(–)	–0.13	0.22	–0.27	0.15	–0.25	0.52**

Ave., Mean values of left and right side.
(+), Vector which shows anterior area or superior area to point S.
(–), Vector which shows posterior area or inferior area to point S.
**P* < 0.05, ***P* < 0.01.

antero-posterior position of glenoid fossa, and Go–X, Pog–X, or GN–X, and positive correlations between Gf–Y, which showed the supero-inferior position of glenoid fossa, and Go–X or Pog–Y. Similarly, negative correlations were observed for Ba–X and Go–X, Pog–X, or GN–X, and a positive correlation between Ba–Y and Go–Y (Table 4).

The means and standard deviations for the small and large group samples are shown in Table 5. S–SE, ∠FH to S–Ba and Ba–X ($P < 0.05$), A–Y and ANS–Y ($P < 0.01$) in the small group were significantly larger. SE–N ($P < 0.05$), and GfR–X, GfL–X ($P < 0.01$). Ba–Y ($P < 0.05$) and A–X, ANS–X, or PNS–X ($P < 0.01$) in the large group, which showed the antero-posterior position of the maxilla located anteriorly. These findings demonstrated that in comparison with the small group, S–SE was shorter, the maxilla was located more anteriorly, the vertical position of points A and ANS were located more superiorly, inclination of the posterior cranial base angle was small, and the glenoid fossa was in a more anterior position in the large group.

Discussion

The results of this study show that S–SE is an important component factor in the length of the cranial base, and Ba is an important component factor for the degrees of inclination of the cranial base. Embryologically, growth fields with different genesis are present in the cranial base (Sejrsen *et al.*, 1997), and it has been accepted that inter-sphenoidal synchondrosis ossify immediately before birth, and ethmoidal synchondrosis 7 years after birth. These findings suggest that growth of the central area of the cranial base is complete in the early stage,

Table 4 Correlation coefficients between co-ordinates of the cranial base and mandible.

	N–X(+)	N–Y(–)	Ba–X(–)	Ba–Y(–)	Gf–XAve.(–)	Gf–YAve.(–)
Go–XAve.(–)	0.28	0.36**	0.39**	–0.27	0.48**	–0.05
Go–YAve.(–)	–0.16	0.30	–0.17	0.44**	0.02	0.59**
Pog–X(+)	0.41**	0.24	0.30*	–0.28	0.31*	–0.34*
Pog–Y(–)	0.13	0.21	0.17	0.07	0.24	0.40**
Gn–X(+)	0.38**	0.19	0.38**	–0.36*	0.40**	–0.33*
Gn–Y(–)	0.05	–0.07	0.24	–0.05	0.28	0.29

Ave., Mean values of left and right side.
(+), Vector which shows anterior area or superior area to point S.
(–), Vector which shows posterior area or inferior area to point S.
**P* < 0.05, ***P* < 0.01.

Table 5 Comparison of small (N–A line < 1.5 mm) and large groups (N–A line > 1.5 mm).

	Small group (n = 23)		Large group (n = 22)		P
	Mean	SD	Mean	SD	
N–Ba	102.65	4.84	101.74	4.26	
S–N	66.15	2.92	65.53	3.19	
SE–N	41.99	5.10	44.53	4.26	*
S–SE	24.47	5.01	21.29	5.36	*
S–Ba	45.13	2.70	44.69	2.68	
∠N–S–Ba	135.10	5.73	133.81	4.01	
∠SN–FH	8.39	3.18	9.21	2.69	
∠FH to S–Ba	127.12	5.25	124.37	2.61	*
ANS–PNS	49.00	2.44	49.91	2.14	
∠SNA	82.40	3.94	84.70	2.93	*
∠FH to N–Pr	93.01	2.49	96.62	2.28	**
N–X(+)	65.07	2.48	63.94	2.93	
N–Y(+)	9.03	4.34	10.69	3.16	
Ba–X(–)	–27.68	3.64	–25.55	2.44	*
Ba–Y(–)	–35.25	3.30	–36.96	2.89	*
GfL–X(–)	–11.67	1.85	–9.76	2.48	**
GfL–Y(–)	–14.04	3.08	–14.10	2.41	
GfR–X(–)	–11.21	1.94	–9.45	1.97	**
GfR–Y(–)	–14.69	2.68	–14.89	2.18	
A–X(+)	63.61	4.17	68.28	3.05	**
A–Y(–)	–49.56	5.27	–44.38	4.43	**
ANS–X(+)	66.36	4.09	70.20	3.01	**
ANS–Y(–)	–44.78	4.79	–40.13	3.79	**
PNS–X(+)	17.47	3.65	20.37	2.10	**
PNS–Y(–)	–41.45	3.19	–40.34	2.67	

(+), Vector which shows anterior area or superior area to point S.
(–), Vector which shows posterior area or inferior area to point S.
*P < 0.05, **P < 0.01.

and thereafter growth and development are a result of anterior growth of the frontal bone, and growth and development of the posterior cranial base due to the activity of the spheno-occipital synchondrosis. Lozanoff *et al.* (1994) reported that during the growth stage, growth and development of the sphenoid bone in the area around SE influences maxillofacial morphology. This evidence shows that growth of the maxilla is significantly influenced by the anterior cranial base and if there are relationships between the morphology of the cranial base and the position of the maxilla, it is speculated that the position and structure of maxilla can be predicted from the morphology of the cranial base.

The findings of the present study show that the antero-posterior position of the maxilla is related to the length of the anterior area of the sphenoid bone and the length of the anterior cranial base, and also to the posterior cranial base. PNS–X showed negative correlations with ∠FH to S–Ba, Ba–X, and Gf–X, demonstrating that in subjects in which PNS was located posteriorly, Ba and Gf were also located in the posterior position.

With regard to the morphology of the cranial base angle and maxillofacial morphology, Singh *et al.* (1997) found morphological differences in the cranial base between subjects with Class I and Class III malocclusions. Renfroe (1948) and Kasai *et al.* (1995) reported that the cranial base angle increases in patients with a Class II malocclusion. The relationship between the cranial base angle and position of glenoid fossa have been studied, and it has been reported that the glenoid fossa in patients with a Skeletal II malocclusion is located in the posterior position, and that of Skeletal III subjects in the anterior position (Droel and Isaacson, 1972; Baccetti *et al.*, 1997; Sekiya *et al.*, 1999).

Because correlations were observed in ∠FH to S–Ba, Ba, and Gf between the vertical and horizontal positions, it was speculated that the position of the glenoid fossa was influenced by the inclination of the posterior cranial base. When point S was set to the origin, the more glenoid fossa was located anteriorly, and the more Pog and Gn were located in an anterior position; therefore, the morphology of the posterior cranial base influenced the position of the glenoid fossa, and thereafter the position of the mandible. However, the position of glenoid fossa and the size of the mandible was also thought to be involved in the development of skeletal malocclusion, and positional abnormalities in the mandible to the cranial base to be caused by complex factors such as the size and morphology of the mandible and cranial base, position of the glenoid fossa, and the maxilla. It is difficult therefore to simply relate malocclusion to the morphology of the cranial base.

There were significant differences between the small and large groups classified by N line–A. In the large group, S–SE was shorter, the maxilla more anteriorly positioned, the inclination angle of the posterior cranial base was smaller, and the glenoid fossa more anterior than in the large group. However, no significant differences were observed in the length of the anterior cranial base and the maxilla between the small and large groups. Wilhelm *et al.* (2001) found no significant difference in the cranial base between Class I and II subjects. Therefore, morphological differences between the small and large groups may be caused by differences in the positional relationship of the maxilla. The maxilla and glenoid fossa were located in the anterior position in the large group, whilst the vertical position of the maxilla, A–Y and ANS–Y, was located more superiorly in the large than in the small group. This hypothesis of morphological characteristics is shown in Figure 6. These findings suggest that the morphology of the cranial base is influenced by the position of the maxilla. However, in evaluating skeletal disorders, the morphology and size of the mandible also need to be considered.

Conclusion

S–SE, which is a main component factor of the anterior cranial base, and the antero-posterior position of glenoid fossa were related to the position of the maxilla, and the length and inclination of the posterior cranial base, which is related to Ba, influenced the position of the glenoid fossa. Clockwise rotation of the maxilla was observed in the skulls with a long S–SE (the frontal area of the sphenoid bone), and counter-clockwise rotation of the maxilla in skulls with a short S–SE. Since SE is ossified 7 years after birth, it is possible to predict the future growth pattern of the maxilla based on the position of the SE. Furthermore, the glenoid fossa was anteriorly located in the skulls with a short S–SE, and posteriorly located in skulls with a long S–SE.

However, although the morphology of the cranial base has an effect on the position of the maxilla and mandible, mandibular morphology influences the malocclusion. For this reason, the relationship between malocclusion and the cranial base is complicated, and skeletal discrepancies could occur for any type of cranial base. Therefore, the position and morphology of the mandible must be considered when evaluating skeletal discrepancies.

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