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A comparison of craniofacial morphology in patients with and without facial asymmetry—a three-dimensional analysis with computed tomography

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Abstract. This study intended to evaluate the morphological characteristics of the cranial base and maxillomandibular structures of facial asymmetry in adult patients, so as to determine whether mandibular asymmetry is a result of primary mandibular deformity or if it is influenced by cranial base deformity.

Forty-two adult patients with dentofacial deformity were placed into two groups according to the deviation of the chin: Asymmetry group ($n = 24$) and Non-asymmetry group ($n = 18$). They were compared with three-dimensional (3D) CT reformatted images using a 3D visualization and analyzing program. The differences between the two groups, the correlation between the cranial base and maxillomandibular asymmetry were evaluated statistically.

The degree of cranial base asymmetry in the Asymmetry group was not statistically different from the Non-asymmetry group. The asymmetric condyle position was found to be associated with skull base characteristics. The 3D position of the condyle and cranial base, however, was not closely related with mandibular asymmetry. The results showed that the cranial measurement variables were not the dominant factors that determined the degree of facial asymmetry.

It seems that the mandibular skeletal factors itself, functional or intrinsic asymmetric growth potential, compensate or aggravate the influence of cranial asymmetry during the growth period.

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The human face is not always symmetrical over the facial midline. However, when asymmetry of the craniofacial skeleton causes functional and aesthetic problems, special attention is needed.

Various etiological factors have been proposed concerning the expression of facial asymmetry. The most common type of facial asymmetry is a result of unilateral mandibular enlargements characterized by a surplus growth in the length or mass of hemimandible, which could be caused by condylar hyperactivity[17]. The functional disharmony of the masticatory muscle could be regarded as another factor related to facial asymmetry[21]. Craniofacial asymmetry of the fetus or infant, however, before the development of the chewing habit, shows that the masticatory function is not the determining factor in these age groups[22]. Asymmetry can be expressed by the hemisphere dominance of the brain[1] or positioning of the head during the early infancy period[19]. It was noted that in a patient with a twisted head shape (plagiocephaly), the temporomandibular joint (TMJ) position and mandibular shape could also be changed[9,23,25]. Therefore, it is generally accepted that the expression of craniofacial asymmetry would be related to hereditary as well as environmental factors during the fetal, infant or adolescent periods[20].

Using three-dimensional (3D) CT images for clinical diagnosis, we have observed in our clinic that facial asymmetry is often accompanied by various degrees of cranial asymmetry. There was a question whether these types of facial asymmetry are plagiocephaly related malformations or if it is because of the influence of asymmetric mandibular growth on the skull base. We, however, have limited knowledge of the fate of untreated craniofacial asymmetry and its influence on the mandible because most of the previous reports on 3D craniofacial structures[3,4,8,13,14] analyzed the plagiocephaly in early age groups.

The present study intended to evaluate the morphological characteristics of the cranial base and maxillomandibular structures in adult patients with facial asymmetry. If we evaluate the 3D structural correlation between the cranial structures and facial landmarks, it would be possible to verify whether mandibular asymmetry is a result of primary mandibular deformity or if it is influenced by cranial base deformity.

Materials and methods

Patients

The present study consisted of 42 adult patients (20 males, 22 females) with dentofacial deformity who had undergone a 3D CT scan for the purpose of presurgical evaluation at the Department of Oral and Maxillofacial Surgery, Kyungpook National University Hospital. The subjects were divided into two groups: Asymmetry group ($n = 24$, average age = 23.4) and Non-asymmetry group ($n = 18$, average age = 22.6). As the mandibular chin has the greatest effect in determining facial appearance[15], facial asymmetry was defined as deviation of the chin (menton and pogonion), where the deviation is more than 4 mm from the facial midline[5]. The patients in the Asymmetry group had either Skeletal Class III or I malocclusion. When applying the diagnostic criteria of Obwegeser & Makek[17] and Obwegeser[16] in classifying mandibular asymmetry, the group could be subdivided into bilateral hemimandibular elongation ($n = 17$), unilateral hemimandibular elongation ($n = 2$), hemimandibular hypoplasia ($n = 3$), unilateral hybrid form ($n = 1$), and unilateral hemimandibular elongation with contralateral hemimandibular hypoplasia ($n = 1$).

The Non-asymmetry group was composed of cases of Skeletal Class II or III malocclusion without asymmetry. Patients with a cleft lip and palate or clinically significant pathology affecting facial deformity, such as a history of facial trauma or infection, were excluded from the study. There were no cases of hemifacial microsomia or congenital muscular torticollis within the subjects.

Methods

CT scanning and 3D image reconstruction

To evaluate the geometry of craniomaxillofacial structures, a spiral computed tomography (CT) scan was used with contiguous slices, 1–3 mm thickness. A spiral CT was taken with a Highspeed CT (GE Co., USA). All CT data were stored in a DICOM file format and transferred to an 80 GB hard drive with a Windows-based personal computer running 3D reconstruction and measurement software programmes V-Works 4.0 and V-Surgery 1.0 (CyberMed, Seoul). With the function of grayscale thresholding, soft tissue was removed from the bony structure.

Angular and linear measurements in 3D image

To establish the standard orientation of the craniofacial structure, 3D reference planes (horizontal, sagittal and coronal plane) were first set consecutively. The horizontal plane (*xy* plane) was defined as a plane passing the bilateral porion (Po) and left inferior orbitale (Or). The sagittal plane (*yz* plane) was defined as a plane perpendicular to the horizontal plane passing through the crista galli (Cr) and the middle of the anterior clinoid process (Cl) and became the reference for the facial midline. Finally, the plane perpendicular to the horizontal and sagittal planes, including the opisthion (Op) was defined as the coronal plane (*zx* plane). In 3D reconstructed image, landmarks on the surface of the skeleton were identified with a digitizer (Fig. 1). For the convenience of comparison, the mandibular deviation side was set to the left side, which was easily performed by changing the *x* coordinates.

Three-dimensional skull image from the top and bottom was defined as endo- and exo-cranial base, respectively. Definitions of the cranial landmarks were similar to Kane et al[9]. The inter-landmark distances and angles were calculated between the coordinates of the skeletal structures in 3D space, thus the error of magnification or head positioning was avoided. The *ramal height* was defined as the distance from the condyle head (Con) to gonion (Go), the *body length* was the distance from Go to menton (Me), and the *mandibular length* was the distance from Con to Me. The

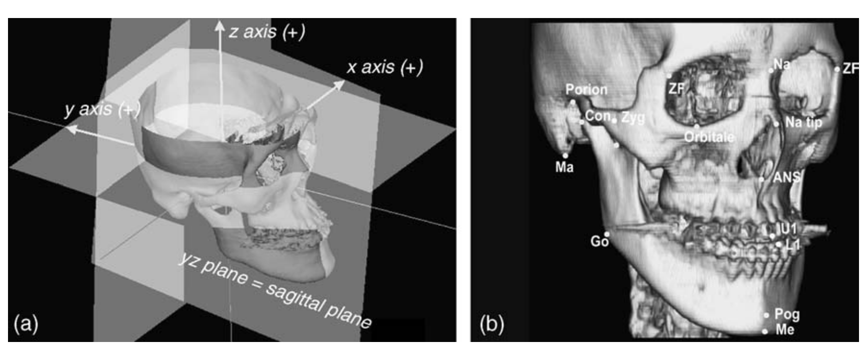

Fig. 1. Cardinal axes (a) and craniofacial landmarks (b) used in the study. Po: porion, Or: orbitale, Na: nasion, Na tip: tip of nasal bone, ANS: ant. nasal spine, PNS: post. nasal spine, Pog: pogonion, Me: menton, U1: center of upper incisors, L1: center of lower incisors, Go: gonion, Con: condylar lateral, Cor: coronoid tip, Sig: sigmoid notch, ZF: zygomatico-frontal suture, Zyg: zygoma lateral, Ma: mastoid process. Mandibular ramal height: Con–Go, body length: Go–Me, mandibular length: Con–Me, mandibular angle: Con–Go–Me.

angle formed by Con–Go–Me was defined as the *mandibular angle*.

The important endocranial landmarks were defined as: the most superior edge of the crista galli (Cr), the center of anterior clinoids (Cl), the midpoint of the posterior arch of the foramen magnum (Op), the most anterior point of the lesser wing of the sphenoid or xiphoid of the lesser wing of the sphenoid bone (S), the junction of the superior ridge of the petrous pyramid and the inner surface of the occipital bone (P). The *endocranial deviation angle* was defined as the deviation of the foramen magnum to the sagittal plane (∠Cr–Cl–Op). If there is complete symmetry, the deviation of the foramen magnum will be 0. The angle formed by the intersection of the landmarks of the anterior and middle cranial fossa was defined as the *ant. cranial angle* (∠Cr–Cl–S). The *mid. cranial angle* (∠S–Cl–P), the *petrous ridge angle* (∠Cr–Cl–P) and the *post. cranial angle* (∠P–Cl–Op) were defined similarly. The distance from the middle of the superior orbital rim to the contralateral parieto-occipital area was defined as the *transverse cranial length* (a and b). Thus, the ratio of the bilateral difference between the two was expressed as the *transverse cranial asymmetry*: $(a - b)/a$ (Fig. 2).

The data were analyzed by the Student's t-test within each group and the difference between the two groups was compared using the Student's t-test with a significance of $P < 0.05$. A correlation analysis was performed to detect a relationship between the cranial and mandibulofacial structural deformities. The software used was SPSS PC 10.0 for Windows.

Reliability of method

To prevent inter-observer error, all processes were performed by one author (T.-G.K.). The errors in landmark localization during the 3D image processing and digitization were evaluated by comparing the differences between the 3D coordinates, angular measurements, and the linear measurements of the original and repeated examinations of the 10 patients during a 2-week interval. The method error was calculated as $SE = \sqrt{(\sum d^2/2n)}$, where d is the difference between double measurements and n is the number of paired double measurements[6].

Results

The errors of intra-observer precision were 1.4 mm, 1.0 mm, 1.3 mm for the x, y, and z coordinates, respectively, whereas it was 1.62° for the angular measurements and 1.7 mm for the linear measurements. There was no statistical difference detected between the original and repeated measurements.

Differences between the Asymmetry and Non-asymmetry groups

The Asymmetry group showed an average chin deviation of 10.7 mm (with a range between 5.3 and 20.0 mm), whereas the Non-asymmetry group showed an average deviation of 1.4 mm (with a range between 0.1 and 3.9 mm).

The craniofacial landmarks did not show right or left-side dominant asymmetry in either group. For convenience in terms of calculations and in comparing measurements, the mandibular deviation side was set to the left side. The degree of maxillary deviation (ANS (x)) was not significant in either group. The left–right difference of the bilateral measurements and the statistical difference between the groups are listed in Table 1. Compared with the Non-asymmetry group, the Asymmetry group showed conspicuous differences in mandibular morphology. When the mandible deviated to the left side, the ipsilateral sides of the ramus and body were shorter than the opposite sides. The gonion and coronoid were located more latero-superiorly in the affected side. In the Non-asymmetry group, the mandibular ramal height showed a negative relationship with body length ($r = -0.631$, $P < 0.01$). The condyle position, however, did not show a statistical difference between the two groups. Due to various levels of degree and the amount of bilateral difference in the endo- and exo-cranial measurements, neither group showed a statistical difference in the cranial landmarks.

The correlations between the cranial and mandibulofacial measurements

The relation between each mandibulofacial structure is shown in Table 2. The degree of mandibular deviation was highly correlated with the bilateral difference of the ramal height and body length ($r = 0.656$, 0.810, $P < 0.01$). Gonion deviation followed chin deviation in all directions. The mandibular deviation was also related to nasal projection ($r = 0.448$, $P < 0.01$) and transverse deviation of the maxilla ($r = 0.436$,

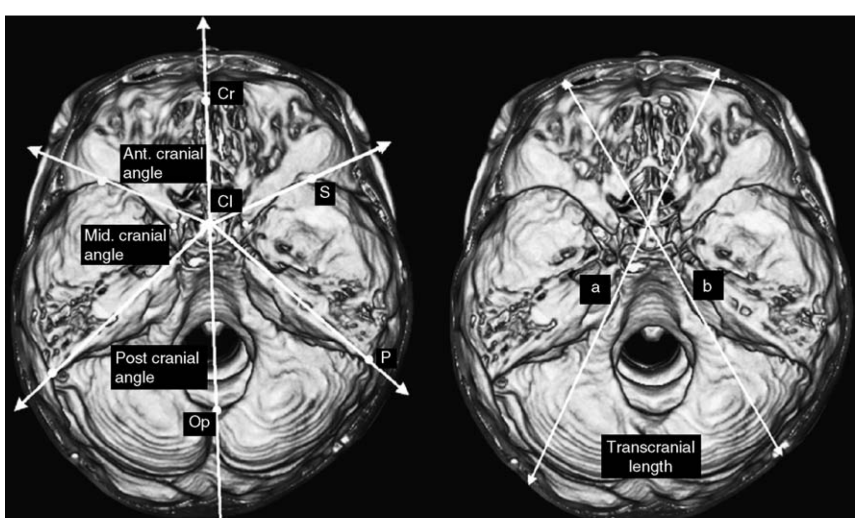

Fig. 2. Measurements for evaluation of the skull base and cranial asymmetry. Cr: crista galli, Cl: clinoid process, Op: opisthion, S: sphenoid, P: petrous pyramid, ant. cranial angle: ∠Cr–Cl–S, mid. cranial angle: ∠S–Cl–P, post. cranial angle: ∠P–Cl–Op, petrous ridge angle: ∠Cr–Cl–P, endocranial deviation angle: ∠Cr–Cl–Op, transverse cranial asymmetry (%): $(a - b)/a$. Mandibular deviation was set to the left side.

Table 1. Comparison of craniofacial coordinates and measurements in Asymmetry vs. Non-asymmetry group

	Asymmetry group ($n = 24$)		Non-asymmetry group ($n = 18$)		
Measurements of midline and paired structures	Mean	SD	Mean	SD	*P*
ANS (*x*, deviation to sagittal plane)	1.00	1.70	0.92	1.37	0.876
Me (*x*, deviation to sagittal plane)	10.66	3.50	1.41	1.36	<0.001
Go (*x*, L–R) (mm)	6.88	4.04	−0.46	4.24	<0.001
Go (*y*, L–R) (mm)	3.61	4.04	2.11	3.12	0.197
Go (*z*, L–R) (mm)	3.60	4.58	−1.33	2.08	<0.001
Con (*x*, L–R) (mm)	−0.18	3.11	−0.89	2.20	0.412
Con (*y*, L–R) (mm)	0.17	4.25	1.88	2.88	0.151
Con (*z*, L–R) (mm)	−0.41	4.41	1.67	3.54	0.108
Cor (*x*, L–R) (mm)	3.69	3.82	0.99	2.16	<0.001
Cor (*y*, L–R) (mm)	2.68	4.75	2.63	2.53	0.966
Cor (*z*, L–R) (mm)	3.87	3.93	0.52	1.61	<0.05
Ramal height (L–R) (mm)	−4.68	5.47	0.91	1.89	<0.001
Body length (L–R) (mm)	−3.60	2.63	−0.76	2.11	<0.001
Mandibular length (L–R) (mm)	−8.71	3.56	−1.19	2.00	<0.001
Mandibular angle (L–R) (°)	−2.77	3.64	−2.21	2.36	0.571
Ant. cranial angle (L–R) (°)	0.39	3.99	1.81	3.26	0.225
Mid. cranial angle (L–R) (°)	−0.41	3.94	0.01	2.17	0.685
Petrous ridge angle (L–R) (°)	−0.02	3.44	1.82	2.54	0.063
Post. cranial angle (L–R) (°)	−0.24	3.22	0.19	2.88	0.654
Endocranial deviation angle (°)	−0.13	1.79	1.01	1.38	<0.05
Transverse cranial asymmetry (%)	1.02	8.29	−0.48	5.52	0.533

L–R: difference between the paired structures, left–right. Positive values indicate left (*x* coordinates), posterior (*y* coordinates), superior (*z* coordinates) dominant in the left side, where mandibular deviation was set to the left side in this study. *P* value indicates statistical difference between the two groups.

$P < 0.01$). No significant correlation, however, was found between the degree of asymmetry and the condyle position. Endo- and exo-cranial asymmetry exhibited correlations with the condyle position but not with maxillary or mandibular chin deviation.

The degree of cranial base asymmetry (endocranial deviation and petrous ridge angle) showed significant correlation with the anterio-posterior position of the condyle ($r = -0.570$, 0.688, $P < 0.01$), and it was related to the mastoid position in the axial plane. Transcranial asymmetry, which is a characteristic feature of plagiocephaly, showed a significant correlation with various exo- and endo-cranial measurements (Table 3).

Among the patients with skull base asymmetry and mandibular deviation, we determined that four patients could be categorized as deformational plagiocephaly, following the definition of Bruneteau & Mulliken[2] and Captier et al.[3]

Discussion

This study intended to quantify craniofacial morphology in adult patients who visited our clinic in order to correct their facial asymmetry. Relating factors of morphological deformity between the cranial and maxillomandibular structures in the three planes of space were investigated, which had not been thoroughly analyzed before. Previously, the morphological characteristics of an asymmetric face had been analyzed by two-dimensional (2D) radiographs. In the 3D study, measurements (distance, angle) are of actual 3D dimensions without any radiographic magnification, thus a direct comparison of paired and midline structures are possible. However, there is an inherent problem in establishing the standard reference axes for the evaluation of craniofacial asymmetry because there are difficulties in finding anatomical landmarks that are

Table 2. Correlation between the measurements of the mandibulofacial landmarks

Correlation coefficients	Me (*x*, L–R) (mm)	Con (*x*, L–R) (mm)	Con (*y*, L–R) (mm)	Con (*z*, L–R) (mm)
Go (*x*, L–R) (mm)	0.812	0.249	0.082	−0.027
Go (*y*, L–R) (mm)	**0.729**	**−0.308**	0.001	0.043
Go (*z*, L–R) (mm)	**0.620**	−0.076	0.001	0.042
Con (*x*, L–R) (mm)	−0.079	–	0.290	−0.133
Con (*y*, L–R) (mm)	0.263	−0.290	–	0.095
Con (*z*, L–R) (mm)	0.037	−0.133	0.095	–
Cor (*x*, L–R) (mm)	**0.646**	**0.342**	0.110	−0.201
Cor (*y*, L–R) (mm)	**0.548**	−0.153	0.234	−0.112
Cor (*z*, L–R) (mm)	**0.824**	−0.232	**0.416**	0.282
Ramal height (L–R) (mm)	**−0.656**	0.138	0.093	0.059
Body length (L–R) (mm)	**−0.810**	0.118	−0.098	−0.042
Mandibular length (L–R) (mm)	**−0.939**	0.179	−0.054	0.016
Mandibular (L–R) (°)	**−0.563**	0.150	0.209	0.006
Na–Na tip to sagittal plane (°)	**−0.448**	0.156	**0.403**	0.160
Cr–ANS to sagittal plane (°)	**−0.611**	0.009	**−0.417**	−0.060
ANS–PNS to sagittal plane (°)	**−0.436**	**0.351**	**−0.505**	0.041

Statistically significant results ($P \leq 0.05$) in bold.

Table 3. Correlation between the measurements of the cranial and mandibulofacial landmarks

Correlation coefficients	Na–Na tip to sagittal plane	Me (*x*)	Con (*x*)	Con (*y*)	Endocranial deviation angle	Transverse cranial asymmetry	ANS–PNS to sagittal plane
Ma (*x*)	0.426	0.059	**0.491**	−0.378	**0.707**	**−0.334**	**0.493**
Ma (*y*)	**−0.326**	0.088	−0.142	**0.608**	**0.428**	−0.238	−0.247
Zyg (*x*)	−0.076	0.243	**0.764**	−0.108	0.123	0.093	0.078
ZF (*x*)	**−0.483**	0.276	−0.008	**0.408**	**−0.505**	**0.417**	**−0.508**
ZF (*y*)	**−0.474**	0.175	−0.234	**0.614**	**−0.536**	−0.043	**0.604**
Ant. cranial angle (°)	−0.195	0.127	**−0.506**	**0.423**	−0.169	−0.100	−0.328
Mid. cranial angle (°)	−0.235	−0.016	0.319	0.175	−0.383	0.176	−0.077
Petrous ridge angle (°)	**−0.473**	0.138	−0.290	**0.688**	**−0.591**	0.056	**−0.474**
Post. cranial angle (°)	−0.144	−0.084	0.036	−0.071	**−0.524**	**0.474**	−0.189
Endocranial deviation angle	**0.561**	−0.054	0.235	**−0.570**	–	**0.464**	**0.600**
Transverse cranial asymmetry	−0.271	0.038	−0.045	0.056	**0.464**	–	−0.302

Statistically significant results ($P \leq 0.05$) in bold.

not affected by deformity. At present, the external acoustic meatus has been proposed as a suitable reference for the analysis of craniofacial asymmetry because this area is thought to maintain a stable shape[10]. Therefore, most 3D studies on craniofacial deformity usually use the FH plane as a reference[3,13,26].

To minimize the error in axes orientation, the FH plane was used only as an axial reference and other endocranial landmarks were utilized to establish the sagittal and coronal planes in our study. Anteroposterior and mediolateral positional differences of the external acoustic meatus were found to be possible. In addition, the 3D linear and angular measurements were also compared, thus minimizing the error in interpreting the left–right positional differences of the 3D landmarks.

It was interesting to note that in patients without asymmetry, there was a negative correlation between the ramal height and body length ($r = -0.631$, $P < 0.01$). The facial asymmetry patients exhibited a shortening of the ramal and body length on the deviated side, but there was no correlation between the two linear measurements. Legrell & Isberg[12] also reported a shorter ramus on the experimentally induced disc displacement side, which was partially compensated by growth at the base of the mandible, so that the total body and ramus length was not reduced. From this research, it is assumed that there is an attempt during growth to maintain chin symmetry as the primary response to unequal stimuli from the mandible. A three-dimensional longitudinal study on normal populations might be able to clarify this assumption.

Facial asymmetry can be a result of various kinds of mandibular growth. Obwegeser[16] classified three groups of mandibular asymmetry according to the etiology: embryonic maldevelpoment of the mandible, postnatal condylar damage induced growth disturbance, and misregulation of growth after birth. Typical mandibular asymmetry, such as hemimandibular hyperplasia, hemimandibular elongation and condylar hyperplasia was thought to occur irrespective of cranial base considerations. In our patients, asymmetric prognathism comprised 71% (17/24) of the Asymmetry group and these patients were regarded as having a bilateral expression of hemimandibular elongation. None of our patients exhibited pure condylar hyperplasia or unilateral hemimandibular hypertrophy according to Obwegeser & Makek's definition[17].

Among our patients, there was no diagnosis of hemifacial microsomia or congenital muscular torticollis. Four patients, however, could be diagnosed as having facial asymmetry accompanied with a mild degree of deformational plagiocephaly, according the preceding reports[2,3]. Transcranial and maxillomandibular asymmetry, nasal root deviation, bilateral height difference in orbit, with endocranial deviation, was noted in these patients.

In terms of plagiocephaly, a twisted head shape, it has been proven that cranial deformity influences the facial form. Mandibular asymmetry in deformational plagiocephaly is secondary to the rotation of the cranial base and the anterior displacement of TMJ, and it is not a result of primary mandibular deformities in infants[25]. Kreiborg et al.[11] observed that in plagiocephaly, mandibular asymmetry has developed in early infancy, and is secondary and compensatory to the primary asymmetry of the cranial base. Most of the studies, however, were carried out with young age groups. There was no quantitative data that could prove cranial asymmetry is a direct result of facial asymmetry after growth period.

There is some difficulty in defining 'remarkable cranial asymmetry' or 'definitive plagiocephaly' in adults because there was no reference suggesting the objective value. For infants, a bilateral difference over 4 mm was defined as 'cranial asymmetry'[18] in *transverse cranial length*, and the mean difference in this length was 10.8 mm in deformational plagiocehaly[25]. If this mean value was converted to the *transverse cranial asymmetry* (definition of the present report), it would be 7.3% in infants. Our patients, who had mild plagiocephaly, showed a difference in bilateral *transverse cranial length* that ranged between 11.6 and 19.2 mm and percentage of the *transverse cranial asymmetry* ranged between 7.1 and 12%. As adult patients with plagiocephaly showed the effects of uncontrolled early deformity, an analysis of the morphological characteristics of these patients will provide valuable data regarding growth. Further studies should be conducted with a larger sample number.

There are some limitations in classifying mandibular asymmetry only by abnormal activity of condyle cartilage, such as Obwegeser & Makek's classification[17]. This classification is considerably less effective in explaining clinically significant variations in facial asymmetry, such as plagiocephaly related mandibular asymmetry. Moreover, as Obwegeser mentioned[16], a histopathological distinction of the different type of mandibular asymmetry in this classification system is not possible and the existence of condylar growth regulators that stimulate the length or mass of the bone has not yet been verified. Therefore, the new classification system needed would have to be based on not only the 2D maxillomandibular structure, but also the 3D cranial base landmarks, reflecting the etiological background of craniofacial asymmetry.

An investigation of normal growth patterns of skulls revealed that skull base growth changes occur in the first 5 years of life[24]. Cranial asymmetry, due to occipital flattening, becomes fixed 1 year after birth[19], which means the early structural establishment of the cranium. Therefore, any influence of exo- or endo-cranial deformation on facial asymmetry may be limited in early childhood.

The results also showed that there was a significant correlation found between the condyle, mastoid and petrous positions. As the petrous ridge, condyle fossa and mastoid are components of the same osseous unit (temporal bone), and the position of condyle might reflect the positional change of the petrous ridge. As Hoyte[7] reported, petrous bone grows and doubles the infantile length during the infantile period until adulthood. It would be possible to have a correlation between these structures because the growth periods overlap each other. The result manifests the idea that cranial base deformity can influence the position of the condyle, which is one of the many factors related to facial asymmetry.

In our results, degree of cranial base asymmetry was not different between the Asymmetry and Non-asymmetry group. The skull base characteristics was found to be associated with the mandibular condyle asymmetry but not with the asymmetry of the mandibular chin in adults. This means the cranial base structures were not the dominant factors that explained the degree of facial asymmetry in our patients.

Therefore, our results can be explained as follows: functional factors or the intrinsic asymmetric growth potential of the mandible compensate or aggravate the influence of cranial asymmetry during the growth period.

In summary, even though facial asymmetry is accompanied various degrees of cranial base asymmetry, our results showed that severity of cranial asymmetry is not the dominant factor that determines the degree of facial asymmetry. This may be attributed to the compensational growth of mandibulofacial structures after the establishment of cranial asymmetry in early ages.

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