ABSTRACT

Relationships between facial asymmetry and bilateral differences of the condylar morphology
—Three-dimensional (3D) morphological analysis—

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[Introduction]

Facial asymmetry involves bilateral differences in morphological structures of the maxillofacial skeleton. The facial asymmetry is thought to be caused by congenital abnormalities, disorder of orofacial functions including temporomandibular disorders (TMD), and traumatic injuries. The mandible is regarded as a three-dimensional structure, which provides individual variation in morphology of the maxillofacial skeleton. Anatomically, the mandible can be divided into three main functional regions; (1) the core of bone surrounding the inferior alveolar nerve, (2) the condylar process engaged in joint functions, and (3) the alveolar and the muscular processes which are functional prominence. Among these, the condylar process which is covered with the cartilaginous tissue (condylar cartilage) is a major growth site for the mandible. Growth of the mandibular condyle contributes not only to increased mandible size, but also to anteroinferior displacement of the mandible. The condylar process grows in a wide range of directions from anterosuperior to posterior. This divergent growth allows for highly diverse growth and morphology of the mandible. Growth of the mandible has a considerable influence on final morphology of the maxillofacial skeleton and occlusion. Therefore if there is asymmetry in the face, the difference in the mandibular growth exists in both the left and right sides, it is presumed to be related to the position and attitude of the mandible. From clinical aspects of orthodontics, it is important to know the relationships of facial asymmetry and condylar morphology. A lot of studies concerning morphological characteristics of facial asymmetry including 3D estimation have been conducted, in which the external auditory canals and infraorbital margins were commonly used as references to represent each craniofacial structure. However, there are little studies using three-dimensional (3D) references in the mandible basis. The aim of the present study was to clarify 3D relationships between morphological differences of the mandibular condyles on the deviated and non-deviated sides and spatial position of the mandible to the craniomaxillary complex in facial asymmetry cases.

[Materials and methods]

Virtualized patient models, which had been reconstructed from 30 patients with severe facial asymmetry, were used in the present study.

1. Setting of the reference coordinate of the mandible

The virtualized models were segmented into two components, i.e., the craniomaxillary complex and the mandible. In addition, global and local coordinate systems were established in each segmented component.

2. Quantification of relative attitude and position of the craniomaxillary complex and mandible

Each projection of the coordinate axes of the mandibular coordinate system was projected onto the frontal plane and the axial plane of the craniomaxillary coordinate system. Relative attitude of the craniomaxillary complex and mandible on the frontal plane (referred to here as rolling), relative attitude of the craniomaxillary complex and mandible on the axial plane (yawing) and relative position of the craniomaxillary and mandible on the frontal plane (swaying) of the mandible were measured.

3. Setting of the condylar long axis (CLA) and quantification of the length and angle of the CLA

In the mandibular coordinate system, the medial and lateral surfaces of the condyle were arbitrarily selected to calculate the approximate sphere to determine the straight line L passing through the center of the two spheres obtained. Then, the point located in the most medially and laterally along straight line in the three-dimensional shape of condyle was defined as the medial and lateral poles, respectively. The line connecting the mesial and lateral poles was defined as the condylar long axis (CLA). The difference in length of the CLA between the deviation and non-deviation sides was measured. The angles between the projected lines of the CLA on the axial and frontal planes of the mandibular coordinate system and corresponding horizontal reference axis were measured. The difference in each angle between the deviation and non-deviation sides were defined as the angle of the CLA on the axial plane and the angle of the CLA on the frontal plane, respectively. To verify the accuracy of the method was carried out measurement errors test of distance and angle measurements using the Dahlberg formula.

4. Quantification of the condylar position

The center point of the CLA (Cd) was established on the deviation and non-deviation sides. The differences in the horizontal distance from the point Cd to the mid-sagittal plane, the

anterior-posterior distance from the point Cd to the frontal plane, and the vertical distance from the point Cd to the axial plane were defined as ΔCd-trans, ΔCd-ap, and ΔCd-ver, respectively.

5. Statistical analysis

The paired t-test was used to determine the possible statistically significant differences in the CLA, the angle of the CLA, and the condylar position between the both sides. The Spearman rank-correlation coefficient was used to determine relationships between the linear and angular measurements of CLA (Δcd-trans, Δcd-ap and Δcd-ver) and the mandibular attitudes (rolling, yawing and swaying). Statistical analysis was performed using the SPSS software. The results were regarded as statistically significant at $P < 0.05$.

[Results]

1. Morphological differences of the mandibular condyles on the deviated and non-deviated sides

The length of CLA on the deviation side was significantly smaller than that on the non-deviation side ($p = 0.003$). The angle of CLA on the axial plane on the deviation side was significantly larger than that on the non-deviation side ($p < 0.001$). Cd-ap and Cd-ver on the deviation side were significantly smaller than those on the non-deviation side ($p < 0.001$). However, there were not significant differences in the other measurements between the both sides.

2. The relationship between deviation of the jaw relationships and the bilateral differences in condylar morphology

There was a significant negative correlation between the bilateral difference in the length of CLA and swaying ($r = -0.44$). There were significant positive correlations between the difference in the angle of CLA on the axial plane and yawing ($r=0.41$), and ΔCd-trans and rolling ($r = 0.61$). There were significant negative correlations between ΔCd-ap and yawing (-0.74), ΔCd-ap and swaying ($r = -0.49$), and ΔCd-ver and rolling ($r = 0.79$). There was a significant positive correlation between ΔCd-ver and yawing ($r=0.38$). The significant differences between the both sides could not be observed in the other measurements.

3. Accuracy of the measurements

Measurement errors of the average of the distance measurement and the average of angle measurement were is 0.08 mm and 0.27 degrees, respectively.

[Discussion]

To accurately access the differences in the condylar morphology between the deviation and non-deviation sides, not only the spatial reference coordinate system of the maxillofacial complex (global coordinate system), but also mandibular (local coordinate system) coordinate system were employed in this study. Since the maxillofacial skeleton consists of the three-dimensionally complicated structures, three-dimensional information concerning maxillofacial morphology is prerequisite for evaluate their structures. However, it is difficult to identify three-dimensional landmarks of the mesial lateral poles and to define the CLA of the condyle. In this study, to define the CLA in a highly reproducible fashion without being influenced by the point of view, the landmarks were defined based on three-dimensional shape of the condyle. The length of the CLA on the deviation side was significantly smaller than that on the non-deviation side. In addition, significant correlation was seen between the length of the CLA and the deviation amount in the horizontal direction of the mandible. The angle of the CLA on the axial plane on the deviation side was significantly larger than that of the non-deviation side. In addition, a significant correlation was seen between the angle of the CLA on the axial plane and the inclination of the mandible on the axial plane. Condylar growth is closely related to the displacement direction of the mandible and horizontal and vertical jaw deviations. In individuals with low angles, mandibular growth is characterized by anterosuperior growth of the condyle, absorption of the inferior gonial border, and anterior displa-cement of the mandible. In contrast, individuals with high angles show posterosuperior growth of the condyle, apposition at the inferior gonial border, and inferoposterior displacement of the mandible. If there are differences in growth amount and direction of the condyle, facial asymmetry, such as deviation of the menton, difference in inclination of the mandibular plane angle and ramus height. Condylar growth is thought to be affected by the characteristics of the load applied to the condyle. The bilateral differences in mechanical environments in the temporomandibular joint caused by imbalance of the masticatory muscle activities, occlusal asymmetry, and unilateral temporomandibular disorders may modify endochondral ossification of the condyle and intramembranous ossification of the surrounding

bone, and intensify skeletal asymmetry of the maxillofacila skeleton. The condyle on the deviated side was located at more forward and downward position compared with that of the non-deviated side. A significant correlation between the anteroposterior position of the condyle and the deviation amount of the mandible was observed. Linear measurements concerning mandibular size, such as total length, ramus height and body length, on the deviated side are smaller than those on the non-deviated side, which resulting in exaggeration of backward and upward deviation of the menton and gonion of the mandible. Therefore, it is plausible that forward and downward position of the condyle on the deviated side may be compensatory mechanisms for maintaining the mandibular positon with being symmetry.

[Conclusion]

The results obtained from the 3D analysis using the local coordinate system in the mandible *per se*, indicated close relationships between bilateral morphological difference of the condyles and facial asymmetry.