Three-dimensional Analysis and Evaluation in Orthognathic Surgical Cases with Facial Asymmetry

Tadashi Kogou, Takashi Takaki and Takahiko Shibahara

Department of Oral and Maxillofacial Surgery, Tokyo Dental College, 1-2-2 Masago, Mihama-ku, Chiba 261-8502, Japan

Received 1 March, 2017/Accepted for publication 20 November, 2017

Abstract

Two-dimensional cephalometric analysis is commonly used in planning and evaluating the outcome of orthognathic surgery. It is difficult to arrive at an accurate evaluation with this method, however, as the jaw bones overlap in profile. Therefore, the purpose of this study was to use 3-dimensional (3-D) orthognathic treatment planning software for measurement of distances and angles to evaluate change in dentofacial morphology and stability after orthognathic surgery in patients with jaw deformity and facial asymmetry. Computed tomography with SimPlant O&O® (Materialize Dental, Belgium) was used to obtain data at before surgery (T1) and at 1 month (T2) and 1–2 years postoperatively (T3). Reference points, reference planes, and evaluation items were set to measure angles and distances. The average values at T1, T2, and T3 and the standard deviations were obtained. The analyses of change in distance and angle between T1 and T2 in both the maxilla and mandible revealed that the amount of postoperative deviation and change was greatest in the mandible (p<0.05). These findings showed a correlation between postoperative change in position of the chin and symmetry. Only a minimal amount of change was observed between T2 and T3 in both the maxilla and mandible. The results also revealed a correlation between positional change in both the proximal and distal bone segments and stability. It was found to be possible to determine change in horizontal, vertical, and anterior/posterior angle in both the maxilla and mandible by such 3-D analysis. The results suggest that the chin is the most appropriate facial element for evaluation of symmetry after orthognathic surgery.

Key words: Three-dimensional analysis — Orthognathic surgery — Skeletal class III — Computed tomography — Postoperative evaluation
**Introduction**

The introduction of X-ray imaging to the field of orthodontics was first proposed by Broadbent in 1931\(^1\). Since then, it has become widely used in treatment planning and post-operative assessment of jaw deformity. These X-ray images are obtained by 2-dimensional (2-D) projection of the maxillofacial frame. Lateral cephalometric analysis\(^2,23,25\) involves anterior or posterior imaging and is used to determine vertical characteristics in cases of jaw deformity, whereas frontal cephalometric analysis is used to determine bilateral symmetry\(^5,7,18,30\). Some studies have achieved assessment equivalent to pseudo 3-D analysis by further incorporating axial direction imaging\(^20,22\). Standard X-ray imaging of the head has a number of disadvantages, however: it is not possible to obtain uniform magnification of the cephalogram throughout the entire area measured\(^12\); being 2-D, there is the possibility of overlap, which may complicate identification of points to be ascertained\(^17\); and, in frontal photographs, the position of the head influences the imaging\(^11,15\). Our team has been looking for ways to overcome these disadvantages. We believe that 3-D reconstructed images based on X-ray computed tomography (CT) data would enable high-precision 3-D assessment of the maxillofacial frame. Three-dimensional assessment of the positional relationship of the frame is considered to be especially important in analysis in patients with facial asymmetry.

Several previous studies have examined facial asymmetry by using X-ray CT images. In one study, a group of patients with skeletal mandibular protrusion were divided into bilateral symmetric and asymmetric groups and skull shape measured\(^23\). In another study, horizontal and vertical angular displacements of the lower jaw were calculated as an index of the degree of mandibular deformity\(^7\). Another study performed a 3-D analysis of complicated facial deformities, such as bilateral structural asymmetry, twists, and deformations, which are difficult to analyze using only 2-D methods\(^6\). To our knowledge, however, no studies to date have compared pre- and post-operative measurements of the symmetry and stability of the dentofacial morphology.

Therefore, reference points were set on 3-D images reconstituted using X-ray CT data obtained from patients with jaw deformity and facial asymmetry to obtain reference planes. Distances and angles were measured and dentofacial morphology determined pre- and post-operatively. The purpose of this study was to establish the efficacy of this method in predicting postoperative dentofacial morphology and stability.

**Patients and Methods**

1. **Patients**

Patients with skeletal mandibular protrusion and facial asymmetry undergoing Le Fort I osteotomy and sagittal splitting ramus osteotomy by the short lingual splitting method at Tokyo Dental College Chiba Hospital were enrolled in the study. The inclusion criteria were as follows: no history of orthodontic treatment; no tooth crown prostheses; and the absence of jaw abnormalities due to congenital disease. A frontal cephalometric photograph was obtained in each patient, on which lines forming a cross-point with the bilateral orbital lateral margin and oblique line (LoR-LoL) were then traced. The line perpendicular to the LoR-LoL passing through the ethmoid comb was considered as the midsagittal reference line (MSR).

A deviation of >4 mm to the side from the center of the MSR was identified in 9 patients (6 men and 3 women) (Table 1).

Written informed consent was obtained from each of the patients prior to inclusion in the study. The study protocol was approved by the Ethics Committee of Tokyo Dental College (Number 535).

2. **Methods**

The SOMATOM Plus4 Volume Zoom (Siemens, Germany), a multi-detector array, was used to obtain CT data. The head of the
patient was fixed during measurement by means of a specialized cephalostat. This ensured that the median sagittal and occlusal planes were perpendicular to the floor and that the images were taken with the head in the occlusal position (Fig. 1).

The imaging conditions were as follows: X-ray tube voltage, 120 kV; X-ray tube current, 117 mA; depth of beam (width), 1.0 mm × 4 rows; table movement distance, 3.5 mm; scan speed, 0.75 sec/rotation; angle of inclination of gantry, 0°; reconstructed slice thickness, 1.25 mm; reconstructed slice interval, 1.0 mm; and field of view, 230 mm.

Images were obtained at just before commencement of the surgical procedure (T1); 1 month postoperatively (T2); and 1–2 years postoperatively (T3). For 3-D analysis, DICOM 3 data obtained from the CT images were inputted to Simplant O&O® (Materialise Dental, Belgium). Voxel data were created after completing linear interpolation between sliced images using a 3-D processing program. The CT level was 250 Hounsfield units (HU) to 3,071 HU in all cases (Fig. 2).

### 3. Reference points

The following 10 reference points were set for measurement of distances and angles in the 3-D analysis (Figs. 3-1 and 3-2): the anterior nasal spine (ANS); the lowest external point of the chin (Me); the tooth cervix (TC) (U6TCR, U6TCL, L6TCR, L6TCL), up/down, left/right deepest part of the first molar tooth cervix alveolar crest; the cross-point of the bilateral orbital border and fronto-zygomatic suture (Z, ZR, ZL); the lowest external point of left/right mandibular condyle (Co, CoR, CoL); the front-most point of the orbital bone (Or, OrR, OrL); the top point of the external auditory canal superior margin (Po, PoR, PoL); the foramen spinosum (FS, FSR, FSL); and the lowest facing point of the front margin of the foramen magnum (Ba).

The ANS, Z, N, FS, and Ba were directly plotted on the 3-D images to determine standard settings. For Co, TC, Me, Or, and Po, the standard settings were determined by simultaneously referring to the 3-D and multiplanar reconstruction (MPR) images.

### 4. Reference planes (Fig. 3-3)

Three planes were determined as reference planes in the 3-D analysis: the horizontal reference plane, which was defined by Po, Or, and the midpoint of the bilateral Or; the OrRLmidpoint; the sagittal reference plane, which was defined by Ba, N, and the OrRL mid-point; and the frontal reference plane, which comprised the plane perpendicular to the horizontal reference plane, which passes the bilateral FS.
5. Items assessed

A total of 22 items were assessed, of which 14 were used during distance measurement and the other 8 in angle measurement.

The following 4 items were used in distance measurement (Fig. 4-1): the distance in the horizontal direction to each reference point from the sagittal reference plane, which was set as X (U6TCR-X-U6TCL-X, ANS-X, L6TCR-X-L6TCL-X, Me-X); the forward/backward distance to each reference point from the frontal reference plane, which was set as Y (U6TCR-Y-U6TCL-Y, L6TCR-Y-L6TCL-Y); the vertical distance to each reference point from the horizontal reference plane, which was set as Z (U6TCR-Z-U6TCL-Z, L6TCR-Z-L6TCL-Z); and the assessment items used in angle measurement (Fig. 4-2).

6. Items for evaluation in maxilla

Reference points ZR-ZL, U6TCR-U6TCL, and ANS were used to create the basic figure and measure each interior angle: the ZR angle, formed by ZR-ZL and ZR-U6TCR; the U6TCR angle, formed by ZR-U6TCR and U6TCR-ANS; the ZL angle, formed by ZR-ZL and ZL-U6TCL; and the U6TCL angle, formed by ZL-U6TCL and U6TCL-ANS.

7. Items for evaluation in mandible

Reference points CoR-CoL, L6TCR-L6TCL, and Me were used to create a basic figure and measure each interior angle: the CoR angle, formed by CoR-CoL and CoR-L6TCR; the L6TCR angle, formed by CoR-L6TCR and L6TCR-Me; the CoL angle, formed by CoR-CoL and CoL-L6TCL; and the L6TCL angle, formed by CoL-L6TCL and L6TCL-Me.

Analysis

For the analysis of measured values, crosswise differences between U6TCR-X and U6TCL-X, U6TCR-Y and U6TCL-Y, U6TCR-Z and U6TCL-Z, L6TCR-X and L6TCL-X, L6TCR-Y and L6TCL-Y, and L6TCR-Z and L6TCL-Z were calculated to obtain absolute values. Because Me and ANS are single points without crosswise measurement, only X was measured. The average value and standard deviation for each of these measurements were then calculated. Crosswise differences in

Fig. 2 DICOM 3 data obtained from CT images were sent to Simplant O&O® (Materialise Dental, Belgium)
3-D images and MPR images were displayed on same screen
3-1 Reference point for 3-dimensional analysis (Part 1)
Reference point
• Z (ZR, ZL): Cross-point of left/right orbital border and frontozygomatic suture
• Co (CoR, CoL): Lowest external point of left/right mandibular condyle
• ANS: Anterior nasal spine
• Tooth cervix (hereinafter TC: U6TCR, U6TCL, L6TCR, L6TCL): up/down, left/right deepest part of the first molar tooth cervix alveolar crest
• Me: Lowest external of chin

3-2 Reference point for 3-dimensional analysis (Part 2)
• N: Frontmost point of the sutura nasofrontalis
• Or (OrR, OrL): Lowest point of the orbital bone
• Po (PoR, PoL): Top point of the external ear canal superior margin
• FS (FSR, FSL): Foramen spinosum
• Ba: Lowest facing point of the front margin of foramen magnum

3-3 Reference plane for 3-dimensional analysis
Reference planes
(1) Horizontal reference Plane
Top point of the external ear canal superior margin (Po), Lowest point of the orbital bone (Or), Midpoint of the left and right side Or (OrRLmidpoint).
(2) Sagittal reference Plane
Lowest facing point of the front margin of foramen magnum (Ba), Frontmost point of the sutura nasofrontalis (N) and OrRLmidpoint.
(3) Frontal reference plane
A plane perpendicular to the horizontal reference plane which passes the right/left foramen spinosum (FS).
### 4-1 Measurement distance for 3-dimensional analysis

**Assessment items**

1. The distance of the horizontal direction to each reference point from the sagittal reference plane was set as X.
   - \( U6TCR \times U6TCL \times X, \ ANS \times X, \ L6TCR \times L6TCL \times X, \ Me \times X \)
2. The anterior/posterior distance to each reference point from the frontal reference plane was set as Y.
   - \( U6TCR \times U6TCL \times Y, \ L6TCR \times L6TCL \times Y \)
3. The vertical distance to each reference point from the horizontal reference plane was set as Z.
   - \( U6TCR \times U6TCL \times Z, \ L6TCR \times L6TCL \times Z \)

### 4-2 Measurement angle for 3-dimensional analysis

**Assessment items**

- **Upper jaw**
  1. Angle formed by \( ZR-ZL \) and \( ZR-U6TCR \) (ZR Angle)
  2. Angle formed by \( ZR-U6TCR \) and \( U6TCR-ANS \) (U6TCR Angle)
  3. Angle formed by \( ZR-ZL \) and \( ZL-U6TCL \) (ZL Angle)
  4. Angle formed by \( ZL-U6TCL \) and \( U6TCL-ANS \) (U6TCL Angle)

- **Lower jaw**
  1. Angle formed by \( CoR-CoL \) and \( CoR-L6TCR \) (CoR Angle)
  2. Angle formed by \( CoR-L6TCR \) and \( L6TCR-Me \) (L6TCR Angle)
  3. Angle formed by \( CoR-CoL \) and \( CoL-L6TCL \) (CoL Angle)
  4. Angle formed by \( CoL-L6TCL \) and \( L6TCL-Me \) (L6TCL Angle)

Fig. 4

Angles measured between the ZR angle and ZL angle, the U6TCR angle and U6TCL angle, the CoR angle and CoL angle, the L6TCR angle and the L6TCL angle were also calculated to obtain absolute values. The average value and standard deviation for each of these measurements were further calculated.

To determine amount of change, change between T1 and T2 (T1-T2) and between T2 and T3 (T2-T3) was calculated and the Wil-
Coxon signed rank test performed. The statistical software application SPSS (Statistical Package for Social Science, Version 10.3, Chicago) was used for the statistical analysis. A p value of <0.05 was considered to indicate significance.

Results

1. Maxillary distance measurements (Fig. 5 and Table 2)

1) T1 and T2

The average value and standard deviation were as follows: in U6TC-X, 2.5 ± 2.1 mm at T1 and 1.5 ± 1.1 mm at T2; in U6TC-Y, 1.8 ± 0.8 mm at T1 and 3.0 ± 1.0 mm at T2; in U6TC-Z, 1.5 ± 1.3 mm at T1 and 1.2 ± 0.5 mm at T2; and in ANS-X, 1.0 ± 0.8 mm at T1 and 0.8 ± 0.5 mm at T2. A lower value was observed in U6TC-X and -Z and ANS-X at T2 than at T1; a higher value was observed in U6TC-Y at T2 than at T1.

The amount of change between T1 and T2 was as follows: 1.0 mm in U6TC-X; 1.2 mm in U6TC-Y; 0.3 mm in U6TC-Z; and 0.2 mm in ANS-X. These values ranged between 0.2 and 1.2 mm, with only that of U6TC-Y showing significant change (p = 0.021).

2) T2 and T3

The average value and standard deviation were as follows: in U6TC-X, 1.5 ± 2.1 mm at T2 and 1.6 ± 1.1 mm at T3; in U6TC-Y, 3.0 ± 0.8 mm at T2 and 2.5 ± 1.0 mm at T3; in U6TC-Z, 1.2 ± 1.3 mm at T2 and 1.2 ± 0.8 mm at T3; and in ANS-X, 0.8 ± 0.8 mm at T2 and 0.8 ± 0.5 mm at T3.

The amount of change between T2 and T3 was as follows: 0.1 mm in U6TC-X; 0.5 mm in U6TC-Y; 0 mm in U6TC-Z; 0 mm in ANS-X; and 0 to 0.5 in U6TC-X, -Y, and -Z, and ANS-X; no significant difference was observed in any
2. Lower jaw distance measurements (Fig. 6 and Table 2)

1) T1 and T2

The average value and standard deviation were as follows: in L6TC-X, $7.7 \pm 2.1$ mm at T1 and $2.6 \pm 1.1$ mm at T2; in L6TC-Y, $3.7 \pm 0.8$ mm at T1 and $3.0 \pm 1.0$ mm at T2; in L6TC-Z, $2.5 \pm 1.3$ mm at T1 and $1.3 \pm 1.5$ mm at T2;
and in Me-X, 7.0 ± 0.8 mm at T1 and 2.1 ± 0.5 mm at T2.

The amount of change between T1 and T2 was as follows: 5.1 mm in L6TC-X; 0.7 mm in L6TC-Y; 1.2 mm in L6TC-Z; 4.9 mm in Me-X; and 0.7 to 5.1 mm in L6TC-X, -Y, and -Z, and Me-X. Only change in the T1-T2 value in Me-X was found to be significant (p = 0.021).

2) T2 and T3

The average value and standard deviation were as follows: in L6TC-X, 2.6 ± 2.1 mm at T2 and 3.2 ± 1.1 mm at T3; in L6TC-Y, 3.0 ± 1.6 mm at T2 and 2.8 ± 1.0 mm at T3; in L6TC-Z, 1.3 ± 1.3 mm at T2 and 1.5 ± 0.8 mm at T3; and in Me-X, 2.1 ± 0.8 mm at T2 and 2.5 ± 0.5 mm at T3.

The amount of change between T2 and T3 was as follows: 0.1 mm in L6TC-X; 0.6 mm in L6TC-Y; 0.4 mm in L6TC-Z; 0 mm in Me-X; and 0.2–0.5 mm in L6TC-X, -Y, and -Z, and Me-X. None of these values indicated significant change.
3. Maxillary angle measurements (Fig. 7 and Table 3)

1) T1 and T2

The average value and standard deviation were as follows: in Z angle, $2.1 \pm 1.4^\circ$ at T1 and $2.6 \pm 2.0^\circ$ at T2; and in U6 angle, $2.6 \pm 1.9^\circ$ at T1 and $3.0 \pm 2.4^\circ$ at T2.

The amount of change between T1 and T2 was as follows: $0.5^\circ$ in Z angle; $0.4^\circ$ in U6 angle; and $0.4$ to $0.5^\circ$ in Z and U6 angles; no item showed significant change.

2) T2 and T3

The average value and standard deviation were as follows: in Z angle, $2.6 \pm 2.0^\circ$ at T2 and $2.4 \pm 1.7^\circ$ at T3; and in U6 angle, $3.0 \pm 2.4^\circ$ at T2 and $2.6 \pm 1.9^\circ$ at T3.

The amount of change between T2 and T3 was as follows: $0.2^\circ$ in Z angle; $0.4^\circ$ in U6 angle; and 0.2 to 0.4° in Z and U6 angles. No item showed significant change.

4. Mandibular angle measurements (Fig. 7 and Table 3)

1) T1 and T2

The average value and standard deviation were as follows: in Co angle, $4.8 \pm 3.0^\circ$ at T1 and $3.2 \pm 1.4^\circ$ at T2; and in L6 angle, $5.5 \pm 4.7^\circ$ at T1 and $3.0 \pm 2.9^\circ$ at T2.

The amount of change between T1 and T2 was as follows: $1.6^\circ$ in Co angle; $2.2^\circ$ in L6 angle; and 1.6 to 2.2° in Co and L6 angles. No item showed significant change.

2) T2 and T3

The average value and standard deviation were as follows: in Co angle, $3.2 \pm 1.4^\circ$ at T2 and $4.0 \pm 1.4^\circ$ at T3; in L6 angle, $3.0 \pm 2.9^\circ$ at T2 and $3.7 \pm 3.4^\circ$ at T3.

The amount of change between T2 and T3 was $0.8^\circ$ in Co angle; $0.7^\circ$ in L6 angle; and 0.7 to 0.8° in Co and L6 angles. Only change in Co angle was found to be significant ($p = 0.028$).

Discussion

1. Setting of reference points

It has been noted that Lo, Mx, ANS, Co, and Me are relatively easy to interpret when assessing facial symmetry based on frontal cephalograms. Go has been used to assess horizontal and vertical symmetry. On the other hand, reproducibility was reported to be high with Co, ANS, and Me when setting reference points for 3-D imaging. Another study has described measuring the distances from the median sagittal plane to the selected reference points and further using ANS and Me to assess amount of change in skeletal shape. In the present study, ANS, Co, and Me were selected on the 3-D and MPR images in reference to these earlier reports, then setting Z instead of Lo, U6TC instead of Mx, and L6TC instead of Go.

1) Upper jaw reference point (Lo, Mx) settings

The median sagittal plane was set to pass through the center points of ZR and ZL on 3-D images in assessing facial asymmetry. Another study used Z as a reference point in 3-D cephalometric analysis, but does not discuss the accuracy of those measurements. In the present study, Z was used instead of Lo to measure distance and calculate bilateral differences to obtain absolute values. The results showed $0.1$ mm for Z-X at T1, $0.8$ mm at T2, and $0.4$ mm at T3; $1.1$ mm for Z-Y at T1, $1.03$ mm at T2, and $0.3$ mm for Z-Z at T1, 0.7 mm at T2, and $0.3$ mm at T3. The differences in the bilateral values for Z among T1, T2, and T3 were minimal. This indicates that while Lo appears on frontal cephalograms, it is not an anatomical reference point, so setting Z as the reference point is likely to increase reliability.

In an earlier study of maxillary and mandibular bone shape in patients with facial asymmetry, Mx was set as the reference point in 3-D images. However, when change in distance in MxR-X, -Y, and -Z and MxL-X, -Y, -Z, between T2 and T3 was determined in the present study to assess stability, the results were as follows: MxR-X, $0.7$ mm; MxL-X, $1.1$ mm; MxR-Y, $5.2$ mm; MxL-Y, $6.8$ mm; MxR-Z, $5.5$ mm; and MxL-Z, $4.1$ mm. Thus, the highest values were observed in MxY and Mx-Z. Here, Mx was set on the 3-D and MPR images. However, there was overlapping of the oste-
otomy line and bone fixation metal plate at T2. Moreover, hindrance of bone regeneration was suggested at T3. This suggests that the reliability of Mx as a measurement point is low. On the other hand, another study examined bilateral differences in position of the teeth in the middle of the face and 3-D symmetry in mandibular protrusion accompanied by facial asymmetry and described the use of the bilateral maxillary first molar mesiobuccal cusp as the reference point.

Another study describes using the center of the first molar pulp cavity in the maxilla as the reference point in 3-D images when measuring bilateral differences in maxillary and mandibular jaw form in facial asymmetry patients. In the present study, also, stability was assessed between T2 and T3 by measuring the distances of U6TCR-X, -Y, -Z and U6TCL-X, -Y, and -Z. The results were as follows: U6TCR-X, 0.2 mm; U6TCL-X, 0.1 mm; U6TCR-Y, 0.6 mm; U6TCL-Y, 0.7 mm; U6TCR-Z, 0.1 mm; and U6TCL-Z, 0.1 mm. All these values showed only minimal change, indicating the reliability of U6TC as a reference point to be high. Therefore, this was used instead of Mx, taking the bilateral maxillary first molar tooth cervix alveolar crest as the reference point. The tooth cervix alveolar crest was used in CT imaging, because artifacts can sometimes influence the first molar due to crown restorations.

2) Lower jaw reference points setting

One study describes using the bilateral mandibular angular point as the reference point on 3-D images when examining bilateral differences in mandibular form in patients with facial asymmetry. Meanwhile, another report describes using Go as the reference point in 3-D cephalometric analysis. The reproducibility of Go has also been noted to be high when setting reference points. However, in assessing change in distance between T2 and T3 to assess stability in the present study, the following results were obtained: GoR-X, 2.2 mm; GoL-X, 1.7 mm; GoR-Y, 2.1 mm; GoL-Y, 5.9 mm; GoR-Z, 7.9 mm; and GoL-Z, 5.2 mm, demonstrating high values for Go-Y and Go-Z. When setting Go in the 3-D and MPR images, its reliability as a measurement point was considered to be low in cases with a large amount of backward movement of the mandible due to sagittal split ramus osteotomy. This was due to protrusion of the back edge of the distal segment of the mandibular ramus, even when using the short lingual splitting method, and because mandibular bone regeneration showed evidence of hindrance at T3. On the other hand, one earlier study of maxillary and mandibular bone shape in patients with facial asymmetry has described use of the center of the bilateral mandibular first molar pulp cavity as the reference point in 3-D images. When assessing change in stability between T2 and T3 in the present study, the following values were obtained: L6TCR-X, 0.1 mm; L6TCL-X, 0.1 mm; L6TCR-Y, 1.2 mm; L6TCL-Y, 1.0 mm; L6TCR-Z, 0.5 mm; L6TCL-Z, 0.7 mm. Thus, change was minimal, indicating the reliability of L6TC as a reference point to be high. Therefore, this was used instead of Go, taking the bilateral maxillary first molar tooth cervix alveolar crest as the reference point.

2. Distance measurement
1) T1 and T2 assessment

Regarding the horizontal direction (X-direction), one study has described using 2-D imaging for analysis of facial asymmetry. The results showed clear facial asymmetry in 34% of 1,460 cases of jaw deformity, among whom 5% had upper facial asymmetry, 36% midfacial asymmetry, and 74% that of the chin. Another study also used the frontal view in facial asymmetry cases in which Le Fort I osteotomy and sagittal splitting ramus osteotomy were performed on both sides. It was noted that because both the maxilla and mandible move in the same concentric circular direction, the movement of the mandible was approximately twice that of the maxilla. Regarding the use of 3-D CT imaging for analysis, one report notes that whereas cases with remarkable asymmetry in the maxilla are rare, as is dispersion between cases, there are also cases in which the maxilla is in a location asymmetrical to the skull. It was also noted
that in the mandible, in most cases, asymmetry was found in the mandible itself, but no large difference was observed between cases. Measurement of horizontal (X) change in distance between T1 and T2 in the maxilla in the present study revealed values of 1.0 mm for U6TC and 0.2 mm for ANS, indicating only minimal change. On the other hand, in the mandible, this was 4.9 mm for Me between T1 and T2 and 5.1 mm for L6TC, demonstrating a considerable change. This agrees with the tendency for the mandible to move more than the maxilla. It has been noted that Me in the mandible is the furthest reference point from the upper face, and that even a minimal deviation in the lower face from the upper- or mid-face is easily noticed. Indeed, a significant difference was found in ME between T1 and T2 in the present study (p = 0.021). Therefore, horizontal direction (X) mandibular postoperative symmetry assessment was considered possible with this method.

Regarding the anterior/posterior direction (Y direction), it has been noted that the middle endocranial blood vessel and ramus meningeus nervi mandibularis run through the comparatively symmetrical bone found in the base of the cranium via the foramen spinosum located in the sphenoid bone. As such, they are not easily influenced by maxillofacial growth, making reliability here relatively high. Other studies have described the sphenoid bone as having superior symmetry. It has also been noted that the most reliable location in axial projection of head X-ray photographs is the sphenoid bone. In the Ritschel analysis referenced by Ritschel and Burston, the bilateral sphenoid bone was used to set reference points. In the present study, the bilateral sphenoid bone was used to set reference points. A significant difference was found in U6TC-Y between at T1 and T2 (p = 0.021), indicating that this would allow assessment of postoperative symmetry in the anterior/posterior direction (Y) of the maxilla.

The results in the vertical direction (Z direction) revealed a difference of 0.3 mm in U6TC between T1 and T2 in the maxilla. On the other hand, in the mandible, a value of 1.2 mm was observed for change in L6TC between T1 and T2, a value higher than that obtained in the maxilla, which agrees with the tendency for the maxilla to exhibit a greater amount of movement than the mandible.

2) Change in stability between T2 and T3

It has been noted that a bilateral difference in retrograde movement in the mandible in frontal and lateral cephalograms influences horizontal and anterior/posterior stability. In the present study, a change of only 0 to 0.6 mm was observed in distance between T2 and T3 in both the maxilla and mandible, which was insignificant. This suggested that 3-D imaging for assessment of postoperative stability would be feasible.

3. Angle measurement

1) T1 and T2 assessment

In the maxilla, change in the Z angle between T1 and T2 was 0.5° while that in the U6 angle was 0.4° indicating only minimal change. On the other hand, in the mandible, change in the Co angle between the two time points was 1.6° while that for the L6 angle was 2.2° indicating greater change in the mandible. However, the amount of change in angle in the mandible was minimal compared with that in distance. This suggests that 3-D angle measurement is not effective in assessing amount of change due to surgical procedures. In addition, no significant difference was observed between T1 and T2 in any of the angles measured, indicating that these are unsuitable for assessment of postoperative symmetry.

2) Change in stability between T2 and T3

Between T2 and T3, the Z angle showed a change of 0.2° while that for the U6 angle was 0.4° and L6 angle was 0.7° with no significant difference being found among them. This allowed assessment of postoperative stability in all the cases examined. A number of factors affect postoperative stability. The short lingual splitting method, in which the segment is mesiodistally separated, mostly in the center of the ramus, has been recommended to minimize protrusion of the back of the proxi-
mal segment at the back of the distal segment, a factor in hindrance of postoperative stability 2,3,5. However, another study reported that in cases of sagittal split ramus osteotomy using the short lingual splitting method for facial asymmetry, assessment of postoperative stability using lateral and frontal cephalograms revealed anterior/posterior and lateral movement of the returning distal segment in some cases, but not of the proximal segment 4. The Co angle comprises CoR-CoL and Co-L6TC, and is affected by both measure point (L6TC) on the distal segment and measure point (Co) on the proximal segment. In the present study, a significant difference was found in the Co angle, indicating that long-term postoperative stability of the mandible had not been obtained. In hypothesizing as to why, we referred to the above-mentioned study by Fujita et al. 4 They reported no return of the proximal segment based on 2-D cephalograms. Therefore, if Co is indicative of postoperative stability in the proximal segment, this suggests that L6TC in the distal segment hinders postoperative stability.

Considering overall change in distance and angle in both the maxilla and mandible between T1 and T2, both the average value and amount of change showed higher values in the mandible horizontally (X), front-to-back (Y) and vertically (Z). This suggests that amount of postoperative deviation and change is greater in the mandible than in the maxilla. However, a significant difference between T1 and T2 was only found in the horizontal direction of Me. Therefore, in cases of facial asymmetry, it can be assumed that postoperative change in the position of the chin will affect symmetry. On the other hand, consideration of overall change in distance and angle in both the maxilla and mandible between T2 and T3 revealed only minimal differences horizontally (X), front-to-back (Y), and vertically (Z). However, a significant difference was found between T2 and T3 in Co angle. This suggests that change in the positional relationship between the proximal and distal segments is associated with postoperative stability.

Conclusions

The results of this study revealed that it was possible to determine amount of horizontal, vertical, and anterior/posterior change in both the maxilla and mandible by 3-D analysis in patients with jaw deformity accompanied by facial asymmetry. The findings suggest that amount of postoperative deviation and change is greater in the mandible than in the maxilla. However, change in angle was minimal in comparison with that in distance in the mandible. This indicates that 3-D angle measurement is less effective in evaluating postoperative change.

We believe that the chin is the most appropriate location for evaluating postoperative symmetry. The present results indicate that it is difficult to evaluate the effect of positional change of the proximal and distal segments on postoperative stability in the mandible based on change in angle. On the other hand, the present findings also indicate that change in distance in both the maxilla and mandible together with change in angle in the maxilla are useful for such assessment.

This study likely contributes not only to improved diagnostic accuracy, but also quality of treatment, which should hopefully provide greater benefit to the patient.

Acknowledgements

We gratefully acknowledge the work of past and present members of our laboratory.

References

1) Broadbent BH (1931) A new X-ray technique and its application to orthodontics. Angle Orthod 1:45–66.
2) Epker BN (1977) Modification in the sagittal osteotomy of the mandible. J Oral Surg 35: 157–159.
3) Fujinami J, Takaki T, Noma H (2005) Research on the facial symmetry of Japanese people—Standard diagram of posterior-anterior roent-
genographic cephalometrics—. Jpn J Jaw Deform 15:68–77.
4) Fujita M, Otsuka Y, Nishino H (2014) Postoperative evaluation on SSRO performed by Short Lingual Osteotomy and IVRO. J Meikai Dent Med 43:140–147. (in Japanese)
5) Grummons DC (1987) A frontal asymmetry analysis. J Clin Orthod 21:448–465.
6) Kamijo Y (1966) Illustrated oral anatomy, p.151, Anatome, Tokyo. (in Japanese)
7) Kato O, Tengan T, Shimizu R, Uji M, Motohashi N, Kuroda T (1994) Frontal cephalometric analysis of facial asymmetry. Jpn J Jaw Deform 4:87–95.
8) Kawakami S, Tsukada S, Okada T, Hayashi H, Kojima M, Takada Y (1987) Clinical management of mandibular and maxillar osteotomies for facial asymmetry. Jpn J Plast Surg 4:338–350.
9) Keith A, Campion CG (1922) A contribution to the mechanism of growth of the human face. Int J Orthod 8:607–633.
10) Kim TY, Baik JS, Park JY, Chae HS, Huh KH, Choi SC (2011) Determination of midsagittal plane for evaluation of facial asymmetry using three-dimensional computed tomography. Imaging Sci Dent 41:79–84.
11) Kimura K, Sugawara J, Mitani H (1989) A study on the postero-anterior cephalograms of human dry skulls Part2. Changes of cephalometric images following upper and lower rotation of head. Tohoku Univ Dent J 8:51–61. (in Japanese)
12) Kondo E (1972) Posteroanterior cephalometric study of craniofacial and arch widths. Jpn Orthod Soc 31:117–136. (in Japanese)
13) Kwon TG, Park HS, Ryoo HM, Lee SH (2006) A comparison of craniofacial morphology in patients with and without facial asymmetry. Int J Oral Maxillofac Surg 35:43–48.
14) Lee H, Bayome M, Kim SH, Kim KB, Behrents RG, Kook YA (2012) Mandibular dimensions of subjects with asymmetric skeletal Class III malocclusion and normal occlusion compared with cone-beam computed tomography. Am J Orthod Dentofacial Orthop 142:179–185.
15) Major PW, Johnson DE, Hesse KL, Glover KE (1996) Effect of head orientation on posterior and anterior cephalometric landmark identification. Angle Orthod 66:51–60.
16) Marmar Y, Zilberman Y, Mirsky Y (1979) Use of foramina spinosa to determine skull mid-lines. Angle Orthog 49:263–268.
17) Motohashi K, Kameda A, Kondo E (1972) Some elementary facts to be considered in studying of posteroanterior cephalogram. J Jpn Orthod Soc 31:105–116. (in Japanese)
18) Muguruma T, Yamazaki A, Yokoyama K, Iijima M, Hayashi K, Mizoguchi I (2000) Morphological characteristics of skeletal asymmetry in the cases with skeletal Class III. J Hokkaido Orthod Soc 28:42–49. (in Japanese)
19) Nagai Y, Nishiyama H (2013) A study on reproducibility of three-dimensional measurement for an evaluation of craniofacial morphology. Journal of Japanese Society of Bone Morphometry 23:145–155. (in Japanese)
20) Okoshi M, Takaki T, Yamane G, Kikizawa T, Noma H (1989) Studies on axial roentgenographic cephalometric system. Jpn Soc Jaw Deform 8:178–180.
21) Park JW, Kim N, Chang Y-I (2008) Comparison of landmark position between conventional cephalometric radiography and CT scans projected to midsagittal plane. Korean J Orthod 38:427–436.
22) Pearson K, Woo TL (1935) Further investigation of the individual bones of the human skull. Biometrika 2:423–465.
23) Ricketts RM (1961) Cephalometric analysis and synthesis. Angle Orthod 31:141–156.
24) Ritucci R, Burston CJ (1981) Use of the submental-vertical radiograph in the assessment of asymmetry. Thesis. August. (unpublished)
25) Sassouni V, Forrest EJ (1971) Orthodontics in dental practice, p.573, Mosby, St Louis.
26) Segawa K, Sasahara K, Satoh K (1994) Investigation of postoperative stability of mandibular asymmetry cases. Jpn J Jaw Deform 4:77–86.
27) Severt TR, Proffit WR (1997) The prevalence of facial asymmetry in the dentofacial deformities population at the University of North Carolina. Int J Adult Orthod Orthognath Surg 12:171–176.
28) Shibazaki R, Chen HK, Kubota M, Nakano H, Maki K (2006) Three-dimensional maxillofacial characteristics in skeletal Class-3 asymmetrical jaw deformity cases using cone beam CT. The Journal of Showa University Dental Society 26:39–50. (in Japanese)
29) Swennen GRJ, Schutyser F, Hausamen JE (2010) Three-Dimensional Cephalometry, p.366, Springer-Verlag Berlin and Heidelberg GmbH & Co. KG, Berlin.
30) Tsurumi F, Takagi H, Fushima K (2007) A multivariate analysis for classification of craniofacial morphology in facial asymmetry. Bull Kanagawa Dent Coll 28:15–28.
31) Wakamatsu T, Yamaki M, Hanada K. Three-dimensional evaluation of morphological asymmetry of maxillofacial complex in patients showing mandibular prognathism with facial asymmetry. Jpn J Jaw Deform 17:29–36.
32) Williamson PC, Major PW, Nebbe B, Glover
KE (1998) Landmark identification error in submentovertex cephalometrics. A computerized method for determining the condylar long axis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 86:360–369.

33) Wolford LM, Bennett MA, Rafferty CG (1987) Modification of the mandibular ramus sagittal split osteotomy. Oral Surg Oral Med Oral Pathol 64:146.

34) Yáñez-Vico RM, Iglesias-Linares A, Torres-Lagares D, Gutiérrez-Pérez JL, Solano-Reina E (2013) A new three-dimensional analysis of asymmetry for patients with craniofacial syndromes. Oral Dis 19:755–762.

Correspondence:
Dr. Tadashi Kogou
Department of Oral and Maxillofacial Surgery,
Tokyo Dental College,
1-2-2 Masago, Mihama-ku,
Chiba 261-8502, Japan
Tel: +81-43-270-3901
Fax: +81-43-270-3979
E-mail: kogoutadashi@tdc.ac.jp