Characterization of facial asymmetry phenotypes in adult patients with skeletal Class III malocclusion using three-dimensional computed tomography and cluster analysis

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**Objective:** To classify facial asymmetry (FA) phenotypes in adult patients with skeletal Class III (C-III) malocclusion. **Methods:** A total of 120 C-III patients who underwent orthognathic surgery (OGS) and whose three-dimensional computed tomography images were taken one month prior to OGS were evaluated. Thirty hard tissue landmarks were identified. After measurement of 22 variables, including cant (°, mm), shift (mm), and yaw (°) of the maxilla, maxillary dentition (Max-dent), mandibular dentition, mandible, and mandibular border (Man-border) and differences in the frontal ramus angle (FRA, °) and ramus height (RH, mm), K-means cluster analysis was conducted using three variables (cant in the Max-dent [mm] and shift [mm] and yaw [°] in the Man-border). Statistical analyses were conducted to characterize the differences in the FA variables among the clusters. **Results:** The FA phenotypes were classified into five types: 1) non-asymmetry type (35.8%); 2) maxillary-cant type (14.2%; severe cant of the Max-dent, mild shift of the Man-border); 3) mandibular-shift and yaw type (16.7%; moderate shift and yaw of the Man-border, mild RH-difference); 4) complex type (9.2%; severe cant of the Max-dent, moderate cant, severe shift, and severe yaw of the Man-border, moderate differences in FRA and RH); and 5) maxillary reverse-cant type (24.2%; reverse-cant of the Max-dent). Strategic decompensation by pre-surgical orthodontic treatment and considerations for OGS planning were proposed according to the FA phenotypes. **Conclusions:** This FA phenotype classification may be an effective tool for differential diagnosis and surgical planning for Class III patients with FA. [Korean J Orthod 2022; 52(2):85-101]

**Key words:** Facial asymmetry, Class III malocclusion, Cluster analysis

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The etiology of facial asymmetry (FA) includes genetic or congenital malformations, acquired or developmental deformities, environmental factors including habits or trauma, and functional deviations.\(^1\) Piao et al.\(^2\) reported that the prevalence of FA in Korean orthodontic patients was the highest in skeletal Class III malocclusion, followed by skeletal Class I and Class II malocclusions (16.6%, 10.1%, 6.9%, \(p < 0.001\)), despite data from a single dental hospital.

FA has been diagnosed using facial photographs, posteroanterior (PA) cephalograms, or submentovertex projections. Although facial photographs can provide an intuitive impression of FA, it is difficult to accurately measure the amount of asymmetry. PA cephalograms and/or submentovertex projections are useful for diagnosis and orthognathic surgical planning of oral and maxillofacial deformities. However, these modalities have limitations due to magnification, projection errors, and two-dimensional (2D) assessments of the three-dimensional (3D) structures.\(^3\) Therefore, the use of 3D computed tomography (3D-CT) or cone-beam CT has become popular for the accurate measurement of craniofacial anatomic structures.\(^4\)\(^-\)\(^8\)

The major limitations in previous studies on FA can be summarized as follows: 1) Most studies investigated subjects with skeletal Class I, II, and III malocclusion, causing a problem in sample purity;\(^9\)\(^-\)\(^12\) 2) PA cephalograms or facial photographs have inevitable errors in the 2D analysis of a 3D object;\(^9\)\(^,\)\(^11\) 3) Although some previous study used 3D-CT analysis, the number of FA patients was insufficient to draw a robust statistical significance;\(^10\) 4) Some previous studies did not provide statistical evidence for the classification of FA;\(^13\)\(^-\)\(^15\) 5) Although FA was classified in a 3D manner, most previous studies have focused only on cant, shift, and yaw. Furthermore, they did not pay attention to the yaw as well as the differences in the frontal ramus angle (FRA) and ramus height (RH);\(^9\)\(^-\)\(^13\),\(^15\),\(^16\) 6) It is important to analyze the asymmetry in the maxilla, maxillary dentition, mandibular dentition, mandible, and mandibular border separately; and 7) Some previous studies failed to consider the clinical significance in relation to pre-operative orthodontic treatment and orthognathic surgery.\(^14\),\(^16\)

For clinically significant and statistically valid classification of FA, it is important to conduct studies using 3D-CT images with a large number of patients and full consideration of cant, shift, and yaw. Therefore, the purpose of this study was to classify and characterize the FA phenotypes in Korean adult patients with skeletal Class III malocclusion who had undergone orthognathic surgery using 3D-CT and cluster analysis.

The initial samples were Korean adult patients who had undergone pre-operative orthodontic treatment and orthognathic surgery at Seoul National University Dental Hospital (SNUDH) in Seoul, Republic of Korea between 2015 and 2020. The inclusion criteria were 1) patients with completed facial growth (over the age of 18 years); 2) patients who were diagnosed with skeletal Class III malocclusion; and 3) patients whose 3D-CT images were taken at least one month prior to orthognathic surgery. The 3D-CTs taken before orthognathic surgery were used to analyze the skeletal problems and set up precise surgical planning and to minimize cost and radiation exposure issues from sequential 3D-CT taken from the initial visit to the post-operative stage. The exclusion criteria were 1) patients whose posterior teeth were missing or abnormally shaped; 2) patients who had a degenerative joint disease, tumor, or trauma history in the temporomandibular joints; and 3) patients who had hemifacial microsomia or other craniofacial anomaly syndromes.

As a result, 120 Korean adult patients who had undergone pre-operative orthodontic treatment and orthognathic surgery for correction of skeletal Class III malocclusion were recruited as the final sample (72 males and 48 females; mean age at the time of 3D-CT taking, 22.9 ± 4.4 years). This study was reviewed and approved by the Institutional Review Board Committee of SNUDH (ERI20029).

3D-CTs (Sensation 10; Siemens, München, Germany; axial slice thickness, 1.0 mm) were taken with centric relation and lips in repose. After each data set was imported into the ON3D program (3DONS, INC., Seoul, Korea), 3D-CT images were re-orientated using the horizontal, coronal, and mid-sagittal planes (Figures 1 and 2, Table 1). The definitions of landmarks and reference planes used in the present study were adopted from the methodology of Hong et al.\(^17\) The N point was registered as the origin (0, 0, 0) of the Cartesian coordinate system.

The definitions of 30 hard tissue landmarks, six lines, and seven planes are enumerated in Figures 1 and 2 and Table 1. These landmarks were identified on each 3D-CT image by a single operator (SWH) with ON3D software. The definitions of 22 measurement variables are enumerated in Figure 3 and Table 2. In the present study, a novel 3D measurement method was developed to express the cant, shift, and yaw of the maxilla, maxillary dentition, mandibular dentition, mandible, and mandibular border. When asymmetry occurred in the same direction of the Me deviation, the sign of the measurement variables was designated as positive (+); otherwise, the sign was designated as negative (−).
Twelve randomly selected CT images were re-digitized and re-measured after two weeks by the same operator (SWH). Since there was no significant difference in the values of the measurement variables between the first and second measurements in the Wilcoxon signed rank test ($p > 0.05$), the first set of measurements was used for further analysis.

K-means cluster analysis was conducted to classify the FA phenotypes using the three representative variables (cant in the maxillary dentition [molar height difference, mm] and shift [Me deviation, mm] and yaw [°] in the mandibular border), which provide significant clinical information for diagnosis and surgical planning. The reasons were as follows: 1) The cant of the maxillary dentition was used in clustering because it is one of the main targets of orthognathic surgery; and 2) Since the degree of asymmetry worsens from top to bottom, the shift and yaw of the mandibular border were used for clustering. In addition, although we measured both the angle and distance of the cant in the maxillary dentition, only the cant distance (molar height difference) was utilized for clustering to prevent overfitting and to provide clinical information for easy application in surgical planning.

According to the total within-cluster sum of squares, the appropriate number of clusters was 4 to 6. After analyzing the results of clustering by the number of clusters with a 3D scatter plot, the final number of clusters was determined to be five.

Among the five clusters, the cluster with the least amounts of shift, cant, and yaw was designated as the non-asymmetry type (Table 3). The degree of asymmetry in each measurement variable was classified into normal, mild, moderate, and severe based on the means and standard deviations (SD) of the non-asymmetry type (Table 3). The cut-points were 1 SD to 2 SD or –1 SD to –2 SD for mild degree, 2 SD to 3 SD or –2 SD to –3 SD for moderate degree, and > 3 SD or < –3 SD for severe degree. The one-way analysis of variance test and multiple comparisons with Tukey’s honestly significant difference test were conducted to characterize the differences in the FA variables among the five clusters.
Table 1. Definition of the landmarks, lines, and planes used in this study

| Landmarks, lines and planes | Abbreviation | Definition                                                                 |
|-----------------------------|--------------|---------------------------------------------------------------------------|
| Cranial landmarks           |              |                                                                           |
| Nasion                      | N            | The middle point of nasofrontal suture                                   |
| Right frontozygomatic suture| RFZP         | The intersection of the right frontozygomatic suture and the inner rim of the orbit |
| Left frontozygomatic suture | LFZP         | The intersection of the left frontozygomatic suture and the inner rim of the orbit |
| Right porion                | RPo          | The most superior point of the right external auditory meatus             |
| Left porion                 | LPo          | The most superior point of the left external auditory meatus              |
| Maxillary skeletal landmarks|              |                                                                           |
| Right orbitale              | ROr          | The most inferior point of the right orbital contour                       |
| Left orbitale               | LOr          | The most inferior point of the left orbital contour                        |
| Right jugal process point   | RJ           | The intersection point between the lateral contour of the alveolar process and the lower contour of the zygomatic buttress of the right maxilla |
| Left jugal process point    | LJ           | The intersection point of the lateral contour of the alveolar process and the lower contour of the zygomatic buttress of the left maxilla |
| A point                     | A            | The deepest point between the anterior nasal spine and the upper incisal alveolus in the mid-sagittal plane |
| Maxillary dental landmarks  |              |                                                                           |
| Maxillary central incisor   | U1MP         | Upper dental midline point                                               |
| Cusp of the maxillary right first molar | RU6CP | The tip of the mesiobuccal cusp of the maxillary right first molar crown |
| Cusp of the maxillary left first molar | LU6CP | The tip of the mesiobuccal cusp of the maxillary left first molar crown |
| Mandibular skeletal landmarks|              |                                                                           |
| Right mandibular foramen    | RMdF         | The most inferior point of the right mandibular foramen                   |
| Left mandibular foramen     | LMdF         | The most inferior point of the left mandibular foramen                    |
| B point                     | B            | The deepest point between pogonion and the lower incisal alveolus in the mid-sagittal plane |
| Menton                      | Me           | The most inferior point in the middle of the mandibular chin in the coronal plane |
| Right condyilon             | RCd-S        | The most superior point of the right condyilon in the condylar sagittal plane within the range of glenoid fossa |
| Left condyilon              | LCd-S        | The most superior point of the left condyilon in the condylar sagittal plane within the range of glenoid fossa |
| Lateral pole of the right condyle | RCd-L | The most lateral point of the right condyilon head                           |
| Lateral pole of the left condyle | LCd-L | The most lateral point of the left condyilon head                           |
| Medial pole of the right condyle | RCd-M | The most medial point of the right condyilon head                           |
| Medial pole of the left condyle | LCd-M | The most medial point of the left condyilon head                           |
| Right condylar center       | RCD-C        | A mid-point between the RCd-L and RCd-M                                   |
| Left condylar center        | LCD-C        | A mid-point between the LCD-L and LCD-M                                   |
| Right inferior gonion       | RInf-Go      | The most inferior point of the inferior border of the lower half of the right ramus |
| Left inferior gonion        | LInf-Go      | The most inferior point of the inferior border of the lower half of the left ramus |
All statistical analyses were conducted using Language R, version 3.6.3 (The R Foundation for Statistical Computing, Vienna, Austria). *p*-value less than 0.05 was considered statistically significant.

**RESULTS**

**Morphological characteristics of five FA phenotypes (Table 4, Figure 4)**

The FA phenotypes in Class III patients were classified into five types according to their distinct morphological characteristics: non-asymmetry type (n = 43, 35.8%), maxillary-cant (Max-Cant) type (n = 17, 14.2%), mandibular-shift and yaw (Man-Shift-Yaw) type (n = 20, 16.7%), complex type (n = 11, 9.2%), and maxillary reverse-cant (Max-Rev-Cant) type (n = 29, 24.2%). In the non-asymmetry type, no significant asymmetry was observed.

The Max-Cant type demonstrated severe cant in the maxillary dentition (MxD-Cant, 2.9°, 2.7 mm) and mild cant in the mandibular dentition (MdD-Cant, 2.2°, 1.8 mm). A mild shift was observed in the mandible and mandibular border (MdB-Shift, 4.1 mm; MdB-Shift, 4.1 mm).

The Man-Shift-Yaw type exhibited moderate shift and mild yaw in the mandibular dentition (MdD-Shift, 4.7 mm; MdD-Yaw, 3.7°), moderate shift and yaw in the mandible (MdS-Shift, 5.4 mm; MdS-Yaw, 4.1°) and the mandibular border (MdB-Shift, 6.5 mm; MdB-Yaw, 4.5°), and mild RH-difference (3.4 mm). In addition, a mild cant was observed in the mandibular dentition (MdD-Cant, 2.2°, 1.8 mm).

The complex type demonstrated severe cant in the maxillary dentition (MxD-Cant, 3.4°, 3.2 mm); severe
shift and yaw in the mandibular dentition (MdD-Shift, 8.7 mm; MdD-Yaw, 7.0°), mandible (MdD-Shift, 10.3 mm; MdD-Yaw, 7.1°), and mandibular border (MdB-Shift, 13.7 mm; MdB-Yaw, 8.5°); and moderate FRA-difference (7.3°) and RH-difference (8.4 mm). Mild cant in the maxilla (MxS-Cant, 2.1°, 2.1 mm), severe cant in

| Variables | Maxilla | Maxillary dentition | Mandible | Mandibular border |
|-----------|---------|---------------------|----------|------------------|
| MidS plane | MidS plane | MidS plane | MidS plane | MidS plane |
| MxS-Cant (°) | MxS-Cant (mm) | MxS-Cant (°) | MxS-Cant (mm) | MxS-Cant (°) | MxS-Cant (mm) |
| MxS-Shift (mm) | MxS-Yaw (°) | MxS-Shift (mm) | MxS-Yaw (°) | MxS-Shift (mm) | MxS-Yaw (°) |
| MxD-Cant (°) | MxD-Cant (mm) | MxD-Cant (°) | MxD-Cant (mm) | MxD-Cant (°) | MxD-Cant (mm) |
| MxD-Shift (mm) | MxD-Yaw (°) | MxD-Shift (mm) | MxD-Yaw (°) | MxD-Shift (mm) | MxD-Yaw (°) |
| MdS-Cant (°) | MdS-Cant (mm) | MdS-Cant (°) | MdS-Cant (mm) | MdS-Cant (°) | MdS-Cant (mm) |
| MdS-Shift (mm) | MdS-Yaw (°) | MdS-Shift (mm) | MdS-Yaw (°) | MdS-Shift (mm) | MdS-Yaw (°) |
| MdD-Cant (°) | MdD-Cant (mm) | MdD-Cant (°) | MdD-Cant (mm) | MdD-Cant (°) | MdD-Cant (mm) |
| MdD-Shift (mm) | MdD-Yaw (°) | MdD-Shift (mm) | MdD-Yaw (°) | MdD-Shift (mm) | MdD-Yaw (°) |
| MdB-Cant (°) | MdB-Cant (mm) | MdB-Cant (°) | MdB-Cant (mm) | MdB-Cant (°) | MdB-Cant (mm) |
| MdB-Shift (mm) | MdB-Yaw (°) | MdB-Shift (mm) | MdB-Yaw (°) | MdB-Shift (mm) | MdB-Yaw (°) |

Figure 3. The variables used in this study. Maxillary skeletal (MxS)-Cant (°), MxS-Cant (mm), MxS-Shift (mm), MxS-Yaw (°), maxillary dental (MxD)-Cant (°), MxD-Cant (mm), MxD-Shift (mm), MxD-Yaw (°), mandibular dental (MdD)-Cant (°), MdD-Cant (mm), MdD-Shift (mm), MdD-Yaw (°), mandibular skeletal (MdS)-Cant (°), MdS-Cant (mm), MdS-Shift (mm), MdS-Yaw (°), mandibular border (MdB)-Cant (°), MdB-Cant (mm), MdB-Shift (mm), MdB-Yaw (°), frontal ramus angle (FRA, °) (R and L, difference), Ramus height (RH, mm) (R and L, difference).

MidS, mid-sagittal; R, right; L, left.

See Figure 1 for definitions of the other landmarks.
| Variable                  | Abbreviation            | Definition                                                                 |
|--------------------------|-------------------------|-----------------------------------------------------------------------------|
| Cant Angulation          | MxS-Cant (°)            | The angle formed between the RJ–LJ line and the FZP line projected to the Coronal plane |
| Maxillary dental Cant (°) | MxD-Cant (°)            | The angle formed between the RU6CP–LU6CP line and the FZP line projected to the Coronal plane |
| Mandibular dental Cant (°) | MdD-Cant (°)            | The angle formed between the RL6CP–LL6CP line and the FZP line projected to the Coronal plane |
| Mandibular skeletal Cant (°) | MdS-Cant (°)            | The angle formed between the RMdF–LMdF line and the FZP line projected to the Coronal plane |
| Mandibular border Cant (°) | MdB-Cant (°)            | The angle formed between the RInf-Go–LInf-Go line and the FZP line projected to the Coronal plane |
| Distance                 | MxS-Cant (mm)           | The difference in the coordinates on the z-axis of RJ and LJ |
| Maxillary dental Cant (mm) | MxD-Cant (mm)           | The difference in the coordinates on the z-axis of RU6CP and LU6CP |
| Mandibular dental Cant (mm) | MdD-Cant (mm)           | The difference in the coordinates on the z-axis of RL6CP and LL6CP |
| Mandibular skeletal Cant (mm) | MdS-Cant (mm)           | The difference in the coordinates on the z-axis of RMdF and LMdF |
| Mandibular border Cant (mm) | MdB-Cant (mm)           | The difference in the coordinates on the z-axis of RInf-Go and LInf-Go |
| Shift                    | MxS-Shift (mm)          | The x-axis coordinate of A point |
| Maxillary dental Shift (mm) | MxD-Shift (mm)          | The x-axis coordinate of U1MP |
| Mandibular dental Shift (mm) | MdD-Shift (mm)          | The x-axis coordinate of L1MP |
| Mandibular skeletal Shift (mm) | MdS-Shift (mm)          | The x-axis coordinate of B point |
| Mandibular border Shift (mm) | MdB-Shift (mm)          | The x-axis coordinate of Me |
| Yaw                      | MxS-Yaw (°)             | The angle between the bisector of the RJ–A–LJ angle and the MidS plane projected to the Horizontal plane |
| Maxillary dental Yaw (°) | MxD-Yaw (°)             | The angle between the bisector of the RU6CP–U1MP–LU6CP angle and the MidS plane projected to the Horizontal plane |
| Mandibular dental Yaw (°) | MdD-Yaw (°)             | The angle between the bisector of the RL6CP–L1MP–LL6CP angle and the MidS plane projected to the Horizontal plane |
| Mandibular skeletal Yaw (°) | MdS-Yaw (°)             | The angle between the bisector of the RMdF–B–LMdF angle and the MidS plane projected to the Horizontal plane |
| Mandibular border Yaw (°) | MdB-Yaw (°)             | The angle between the bisector of the RInf-Go–Me–LInf-Go line and the MidS plane projected to the Horizontal plane |
| Ramus                    | FRA-difference (°)      | The difference between the RFRA (the angle formed between RRamal line and the FZP line projected to the Coronal plane) and the LFRA (the angle formed between the LRamal line and the FZP line projected to the Coronal plane) |
| Ramus height difference between the right and left sides (mm) | RH-difference (mm) | The difference between the RH (the linear distance from RInf-Go to RCD-S) and the LRH (the linear distance from LInf-Go to LCD-S) |

See Table 1 for definitions of each landmark, line, and plane.
### Table 3. Severity of the measurement variables

| Variable | Severe \((<-3\, SD)\) | Moderate \((\geq -3\, SD\, and\, < -2\, SD)\) | Mild \((\geq -2\, SD\, and\, < -1\, SD)\) | Normal \((\geq -1\, SD\, and\, \leq 1\, SD)\) | Mild \((> 1\, SD\, and\, \leq 2\, SD)\) | Moderate \((> 2\, SD\, and\, \leq 3\, SD)\) | Severe \((> 3\, SD)\) |
|----------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Cant     | -3.30            | -3.30 to -2.06   | -2.06 to -0.82   | -0.82 to 1.65    | 1.65 to 2.89     | 2.89 to 4.13     | > 4.13           |
| MxD-Cant | -0.69            | -0.69 to -0.18   | -0.18 to 0.32    | 0.32 to 1.33     | 1.33 to 1.84     | 1.84 to 2.34     | > 2.34           |
| MdD-Cant | -2.07            | -2.07 to -1.11   | -1.11 to -0.16   | -0.16 to 1.75    | 1.75 to 2.71     | 2.71 to 3.67     | > 3.67           |
| MdS-Cant | -2.72            | -2.72 to -1.61   | -1.61 to -0.50   | -0.50 to 1.72    | 1.72 to 2.82     | 2.82 to 3.93     | > 3.93           |
| MdB-Cant | -3.92            | -3.92 to -2.44   | -2.44 to -0.96   | -0.96 to 2.00    | 2.00 to 3.48     | 3.48 to 4.96     | > 4.96           |
| MxS-Cant (°) | -3.50         | -3.50 to -2.18   | -2.18 to -0.87   | -0.87 to 1.76    | 1.76 to 3.08     | 3.08 to 4.40     | > 4.40           |
| MxD-Cant (°) | -0.60            | -0.60 to -0.15   | -0.15 to 0.30    | 0.30 to 1.20     | 1.20 to 1.65     | 1.65 to 2.10     | > 2.10           |
| MdD-Cant (°) | -1.72            | -1.72 to -0.92   | -0.92 to -0.13   | -0.13 to 1.46    | 1.46 to 2.26     | 2.26 to 3.05     | > 3.05           |
| MdS-Cant (°) | -4.03            | -4.03 to -2.39   | -2.39 to -0.74   | -0.74 to 2.54    | 2.54 to 4.19     | 4.19 to 5.83     | > 5.83           |
| MdB-Cant (°) | -6.36            | -6.36 to -3.96   | -3.96 to -1.55   | -1.55 to 3.25    | 3.25 to 5.65     | 5.65 to 8.05     | > 8.05           |
| Shift    | MxS-Shift (mm)   | -3.14            | -3.14 to -2.01   | -2.01 to -0.87   | -0.87 to 1.39    | 1.39 to 2.52     | 2.52 to 3.66     | > 3.66           |
| MxD-Shift (mm) | -4.07            | -4.07 to -2.56   | -2.56 to -1.05   | -1.05 to 1.96    | 1.96 to 3.46     | 3.46 to 4.97     | > 4.97           |
| MdD-Shift (mm) | -3.01            | -3.01 to -1.50   | -1.50 to 0.02    | 0.02 to 3.06     | 3.06 to 4.58     | 4.58 to 6.10     | > 6.10           |
| MdS-Shift (mm) | -3.08            | -3.08 to -1.53   | -1.53 to 0.03    | 0.03 to 3.13     | 3.13 to 4.69     | 4.69 to 6.24     | > 6.24           |
| MdB-Shift (mm) | -2.21            | -2.21 to -0.74   | -0.74 to 0.73    | 0.73 to 3.67     | 3.67 to 5.14     | 5.14 to 6.61     | > 6.61           |
| Yaw      | MxS-Yaw (°)      | -4.84            | -4.84 to -3.27   | -3.27 to -1.71   | -1.71 to 1.43    | 1.43 to 3.00     | 3.00 to 4.56     | > 4.56           |
| MxD-Yaw (°) | -6.16            | -6.16 to -4.29   | -4.29 to -2.42   | -2.42 to 1.32    | 1.32 to 3.19     | 3.19 to 5.06     | > 5.06           |
| MdD-Yaw (°) | -5.39            | -5.39 to -3.46   | -3.46 to -1.52   | -1.52 to 2.34    | 2.34 to 4.27     | 4.27 to 6.21     | > 6.21           |
| MdS-Yaw (°) | -4.17            | -4.17 to -2.66   | -2.66 to -1.15   | -1.15 to 1.87    | 1.87 to 3.39     | 3.39 to 4.90     | > 4.90           |
| MdB-Yaw (°) | -3.76            | -3.76 to -2.33   | -2.33 to -0.90   | -0.90 to 1.97    | 1.97 to 3.40     | 3.40 to 4.83     | > 4.83           |
| Ramus    | FRA-difference (°) | -5.65            | -5.65 to -3.21   | -3.21 to -0.77   | -0.77 to 4.10    | 4.10 to 6.53     | 6.53 to 8.97     | > 8.97           |
| RH-difference (mm) | -7.25            | -7.25 to -4.62   | -4.62 to -1.98   | -1.98 to 3.29    | 3.29 to 5.92     | 5.92 to 8.56     | > 8.56           |

The mean and standard deviation (SD) from the non-asymmetry group were used for deciding the severity of each variable. See Table 2 for definitions of each measurement variable.
## Table 4. Comparison of measurement variables among the facial asymmetry types

| Parameter       | Non-asymmetry type (n = 43, 35.8%, 1) | Max-Cant type (n = 17, 14.2%, 2) | Man-Shift-Yaw type (n = 20, 16.7%, 3) | Complex type (n = 11, 9.2%, 4) | Max-Rev-Cant type (n = 29, 24.2%, 5) | p-value | Multiple comparison |
|-----------------|--------------------------------------|----------------------------------|--------------------------------------|---------------------------------|--------------------------------------|---------|---------------------|
| Cant Angulation |                                      |                                  |                                      |                                 |                                      |         |                     |
| MxS-Cant (°)    | 0.41 ± 1.24                          | 1.15 ± 1.11                      | 1.04 ± 2.24                         | 2.05 ± 1.54                    | -0.80 ± 1.17                        | < 0.001*** | 5 < (1, 3, 2) < (3, 2, 4) |
| MxD-Cant (°)    | 0.83 ± 0.50                          | 2.87 ± 0.96                      | 1.03 ± 0.85                         | 3.40 ± 1.67                    | -0.87 ± 0.61                        | < 0.001*** | 5 < (1, 3) < (2, 4)   |
| MdD-Cant (°)    | 0.80 ± 0.96                          | 2.35 ± 1.05                      | 2.15 ± 1.56                         | 5.44 ± 1.46                    | 0.01 ± 1.13                         | < 0.001*** | (5, 1) < (3, 2) < 4  |
| MdS-Cant (°)    | 0.61 ± 1.11                          | 1.05 ± 0.91                      | 1.30 ± 1.58                         | 3.81 ± 1.46                    | -0.30 ± 1.74                        | < 0.001*** | (5, 1) < (1, 2, 3) < 4 |
| MdB-Cant (°)    | 0.52 ± 1.48                          | 1.17 ± 0.98                      | 1.36 ± 1.60                         | 3.94 ± 1.80                    | 0.17 ± 1.73                         | < 0.001*** | (5, 1, 2, 3) < 4    |
| p-value         | 0.363                                | < 0.001***                       | 0.207                                | < 0.001***                     | < 0.011*                            |         |                     |
| Multiple comparison |                                         | (MdS, MxS, MdB)               | (MdS, MxD, MdD)                  | (MdS, MxD, MdD)                | (MdS, MxD, MdD)                      |         |                     |
| Distance        |                                      |                                  |                                      |                                 |                                      |         |                     |
| MxS-Cant (mm)   | 0.45 ± 1.32                          | 1.26 ± 1.22                      | 1.07 ± 2.22                         | 2.13 ± 1.51                    | -0.84 ± 1.22                        | < 0.001*** | 5 < (1, 3, 2) < (3, 2, 4) |
| MxD-Cant (mm)   | 0.75 ± 0.45                          | 2.69 ± 0.91                      | 0.94 ± 0.79                         | 3.20 ± 1.56                    | -0.81 ± 0.58                        | < 0.001*** | 5 < (1, 3) < (2, 4)   |
| MdD-Cant (mm)   | 0.67 ± 0.79                          | 2.01 ± 0.89                      | 1.82 ± 1.34                         | 4.65 ± 1.35                    | 0.02 ± 0.93                         | < 0.001*** | (5, 1) < (3, 2) < 4  |
| MdS-Cant (mm)   | 0.90 ± 1.64                          | 1.63 ± 1.39                      | 2.00 ± 2.36                         | 5.74 ± 2.12                    | -0.42 ± 2.54                        | < 0.001*** | (5, 1) < (1, 2, 3) < 4 |
| MdB-Cant (mm)   | 0.85 ± 2.40                          | 1.92 ± 1.67                      | 2.17 ± 2.57                         | 6.39 ± 2.95                    | 0.27 ± 2.83                         | < 0.001*** | (5, 1, 2, 3) < 4    |
| p-value         | 0.664                                | < 0.028*                         | 0.204                                | < 0.001***                     | < 0.096                             |         |                     |
| Multiple comparison |                                         | (MxS, MdS, MdD)               | (MxS, MdS, MdD, MdD)               | (MxS, MdS, MdD, MdD)            | (MxS, MdS, MdD, MdD)                |         |                     |
| Shift           |                                      |                                  |                                      |                                 |                                      |         |                     |
| MxS-Shift (mm)  | 0.26 ± 1.13                          | -0.23 ± 1.86                     | 0.69 ± 1.30                         | 0.88 ± 1.17                    | 0.48 ± 0.79                         | 0.122                             |         |                     |
| MxD-Shift (mm)  | 0.45 ± 1.51                          | 2.53 ± 2.17                      | 1.37 ± 1.28                         | 1.92 ± 1.52                    | 0.49 ± 1.45                         | 0.029*                            |         |                     |
| MdD-Shift (mm)  | 1.54 ± 1.52                          | 5.39 ± 1.47                      | 10.25 ± 2.11                        | 1.82 ± 1.49                    | < 0.001***                          | (1, 5, 2) < 3 < 4                |         |                     |
| MdS-Shift (mm)  | 1.58 ± 1.55                          | 4.05 ± 2.07                      | 6.51 ± 1.58                         | 13.73 ± 2.79                   | 2.19 ± 1.49                         | < 0.001***                          | (5, 1) < 2 < 3 < 4            |         |                     |
| MdB-Shift (mm)  | 2.20 ± 1.47                          | 4.68 ± 1.58                      | 6.85 ± 1.74                         | 1.83 ± 1.68                    | < 0.001***                          | (1, 5, 2) < 3 < 4                |         |                     |
| p-value         | < 0.001***                           | < 0.001***                       | < 0.001***                          | < 0.001***                     | < 0.001***                          |         |                     |
| Multiple comparison |                                         | (MxS, MdS, MdD)               | (MxS, MdS, MdD, MdD)               | (MxS, MdS, MdD, MdD)            | (MxS, MdS, MdD, MdD)                |         |                     |
| Yaw             |                                      |                                  |                                      |                                 |                                      |         |                     |
| MxS-Yaw (°)     | -0.14 ± 1.57                         | -0.03 ± 1.81                     | 0.64 ± 1.49                         | 1.19 ± 1.37                    | -0.24 ± 1.35                        | 0.042*                            |         |                     |
| MxD-Yaw (°)     | -0.55 ± 1.87                         | -0.12 ± 1.60                     | 0.18 ± 2.00                         | -0.14 ± 1.20                   | -0.32 ± 1.92                        | 0.677                             |         |                     |
| MdD-Yaw (°)     | 0.41 ± 1.93                          | 1.42 ± 1.74                      | 3.72 ± 1.63                         | 6.92 ± 2.29                    | 1.03 ± 1.85                         | < 0.001***                          | (1, 5, 2) < 3 < 4            |         |                     |
| MdS-Yaw (°)     | 0.36 ± 1.51                          | 1.62 ± 1.47                      | 4.05 ± 1.40                         | 7.13 ± 2.29                    | 1.08 ± 1.09                         | < 0.001***                          | (1, 5) < (5, 2) < 3 < 4      |         |                     |
| MdB-Yaw (°)     | 0.53 ± 1.43                          | 1.73 ± 1.29                      | 4.52 ± 1.42                         | 8.54 ± 2.37                    | 1.36 ± 1.32                         | < 0.001***                          | (5, 1, 2) < 3 < 4            |         |                     |
| p-value         | 0.017*                               | < 0.001***                       | < 0.001***                          | < 0.001***                     | < 0.001***                          | < 0.001***                          |         |                     |
| Multiple comparison |                                         | (MxS, MdS, MdD)               | (MxS, MdS, MdD)                  | (MxS, MdS, MdD)                | (MxS, MdS, MdD)                      |         |                     |
the mandibular dentition (MdD-Cant, 5.4°, 4.7 mm), and moderate cant in the mandible (MdS-Cant, 3.8°, 5.7 mm) and mandibular border (MdB-Cant, 3.9°, 6.4 mm) were also observed.

The Max-Rev-Cant type revealed that the cant in the maxillary dentition (MxD-Cant, −0.9°, −0.8 mm) was expressed into the opposite direction of the Me deviation. However, there was no significant asymmetry in the mandibular border (MdB-Cant, 0.2°, 0.3 mm; MdB-Shift, 2.2 mm; MdB-Yaw, 1.4°).

Comparison of cant, yaw, and shift among the FA phenotypes (Table 4, Figure 4)

Cant was most significant in all parts in the complex type (MxS-Cant, 2.1°, 2.1 mm; MxD-Cant, 3.4°, 3.2 mm; MdD-Cant, 5.4°, 4.7 mm; MdS-Cant, 3.8°, 5.7 mm; MdB-Cant, 3.9°, 6.4 mm); followed by the maxillary and mandibular dentition in the Max-Cant type (MxD-Cant, 2.9°, 2.7 mm; MdD-Cant, 2.4°, 2.0 mm); and the mandibular dentition in the Man-Shift-Yaw type (MdD-Cant, 2.2°, 1.8 mm) (all p < 0.001). However, in the Max-Rev-Cant type, reverse cant was observed at the maxilla and maxillary dentition (−0.8°, −0.8 mm and −0.9°, −0.8 mm; all p < 0.001).

Shift was most significant in the mandibular dentition, mandible, and mandibular border of the complex type (MdD-Shift, 8.7 mm; MdS-Shift, 10.3 mm; MdB-Shift, 13.7 mm); followed by the Man-Shift-Yaw type (MdD-Shift, 4.7 mm; MdS-Shift, 5.4 mm; MdB-Shift, 6.5 mm); and the mandible and mandibular border of the Max-Cant type (MdS-Shift, 3.1 mm; MdB-Shift, 4.1 mm) (all p < 0.001).

Yaw was most significant in the mandibular dentition, mandible, and mandibular border of the complex type, followed by the Man-Shift-Yaw type (MdD-Yaw, 7.0°, 3.7°; MdS-Yaw, 7.1°, 4.1°; MdB-Yaw, 8.5°, 4.5°; all p < 0.001).

**DISCUSSION**

Classification of the FA phenotypes (Tables 4 and 5, Figure 5)

Approximately two-thirds (64.2%) of Class III patients who underwent orthognathic surgery had a significant FA. They were divided into four major FA clusters according to the existence of the shift and yaw in the mandibular border, the cant in the maxillary dentition, and a combination of these asymmetries (Man-Shift-Yaw type, Max-Cant type, Max-Rev-Cant type, and complex type; Figure 6). This finding was somewhat different from the classification of previous cluster analysis studies^9,10,18^ and a non-cluster analysis study (Table 5).^15^
Characteristics of each FA phenotype (Tables 4 and 5, Figure 5)

The Max-Cant type was characterized by severe cant and molar height differences in the maxillary dentition, and mild cant and molar height differences in the mandibular dentition. These values indicated the remaining amounts of transverse occlusal plane (OP) cant and molar height difference after vertical decompensation by pre-operative orthodontic treatment. In addition, a mild shift of the mandibular border (Me deviation) into the deviated side, which might be induced by the cant of the maxilla. Since there was no significant difference in RH, the FA of the Max-Cant type in this study might not be caused by unilateral condylar hyperplasia.

The Man-Shift-Yaw type was characterized by moderate shift and yaw in the mandibular border and mild RH-difference. When the shift of the mandible occurs in the deviated side, it usually exhibits different molar inclinations (transverse buccolingual compensation). When the yaw of the mandible occurs in the deviated side, it results in an asymmetric molar relationship, distorted dental arch form, and discrepancy between the dental and basal arches (horizontal compensation). Moreover, the Man-Shift-Yaw type exhibited a mild cant and molar height difference in the mandibular. Since there was no significant cant in the maxillary dentition, the cant and molar height difference in the mandibular dentition might occur due to the shift and yaw of the mandible. Joondeph suggested that a functional shift at an early age might lead to remodeling of the condyle and glenoid fossa, resulting in asymmetric growth of the mandible.

Since the complex type was characterized by a combination of the Max-Cant type and the Man-Shift-Yaw type, it showed more complicated features of vertical, transverse, and horizontal dentoalveolar compensation. Since patients with hemifacial microsomia and other craniofacial anomalies were excluded in this study, the asymmetric growth of the mandible and compensation of the maxilla might be the causes of this FA type rather than a problem of the cranial base, at least in Class III patients.

In the Max-Rev-Cant type, since there was no significant asymmetry in the mandibular border, the reverse
### Table 5. Comparison of facial asymmetry classifications between this and previous studies

| Phenotype | This study | Hwang et al.\(^a\) | Baek et al.\(^b\) | Chen et al.\(^c\) |
|-----------|------------|---------------------|-------------------|-------------------|
| Samples   |            |                     |                   |                   |
| Ethnicity | Korean     | Korean              | Korean            | Taiwanese         |
| Subjects  | Patients who underwent orthognathic surgery | Patients who were diagnosed with facial asymmetry | Patients who wanted correction of facial asymmetry | Patients who wanted correction of facial asymmetry |
| Number    | 120        | 100                 | 43                | 70                |
| Study design |          |                     |                   |                   |
| Angle classification | Skeletal Class III | Skeletal Class I, II, and III | Skeletal Class I, II, and III | Skeletal Class III |
| Exclusion criteria | • Posterior teeth were missing or abnormally shaped  
• Degenerative joint disease, tumor, or trauma history in the temporomandibular joints  
• Hemifacial microsomia and other craniofacial syndromes | • Not mentioned | • Cleft lip and/or palate, plagiocephaly, hemifacial microsomia  
• Congenital muscular torticollis  
• Degenerative temporomandibular joint disease  
• Mandibular tumors  
• History of trauma to the jaw | • Congenital anomalies  
• History of maxillofacial trauma |
| Reference planes | Horizontal plane  
Coronal plane  
Mid-sagittal plane | Frankfort horizontal plane  
Mid-sagittal reference line | Frankfort horizontal plane  
Coronal plane  
Mid-sagittal plane | Mid-sagittal plane  
Horizontal plane  
Coronal plane |
| Origin (0, 0, 0) | N point | None | Not mentioned | Not mentioned |
| Variables for classification | Max-dental Cant (mm)  
Man-border Shift (mm)  
Man-border Yaw (°) | Menton deviation (°)  
Apical base midline discrepancy (mm)  
Vertical difference of the right and left Ag (mm)  
Horizontal difference of the right and left Ag (mm)  
Maxillary base canting (°)  
Maxillary alveolar canting (°)  
Bulkiness difference of the mandibular inferior border  
Lip line canting (°) | Upper midline deviation (mm)  
Maxilla canting of U3 and U6 (mm)  
Arch form discrepancy (mm)  
Gonion to the mid-sagittal plane (mm)  
Ramus height (mm)  
Frontal ramus inclination (°)  
Menton deviation (mm) | The direction and magnitude of transverse ramus discrepancy relative to menton deviation |
| Inclusion of yaw | Yes | No | No | No |
| Analyzed data | 3D-CT | PA cephalogram and frontal photograph | 3D-CT | CBCT |
| Statistical method | Cluster analysis | Cluster analysis | Cluster analysis | No cluster |
| Phenotype                  | This study                                    | Hwang et al.\(^5\) | Baek et al.\(^6\) | Chen et al.\(^15\) |
|---------------------------|-----------------------------------------------|---------------------|-------------------|-------------------|
| Types                     | Non-asymmetry type (35.8%)                    | Group E (Normal, 28%) | Not mentioned     | Not mentioned     |
|                           |                                               | • All variables were within normal limits |                   |                   |
| Max-Cant type (14.2%)     | Not mentioned                                 | Group 2 (Universal lateral condylar hyperplasia asymmetry, 39%) | • Significant difference between the left and right ramus height | Not mentioned     |
|                           |                                               | • Menton deviation to the short side |                   |                   |
| Man-Shift-Yaw type (16.7%)| Group C (Menton type, 21%)                    | Group 1 (Mandibular body asymmetry, 44%) | • Shift or lateralization of the mandibular body | Group 2 (27%)     |
|                           |                                               | • No ramus height difference between the deviated and non-deviated sides |                   | • Menton and ramus deviation to the same side |
|                           |                                               | • Deviation of menton and lower apical base midline to the same side |                   | • Discrepancy in the ramus width was larger than the menton shift |
|                           | Group D (Bulkiness type, 28%)                 | Group 4 (C-shaped asymmetry, 5%) | • Severe maxillary canting | Group 1 (47%)     |
|                           |                                               | • Severe maxillary canting | • Significant ramus height differences | • Large shift of menton |
|                           |                                               | • Significant menton deviation to the short side | • Significant menton deviation to the short side | • Synchronous but smaller ramus deviation |
| Complex type (9.2%)       | Group A (Ramus–Menton type, 7%)               | Group 3 (Atypical asymmetry, 5%) | • Reverse maxillary canting | Group 3 (26%)     |
|                           | • Significant canting of the maxillary basal and alveolar bone | • Deviation of the menton to the short side | • Deviation of the menton to the shorter side | • Menton and ramus deviation in opposite directions, which seemed secondary to a yaw rotation |
|                           | • Deviation of menton and mandibular apical base midline to the side of the shorter ramus | • Prominence of the angle/gonion on the larger side | • Prominence of the angle/gonion on the larger side |                   |
|                           | • Difference of the right and left ramus height |                   |                   |                   |
| Max-Rev-Cant type (24.2%) | Group B (Ramus-Angle type, 16%)               | Group 3 (Typical asymmetry, 12%) | • Reverse maxillary canting |                     |
|                           | • Same ramus height difference between the deviated and non-deviated sides as group A | • Deviation of the menton to the short side | • Deviation of the menton to the short side |                     |
|                           | • Menton was deviated in the opposite direction to shorter ramus | • Prominence of the angle/gonion on the larger side | • Prominence of the angle/gonion on the larger side |                     |
|                           |                                               | • Reverse maxillary canting | • Deviation of the menton to the short side |                     |
|                           |                                               | • Prominence of the angle/gonion on the larger side | • Prominence of the angle/gonion on the larger side |                     |
|                           | Not matched                                   |                     |                   |                   |
|                           | Group D (Bulkiness type, 28%)                 | • Similar to group A | • Small difference in magnitude |                   |

Max-Cant, maxillary-cant; Man-Shift-Yaw, mandibular-shift and yaw; Max-Rev-Cant, maxillary reverse-cant; Ag, antegonion; U3, distance between Frankfort horizontal plane and midpoint of bracket slot of upper canine; U6, distance between Frankfort horizontal plane and midpoint of bracket slot of upper first molar; 3D-CT, three-dimensional computed tomography; PA, posteroanterior; CBCT, cone beam computed tomography.
cant in the maxillary dentition may conceal the shift of the maxilla. Tay suggested that unilateral mastication on the Me deviation side was related to this FA type.

Strategic decompensation according to the FA phenotypes (Figure 6)

Cant correction is required for the Max-Cant type, complex type, and Max-Rev-Cant type. Maxillary and mandibular molar height discrepancies less than 3 mm and 1.5 mm, respectively, can be treated by unilateral intrusion/extrusion of these teeth using miniscrews (known as a temporary anchorage device [TAD]) during pre-operative orthodontic treatment. Then, the remaining molar height discrepancy and OP cant after pre-operative orthodontic treatment should be corrected by orthognathic surgery.

In the Man-Shift-Yaw type and the complex type, both transverse and horizontal decompensations are required to correct the shift and yaw in the mandibular dentition simultaneously. In terms of transverse decompensation of the molar inclinations, we can upright the posterior teeth on the basal arch and expand the inter-premolar width up to 4 mm and the inter-molar width up to 2 mm. Then, we have to decide whether we should intentionally create the posterior crossbite on the deviated side and increase the amount of maxillary and mandibular dental midline-off for maximizing the surgical correction of the shift.

During horizontal decompensation, it is important to coordinate the dental and basal arch forms and correct the asymmetric molar relationship. Since the amount of distalization of the mandibular posterior teeth is considered to be 3 mm, we can apply unilateral distalization of the mandibular posterior teeth in the deviated...
side up to 3 mm with TAD to maximize the surgical correction of the yaw.

Strategic surgical planning according to the FA phenotypes (Figure 6)

For correction of the remaining OP cant and molar height difference of the maxillary dentition after pre-operative orthodontic treatment in the Max-Cant type and the complex type, differential impaction of the maxilla can be performed. However, interference by the inferior nasal concha and nasal septum during impaction of the maxilla can result in deviation of the nasal septum and asymmetry of the nasal tip. To prevent these adverse effects, trimming of the nasal septum and inferior turbinectomy can be considered.

If the difference in the amount of mandibular setback between the deviated and non-deviated sides is large in the Man-Shift-Yaw type and the complex type, there is a high probability of bony interferences between the proximal and distal segments of the mandible. This can cause displacement and torque of the condyle, which is one of the main causes of post-surgical relapse. To prevent these problems, the following should be considered: (1) meticulous removal of the bony interference between the proximal and distal segments, (2) a distal cutting technique and/or posterior bending osteotomy of the distal segment, (3) minimization of the vertical step interference between the proximal and distal segments, and (4) 3D simulation to correct yaw and FRA asymmetry.

When the patient has a large difference in the soft tissue thickness or the degree of bony protuberance of the mandibular border between the deviated and non-deviated sides, angle reduction, centering genioplasty, and border contouring procedures can be considered in conjunction with orthognathic surgery or as the secondary operation after orthognathic surgery.

This FA phenotype classification might be an effective tool for the differential diagnosis and for proper surgical planning of Class III patients with FA. Although this study provided meaningful results and compared the results with previous studies (Table 5), the morphology of the mandible was not analyzed in this study. In the future, it would be necessary to investigate the morphological abnormalities, such as hemimandibular elongation and hemimandibular hyperplasia.

CONCLUSION

- In the present study, the classification and percentage distribution of the FA phenotypes obtained from K-means cluster analysis were as follows: Non-asymmetry type (35.8%); Max-Cant type (14.2%), which showed severe cant of the maxillary dentition, mild shift of the...
mandibular border; Man-Shift-Yaw type (16.7%), which presented moderate shift and yaw of the mandibular border, mild RH-difference; Complex type (9.2%) with severe cant of the maxillary dentition, moderate cant, severe shift, and severe yaw of the mandibular border, moderate differences in FRA and RH; and Max-Rev-Cant type (24.2%), which showed reverse-cant of the maxillary dentition.

Important measurement variables for differential diagnosis and a primary guideline of pre-operative orthodontic treatment and orthognathic surgery planning according to FA classification in Class III patients were also presented.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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