Aim: Facial asymmetry not only affects the mandible, but jaw deformation also extends to the cranial base, maxilla, alveolar bone, and dentition. The position of teeth and the form of the dental arch, which are located on the alveolar bone, are also affected by jaw deformity. The purpose of this study was to analyze the tooth position and arch form of mandibular dentition in skeletal Class III facial asymmetry patients.

Materials and methods: Skeletal Class III patients diagnosed with facial asymmetry who had undergone surgical orthodontic treatment were selected as subjects. The control group consisted of skeletal Class III patients without facial asymmetry who had undergone surgical orthodontic treatment. Twenty patients (10 males and 10 females) were selected for each group. For evaluation, mandibular study models of selected patients were scanned using a laser scanner. Using a 3D digital model, the cusp-tip and facial axis points were projected on the occlusal plane, and point dimensions were measured using modeling software. Arch forms of the two groups were drawn and compared using a polynomial formula and compared.

Results: In the molar region of the facial asymmetry group, the cusp-tip and facial axis points were located lingually on the deviated side and buccally on the non-deviated side, and a significant difference was indicated. A symmetric arch form was expressed with the 6th polynomial formula in the facial symmetry group. Meanwhile, an asymmetric arch form with an S curve on the deviated side was expressed with a 6th polynomial formula in the facial asymmetry group.

Conclusion: This study confirmed that the asymmetrical arch form is caused by differences in transverse positioning of the molars in cases with skeletal Class III facial asymmetry.

Key words: facial asymmetry, mandibular arch form, pre-surgical orthodontic treatment

Introduction
Facial asymmetry consists of numerous complications, which manifests itself in various degrees, size, and forms, and as a result influencing the arrangement of the facial features on either side of the median sagittal plane. The morphology of the cranial base influences the positions of the maxilla and mandible. The position and morphology of the temporomandibular joint, mandibular body, and mandibular ramus are altered in facial asymmetry. Alveolar bone and teeth located on the mandible also undergo changes due to mandibular deviation.

In skeletal Class III facial asymmetry, the premolars and molars on the deviated and non-deviated sides incline lingually and buccally respectively to compensate for the mandibular transverse deviation, which results in distortion of arch form. Three-dimensional (3D) analysis of tooth position and arch form in mandibular asymmetry patient have not been performed in detail. Rapid evolution of digital technology has allowed progressive development of the 3D digital scanner. Accordingly, the accuracy or the reliability of the 3D digital scanner is guaranteed. In addition, 3D measurement can be performed by the computer software. In this study, tooth position on the deviated and non-deviated sides were determined using 3D scanner images to analyze the arch form of mandibular dentition in skeletal Class III adults with facial asymmetry.

Material and Methods
The sample was selected retrospectively from study models at pretreatment stages of patients from Tokyo Dental College Chiba Hospital. Sample selection was based on facial asymmetry. The mandibular model selection criteria for the asymmetry group were the following:
1. Diagnosis of skeletal Class III with facial asymmetry
2. Menton deviation of more than 4mm on frontal cephalogram
3. ANB ranging from −45° to 2°
4. Wits ranging from −15mm to −13mm
5. No crowding or, at most, crowding up to 2 mm
6. No previous orthodontic treatment
7. No ectopic teeth or anomalies in tooth shape
8. No congenital malformation such as cleft lip and palate

The same selection criteria were used for the symmetry (control) group except for criteria 2, which was changed to menton deviation up to 3 mm.

Twenty individuals, 10 males and 10 females, were selected for each group. Mean ages for the subject and control groups were 26.4 ±0.1 and 23.1 ±0.6, respectively.

Research protocol was approved by the Tokyo Dental College Review Board (Approval No.757). Personal information was treated carefully according to privacy policy of Tokyo Dental College.

All study models were transformed into 3D digital data using a 3D laser scanner (D250 3D Dental Scanner; 3 Shape A/S, Copenhagen, Denmark) (Fig. 1). The 3D digital data set was developed using a modeling software (Imageware 13; Siemens PLM Software, Texas USA). On the 3D digital model, the occlusal plane was used as a reference plane for measurement, was established using 3 points; the mesial buccal cusp tip on the right and left first molars, and the midpoint of the line connecting the mesial corners of the central incisors in the mandible.

The mid reference line was established through the following steps: 1. A maxillary midline was drawn connecting the center of the incisive papilla and median palatal suture point (on the digital model, this was the point of intersection of the line connecting the left and right 1st maxillary molar mesio-lingual cusp and the the median palatal suture15) (Fig. 2). 2. The maxillary midline was projected onto the occlusal plane at centric occlusion. 3. The maxillary midline projected on the occlusal plane was moved parallel to the midpoint between the mandibular central incisors.

The transverse reference line was constructed perpendicular to the mid-reference line through the midpoint between the central incisors on the occlusal plane (Fig. 3). The cusp tip
points (CT), defined as the midpoint of the incisal edge and buccal cusp tip in premolars and molars, were plotted on the 3D digital model. The facial axis points (FA), which is the center of clinical tooth crown as defined by Andrews,16 usually used as a reference point for bracket placement, were determined in accordance to the method used for the 3D digital model by Kodaka et al17 and Sakurai et al18 (Fig. 3).

Antero-posterior and transverse linear measurements were made from bilateral tooth landmarks where CT and FA were projected onto occlusal plane (Fig. 4). Measurements for the symmetry group were averaged between the left and right sides, since an independent t-test showed that differences between the two sides were negligible. The arch form curve fittings of CT and FA projected on the occlusal plane in each group were determined and processed with a least squared method by 6th polynomial on the spreadsheet program (Microsoft Excel ver. 15.32, Microsoft Japan, Japan). Comparing the arch form curve, each acquired curve was superimposed on the same coordination graph with a spreadsheet program.

**Statistical analysis**

Measurement error: One individual performed all the measurements. To assess measurement method, data on 10 patients were selected randomly and manually, re-measured at all points (incisive papilla, mid palatal suture point, CT, FA) after one week to compare with initial measurements. A paired t-test was used to evaluate method error about all manual points in an identical procedure. The method error varied between 0.08mm at 1st premolar CT to 0.58mm at mid palatal suture point with no significant difference. The measurement error was, therefore, considered negligible.

Descriptive Statistics: Means, standard deviation in tooth dimension of bilateral CT and FA in each group were determined as shown in Fig. 2. The difference in distance between bilateral CT and FA on transverse and antero-posterior dimension in each group was calculated. The arch form curve described with 6th polynomial formula was drawn with approximation formula polynomial, and was used in each group as shown in Fig. 3-5 and were superimposed (Fig. 6).

Inferential Statistics: The dimension and difference of bilateral CT and FA in each group was compared by an independent t-test. (SPSS Inc., Statistical Software for Macintosh, Version 16.0, Chicago, Ill). All measuring values were rounded off to two decimals.

**Results**

The mean, standard deviation, and P value of the transverse and antero-posterior dimension of projection points on the occlusal plane of bilateral CT and FA in the symmetry group are listed in Table 1. Both dimensions showed increase in value.

![Fig. 4 CT (black dots) and FA (white dots) on 3D mandibular digital model](image1)

![Fig. 5 Antero-posterior and transverse linear measurements of CT (black dots) and FA (white dots), which were projected onto the occlusal plane, the mid reference line (a) and the transverse reference line (b) on the occlusal plane](image2)

![Fig. 6 Drawn arch form (white curve) with 6th polynomial formula by using least square method on all plotted landmark location (CT or FA)](image3)
as tooth position moved distally. No significant differences between right and left dimensions were indicated in the symmetry group as mentioned in the statistic section. The mean and standard deviation of the symmetry group are listed in Table 2.

The asymmetry group also showed gradual increase in value as the tooth position moved distally. However, larger values were indicated on the non-deviated side for both CT and FA in transverse dimension. Significant differences between dimensions were detected in molar regions for both

Table 1 Dimension measurements in mandibular CT and FA in the symmetry group (mm)

| Tooth | Transverse | Antero-Posterior |
|-------|------------|------------------|
|       | CT         | FA               | CT               | FA               |
|       | Ave. | SD | t-test of right and left side | Ave. | SD | t-test of right and left side |
| 1     | 2.90 | 0.26 | 0.08 | 2.92 | 0.18 | 0.87 |
| 2     | 8.66 | 0.28 | 0.48 | 8.96 | 0.24 | 0.92 |
| 3     | 14.00 | 0.49 | 0.29 | 15.57 | 0.28 | 0.78 |
| 4     | 18.84 | 0.77 | 0.69 | 21.05 | 0.49 | 0.70 |
| 5     | 21.81 | 1.05 | 0.58 | 24.33 | 0.75 | 0.57 |
| 6     | 24.24 | 1.08 | 0.66 | 28.15 | 1.20 | 0.86 |
| 7     | 26.12 | 1.28 | 0.92 | 30.54 | 1.20 | 0.99 |

Table 2 Dimension measurements in mandibular CT and FA in the asymmetry group (mm)

| Tooth | Transverse | Antero-Posterior |
|-------|------------|------------------|
|       | CT         | FA               | CT               | FA               |
|       | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| D1    | 2.70 | 0.57 | 2.58 | 0.63 | 0.48 | 0.37 | 1.09 | 0.68 |
| D2    | 8.27 | 1.07 | 8.67 | 0.65 | 1.01 | 0.76 | 2.53 | 1.09 |
| D3    | 13.30 | 1.23 | 15.39 | 0.93 | 4.07 | 1.30 | 5.33 | 0.99 |
| D4    | 18.24 | 1.17 | 20.14 | 1.29 | 10.18 | 1.39 | 10.97 | 0.99 |
| D5    | 20.28 | 1.69 | 22.44 | 1.54 | 16.06 | 1.90 | 17.86 | 1.11 |
| D6    | 24.01 | 1.87 | 26.78 | 1.01 | 25.55 | 2.19 | 26.86 | 1.34 |
| D7    | 25.91 | 2.07 | 28.75 | 1.79 | 36.80 | 1.97 | 37.95 | 1.28 |
| ND1   | 2.57 | 0.33 | 2.60 | 0.49 | 0.51 | 0.42 | 1.41 | 1.13 |
| ND2   | 8.20 | 0.87 | 8.74 | 0.62 | 1.58 | 0.91 | 2.95 | 0.99 |
| ND3   | 13.63 | 1.02 | 15.28 | 0.96 | 4.18 | 1.15 | 5.96 | 1.16 |
| ND4   | 17.87 | 1.11 | 20.07 | 1.06 | 10.17 | 1.02 | 11.64 | 1.00 |
| ND5   | 21.04 | 1.03 | 23.03 | 0.91 | 16.24 | 2.13 | 18.06 | 0.93 |
| ND6   | 26.04 | 0.78 | 28.44 | 0.64 | 25.23 | 2.81 | 26.39 | 1.28 |
| ND7   | 28.71 | 2.12 | 31.42 | 1.23 | 36.12 | 2.80 | 37.39 | 1.91 |

D: deviated side ND: non-deviated side 1: Central incisor 2: Lateral incisor 3: Canine 4: 1st premolar 5: 2nd premolar 6: 1st molar 7: 2nd Molar
CT and FA in the asymmetry group as shown in Table 3. On one hand, negative difference values on Table 3 indicated that the molars on the deviated side were positioned lingually compared to the non-deviated side in transverse dimension. On the other hand, no significant difference was indicated for antero-posterior dimension. The dimension differences between symmetry group and asymmetry group are listed in Table 4. CT on the deviation side was positioned lingually except for the 2nd premolar; however, no significant difference was indicated. Significant differences were indicated for CT of molars on the non-deviated side and FA of the deviated side for transverse dimension. A significant difference was indicated on teeth of antero-posterior dimension between symmetry and asymmetry group.

| Table 3 | Difference in the dimension measurements between the non-deviated (mm) |
|---------|---------------------------------------------------------------|
|         | Transverse                                                   |
| Tooth   | CT Mean | SD | t-test | FA Mean | SD | t-test |
| 1       | 0.12    | 0.64 | 0.28   | 0.04    | 0.34 | 0.46   |
| 2       | 0.07    | 0.96 | 0.44   | 0.05    | 0.60 | 0.37   |
| 3       | -0.33   | 0.97 | 0.26   | 0.28    | 1.15 | 0.38   |
| 4       | 0.38    | 1.49 | 0.23   | 0.30    | 1.61 | 0.43   |
| 5       | -0.76   | 1.32 | 0.12   | -0.26   | 1.04 | 0.10   |
| 6       | -2.03   | 2.13 | 0.00   | -1.21   | 0.68 | 0.00   |
| 7       | -2.79   | 2.62 | 0.00   | -2.10   | 1.30 | 0.00   |

| Antero-posterior |
|-------------------|
| Tooth  | CT Mean | SD | t-test | FA Mean | SD | t-test |
| 1      | 0.11    | 1.03 | 0.36   | 0.68    | 0.89 | 0.43   |
| 2      | 0.16    | 1.08 | 0.16   | 0.32    | 0.53 | 0.72   |
| 3      | 0.37    | 1.40 | 0.14   | -0.18   | 0.73 | 0.80   |
| 4      | 0.44    | 1.12 | 0.08   | 0.01    | 0.73 | 0.98   |
| 5      | 0.39    | 0.94 | 0.32   | -0.11   | 0.66 | 0.81   |
| 6      | -0.42   | 1.12 | 0.24   | -0.57   | 0.96 | 0.06   |
| 7      | -0.60   | 1.09 | 0.23   | -0.03   | 0.07 | 0.83   |

Difference: Non-deviated side minus deviated side
1: Central incisor
2: Lateral incisor
3: Canine
4: 1st premolar
5: 2nd premolar
6: 1st molar
7: 2nd Molar

| Table 4 | Difference in the dimension measurements between asymmetry and symmetry group independant t-test (mm) |
|---------|---------------------------------------------------------------|
|         | CT    | FA    | CT    | FA    |
| Tooth   | Mean t-test | Mean t-test | Mean t-test | Mean t-test |
| D1      | -0.20 0.13 | -0.34 0.03 | 0.15 0.55 | 0.27 0.05 |
| D2      | -0.39 0.10 | -0.29 0.06 | -0.19 0.59 | -0.70 0.00 |
| D3      | -0.70 0.04 | -0.18 0.24 | -0.96 0.01 | -0.95 0.01 |
| D4      | -0.60 0.07 | -0.91 0.01 | -1.35 0.00 | -1.05 0.01 |
| D5      | 1.53 0.01 | 1.89 0.00 | 1.43 0.00 | 2.25 0.00 |
| D6      | -0.23 0.35 | -1.37 0.00 | 1.07 0.02 | -2.39 0.00 |
| D7      | -0.21 0.37 | -1.79 0.00 | 0.58 0.10 | -0.31 0.03 |
| ND1     | -0.33 0.01 | -0.32 0.02 | 0.31 0.35 | 0.29 0.04 |
| ND2     | -0.46 0.04 | -0.22 0.11 | 0.30 0.66 | -0.13 0.60 |
| ND3     | -0.37 0.12 | -0.29 0.14 | -0.40 0.12 | -0.85 0.01 |
| ND4     | -0.97 0.01 | -0.98 0.00 | -0.70 0.08 | -1.18 0.00 |
| ND5     | -0.77 0.04 | -1.30 0.00 | -1.20 0.06 | -1.88 0.00 |
| ND6     | 1.80 0.00 | 0.29 0.21 | 0.62 0.46 | -2.71 0.00 |
| ND7     | 2.59 0.00 | 0.88 0.03 | 1.33 0.13 | -0.99 0.04 |

Difference: Asymmetry group minus symmetry group
D: deviated side
ND: non-deviated side
1: Central incisor
2: Lateral incisor
3: Canine
4: 1st premolar
5: 2nd premolar
6: 1st molar
7: 2nd Molar
The curve fittings of the CT and FA projection points on occlusal plane of both symmetry and asymmetry groups were processed (Fig. 4, 5). Both CT and FA arch forms in the symmetry group showed symmetry. Meanwhile, both arch forms in the asymmetry group showed asymmetry, and an S-shaped curve was observed on deviation side. The CT and FA point arch form explained by 6th polynomial were the following:

**Symmetry group:**
- **CT:** \( y = -5E-08x^6 - 7E-09x^5 + 9E-05x^4 + 2E-05x^3 - 0.0014x^2 - 0.0135x + 0.7008 \)
  \( R^2 = 0.98213 \)
- **FA:** \( y = -1E-07x^6 + 2E-07x^5 + 0.0001x^4 - 0.0001x^3 + 0.0025x^2 + 0.0094x + 1.3359 \)
  \( R^2 = 0.97625 \)

**Asymmetry group:**
- **CT:** \( y = -5E-08x^6 - 4E-07x^5 + 9E-05x^4 + 0.0006x^3 + 0.0002x^2 - 0.1309x \)
  \( R^2 = 0.9323 \)
- **FA:** \( y = -7E-08x^6 - 6E-07x^5 + 9E-05x^4 + 0.0007x^3 + 0.0169x^2 - 0.1312x \)
  \( R^2 = 0.91052 \)

Arch forms of both groups were superimposed for CT and FA as shown in Fig. 6. In the asymmetry group, arch forms shifted linguually and buccally on the deviated and non-deviated side respectively, compared to the symmetry group for both CT and FA.

![Fig. 7 Arch form drawn with 6th polynomial formula in the symmetry group. Both arch form showed symmetry. (a) : Cusp tip point (CT) (b) : Facial axis point (FA)](image)

![Fig. 8 Arch form drawn with 6th polynomial formula in the asymmetry group. Both arch form showed asymmetry. S-shaped curves were detected on the deviation side. (a) : Cusp tip point (CT) (b) : Facial axis point (FA)](image)
Discussion

Study models are accurate tools to diagnose, study dentition, develop treatment plan, and assess the outcomes of treatment, especially in orthodontics. However, they have been criticized for lacking accuracy due to the manual measuring procedure. 3D digital models were suggested as an alternative to plaster models to solve this problem. 3D digital models offer many advantages not only in clinics but also for research and have spread in popularity. In addition to ease of use and reduction in measuring time, the accuracy of linear dental anatomic measurements obtained from plaster and digital models revealed that the method is more accurate and reliable.

The same the coordinates are needed when comparing tooth dimension and arch form between symmetry and asymmetry group objectively.

The mid-reference line was established by projecting the maxillary midline onto the occlusal plane, then CT and FA points from the digital model were projected onto the occlusal plane. A digital model was used in this study for the reasons above and in order to efficiently perform specific translation procedures.

The critical factor in this study method was establishing a proper mid-reference line because this line affects the dimension evaluation of CT and FA and superimposition of arch form. In this study, the midline should not only be defined by the mandibular molars, but also by the maxillofacial structure at a position close to the mandibular arch. Therefore, the median palatal suture was selected as the base of the mid reference line. CT is defined as the midpoint of the incisal edge and buccal cusp tip in premolars and molars, and FA is the reference point for bracket placement. The former considers the anatomical aspect of teeth but since the latter is used more in clinical settings, both points were analyzed on each tooth in the 3D model.

Our results showed that in the asymmetry group, tooth on the deviated and non-deviated sides were located lingually and buccally, respectively, compared to the symmetry group. Previous reports indicated that the mandible not only translated but also rotated in facial asymmetry patients. In these patients, menton on the mandible shifted towards the deviated side and the gonial region shifted to the non-deviated side. These reports support our result for changes in tooth dimension for asymmetry patients. An explanation for the difference in transverse tooth dimension is transverse compensation where the pre-molars and molars are inclined lingually on the deviated side and buccally on the non-deviated side.

The dental arch form has long been an important topic in orthodontics. Various mathematical models such as ellipse, parabola, conic, cubic polynomial, and polynomial functions have been utilized for dental arch curve fitting. The 4th or 6th polynomial formula have been described to fit a symmetric arch. Our data showed an asymmetrical pattern, therefore attempts were made to fit several polynomial formulas to our data. However, neither the 4th polynomial formula nor the 5th polynomial formulas expressed an asymmetrical arch form; only the 6th polynomial formula properly expressed the asymmetric arch form. Therefore, the 6th polynomial formula was defined as the appropriate method to express asymmetric arch form in our study.

The dimensional difference of CT in arch form between

--- : Asymmetry group

--- : Symmetry group

![Fig. 9 Arch forms of symmetry and asymmetry group superimposed on the same coordinates. Asymmetry arch form shifted lingually at the deviated side and buccally at the nondeviated side. (a): Cusp tip point (CT) (b): Facial axis point (FA)](image)
the symmetry and asymmetry group coincided with the dimensional difference of FA in arch form between the symmetry and asymmetry group (Table 4 and Fig. 6). Results indicated that mandibular arch form in facial asymmetry patients deviated lingually on the deviated side and buccally on the non-deviated side. The dimensional difference was most likely a result of differences in buccal-lingual inclination of molars in the deviated and non-deviated side.\(^{11,12}\)

No previous studies have reported on asymmetric arch form using polynomial formulas. In this study, an S-shaped curve was indicated on the deviation side in the asymmetric group. CT is an anatomical point and in clinical settings during intraoral examination, arch form is interpreted by connecting the cusp tip of each tooth. Meanwhile, FA is less visible compared to CT during oral examination, but it is a critical point for treatment, because FA is utilized as a reference point during bracket placement. The difference in inclination between the deviation and non-deviation side generates the distortion in arch form. Further studies will be needed in order to demonstrate the relationship between mandibular arch form and tooth inclination. Results indicated that more attention should be given to correct asymmetry arch form during pre-surgical orthodontic treatment phases in skeletal Class III facial asymmetry patients.

The limitation of this study was the small sample size. This may have been the reason for large standard deviations for certain measurements in differences; therefore, results should be interpreted cautiously. In addition, the definition of midline is controversial because the location strongly affects the dimension of the arch form, especially large cases where transverse positioning of maxillary first molars have a large influence on the results; in this study however, we did not examine the lateral position of the maxillary first molar. Further investigation is required with larger samples of subjects and discussing the establishment of a suitable midline for the arch form in asymmetry patients.

This study has revealed that skeletal Class III facial asymmetry patients have asymmetric arch form and the molar on the right and left side are located in different transverse positions resulting in an S-shaped arch on the deviation side. These results reflect not only tooth position and arch form from an anatomical standpoint, but also presents clinically useful information. Arch re-forming should be taken into consideration at pre-surgical stages of orthodontic treatment especially in skeletal Class III facial asymmetry patients.

In the future, combining the digital data of the dentition with maxillofacial CT data may allow us to determine how the shape of the maxillofacial face of an asymmetric patient affects dentition. Moreover, it may lead to better treatment prediction and more accurate preoperative orthodontic correction before surgery.

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The authors declare confirming the absence of any conflict of interest.

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デジタル模型を用いた骨格性 Class Ⅲ顔面非対称患者の
下顎アーチフォームの三次元的検討

目的: 顔面非対称は, 顎の変形が下顎のみならず上顎, 上顎, 頭蓋底そして歯列にも及ぶ。歯槽骨上にある歯の位置とアーチフォームもまた顎変形の影響を受ける。本研究の目的は, 骨格性 Class Ⅲ顔面非対称患者の術前における下顎のアーチフォームを解析することである。

方法: 対象は, 骨格性 Class Ⅲの顔面非対称と診断され外科的矯正治療を施行された患者から選択された（非対称群）。外科的矯正治療を施行された顔面非対称を伴わない骨格性 Class Ⅲ患者を対称群とした。20名（男性10名, 女性10名）をそれぞれの群から選択した。評価のためにそれぞれの群の下顎の模型をレザースキャナーにてスキャンを行なった。三次元デジタル模型上で咬頭頂点と歯冠軸点を咬合平面に投影し, モデリングソフトを用いこれらの点の位置計測を行なった。また, 2群のアーチフォームを多項式により描記し, アーチフォームの比較を行なった。

結果: 臼歯部において咬頭頂点と歯冠軸点とともに, 非対称群は偏位側で有意に舌側に位置しており, 他方, 非偏位側では顔側に位置していった。また, 対称群のアーチフォームは6次多項式により対称的なアーチフォームが表現できた。他方, 非対称群のアーチフォームは同じく6次多項式で表現でき, 偏位側がS字状を示す非対称アーチフォームであった。

結論: 本研究により骨格性 Class Ⅲ顔面非対称症例における臼歯の左右的位置の差とその影響により生じる非対称のアーチフォームが確認できた。

キーワード: 顔面非対称, 下顎アーチフォーム, 術前矯正治療

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