

A Multivariate Analysis for Classification of Craniofacial Morphology in Facial Asymmetry

Fumiko Tsurumi, Hirofumi Takagi* and Kenji Fushima

Department of Orthodontics, Kanagawa Dental College

*College of Biomedical Technology of Niigata University

Abstract

Morphological features of 205 subjects with facial asymmetry were investigated by means of postero-anterior (PA) and lateral cephalograms. Multivariate principal component analysis was applied to classify the facial asymmetry into subdivisions. Three factors were considered in this study. These were antero-posterior position and size of the mandible (factor-1), facial asymmetry (factor-2) and overjet as well as the tooth axis of the lower incisor (factor-3). Based on these three factors, facial asymmetry was further classified into eight types. For the PA cephalogram, each group was characterized mainly by its mandibular asymmetry, especially mandibular lateral displacement. The skeletal characteristics showed that the ramus height was smaller, the facial width at the gonion level was larger and a greater infero-lateral inclination of the lateral border of the ramus was found on the mandibular displaced side than on the opposite side. The dental characteristics were of a frontal occlusal plane ascending toward the mandibular displaced side and a lower dental midline displaced along with a mandibular skeletal displacement, while the lower incisors tended to incline toward the opposite side. For the lateral cephalogram, it was demonstrated that facial asymmetry was a morphological characteristic found not only in a mandibular prognathism but also in other various skeletal types, for instance in a mandibular retrognathism. Thus, in patients with facial asymmetry, the treatment plan should be based on the individual skeletal type.

Key words: *Facial asymmetry / Principal component analysis / Cephalogram / Mandibular lateral displacement*

Introduction

Lateral deviation of the denture midlines and difference of the occlusal relationship in the right and left molar are exemplified in patients with facial asymmetry. It seems to be extremely difficult to treat such a malocclusion by orthodontic means. Therefore, orthognathic surgery is a popular choice especially in adult subjects with severe facial asymmetry, in order to solve the occlusal and esthetic problems (1). It has been reported that facial asymmetry presents not only an esthetic problem but also functional disturbance for masticatory muscle activity (2) or condylar path (3). A high incidence of tem-

poromandibular disorder (TMD) in facial asymmetry was reported (4, 5), on the other hand, it was also reported that facial asymmetry was a relatively common problem in TMD patients (6).

In this regard, it is fundamentally significant to understand the morphological features of the craniofacial complex. Morphological studies addressing facial asymmetry have been reported by means of radiographs, as a PA cephalogram (7-13), a submental vertex radiograph, (14-16) and an oblique cephalogram (17). Several studies recommended the PA cephalogram for the analysis of frontal asymmetries.

A single image assessment of the X-ray photographs in these studies is not enough to understand the complicated morphological features of craniofacial asymmetry. Although three dimensional reconstruction of cranio

Accepted for publication on August 5, 1999.

Address for correspondence: Kenji Fushima, Department of Orthodontics, Kanagawa Dental College, 82, Inaoka-Cho, Yokosuka, Kanagawa 238-8580, Japan

facial structures by means of a computed tomography (18, 19) is a modern method for analyzing skeletal morphology, it is not in common use, due to prohibitive costs and excessive exposure to radiation. Few studies have examined craniofacial morphology by means of both frontal and lateral cephalograms (20).

In this study, the craniofacial structures were investigated by means of the frontal and lateral cephalograms in maloccluded subjects with facial asymmetry. Multivariate factor analysis was applied to classify the subjects into subdivisions of facial asymmetry.

Materials and Methods

Sample

The PA and lateral cephalograms of 205 malocclusion cases (105 male and 100 female; mean age: 21.3 years, range: 16-47 years) attending the orthodontic department of the Kanagawa Dental College were utilized in this study. These subjects were diagnosed as having an obvious facial asymmetry by two orthodontists.

Cephalometric analysis

An cephalogram was taken with the patient's head uprighted parallel to the FH plane. After tracing the cephalogram, the selected landmarks were digitized and a cephalometric analysis was performed using originally developed software. The PA cephalograms were analyzed as described in the previous studies (4-6). The midfacial reference plane (MRP) which was used to as-

sess facial asymmetry runs through the crista galli (CG) and anterior nasal spine (ANS) (Fig. 1).

PA cephalometric measurements

Angular measurements (Fig. 1A)

MLD: The angle formed by the intersection of the MRP and the line running through the ANS and menton (ME) is defined as the mandibular lateral displacement (MLD). The positive value indicates mandibular lateral displacement to the left side.

MRP-P: This is a perpendicular line to the MRP. It is utilized to assess the angle against the line through the right and left landmark points on the bilateral structures.

FOP: The angle formed by the intersection of the MRP-P and the line running through the occlusal surface of the right and left upper second molars.

FMP: The angle formed by the intersection of the MRP-P and the line connecting the right and left antegonial notch.

OS: The angle formed by the intersection of MRP-P and the line passing through the most superior points on the orbital contour.

ZYG: The angle formed by the intersection of the MRP-P and the line connecting the right and left center points on the contour of the zygomatic arch (ZYG). The positive value of the FOP, FMP, OS and Zyg indicates that these planes ascend toward the left side.

FRI: The intersection between the contour of the mastoid process and the lateral border of the ramus was

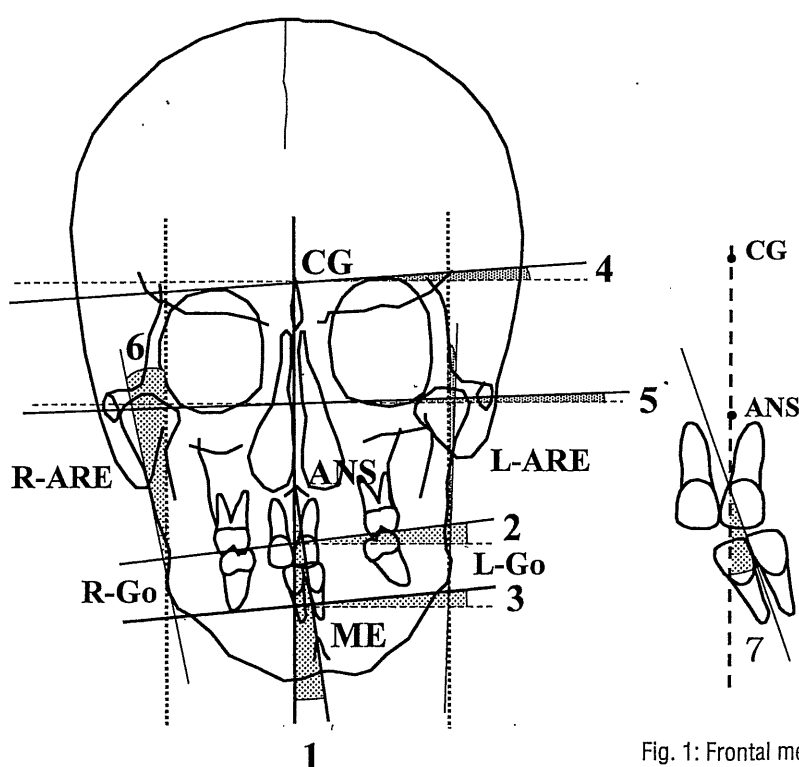


Fig. 1: Frontal measurements

A; Angular measurements in PA cephalogram

1, MLD 2, FOP 3, FMP 4, OS 5, Zyg 6, FRI-D 7, L1-Axis

defined as ARE. The inclination of the line from the ARE tangent to the lateral contour of the gonion against the MRP was measured as the frontal ramus inclination (FRI). The right and left difference of this angle was defined as FRI-D. The positive value of FRI-D indicates that a greater superior-lateral inclination of the ramus is present on the left side than that on the right side.

L1-Axis: A line from the contact point of the lower central incisors to the mid point between their bilateral root apices was drawn. The angle formed by the intersection of this line and the MRP was defined as the L1-Axis. A positive angle reveals that the lower central incisor is inclined toward the left side.

Linear measurements (Fig. 1B)

Linear measurements were made in a horizontal direction from the bilateral landmarks perpendicular to the MRP to indicate facial width. Skeletal asymmetry was evaluated as the difference between the measurements of the right and left sides. The landmark points were as follows:

CW-D: The cranial point was established by the intersection of the line connecting the bilateral OS points and the lateral contour of the cranium.

ZYG-D: Zyg was the middle point on the right and left lateral zygomatic arch.

UC-D: UC was the buccal cervical point on the upper posterior second molar.

GO-D: Go was the most lateral point on the gonion.

A positive value indicates that the facial width on the left side was larger than that on the right side.

U1-Mid: U1 was the contact point of the upper central incisors.

L1-Mid: L1 was the contact point of the lower central incisors.

Mid-D: The transverse distance between the upper and lower midline is defined as Mid-D. In this calculation, U1-Mid was subtracted from L1-Mid. A positive value indicates that the lower midline displaces to the left side against the upper midline.

Lateral cephalometric measurements

Angular measurements (Fig. 2A)

Mandibular plane angle (MP): The angle formed by the intersection of the mandibular plane and FH plane.

Facial Axis (FX): The angle formed by the intersection of the Ba-Na plane and Pt-Gna plane.

Gonial angle (Go-A): The angle formed by the intersection of the mandibular plane and the posterior border of the ramus.

Ramus inclination (Ram-I): The angle formed by the intersection of the FH plane and the posterior border of the ramus.

Palatal plane angle (PP-A): The angle established by the intersection of the FH plane and palatal plane. A positive value was given when the plane inclined downward and forward in relation to the FH plane.

Upper occlusal plane angle (UOP): The upper oc-

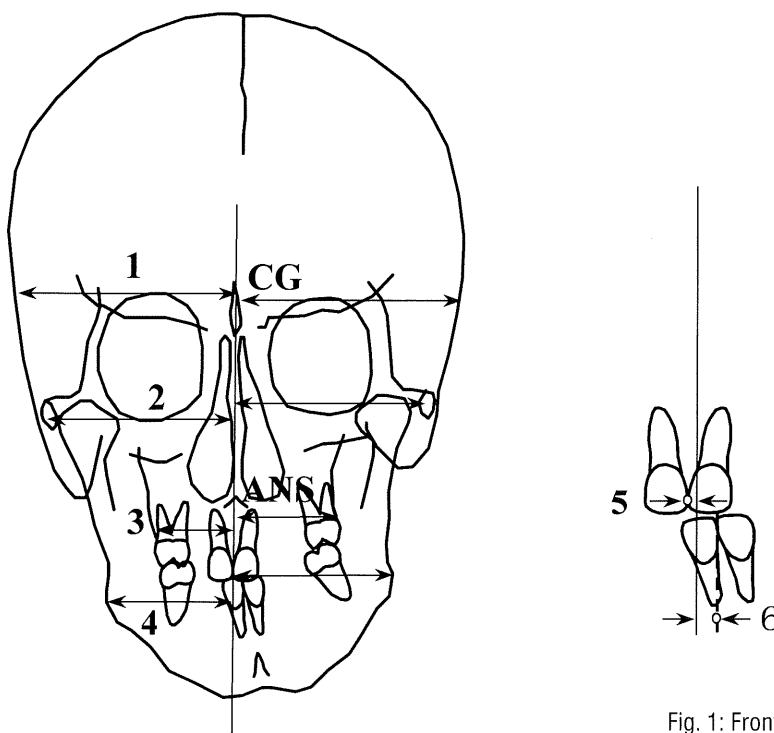


Fig. 1: Frontal measurements

B; Linear measurements in PA cephalogram

1, CW 2, Zyg 3, UC 4, Go 5, U1-Mid 6, L1-Mid

clusal plane is the line running through the occlusal surface of the upper first molar and the upper central incisal edge. The angle between the FH plane and upper occlusal plane is defined as UOP.

Lower occlusal plane angle (LOP): The lower occlusal plane is the line running through the occlusal surface of the lower first molar and the lower central incisal edge. The angle between the FH plane and the lower occlusal plane is defined as LOP. A positive value was given when the upper occlusal plane and lower occlusal plane incline downward and forward in relation to the FH plane.

U1-FH: The posterior-inferior angle formed by the

long axis of the upper central incisor and the FH plane was measured.

L1-MP: The angle formed by the long axis of the lower central incisor and the mandibular plane.

Saddle angle (Sad-A): The angle formed by passing a line through the nasion (Na) and sella turcica (S) and the line through S and articular points (Ar).

FMIA: The angle formed by the long axis of the lower central incisor and the FH plane.

Linear measurements (Fig. 2 B)

Maxillary length (Max-L): The distance from the Ptm to A point projected to the FH plane.

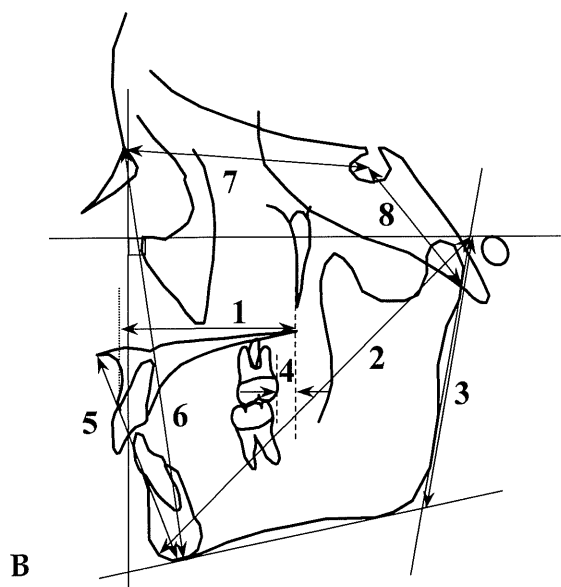
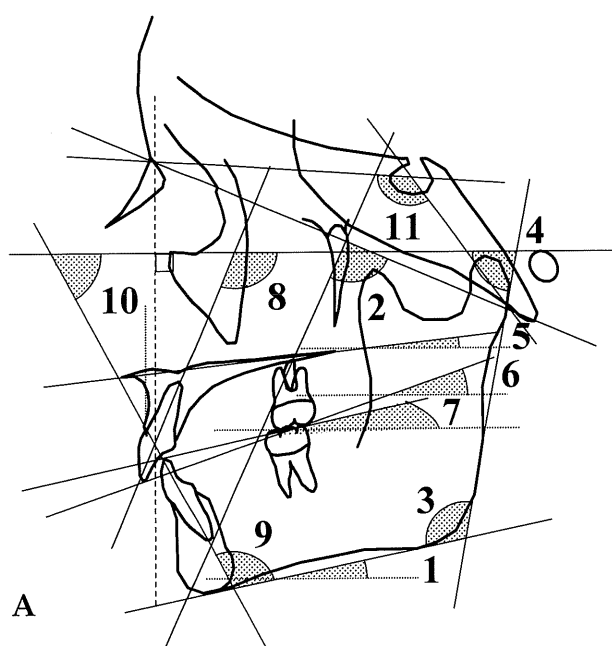


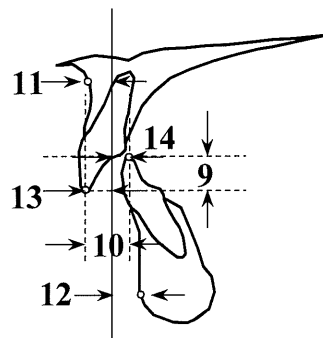
Fig. 2: Lateral measurements

A; Angular measurements in lateral cephalogram

1, MP 2, FX 3, Go-A 4, Ram-I 5, PP-A 6, UOP 7, LOP 8, U1-FH 9, L1-MP 10, FMIA 11, Sad-A

B; Linear measurements in lateral cephalogram

1, Max-L 2, Mand-L 3, Ram-H 4, U6-PTV 5, AFH 6, TFH 7, ACBL 8, PCBL 9, OB 10, OJ 11, A-McN 12, Pog-McN 13, U1-McN 14, L1-McN



Mandibular length (Mand-L): The distance from the intersection of the FH plane and the posterior border of the ramus to gnathion.

Ramus-height (Ram-H): The distance from the intersection of the FH plane and the posterior border of the ramus until it meets with the mandibular plane.

U6-PTV: The distance from the distal proximal surface of the upper first molar to the PT vertical line.

Anterior facial height (AFH): The distance between the ANS and the ME.

Total facial height (TFH): The distance between Na and Me.

Anterior cranial basal length (ACBL): The distance from Na to S.

Posterior cranial basal length (PCBL): The distance from S to Ar.

Overjet (OJ): The horizontal distance between the upper and lower incisal edge projected into FH plane and defined as OJ.

Overbite (OB): The vertical distance between the upper and lower incisal edge projected into the perpendicular plane of FH and defined as OB.

Na perpendicular to A (A-McN): The distance from point A to the line drawn from the nasion perpendicular to the FH plane (McN).

Na perpendicular to Pog (Pog-McN): The distance from the pogonion to the McN.

A-Pog-D: The horizontal distance projected to the FH plane between A to the pogonion is defined as A-Pog - D.

U1-McN: The distance from the upper central incisal edge to the McN.

L1-McN: The distance from the lower incisal edge to the McN.

Data analysis

In order to classify the 205 subjects as having facial asymmetry, the above mentioned forty variables were utilized for the following data analysis. Fig. 3 represents the flow of the data analysis. The first step was to reduce the number of variables into a few compound variables by means of a principal component analysis. In the second step, the subjects were classified into eight types from the obtained principal component scores.

In these types, all variables in PA and lateral cephalometric measurements were tested by means of a one-way ANOVA. The mean value and standard deviations were calculated for each variable. These variables were also standardized into a z score and their mean values were calculated. All analyses were performed with an SPSS statistical package (SPSS 7.5J for Windows).

Results

Principal component analysis

The principal component analysis was applied in

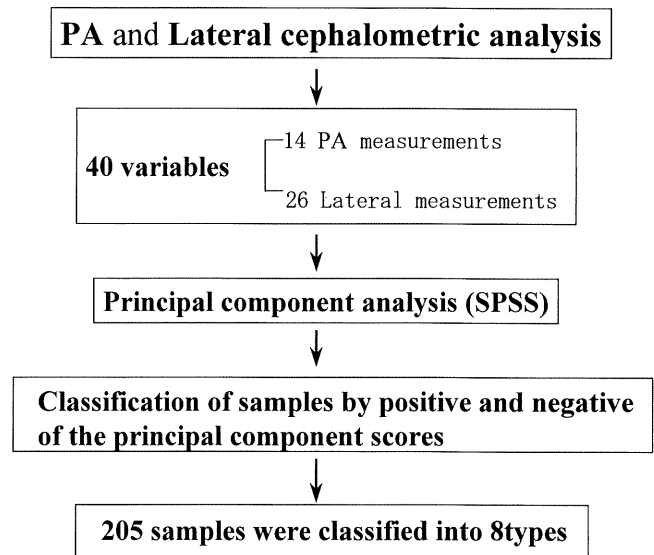


Fig. 3: Flow diagram of data analysis

order to reduce the number of variables into a few compound variables. Eleven components with 1.0 or a large eigenvalue were obtained (Table 1). Three components with the largest eigenvalues were selected for the classification of the facial asymmetry subjects. Their cumulative proportions were 46.0%. Table 2 represents the principal component loading in these components. For factor-1, Pog-McN, A-Pog-D, L1-McN, UOP, Mand-L, LOP, MP, Ram-H and Ram-I were listed as a principal component loading over 0.6. Therefore, factor-1 was interpreted as a factor indicating the antero-posterior position, rotation and size of the mandible in lateral projection. For factor-2, Go-D, MLD, UC-D, FMP, L1-Mid and FRI-D showed a high level of principal component loading. Therefore, factor-2 was interpreted as the factor indicating midfacial and mandibular asymmetry. For factor-3, L1-MP, OJ and Go-A revealed more than 0.6 of principal component loading. Factor-3 was then interpreted as the factor indicating the overbite and the tooth axis of the lower incisor in lateral projection.

Classification of samples

The samples were classified into two types based on the positive or negative value of the principal component scores in the three components, and finally eight types were obtained by a combination (Table 3).

As shown in Table 4, one-way ANOVA was applied in order to confirm which variable contributed to the classification of the eight types of facial asymmetry sample. A significant difference between groups ($p < 0.01$) was shown except for the Sad-A and PCBL. The mean values of standardized variables (z score) in the eight

Tabel 1: Cumulative proportion of total variance in principal component analysis

| Component | Cumulative proportion of total variance |
|-----------|---|
| Factor-1 | 20.5% |
| Factor-2 | 35.2% |
| Factor-3 | 46.0% |
| Factor-4 | 54.3% |
| Factor-5 | 61.4% |
| Factor-6 | 66.2% |
| Factor-7 | 70.8 % |
| Factor-8 | 74.2% |
| Factor-9 | 77.2% |
| Factor-10 | 80.0% |
| Factor-11 | 82.6% |

Tabel 2: Principal component loadings in three factors

| | Factor-1 | | Factor-2 | | Factor-3 |
|---------|----------|--------|----------|-------|----------|
| Pog-McN | -0.80 | Go-D | 0.81 | L1-MP | 0.83 |
| A-Pog-D | 0.77 | MLD | 0.75 | OJ | 0.67 |
| L1-McN | -0.77 | UC-D | 0.69 | Go-A | -0.60 |
| UOP | 0.69 | FMP | 0.69 | FMIA | -0.54 |
| Mand-L | -0.66 | L1-Mid | 0.68 | | |
| LOP | 0.65 | FRI-D | -0.66 | | |
| MP | 0.64 | | | | |
| Ram-H | -0.64 | | | | |
| Ram-I | 0.63 | | | | |
| U6-PTV | -0.60 | | | | |
| FMIA | -0.59 | | | | |

Listed are only variables with over 0.6 of principal component loading.

Table 3: The classification system of 205 cases by respective positive or negative principal component scores

| Type | Factor-1 | Factor-2 | Factor-3 |
|------|----------|----------|----------|
| 1 | — | — | — |
| 2 | — | — | + |
| 3 | — | + | — |
| 4 | — | + | + |
| 5 | + | — | — |
| 6 | + | — | + |
| 7 | + | + | — |
| 8 | + | + | + |

Table 4: One-way ANOVA

| | | variable | | F -value | Sig |
|---------|----------|----------|-------|----------|-----|
| Frontal | Skeletal | MLD | (°) | 33.1 | ** |
| | | FMP | (°) | 22.2 | ** |
| | | Go-D | (mm) | 34.9 | ** |
| | | FRI-D | (°) | 19.2 | ** |
| | | CW-D | (mm) | 8.6 | ** |
| | | Zyg-D | (mm) | 5.6 | ** |
| | | OS | (°) | 4.3 | ** |
| | | Zyg | (°) | 7.1 | ** |
| | Dental | FOP | (°) | 16.0 | ** |
| | | UC-D | (mm) | 22.8 | ** |
| | | Mid-D | (mm) | 17.8 | ** |
| | | U1-Mid | (mm) | 6.6 | ** |
| Lateral | Skeletal | L1-Mid | (mm) | 24.9 | * |
| | | L1-Axis | (°) | 11.4 | ** |
| | | A-Pog-D | (mm) | 30.4 | ** |
| | | A-McN | (mm) | 5.8 | ** |
| | | Pog-McN | (mm) | 30.0 | ** |
| | | MP | (°) | 27.3 | ** |
| | | FX | (°) | 4.6 | ** |
| | | Go-A | (°) | 12.0 | ** |
| | | Ram-I | (°) | 11.8 | ** |
| | | PP-A | (°) | 5.2 | ** |
| | | Max-L | (mm) | 11.7 | ** |
| | | Mand-L | (mm) | 19.5 | ** |
| | | Ram-H | (mm) | 15.7 | ** |
| | | AFH | (mm) | 2.2 | * |
| | | TFH | (mm) | 2.5 | * |
| | Dental | ACBL | (mm) | 3.8 | ** |
| | | PCBL | (mm) | 2.0 | n.s |
| | | Sad-A | (°) | 1.5 | n.s |
| | | OJ | (mm) | 16.2 | ** |
| | | OB | (mm) | 5.7 | ** |
| | | U1-FH | (°) | 15.2 | ** |
| | | U1-McN | (mm) | 14.3 | ** |
| | | L1-McN | (mm) | 18.1 | ** |
| | | FMIA | (°) | 19.3 | ** |
| | | L1-MP | (°) | 30.1 | ** |
| | | UOP | (°) | 16.7 | ** |
| | | LOP | (°) | 15.5 | ** |
| | | U6-PTV | (mm) | 12.3 | ** |

*P<0.05 **P<0.01

Table 5: The means values of standardized variables in eight types of facial asymmetry

| | Type 1 | Type 2 | Type 3 | Type 4 | Type 5 | Type 6 | Type 7 | Type 8 |
|-----------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| number | 21 | 32 | 26 | 29 | 24 | 23 | 24 | 26 |
| Lateral Skeletal Variables | | | | | | | | |
| A-Pog-D | -1.02 | -0.08 | -1.14 | -0.22 | 0.31 | 1.12 | 0.28 | 0.77 |
| A-McN | 0.01 | 0.36 | 0.17 | 0.53 | -0.77 | -0.11 | -0.54 | 0.09 |
| Pog-McN | 0.92 | 0.22 | 1.09 | 0.42 | -0.59 | -1.05 | -0.48 | -0.65 |
| MP | -0.07 | -0.68 | -0.50 | -0.83 | 1.30 | 0.63 | 0.63 | -0.01 |
| FX | 0.22 | 0.21 | 0.27 | 0.29 | -0.26 | -0.92 | -0.08 | 0.09 |
| GO_A | 0.55 | -0.79 | 0.30 | -0.37 | 0.90 | -0.11 | 0.37 | -0.45 |
| Ram_I | -0.73 | 0.26 | -0.87 | -0.39 | 0.22 | 0.77 | 0.18 | 0.53 |
| PP_A | -0.20 | -0.41 | -0.34 | -0.34 | 0.77 | 0.20 | 0.36 | 0.17 |
| Max_L | -0.25 | 0.33 | 0.15 | 0.64 | -1.10 | -0.24 | -0.43 | 0.55 |
| Mand_L | 0.68 | -0.14 | 1.11 | 0.30 | -0.31 | -1.15 | -0.07 | -0.46 |
| Ram_H | 0.13 | 0.38 | 0.82 | 0.63 | -0.83 | -0.90 | -0.34 | -0.22 |
| AFH | 0.08 | -0.30 | 0.06 | -0.25 | 0.39 | -0.06 | 0.46 | -0.20 |
| TFH | 0.20 | -0.21 | 0.27 | -0.19 | 0.36 | -0.44 | 0.32 | -0.21 |
| ACBL | -0.10 | 0.06 | 0.21 | 0.57 | -0.59 | -0.44 | -0.10 | 0.19 |
| PCBL | -0.26 | 0.22 | 0.35 | 0.07 | -0.43 | -0.30 | 0.03 | 0.15 |
| Sad_A | -0.22 | -0.02 | -0.26 | 0.14 | -0.29 | 0.31 | -0.02 | 0.32 |
| Lateral Dental Variables | | | | | | | | |
| OJ | -0.82 | 0.35 | -0.87 | 0.06 | -0.34 | 1.07 | -0.15 | 0.53 |
| OB | -0.21 | 0.06 | -0.11 | 0.15 | -0.82 | 0.40 | -0.25 | 0.65 |
| U1_FH | 0.35 | 0.48 | 0.37 | 0.82 | -0.95 | -0.22 | -0.59 | -0.53 |
| U1_McN | 0.22 | 0.58 | 0.20 | 0.72 | -1.06 | -0.13 | -0.74 | -0.11 |
| L1_McN | 0.73 | 0.29 | 0.74 | 0.61 | -0.75 | -0.81 | -0.56 | -0.44 |
| FMIA | 0.94 | -0.13 | 1.10 | -0.10 | 0.03 | -0.88 | -0.13 | -0.72 |
| L1_MP | -0.93 | 0.62 | -0.79 | 0.70 | -0.97 | 0.47 | -0.31 | 0.75 |
| UOP | -0.17 | -0.68 | -0.49 | -0.72 | 0.91 | 0.51 | 0.57 | 0.46 |
| LOP | -0.23 | -0.54 | -0.56 | -0.59 | 1.12 | 0.44 | 0.61 | 0.09 |
| U6_PTV | 0.25 | 0.24 | 0.41 | 0.88 | -0.78 | -0.77 | -0.36 | -0.16 |
| Frontal Skeletal Variables | | | | | | | | |
| MLD | -0.82 | -1.09 | 0.45 | 0.27 | -0.38 | -0.25 | 1.09 | 0.82 |
| FMP | -0.98 | -0.86 | 0.02 | 0.27 | -0.21 | -0.06 | 0.87 | 0.98 |
| Go-D | -0.93 | -1.07 | 0.56 | 0.45 | -0.45 | -0.27 | 0.88 | 0.86 |
| FRI-D | 0.91 | 0.87 | -0.22 | -0.30 | 0.23 | 0.15 | -0.82 | -0.85 |
| Zyg-D | -0.32 | -0.66 | 0.42 | 0.27 | -0.34 | -0.12 | 0.42 | 0.38 |
| CW-D | -0.25 | -0.84 | 0.52 | 0.29 | -0.23 | -0.31 | 0.52 | 0.40 |
| OS | -0.55 | 0.04 | -0.50 | 0.41 | -0.05 | -0.06 | -0.05 | 0.59 |
| Zyg | -0.92 | -0.25 | -0.30 | 0.46 | 0.00 | -0.04 | 0.20 | 0.68 |
| Frontal Dental Variables | | | | | | | | |
| FOP | -0.97 | -0.69 | -0.15 | 0.41 | -0.20 | -0.04 | 0.69 | 0.91 |
| UC-D | -0.97 | -0.81 | 0.54 | 0.44 | -0.52 | -0.22 | 0.95 | 0.55 |
| Mid-D | -0.24 | -0.82 | 0.94 | -0.08 | -0.08 | -0.58 | 1.03 | -0.01 |
| U1-Mid | -0.74 | -0.17 | -0.19 | 0.32 | -0.53 | 0.15 | 0.34 | 0.69 |
| L1-Mid | -0.67 | -0.87 | 0.78 | 0.11 | -0.39 | -0.47 | 1.17 | 0.40 |
| L1-Axis | -0.62 | -0.79 | -0.16 | 0.34 | -0.30 | 0.27 | 0.63 | 0.72 |

groups are referred to Table 5. Table 6 represents the mean value and standard deviation of the variables in eight types of facial asymmetry, and the skeletal and dental patterns in the frontal projection are represented as radar charts in Fig. 4. Although the eight types of facial asymmetry were demonstrated by their morphological features in the PA and lateral cephalograms, some common results were recognized in these radar charts.

In all types except type 5 and 6, facial asymmetry was characterized by mandibular asymmetry. Addressing to the MLD, four types (Type 3, 4, 7, 8) showed positive values and two types (Type 1, 2) showed a negative value, indicating mandibular lateral displacement to the

left and right side respectively. In all six types, FMP, Go-D, FOP and L1-Mid were positively related to the MLD, whereas the FRI-D and L1-Axis were negatively related to the MLD.

These results suggest that in a facial asymmetry accompanied with a mandibular lateral displacement, skeletal characteristics reveal that the ramus height is smaller, the facial width at gonion level is larger and the lateral border of the ramus more infero-laterally inclines on the mandibular displaced side compared with the opposite side. As for dental characteristics, the frontal occlusal plane ascends toward the mandibular displaced side and the lower dental midline is displaced along with

Table 6: The means and standard deviations of all measurement variables

| | | | Type 1 | Type 2 | Type 3 | Type 4 | Type 5 | Type 6 | Type 7 | Type 8 |
|----------------------------|----------|------|--------|--------|--------|--------|--------|--------|--------|--------|
| number | | | 21 | 32 | 26 | 29 | 24 | 23 | 24 | 26 |
| Lateral Skeletal Variables | A-Pog-D | mean | -5.7 | 3.0 | -6.8 | 1.6 | 6.5 | 14.0 | 6.3 | 10.8 |
| | (mm) | s.d. | 6.8 | 6.8 | 6.1 | 6.9 | 7.7 | 5.5 | 6.6 | 5.3 |
| | A-McN | mean | -0.8 | 0.7 | -0.1 | 1.4 | -4.1 | -1.3 | -3.2 | -0.5 |
| | (mm) | s.d. | 3.4 | 5.0 | 3.7 | 4.6 | 4.3 | 3.0 | 3.3 | 3.3 |
| | Pog_-McN | mean | 5.0 | -2.3 | 6.7 | -0.2 | -10.7 | -15.3 | -9.5 | -11.3 |
| | (mm) | s.d. | 8.2 | 8.2 | 7.2 | 7.4 | 6.3 | 6.7 | 7.9 | 6.1 |
| | MP | mean | 29.6 | 25.4 | 26.7 | 24.4 | 38.9 | 34.3 | 34.3 | 30.0 |
| | (°) | s.d. | 4.7 | 5.5 | 4.0 | 4.2 | 4.7 | 5.3 | 5.6 | 5.3 |
| | FX | mean | 90.8 | 90.8 | 91.2 | 91.3 | 87.6 | 83.2 | 88.8 | 89.9 |
| | (°) | s.d. | 3.8 | 5.0 | 4.2 | 8.9 | 7.4 | 7.8 | 7.5 | 7.5 |
| | GO_A | mean | 132.6 | 121.7 | 130.6 | 125.2 | 135.5 | 127.2 | 131.2 | 124.5 |
| | (°) | s.d. | 5.4 | 8.5 | 8.4 | 6.4 | 6.7 | 6.7 | 5.9 | 6.0 |
| | Ram_I | mean | 77.0 | 83.7 | 76.1 | 79.3 | 83.5 | 87.1 | 83.2 | 85.5 |
| | (°) | s.d. | 4.4 | 7.1 | 6.6 | 5.5 | 5.2 | 6.0 | 4.9 | 5.2 |
| | PP_A | mean | 0.9 | 0.2 | 0.4 | 0.4 | 4.4 | 2.3 | 2.9 | 2.2 |
| | (°) | s.d. | 3.0 | 3.8 | 3.0 | 3.2 | 3.3 | 3.0 | 3.0 | 3.7 |
| | Max_L | mean | 47.9 | 50.0 | 49.3 | 51.1 | 44.8 | 47.9 | 47.2 | 50.8 |
| | (mm) | s.d. | 3.6 | 3.4 | 2.6 | 3.3 | 3.0 | 2.0 | 3.5 | 2.7 |
| | Mand_L | mean | 136.7 | 129.1 | 140.8 | 133.2 | 127.5 | 119.4 | 129.7 | 126.0 |
| | (mm) | s.d. | 8.4 | 5.8 | 7.0 | 7.0 | 10.3 | 6.1 | 8.2 | 6.1 |
| | Ram_H | mean | 66.4 | 68.3 | 71.5 | 70.1 | 59.4 | 58.9 | 63.0 | 63.8 |
| | (mm) | s.d. | 5.7 | 5.2 | 5.8 | 5.9 | 6.7 | 6.1 | 7.0 | 5.7 |
| | AFH | mean | 76.3 | 74.1 | 76.2 | 74.3 | 78.0 | 75.4 | 78.4 | 74.6 |
| | (mm) | s.d. | 5.7 | 5.6 | 5.3 | 6.7 | 6.1 | 5.2 | 6.2 | 4.0 |
| | TFH | mean | 134.1 | 131.1 | 134.6 | 131.3 | 135.3 | 129.4 | 135.0 | 131.1 |
| | (mm) | s.d. | 7.4 | 6.9 | 6.6 | 7.3 | 9.3 | 6.7 | 8.3 | 4.4 |
| | ACBL | mean | 70.2 | 70.8 | 71.4 | 72.7 | 68.4 | 69.0 | 70.2 | 71.3 |
| | (mm) | s.d. | 3.4 | 3.3 | 2.8 | 3.1 | 4.3 | 4.3 | 4.0 | 2.8 |
| | PCBL | mean | 35.7 | 38.2 | 38.9 | 37.4 | 34.8 | 35.5 | 37.2 | 37.9 |
| | (mm) | s.d. | 3.7 | 8.8 | 6.2 | 3.9 | 4.4 | 3.0 | 4.1 | 3.5 |
| | Sad_A | mean | 124.2 | 125.7 | 123.9 | 126.8 | 123.7 | 128.1 | 125.7 | 128.1 |
| | (°) | s.d. | 6.2 | 7.6 | 6.8 | 4.9 | 5.3 | 9.9 | 5.0 | 10.2 |
| Lateral Dental Variables | OJ | mean | -2.0 | 2.9 | -2.2 | 1.7 | 0.0 | 5.8 | 0.8 | 3.6 |
| | (mm) | s.d. | 3.6 | 3.2 | 3.1 | 4.1 | 4.2 | 3.7 | 2.5 | 1.8 |
| | OB | mean | 1.5 | 2.1 | 1.7 | 2.3 | 0.0 | 2.9 | 1.4 | 3.6 |
| | (mm) | s.d. | 1.8 | 2.6 | 1.9 | 2.4 | 3.2 | 2.2 | 1.5 | 1.8 |
| | U1_FH | mean | 119.5 | 120.4 | 119.7 | 122.8 | 110.4 | 115.5 | 113.0 | 113.4 |
| | (°) | s.d. | 3.3 | 6.0 | 5.7 | 6.8 | 5.4 | 7.7 | 4.7 | 4.6 |
| | U1_McN | mean | 7.2 | 9.3 | 7.1 | 10.1 | 0.0 | 5.3 | 1.8 | 5.4 |
| | (mm) | s.d. | 3.9 | 6.6 | 4.3 | 4.9 | 4.5 | 4.4 | 4.1 | 3.5 |
| | L1_McN | mean | 9.2 | 6.4 | 9.3 | 8.5 | -0.1 | -0.5 | 1.0 | 1.8 |
| | (mm) | s.d. | 5.8 | 6.0 | 5.3 | 4.9 | 4.6 | 4.8 | 4.7 | 3.7 |
| | FMIA | mean | 69.5 | 58.9 | 71.1 | 59.2 | 60.6 | 51.5 | 58.9 | 53.1 |
| | (°) | s.d. | 7.6 | 10.1 | 6.9 | 7.1 | 7.9 | 5.9 | 8.8 | 6.1 |
| | L1_MP | mean | 80.9 | 95.7 | 82.2 | 96.4 | 80.5 | 94.2 | 86.8 | 96.9 |
| | (°) | s.d. | 7.4 | 8.5 | 5.6 | 6.5 | 6.7 | 5.0 | 7.2 | 6.0 |
| | UOP | mean | 10.3 | 8.1 | 8.9 | 7.9 | 15.2 | 13.4 | 13.7 | 13.2 |
| | (°) | s.d. | 2.9 | 4.1 | 3.0 | 3.2 | 3.8 | 4.2 | 4.1 | 3.5 |
| | LOP | mean | 5.6 | 3.8 | 3.7 | 3.5 | 13.5 | 9.5 | 10.5 | 7.5 |
| | (°) | s.d. | 3.7 | 5.5 | 3.4 | 4.6 | 6.0 | 4.9 | 4.7 | 4.5 |
| | U6_PTV | mean | 20.9 | 20.9 | 21.6 | 23.8 | 16.2 | 16.2 | 18.1 | 19.1 |
| | (mm) | s.d. | 3.7 | 3.9 | 4.2 | 3.3 | 5.0 | 3.5 | 3.8 | 3.3 |
| Frontal Skeletal Variables | MLD | mean | -1.9 | -3.2 | 3.7 | 2.9 | 0.0 | 0.6 | 6.6 | 5.4 |
| | (°) | s.d. | 3.4 | 2.9 | 3.7 | 2.3 | 3.4 | 2.7 | 3.2 | 3.0 |
| | FMP | mean | -1.7 | -1.3 | 1.1 | 1.8 | 0.5 | 0.9 | 3.4 | 3.7 |
| | (°) | s.d. | 1.3 | 2.6 | 1.3 | 1.8 | 2.7 | 2.0 | 2.6 | 1.8 |
| | Go-D | mean | -4.6 | -5.4 | 4.2 | 3.5 | -1.8 | -0.7 | 6.1 | 5.9 |
| | (mm) | s.d. | 3.74 | 4.09 | 3.33 | 3.5 | 5.32 | 4.26 | 4.38 | 3.23 |
| | FRI-D | mean | 3.2 | 3.0 | -2.7 | -3.1 | -0.3 | -0.8 | -5.8 | -5.9 |
| | (°) | s.d. | 2.7 | 3.7 | 4.0 | 4.0 | 4.7 | 4.5 | 5.0 | 3.3 |
| | CW-D | mean | -3.6 | -6.8 | 0.5 | -0.7 | -3.5 | -3.9 | 0.5 | -0.1 |
| | (mm) | s.d. | 5.2 | 3.5 | 5.1 | 5.1 | 5.5 | 3.5 | 4.8 | 5.4 |
| | Zyg-D | mean | -1.7 | -2.5 | 0.2 | -0.2 | -1.7 | -1.2 | 0.3 | 0.1 |
| | (mm) | s.d. | 2.9 | 2.1 | 2.9 | 1.8 | 2.8 | 1.9 | 2.8 | 2.1 |
| | OS | mean | -0.7 | 0.3 | -0.6 | 0.9 | 0.1 | 0.1 | 0.1 | 1.1 |
| | (°) | s.d. | 1.3 | 1.6 | 1.5 | 1.2 | 1.5 | 1.4 | 1.9 | 1.4 |
| | Zyg | mean | -1.1 | -0.1 | -0.2 | 0.9 | 0.3 | 0.2 | 0.6 | 1.2 |
| | (°) | s.d. | 1.3 | 1.5 | 1.3 | 1.2 | 1.3 | 1.4 | 1.4 | 1.1 |
| Frontal Dental Variables | FOP | mean | -2.0 | -1.3 | 0.2 | 1.7 | 0.1 | 0.5 | 2.4 | 3.0 |
| | (°) | s.d. | 1.8 | 2.4 | 2.3 | 1.5 | 2.6 | 2.3 | 2.5 | 1.8 |
| | UC-D | mean | -2.1 | -1.7 | 1.6 | 1.3 | -1.0 | -0.3 | 2.5 | 1.6 |
| | (mm) | s.d. | 1.4 | 1.8 | 1.9 | 1.7 | 2.3 | 1.9 | 2.0 | 1.6 |
| | Mid-D | mean | -0.1 | -1.7 | 3.2 | 0.3 | 0.3 | -1.1 | 3.4 | 0.5 |
| | (mm) | s.d. | 2.6 | 1.2 | 3.0 | 1.8 | 2.6 | 1.8 | 2.4 | 1.2 |
| | U1-Mid | mean | -1.0 | 0.1 | 0.0 | 0.9 | -0.6 | 0.6 | 0.9 | 1.6 |
| | (mm) | s.d. | 1.8 | 1.8 | 1.3 | 1.3 | 1.9 | 1.8 | 1.7 | 1.1 |
| | L1-Mid | mean | -1.1 | -1.7 | 3.2 | 1.2 | -0.3 | -0.5 | 4.3 | 2.1 |
| | (mm) | s.d. | 2.5 | 2.2 | 3.0 | 2.0 | 2.3 | 1.7 | 1.8 | 1.7 |
| | L1-Axis | mean | 2.3 | 3.5 | -0.5 | -3.5 | 0.4 | -3.1 | -5.3 | -5.9 |
| | (°) | s.d. | 4.9 | 4.9 | 4.1 | 3.9 | 6.4 | 5.7 | 6.3 | 6.1 |

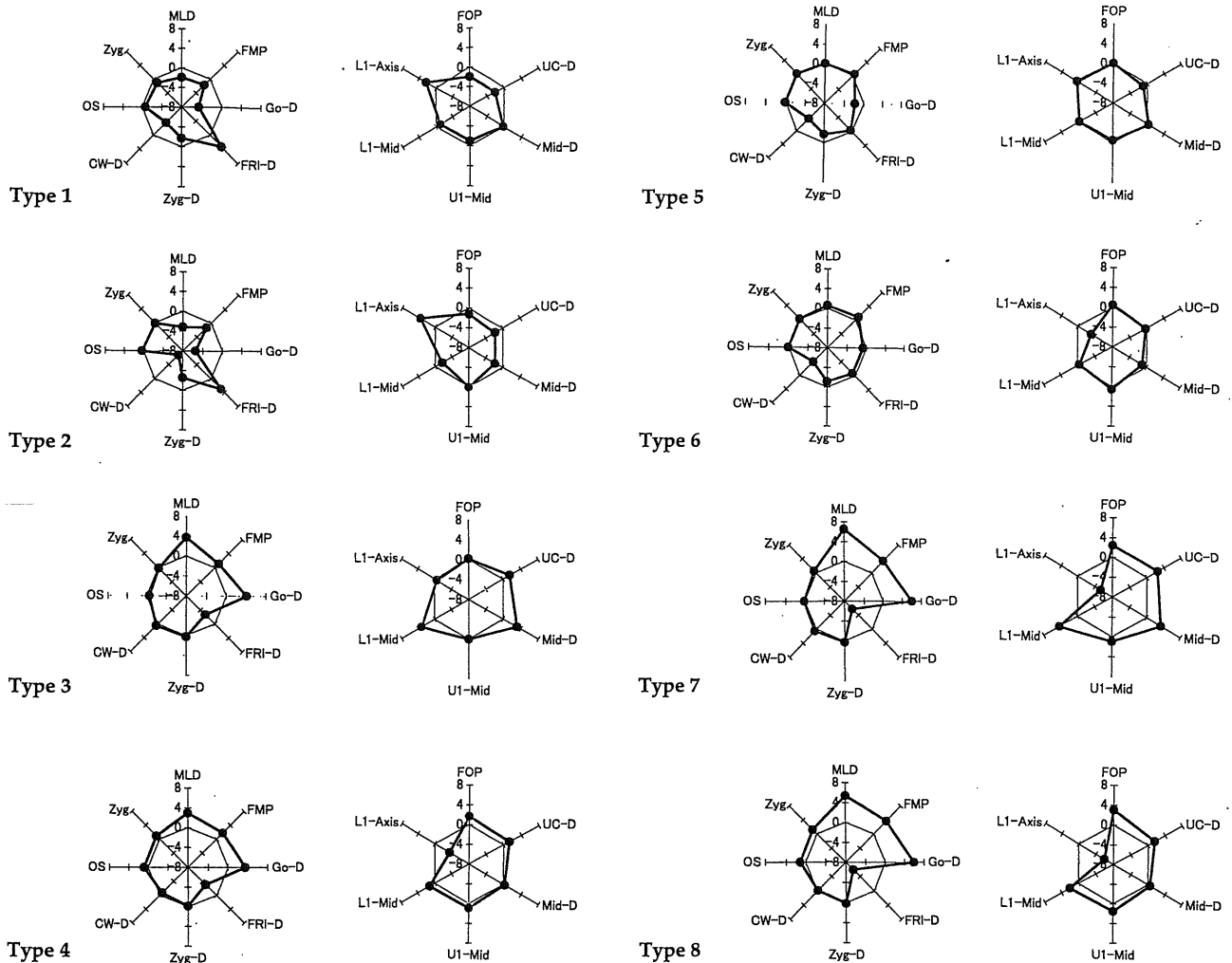


Fig. 4: Radar charts of mean value of PA cephalometric variables in eight types of facial asymmetry
The thick and thin solid lines indicate the mean values in eight types of facial asymmetry and their zero level respectively.

mandibular skeletal displacement. The lateral displacement of the lower dental midline seems to decrease due to the inclination of the lower incisors toward the opposite side of the mandibular displacement.

Midfacial asymmetry was also found in each type of facial asymmetry and was not remarkable unlike the mandibular asymmetry. In the types (Type 1, 2) with mandibular lateral displacement to the right and the types (Type 5, 6) without mandibular skeletal asymmetry, CW-D and Zyg-D are negative, indicating that the midfacial width on the right side is larger than that on the left side. On the other hand, four types (Type 3, 4, 7, 8) with mandibular lateral displacement to the left do not reveal obvious midfacial asymmetry.

For the dental characteristics, the UC-D relates positively to the MLD, indicating that the upper molar width is larger on the mandibular displaced side than that on the opposite side.

The eight types of facial asymmetry which were classified, were demonstrated to be their own characteristic morphology in each PA and lateral cephalogram. These characteristics were compared to normal craniofacial morphology in ninety-three subjects with normal occlusion. Fig. 5 shows the summary of the results of the frontal and lateral profilograms. The PA and lateral profilograms with facial asymmetry were superimposed onto those of the normal, utilizing the MRP at the CG and FH at the nasion, respectively.

Type 1: [Frontal] A mild lateral displacement of the mandible to the right side. The mid-facial width was small on the opposite side of the mandibular displacement (CW-D, Zyg-D). [Lateral] Mandibular prognathism (Pog-McN) with the counter clockwise rotation (Ram-I) was found. Dental characteristics were shown to be anterior crossbite (OJ) accompanied by lingual inclination of the lower incisor (L1-MP, FMIA) which were found

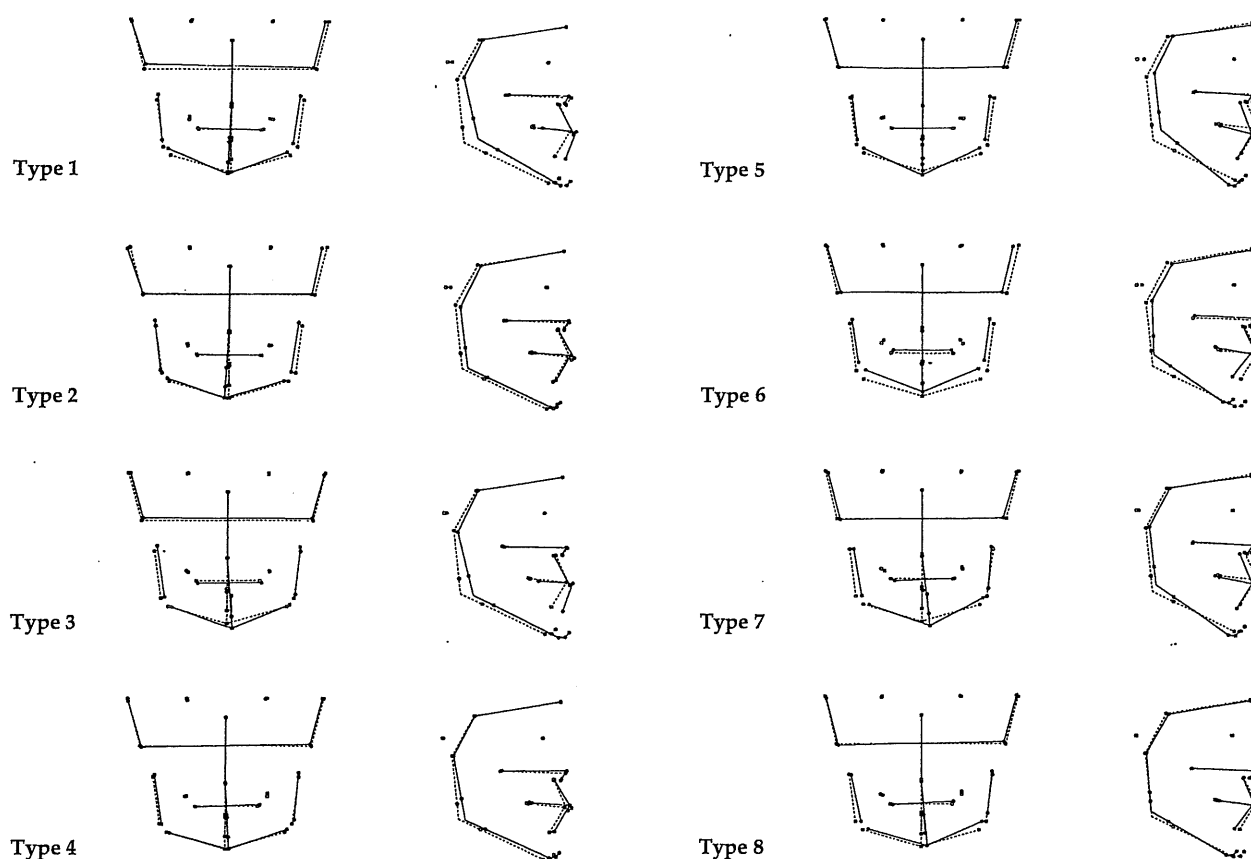


Fig. 5: Frontal and lateral profilograms in eight types of facial asymmetry

The types of facial asymmetry (solid line) were compared with normal control (dotted line).

PA and lateral profilograms were superimposed between facial asymmetry and normal, utilizing MRP at CG and FH at nasion respectively.

to be the typical characteristics in skeletal mandibular prognathism.

Type 2: [Frontal] Mild lateral displacement of the mandible to the right side. Both the right and left gonions were displaced along with the mandibular displacement and the right ramus inclined supero-medially. The midfacial width was small on the opposite side of the mandibular displacement. The lower midline was displaced to the side of the mandibular displacement with the inclination of the lower incisor to the opposite side. [Lateral] Mandibular prognathism and labial inclination of the upper incisor were found.

Type 3: [Frontal] Lateral displacement of the mandible to the left side without obvious midfacial asymmetry. The right ramus was displaced medially along with mandibular displacement. The frontal occlusal plane was flat and the lower denture midline displaced to the left side. [Lateral] A skeletal mandibular prognathism was found with the skeletal and dental characteristics similar to Type 1.

Type 4: [Frontal] A mild lateral displacement of the

mandible to the left side without obvious midfacial asymmetry. No midline discrepancy was found between the upper and lower arch. [Lateral] Labial inclination of the upper incisor and a counter clockwise rotation of the ramus were found, resulting in a bimaxillary protrusion.

Type 5: [Frontal] The midfacial width was larger on the right side with no obvious dental asymmetry and mandibular skeletal asymmetry. [Lateral] A posteriorly dislocated maxilla and mandible was found because of a small maxilla accompanied by mandibular clockwise rotation. Dental characteristic showed a steep occlusal plane.

Type 6: [Frontal] The midfacial width was larger on the right side with no obvious mandibular skeletal asymmetry. [Lateral] The facial size was generally small (ACBL, PCBL, AFH and TFH) accompanied by clockwise rotation of the mandible.

Type 7: [Frontal] Severe mandibular lateral displacement to the left side was documented without midfacial asymmetry. The lower denture midline had also shifted

to the left along with skeletal displacement and this condition seemed to be partly masked by the inclination of the lower incisor to the side opposite to that of the mandibular displacement. [Lateral] Both maxilla and mandible were displaced posteriorly with the mandible rotated in a clockwise direction. The occlusal plane was relatively steep.

Type 8: [Frontal] Severe mandibular lateral displacement to the left side was documented without midfacial asymmetry. Both upper and lower denture midlines had shifted to the mandibular displaced side, but this was more dominant in the latter. [Lateral] Mandibular retrusion was documented with a clockwise rotation. Large overjet and overbite were found with labial inclination of the lower incisor.

Discussion

To evaluate facial asymmetry in the PA cephalogram, a reference plane is a fundamental matter that should be considered. Generally, facial asymmetry is recognized by means of making a vertical line between the eyes connected to the nasal line. In PA cephalometric analysis performed by Sassouni (9), a descending line drawn from the crista galli perpendicular to a line running through the bilateral latero-orbita point was used and is referred to as a midfacial reference plane. However, it is possible for asymmetries to occur not only in the mandible but also in the mid face or cranial part, thus, reference planes which make use of bilateral points are not reliable. In this study, a line connecting the crista galli and the anterior nasal spine was used as midfacial reference plane.

For the classification of facial asymmetries, though eleven principal components were extracted, three major components were selected because the contribution rate of each component was over ten percent. Factor-1, factor-2, and factor-3 indicate the antero-posterior position and size of the mandible, facial asymmetry, overjet and tooth axis of the lower incisor, respectively. Since the sample was collected as one with an obvious facial asymmetry, it was considered to be reasonable that factor-1 would reflect facial asymmetry. Clinically, most facial asymmetry shows a molar relationship of Angle's Class II or III unilaterally. Thus, most cases of asymmetry may contain a skeletal problem in the lateral projection, either mandibular prognathism or retrognathism. This seems to be the reason why the factor interpreting the characteristics in the lateral cephalogram is factor-1.

In this study, the facial asymmetry sample was classified into eight types. As for the midfacial asymmetry, Type 1 and 2 showed mandibular lateral displacement to the right side while Type 5 and 6 showed no obvious mandibular displacement, the left midfacial width was smaller than the right one (CW-D, Zyg-D) and no obvious vertical deviation was found on the mid face (OS, Zyg). Kondo reported on facial asymmetry in Japanese

with normal occlusion and stated that the cranial width on the right side was larger than on the left side (21). In previous studies by Hylander in which the load around the temporomandibular joint was examined using monkeys, it was reported that the load varied rhythmically during mastication and was remarkably different between on the working side and on the non working side (22, 23). It was reported that facial asymmetry exhibited not only a morphological problem but also asymmetrical function for the masticatory muscle activity (2) and the mandibular movement (3). Therefore an asymmetry in oral function may induce a right and left difference in the functional load, consequently the craniofacial skeleton might be distorted.

Midfacial asymmetry was considered not so remarkable as mandibular asymmetry. Our preliminary study on facial asymmetry in a general population suggests that facial asymmetry during growth worsen due to mandibular lateral displacement. This is not the result of midfacial asymmetry and this is in agreement with the present study.

Mandibular lateral displacement was considered to be an essential skeletal problem in facial asymmetry. The mandible was displaced to the left side in four types (Type 3, 4, 7, 8), to the right side in two types (Type 1, 2) and no displacement was found in the remaining two types (Type 5, 6). The value of MLD ranged from -10.04 degrees to 13.66 degrees with a mean value of 1.70 degrees. Therefore, the samples used in this study reveal a predominant left mandibular displacement. In previous studies done in a Japanese population, it was reported that a mandibular deviation to the left side was more prevalent than that to the right side (24, 25). On the other hand, in a Caucasian sample, it was shown that a right sided mandibular displacement was more common (17, 26, 27). Global investigation seems to be necessary to clarify whether race difference relates to the direction of mandibular displacement.

Six types of facial asymmetry show mandibular displacement. Except for Type 5 and Type 6, some common findings relating to the skeletal characteristics were recognized. In facial asymmetry accompanied with a mandibular lateral displacement, the skeletal characteristics reveal that the ramus height was shorter (FMP), facial width at the gonion level (Go-D) was larger and the ramus was inclined more supero-medially (FRI-D) on the mandibular displaced side than on the opposite side.

In most types of mandibular lateral displacement, several common dental characteristics were shown. The lower denture midline (L1-Mid) deviated toward the ipsilateral side of the mandibular lateral displacement. The frontal occlusal plane (FOP) ascended toward the mandibular displaced side, indicating that the upper molar height is shorter on the mandibular displaced side

than the opposite side. The upper arch width at the molar level (UC-D) was larger on the mandibular displaced side than that of the opposite side. These findings were confirmed in a study by means of three-dimensional measurement of cast models on an articulator (28). Inui *et al.* investigated molar relationships in cases with facial asymmetry (6). It was concluded that lower molars occlude more distally against the upper molar on the mandibular displaced side than on the opposite side. It was also suggested that the dental characteristics demonstrated in a facial asymmetry are not due to dental dislocation on the alveolar bone but mainly due to skeletal mandibular displacement.

In a case report for class II division 1 with mandibular asymmetry, similar occlusal characteristics for the asymmetry of upper arch width and canted frontal occlusal plane were found, and it was suggested that during growth the correction of such dental asymmetry could still cause the face to become symmetrical (29). In a study using animals, McNamara (30) reported that excessive growth of the condyle was found after applying a metal splint designated to displace the condyle anteriorly in the glenoid fossa, accompanied with muscular adaptation. This result suggests that the condylar displacement induces adaptive bone growth in TMJ. Owen (16) stated that it was not uncommon to see either anterior or posterior condylar displacement or both on patients with a horizontal dental problem exemplified by a posterior crossbite.

In this study, the frontal occlusal plane was an essential factor in the mandibular lateral displacement. Since the inclination of the frontal occlusal plane was due to the reduced occlusal height of the upper molar on the mandibular displaced side or an increased height of the upper molar on the opposite side, it is possible that the vertical problem contributes to condylar displacement in the mandibular fossa. The difference in the vertical height of the right and left upper molar may create an occlusal fulcrum on the higher posterior molar. In model studies reproducing such a situation, it was demonstrated that the bite force brings a distractive load against the TMJ on the fulcrum side and a compressive force against the TMJ on the opposite side (31, 32). Therefore, during the growth period, it is hypothesized that a continuous tilting of the frontal occlusal plane induces condylar displacement in the fossa thus loading the TMJ asymmetrically, thereby leads to asymmetrical condylar growth.

The cant of the frontal mandibular plane (FMP) shows a strong relationship with the FOP and MLD, indicating that the vertical growth of the ramus is excessive on the descending side of the frontal occlusal plane or suppressed on the ascending side. Therefore, this supports the above mentioned hypothesis that the devia-

tion of the mandibular posture is accompanied by a change in the frontal occlusal plane.

The correction of dental asymmetries can also be carried out by means of orthognathic surgery. When orthognathic surgery is performed, the mandible is fixed into a normal occlusal relationship against the maxillary arch. If the transverse location of maxillary arch is not corrected symmetrically in pre-surgical orthodontic treatment, the mandible will be fixed into an asymmetric position after surgery. If the correction of canted frontal occlusal plane is not achieved, lateral deviation of the chin point (skeletal midline) will remain despite of the correction of denture midline. It is strongly suggested that in the treatment of a facial asymmetry, careful assessment of both dental and skeletal asymmetries should be considered.

With regards to the denture midline, four of the eight types of facial asymmetries showed a small upper midline deviation (U1-Mid) to the mandibular displaced side (less than 1.6 mm). While the lower midline (L1-Mid) showed a greater deviation along with a degree of mandibular lateral displacement. This result suggests that lateral deviation of the lower denture midline is not due to displacement of the lower incisor, but rather to skeletal lateral displacement of the mandible. On the other hand, in most types with mandibular lateral displacement, the lower incisor tends to incline toward the opposite side of the mandibular displacement (L1-Axis), and this contributes to a reduced displacement of the lower denture midline toward the ipsilateral side of the skeletal displacement. Clinically, these results indicate that skeletal mandibular displacement should be considered even if lateral displacement of the lower midline is not so remarkable.

Facial asymmetry with regard to lateral skeletal morphology was divided into four types. These are skeletal mandibular prognathism (Type 1, 3), upper protrusion (large OJ) with clockwise rotation of the mandible (Type 6, 8), both maxillary and mandibular retrognathism with large anterior facial height (Type 5, 7) and bimaxillary protrusion (Type 2, 4). Facial asymmetry is easily recognized in patients with a mandibular prognathism. Therefore, most treatment of facial asymmetry, including orthognathic surgery, has been done only in these cases. Several studies have also reported on the same occurrence (33-35). In this study, it was demonstrated that a facial asymmetry was a morphological characteristic not only found in mandibular prognathism but also in a variety of skeletal types, for instance in mandibular retrognathism. In patients with facial asymmetry, it is important to make a comprehensive treatment plan depending on their own skeletal type.

References

- Proffit, W.R. and White, R.P. Jr. (1991). Surgical-orthodontic treatment. St. Louis, Mosby Press, 483-549.
- Akimoto, S., Fushima, K., Sato, S. and Suzuki, Y. (1995). Masticatory muscle activity of the Facial asymmetry cases - Effects of the different combination of bite blocks-. *J. Jpn. Orthod. Soc.* **54**: 436-40. (in Japanese)
- Fushima, K., Sato, S. and Suzuki, Y. (1992). The analysis of condylar pathway in mandibular lateral displacement cases. *J. Jpn. Soc. Stomatognath. Funct.* **10**: 77-86. (in Japanese)
- Fushima, K., Akimoto, S., Takamoto, K., et al. (1989). Incidence of temporomandibular joint disorders in patients with malocclusion. *J. Jpn. Soc. TMJ.* **1**: 40-50. (in Japanese)
- Fushima, K., Akimoto, S., Takamoto, K., et al. (1989). Morphological feature and incidence of TMJ disorders in mandibular lateral displacement cases. *J. Jpn. Orthod. Soc.* **48**: 322-8. (in Japanese)
- Inui, M., Fushima, K. and Sato, S. (1994). Facial asymmetry in internal derangement of temporomandibular joint disorders. *Euro. J. Orthod.* **16**: 456 (Abstracts).
- Woods, G.A. (1950). Changes in width dimensions between certain teeth and facial asymmetry. *Am J Orthod.* **36**: 676-700.
- Letzer, G.M. and Kronman, J.H. (1967). A postero-anterior cephalometric evaluation of craniofacial asymmetry. *Angle Orthod.* **37**: 205-211.
- Sassouni, V. (1971). Orthodontics in dental practice. 1st ed. St. Louis, Mosby Press, pp. 325-355.
- Vig, P.S. and Hewitt, A.B. (1975). Asymmetry of the human facial skeleton. *Angle Orthod.* **45**: 125-129.
- Chebib, F.S. and Chamma, A.M. (1981). Indices of cranio facial asymmetry. *Angle Orthod.* **51**: 214-226.
- Grummons, D.C. and Kappeyne, M.A.C. (1987). A frontal asymmetry analysis. *J. Clin. Orthod.* **21**: 448-465.
- Araujo, T.M., Wilhelm, R.S. and Almeida, M.A. (1994). Skeletal and dental arch asymmetries in individuals with normal dental occlusions. *Int. J. Adult Orthognath. Surg.* **9**: 111-118.
- O'byrn, B.L., Sadowsky, C., Schneider, B. and BeGole, E. (1995). An evaluation of mandibular asymmetry in adults with unilateral posterior crossbite. *Am. J. Orthod. Dentofac. Orthop.* **107**: 394-400.
- Williamson, E.H. and Simmons, M.D. (1979) Mandibular asymmetry and its relation to pain dysfunction. *Am. J. Orthod.* **76**: 6: 612-617.
- Owen, A.H. III. (1985) Orthodontic / orthopedic treatment of craniomandibular pain dysfunction Part 4 :Unilateral and bilateral crossbite. *Cranio* **3**: 146-161.
- Melnik, A.K. (1992). A cephalometric study of mandibular asymmetry in a longitudinally followed sample of growing children. *Am. J. Orthod. Dentofac. Orthop.* **101**: 355-366.
- Marsh, J.L. and Vannier, M.W. (1983). The "Third" dimension in craniofacial surgery. *Plast. Reconstr. Surg.* **71**: 759-767.
- Ono, I., Ohura, T., Kimura, C., et al. (1989). Three-dimensional analysis of craniofacial bones using three-dimensional computer tomograph. *J. Jpn. Plast. Reconstr. Surg.* **9**: 663-675. (in Japanese)
- Alavi, D.G., BeGole, E.A. and Schneider, B.J. (1988). Facial and dental arch asymmetries in class III subdivision malocclusion. *Am. J. Orthod. Dentofac. Orthop.* **93**: 38-46.
- Kondo, E. (1972). Posteroanterior cephalometric study of craniofacial and arch widths. *J. Jpn. Orthod. Soc.* **31**: 117-136. (in Japanese)
- Hylander, W.L. (1977). In vivo bone strain in the mandible of galago crassicaudatus. *Am. J. Phys. Anthropol.* **46**: 309-326.
- Hylander, W.L. (1979). An experimental analysis of temporomandibular joint reaction force in macaques. *Am. J. Phys. Anthropol.* **51**: 433-456.
- Maruyama, T., Kotani, M., Fujii, Y., Nishida, N. and Miyauti, S. (1981). Analysis of the mandibular position in the dysfunction of stomatognathic system. *J. Jpn. Prosthet. Dent.* **25**: 2: 165-168. (in Japanese)
- Kurihara, K., Fujita, Y. and Soma, K. (1994). An investigation into the relationship between temporomandibular disorders and mandibular lateral displacement in patients with malocclusion -Sampling of orthodontic patients-. *J. Jpn. Soc. TMJ* **6**: 3: 196-207. (in Japanese)
- Williamson, E.H. and Simmons, M.D. (1979). Mandibular asymmetry and its relation to pain dysfunction. *Am. J. Orthod.* **76**: 612-617.
- Pirttiniemi, P. and Kantomaa, T. (1992). Relation of glenoid fossa morphology to mandibulofacial asymmetry, studied in dry human Lapp skulls. *Acta Odontol. Scand.* **50**: 235-243.
- Fushima, K., Odaira, Y. and Saito, N. et al. (1998). Dental asymmetry in facial asymmetry. *Bull. Kanagawa Dent. Col.* **26**: 15-21.
- Fushima, K., Sato, S. and Suzuki, Y. (1993). The orthodontic correction of a Class II deep overbite case with mandibular skeletal asymmetry. *Jpn. J. Orthod. Soc.* **52**: 593-605. (in Japanese)
- McNamara, J.A. (1975). Functional adaptation in the temporomandibular joint. *Dent. Clin. North Am.* **19**: 457-471.
- Hatcher, D.C., Faulkner, M.G. and Hay, A. (1986). Development of mechanical and mathematic models to study temporomandibular joint loading. *J. Prosthet. Dent.* **55**: 377-384.
- Ito, I., Gibbs, C.H., Marguelles-Bonnet, R., Lupkiewicz, S.M., et al. (1986). Loading on the temporomandibular joint with five occlusal conditions. *J. Prosthet. Dent.* **56**: 478-484.
- Kaji, E. (1976). Postero-Anterior cephalometric study of mandibular protrusions-Especially on their facial asymmetries-. *Shigaku* **64**: 3: 465-487. (in Japanese)
- Yailen, D.M. (1994). Correction of mandibular asymmetric prognathism. *Angle Orthod.* **64**: 2: 99-104.
- Baker, R.W. Jr., Subtelny, J.D., and Iranpour B. (1991). Correction of class III mandibular prognathism and asymmetry through orthodontics and orthognathic surgery. *Am. J. Orthod. Dentofac. Orthop.* **99**: 191-201.

