Okajimas Folia Anat. Jpn., 96(1): 31–46, May, 2019

Factors influencing dental arch form

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– Received for Publication, April 3, 2019 –

Key Words: Factor; dental arch form; arch length; incisor; premolar

Summary: Dental arch length, bilateral intermolar distance, morphology of the anterior teeth, and bilateral intercanine distance have been reported as factors influencing the determination of dental arch form. However, studies evaluating the factors that influence the determination of the above-mentioned components are limited. Therefore, to verify these points, the present study aimed to examine factors influencing the determination of dental arch form using statistical methods.

Data obtained from sample dental casts were analyzed using principal component and cluster analyses. By principal component analysis, 23 sets of information were summarized into three components for the maxilla and four for the mandible. As a result of cluster analysis using principal component scores, the maxillary and mandibular dental arches were classified into four forms, respectively.

Dental arch length is an important indicator of dental arch size and is influenced by the bilateral interincisor distance of the maxilla and mandible, and the mesiodistal crown width of the incisors and premolars. In the mandible, canine width also affects dental arch length. Dental arch width also influences the determination of dental arch form. However, the distance between the anterior teeth and the distance between the molars are independent and have no effect on each other.

Introduction

Dental arch forms differ among individuals and their complexity has made them the subject of several morphological studies[1–16]. Accordingly, researchers have been exploring the factors that determine dental arch forms[17–27]. Clarifying these factors is expected to aid in formulating therapeutic regimens for determining arch forms for orthodontic treatment[28–31], predicting treatment courses by considering infantile growth, creating artificial dentures for multiple lost teeth, performing maxillofacial prosthetic surgery, and placing implants.

Previously, Sekikawa[19] has conducted an analysis of maxillary arch forms using a Fourier series and reported that arch forms are characterized by the size of the dental arches, ratio of the dental arch length to its width, and squareness of the dental arches. Similar to Sekikawa[19], Mikami et al.[23] have conducted a similar analysis using different analytical items and observed that dental arch forms are characterized by the size and shape of the dental arches, ratio of dental arch length to its width, curvature of the anterior teeth, and shape of the transition site from the anterior to posterior teeth.

Nakatsuka et al.[24, 25] have conducted a cluster analysis of the dental arches and identified three factors that determine dental arch forms: the arch width, arch length, and anterior teeth shape. Similarly, studies based on factor analysis have suggested that dental arch forms are determined by the curvature of the anterior teeth, arch length, and arch width in the maxilla and the curvature of the anterior teeth, opening of the dentition, and size of the dental arches in the mandible. The possibility that the placement of the canines and intercanine width have a substantial impact on the morphology of dental arch forms has been suggested[26, 27]. In this regard, Nakajima et al.[28] have postulated that intercanine width represents the protrusion of the dental arches. Nodai et al.[32] have stated that intercanine width is the most prominent factor that determines arch forms. Moreover, Horiike et al.[33] have reported that the placement of the canines affects the protrusion of the anterior teeth and the morphology of the posterior teeth.

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However, the eruption of the canines often occurs later than that of the premolars in the maxilla, whereas in the mandible, the placement of the canines is dependent on the morphology of the mandibular bone and the development of masticatory muscles, which further affect dental arch forms. Therefore, factors other than the canines are considered to be possibly involved in the determination of dental arch forms.

Considering the aforementioned aspects, the present study explored the factors that determine the dental arch length and width. We measured the width between the bilateral corresponding teeth, distance from the central incisor, and mesiodistal crown width of each tooth, body height and so on. Data obtained was condensed using principal component analysis (PCA), following which cluster analysis was performed to evaluate the morphological characteristics of each cluster based on the condensed data. The present study explored factors that affect the morphology of the dental arches and those that determine arch length and width and hereby report the novel findings obtained.

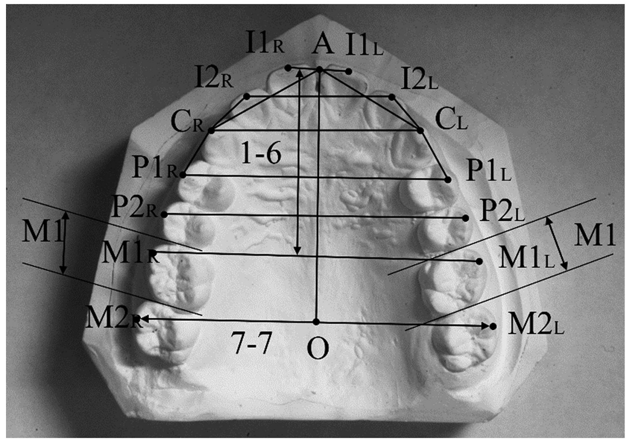

Fig. 1. Measurement points, lines, and angles.

Materials and Methods

The present study conformed to the principles of the Declaration of Helsinki Ethical Principles for Medical Research (1964). The protocol (No. 050507: Morphological Analysis of dental arches) was approved by the Ethic Review Board of Osaka Dental University.

1. Materials

In the study, 396 paired maxillary and mandibular dental casts of young adult students (18 to 26 years old; male: 257, female: 139) at Osaka Dental University (occlusal plane: 30 mm from the mandibular basal plane; distance between the maxillary and mandibular basal planes in occlusal condition: 60 mm) were prepared. In accordance with the previous studies[21–27], we selected 62 sets of maxillary dental arches (male: 36; female: 26), and 53 mandibular dental arches (27 males and 26 females) with normal dentition and occlusion, and dental arches of the standardized casts were investigated for the present analyses.

2. Methods

1) Classification of dental arches and measurement points

As per the methods employed by Sekikawa[19] and that in our previous studies[21–27], a total of 16 points were established. These were the midpoints of the bilateral incisor edges, cusp tips of the canines, buccal cusps of the premolars, mesiobuccal cusps of the molar teeth excluding the third ones, and others (Fig. 1).

a) Midpoints of incisor edges: $I1_R$, $I1_L$, $I2_R$, $I2_L$
b) Cusp tips of the canines: C_R, C_L
c) Buccal cusp tips of the premolars: $P1_R$, $P1_L$, $P2_R$, $P2_L$
d) Mesiobuccal cusp tips of the molar teeth: $M1_R$, $M1_L$, $M2_R$, $M2_L$
e) Midpoint of $I1_R$–$I1_L$: A
f) Midpoint of $M2_R$–$M2_L$: O

2) Imaging procedure

In accordance with the methods employed in our previous studies[21–27], a digital camera (D100, Nikon) fitted with a proprietary lens (AF MICRO NIKKOR 70–180 mm 1:4.5–5.6 D; Nikon, Tokyo, Japan) was attached to a stand (King Copy Stand L4; Asanuma, Tokyo, Japan) ensuring that the long axis of the lens was perpendicular to the occlusal plane. To equalize actual measured values with estimated values on photographs, the focal length was set at 70 mm, the aperture f was set at 29, and the distance between the occlusal plane and the principal point of the lens was set at 310 mm. Image data was imported into a computer (DELL Optiplex GX200, Dell Computer, Kanagawa, Japan), processed using image processing software (Adobe Photoshop 5.0 LE and Adobe PageMaker 6.5J, Adobe Systems, CA, USA), and printed at actual size (LP-8300C, Epson, Nagano, Japan).

3) Items

As per the methods employed in our previous studies[21–27], a total of 23 measurement items, including body height, were established. All measurements were expressed as mm.

a) Body height
b) Width between bilateral corresponding teeth: 1-1, 2-2, 3-3, 4-4, 5-5, 6-6, and 7-7
c) Line segment extending from A toward O: A-O
d) Distances from A to each crosspoint that A-O intersect with 2-2, 3-3, 4-4, 5-5, and 6-6: 1-2, 1-3, 1-4, 1-5, and 1-6
e) Mean of the bilateral mesiodistal crown width of each

tooth: I1, I2, C, P1, P2, M1, M2

f) Angle obtained on connecting C_R, A, and C_L: C_R-A-C_L

g) Mean of the angle obtained on connecting $I2_R$, C_R, and $P1_R$ and the angle obtained on connecting $I2_L$, C_L, and $P1_L$: I2-C-P1

4) Analysis

As per the methods employed in our previous studies[21–27], the means and standard errors were calculated for the aforementioned 23 items in both the maxilla and mandible. Thereafter, the correlation coefficients between items were calculated. Based on the items established, the obtained data was standardized for both the maxilla and mandible, and PCA was performed. Subsequently, principal components scores (PCS) obtained from the PCA were subjected to cluster analysis for both the maxilla and mandible. Finally, to verify the validity of the clustering, another cluster analysis was performed using the standardized data prior to the PCA, and the Rand index (Ri, an external validity index) was calculated.

To determine the correlation coefficients and perform PCA/cluster analysis, BellCurve for Excel (Social Survey Research Information Co., Ltd., Tokyo, JAPAN) was used. In the study, the strength of correlation was represented using correlation coefficients as follows:

a) Strong correlation: ±0.7 − ±1
b) Moderate correlation: ±0.4 − ±0.7
c) Weak correlation: ±0.2 − ±0.4
d) No apparent correlation: 0 − ±0.2

5) Principal component analysis (PCA)

PCA is a process of condensing multidimensional data for analysis into few datasets and simultaneously minimizing the loss of relevant information as much as possible[34, 35]. This analytical method is useful in establishing comprehensive indices that incorporate multiple indices and grouping observation subjects. In the present study, the items established on the dental arches were treated as variables for PCA[34, 35]. In accordance with the methods employed in a previous study[22], 23 variables were condensed into principal components until the cumulative contribution ratio first exceeded 70%[34, 35]. To eliminate differences in units, PCA was performed after the data was standardized. For standardization, each dataset was subtracted by the mean and divided by standard deviation.

6) Cluster Analysis

Regarding principal components (3 for the maxilla and 4 for the mandible) derived from the PCA, cluster analysis was performed using PCS. In accordance with methods employed in previous studies[24, 25], agglomerative hierarchical clustering was performed. For intercluster distance, the standardized Euclidean distance was used. In the present study, Ward's method was used.

7) Rand index (Ri)

The Ri evaluates the validity of classifications by comparing two clustering results for the same dataset X[36]. We investigated whether all pairs (x1; x2 $\in$ X (x1 $\neq$ x2); x: data, X: data set) in the dataset were within the identical cluster for the two clustering results, and the ratio of corresponding pairs was calculated. The Ri value ranges between 0 and 1, and a value closer to 1 is considered better. The number of pairs was represented as M; the number of pairs that were in the same cluster for both clustering results were presented as a11, whereas the number of pairs that were in different clusters for both clustering results as a00. Ri is expressed using the following formula:

$$R = (a11 + a00)/M$$

Results

1. Means and correlation coefficients of respective items (maxilla/mandible shown separately) (Table 1A and 1B)

Table 1A and 1B show the means and correlation coefficients of the respective items, with data for the maxilla and mandible presented separately. The values with a correlation coefficient of ≥ 0.7 when rounded off to the first decimal place are shown in bold font.

In the maxilla, all correlation coefficients were ≥ 0.6 for the distance between 1-1 and 1-4, 1-5, 1-6, and A-O ($p < 0.01$, Table 1A). Moderate positive correlations were observed between 1-1 and 1-2, 1-3, and I1 ($p < 0.01$). However, a moderate positive correlation was observed only for 2-2 in terms of the width between the bilateral corresponding teeth—hardly any correlations were observed for 3-3, 4-4, 5-5, 6-6, and 7-7. In the mandible, a strong positive correlation was noted between 1-1 and 2-2 ($p < 0.01$), and a moderate positive correlation between 1-1 and 3-3, 4-4, 1-3, 1-4, 1-5, 1-6, A-O, I1, and I2 ($p < 0.01$, Table 1B). This strong positive correlation between 1-1 and 2-2 and moderate positive correlation between 1-1 and 3-3 and 4-4 were not observed in the maxilla. However, similar to that in the maxilla, the mandible exhibited hardly any correlation between 1-1 and 6-6 and 7-7. In the maxilla, there was a moderate positive correlation between 1-1 and 1-2, whereas hardly any correlation was observed in the mandible.

In the maxilla, there was a strong positive correlation between 2-2 and 3-3 and a moderate positive correlation with 4-4, 5-5, 1-6, A-O, and I1 ($p < 0.01$, Table 1A), whereas in the mandible, there was a strong positive correlation with I1 and a moderate positive correlation with 3-3, 4-4, 1-5, 1-6, A-O, and I2 ($p < 0.01$, Table 1B).

In the maxilla, a strong positive correlation between 3-3 and 4-4 and a moderate positive correlation with 5-5, 6-6, I1, I2, C, P1, P2, and M2 ($p < 0.01$) were observed (Table 1A), whereas in the mandible, a strong positive

Table 1A. The means and correlation coefficients of measuring data: maxilla.

Variable	Body height	1-1	2-2	3-3	4-4	5-5	6-6	7-7	1-2	1-3	1-4	1-5	1-6	A-O	I1	I2	C	P1	P2	M1	M2	C_R-A-C_L	I2-C-P1
Body height	1.00	0.11	−0.05	−0.05	0.04	0.15	0.24	0.30*	0.17	0.10	0.12	0.09	0.08	0.05	0.26*	0.04	0.24	0.25*	0.12	0.08	0.21	−0.12	−0.09
1-1		1.00	0.46**	0.25	0.26*	0.16	0.12	0.02	0.58**	0.59**	0.61**	0.63**	0.61**	0.61**	0.64**	0.31*	0.36**	0.35**	0.47**	0.38**	0.32*	−0.45**	0.27*
2-2			1.00	**0.76****	0.68**	0.55**	0.37**	0.29*	0.01	0.20	0.30*	0.37**	0.41**	0.43**	0.57**	0.39**	0.29*	0.35**	0.36**	0.35**	0.31*	0.07	0.11
3-3				1.00	**0.85****	0.67**	0.48**	0.30*	−0.04	−0.03	0.14	0.25*	0.37**	0.39**	0.51**	0.46**	0.44**	0.46**	0.44**	0.34**	0.41**	0.33**	−0.36**
4-4					1.00	**0.83****	0.66**	0.47**	−0.12	−0.12	0.00	0.11	0.22	0.24	0.48**	0.34**	0.42**	0.42**	0.41**	0.34**	0.29*	0.39**	−0.10
5-5						1.00	**0.83****	0.64**	−0.18	−0.12	−0.07	−0.02	0.07	0.12	0.39**	0.24	0.40**	0.40**	0.36**	0.31*	0.29*	0.31*	0.07
6-6							1.00	**0.79****	−0.21	−0.14	−0.16	−0.16	−0.08	−0.04	0.30*	0.12	0.36**	0.33**	0.24	0.30*	0.20	0.26*	0.12
7-7								1.00	−0.16	−0.10	−0.11	−0.12	−0.09	−0.13	0.29*	0.07	0.28*	0.27*	0.14	0.27*	0.17	0.17	0.14
1-2									1.00	**0.80****	**0.82****	**0.79****	**0.73****	0.67**	0.48**	0.46**	0.37**	0.37**	0.41**	0.26*	0.34**	**−0.80****	0.13
1-3										1.00	**0.90****	**0.84****	**0.76****	0.69**	0.42**	0.53**	0.41**	0.31*	0.37**	0.25*	0.22	**−0.92****	0.46**
1-4											1.00	**0.96****	**0.92****	**0.87****	0.57**	0.62**	0.54**	0.49**	0.53**	0.39**	0.34**	**−0.83****	0.24**
1-5												1.00	**0.97****	**0.93****	0.61**	0.66**	0.58**	0.61**	0.65**	0.44**	0.39**	**−0.73****	0.15
1-6													1.00	**0.97****	0.61**	0.68**	0.66**	0.64**	**0.71****	0.50**	0.44**	−0.64**	0.09
A-O														1.00	0.62**	0.62**	0.66**	0.67**	**0.72****	0.60**	0.47**	−0.57**	0.05
I1															1.00	0.54**	0.52**	0.55**	0.54**	0.53**	0.52**	−0.27*	0.03
I2																1.00	0.44**	0.57**	0.59**	0.27*	0.30*	−0.40**	0.06
C																	1.00	0.65**	0.61**	0.47**	0.35**	−0.27*	−0.05
P1																		1.00	**0.74****	0.46**	0.35**	−0.20	−0.13
P2																			1.00	0.48**	0.45**	−0.24	0.00
M1																				1.00	0.49**	−0.16	0.08
M2																					1.00	−0.07	−0.23
C_R-A-C_L																						1.00	−0.53**
I2-C-P1																							1.00
Mean±SE	1667.10 ±11.37	8.96 ±0.09	23.75 ±0.17	35.76 ±0.26	44.53 ±0.29	50.44 ±0.34	55.22 ±0.34	61.11 ±0.44	3.89 ±0.12	8.59 ±0.19	16.23 ±0.21	23.11 ±0.26	29.24 ±0.30	40.18 ±0.33	8.62 ±0.06	7.29 ±0.06	8.02 ±0.06	7.53 ±0.05	7.13 ±0.05	10.67 ±0.06	9.99 ±0.07	128.95 ±1.04	314.95 ±2.03

** $p < .01$, * $p < .05$

Table 1B. The means and correlation coefficients of measuring data: mandible.

Variable	Body height	1-1	2-2	3-3	4-4	5-5	6-6	7-7	1-2	1-3	1-4	1-5	1-6	A-O	I1	I2	C	P1	P2	M1	M2	C_R-A-C_L	I2-C-P1
Body height	1.00	−0.06	−0.12	0.04	−0.06	0.08	0.20	0.32*	0.33*	0.41**	0.40**	0.38**	0.32*	0.27	−0.04	0.05	0.31*	0.18	0.18	0.23	0.50**	−0.32*	0.00
1-1		1.00	**0.79****	0.52**	0.42**	0.35**	0.10	0.03	0.15	0.45**	0.42**	0.51**	0.51**	0.57**	**0.70****	0.42**	0.34*	0.39**	0.31*	0.32*	0.22	−0.21	0.19
2-2			1.00	0.63**	0.51**	0.37**	0.12	−0.02	−0.06	0.32*	0.33*	0.44**	0.48**	0.56**	**0.73****	0.54**	0.33*	0.37**	0.39**	0.22	0.10	−0.10	0.21
3-3				1.00	**0.79****	0.64**	0.39**	0.31*	0.15	0.09	0.16	0.36**	0.42**	0.45**	0.54**	0.62**	0.40**	0.45**	0.42**	0.24	0.16	0.25	−0.23
4-4					1.00	**0.78****	0.47**	0.37**	0.00	−0.05	−0.16	0.11	0.19	0.28*	0.41**	0.54**	0.34*	0.48**	0.35**	0.33*	0.14	0.34*	0.13
5-5						1.00	**0.76****	0.54**	0.02	0.07	−0.03	0.08	0.15	0.24	0.33*	0.41**	0.35**	0.51**	0.37**	0.30*	0.14	0.20	0.07
6-6							1.00	**0.71****	0.02	0.05	−0.06	−0.01	0.00	0.08	0.17	0.31*	0.26	0.36**	0.29*	0.35*	0.18	0.12	0.03
7-7								1.00	0.03	−0.03	−0.06	0.00	0.01	−0.01	−0.02	0.14	0.17	0.29*	0.22	0.32*	0.33*	0.12	−0.03
1-2									1.00	0.54**	0.54**	0.56**	0.53**	0.46**	0.25	0.27	0.18	0.36**	0.29*	0.26	0.42**	−0.41**	−0.19
1-3										1.00	**0.86****	**0.80****	**0.71****	**0.70****	0.36**	0.24	0.45**	0.35**	0.27	0.29*	0.37**	**−0.85****	0.33*
1-4											1.00	**0.93****	**0.87****	**0.81****	0.46**	0.31*	0.53**	0.46**	0.43**	0.29*	0.45**	**−0.75****	−0.03
1-5												1.00	**0.97****	**0.92****	0.60**	0.50**	0.65**	0.60**	0.59**	0.45**	0.52**	−0.64**	−0.03
1-6													1.00	**0.95****	0.64**	0.56**	**0.70****	0.65**	**0.70****	0.53**	0.55**	−0.55**	−0.04
A-O														1.00	0.68**	0.60**	**0.72****	0.69**	**0.72****	0.65**	0.52**	−0.51**	0.03
I1															1.00	0.61**	0.45**	0.58**	0.49**	0.37**	0.18	−0.16	0.05
I2																1.00	0.46**	0.58**	0.60**	0.40**	0.37**	−0.03	−0.06
C																	1.00	0.59**	0.58**	0.48**	0.48**	−0.30*	−0.01
P1																		1.00	0.65**	0.53**	0.42**	−0.14	−0.06
P2																			1.00	0.62**	0.54**	−0.16	−0.09
M1																				1.00	0.53**	−0.22	0.15
M2																					1.00	−0.32*	0.04
C_R-A-C_L																						1.00	−0.38**
I2-C-P1																							1.00
Mean±SE	1666.79 ±12.69	5.73 ±0.07	17.05 ±0.16	27.81 ±0.23	36.21 ±0.34	41.55 ±0.34	46.27 ±0.31	51.96 ±0.42	1.72 ±0.09	5.16 ±0.13	11.62 ±0.21	18.63 ±0.24	24.80 ±0.30	36.13 ±0.35	5.78 ±0.04	6.40 ±0.05	7.16 ±0.06	7.51 ±0.05	7.63 ±0.07	11.56 ±0.09	10.91 ±0.09	138.51 ±1.10	313.02 ±2.64

** $p < .01$, * $p < .05$

correlation with 4-4 and a moderate positive correlation with 5-5, 1-6, A-O, I1, I2, C, P1, and P2 ($p < 0.01$) were observed (Table 1B).

In the maxilla, there was a strong positive correlation between 4-4 and 5-5 and a moderate positive correlation with 6-6, 7-7, I1, C, P1, and P2 ($p < 0.01$, Table 1A), and in the mandible, there was strong positive correlation with 5-5 and moderate positive correlation with 6-6, I1, I2, and P1 ($p < 0.01$, Table 1B).

In the maxilla, 5-5 exhibited a strong positive correlation with 6-6 and moderate positive correlations with 7-7 and C (Table 1A). Moreover, there was a strong positive correlation between 6-6 and 7-7. In the mandible, a strong positive correlation between 5-5 and 6-6 ($p < 0.01$) and a moderate positive correlation with 7-7 and P1 ($p < 0.01$) were observed. Furthermore, there was a strong positive correlation between 6-6 and 7-7 ($p < 0.01$, Table 1B).

In the maxilla, there was strong positive correlation between 1-2, 1-3, 1-4, 1-5, 1-6, and A-O in almost all possible combinations ($p < 0.01$, Table 1A). Moreover, the correlation coefficients of 1-5, 1-6, and A-O were ≥ 0.6 with almost all teeth, including the incisors, canines, and premolars ($p < 0.01$). In particular, 1-6 and A-O exhibited strong positive correlations with P2. In the mandible, strong positive correlation was observed between 1-3, 1-4, 1-5, 1-6, and A-O in almost all possible combinations (Table 1B). However, all correlation coefficients were ≤ 0.6 between 1-2 and 1-3, 1-4, 1-5, 1-6, and A-O ($p < 0.01$). Similar to the maxilla, the 1-5, 1-6, and A-O exhibited either strong or moderate positive correlation with the incisors, canines, and premolars ($p < 0.01$). In particular, 1-6 and A-O exhibited strong positive correlations with P2 in the maxilla and C in the mandible.

C_R-A-C_L was negatively correlated with 1-2, 1-3, 1-4, 1-5, 1-6, and A-O in both the maxilla and mandible ($p < 0.01$, Table 1A). Particularly strong negative correlations were observed with 1-2, 1-3, 1-4, and 1-5 in the maxilla and with 1-3 and 1-4 in the mandible (Table 1B).

In the maxilla, the I2-C-P1 exhibited a moderate positive correlation with 1-3, a moderate negative correlation with C_R-A-C_L, and weak positive correlation with 3-3 ($p < 0.01$, Table 1A). In the mandible, there was a weak positive correlation with 1-3 ($p < 0.05$) and a weak negative correlation with C_R-A-C_L ($p < 0.01$, Table 1B).

In terms of relationships between body height and other items, no moderate positive correlations existed in the maxilla (Table 1A). On the other hand, there were a moderate positive correlations with 1-3, 1-4, and M2 and weak positive correlations with 7-7, 1-2, 1-5, 1-6, and C in the mandible. In particular, the correlation coefficient with M2 was 0.21 in the maxilla and 0.50 in the mandible ($p < 0.01$, Table 1B).

Fewer combinations exhibited either positive or negative correlation in the mandible compared with the maxilla.

2. Principal component analysis (PCA)

Table 2 presents the principal components (eigenvalue, contribution ratio, and cumulative contribution ratio) for both the maxilla and mandible. Table 3 presents principal component loading (PCL) values, with values > 0.7 when rounded off to the first decimal place presented in bold font.

The cumulative contribution ratio exceeded by 70% until component 3 in the maxilla and until component 4 in the mandible. The original 23 sets of information were condensed into 3 components for the maxilla and 4 for the mandible (Table 2).

Regarding component 1 of the maxilla, all PCL values for the distances between the incisors and molars (1-4, 1-5, 1-6, and A-O) exceeded 0.8, and all PCL values for the 1-1, 1-2, 1-3, I1, I2, C, P1, and P2 exceeded 0.7 (Table 3). All PCL values were positive except for the C_R-A-C_L. The contribution ratio was 41.34% (Table 2). In the mandible, all PCL values for the distances between the incisors and molars (1-5, 1-6, and A-O) exceeded 0.8, and all PCL values for the 1-4, I1, I2, C, P1, and P2 exceeded 0.7 (Table 3). The contribution ratio was 40.29%, and all PCL values were positive except for the C_R-A-C_L. Results were similar to those for the maxilla.

Regarding component 2 of the maxilla, PCL values for the 3-3, 4-4, 5-5, 6-6, and C_R-A-C_L exceeded 0.7 (Table 3), with a contribution ratio of 21.59% (Table 2). In contrast, all PCL values for the 1-1, 1-2, 1-3, 1-4, 1-5, 1-6, and A-O were negative. In particular, the value for 1-2 was −0.53 and that for 1-3 was −0.54 (Table 3). In the mandible, the PCL values for the 4-4, 5-5, and C_R-A-C_L exceeded 0.7 (Table 3), with a contribution ratio of 17.46% (Table 2). Similar to the maxilla, all PCL values for the distance from the incisor were negative. In particular, the value for 1-3 was −0.53 and that for 1-4 was −0.57.

Regarding component 3 of the maxilla, PCL values for the I2-C-P1 and 7-7 were 0.79 and 0.55, respectively. PCL values for the 2-2, 3-3, and 4-4 were negative (Table 3). The contribution ratio was 7.95%, and the cumulative contribution ratio was 70.88%, which is >70% (Table 2). In the mandible, the 2-2 was 0.6, and PCL values for the body height and 7-7 both exceeded −0.6 (Table 3). The contribution ratio was 10.19% (Table 2).

Regarding component 4 of the mandible, the PCL value for the I2-C-P1 was −0.88 (Table 3), the contribution rate was 6.98%, and the cumulative contribution ratio was 74.91% (> 70%, Table 2).

3. Cluster Analysis

For both maxilla and mandible, cluster analysis was performed using PCS, and a dendrogram was constructed (Figs. 2 and 3). The means of PCS by cluster are presented in Table 4 and as a radar chart (Fig. 4). The maximum and minimum PCS values in each cluster are indicated in bold and italic font, respectively.

Table 2. Eigenvalue, contribution ratio and cumulative contribution ratio of each component of principal component analysis (upper: maxilla, lower: mandible).

		Component 1	Component 2	Component 3	Component 4
Maxilla	Eigenvalue	9.51	4.97	1.83	
	Contribution ratio	41.34%	21.59%	7.95%	
	Cumulative contribution ratio	41.34%	62.93%	70.88%	
Mandible	Eigenvalue	9.27	4.02	2.34	1.6
	Contribution ratio	40.29%	17.46%	10.19%	6.98%
	Cumulative contribution ratio	40.29%	57.75%	67.94%	74.91%

Table 3. Principal component loadings (PCLs, left: maxilla; right: mandible).

Variable	Maxilla			Mandible			
	Component 1	Component 2	Component 3	Component 1	Component 2	Component 3	Component 4
Body height	0.19	0.10	0.29	0.34	−0.26	−0.62	−0.08
1-1	**0.70**	−0.10	0.16	0.65	0.14	0.49	−0.24
2-2	0.54	0.48	−0.03	0.61	0.28	0.60	−0.20
3-3	0.50	**0.70**	−0.36	0.59	0.60	0.18	0.20
4-4	0.41	**0.81**	−0.05	0.45	**0.77**	0.09	−0.10
5-5	0.33	**0.83**	0.25	0.44	**0.73**	−0.18	−0.23
6-6	0.21	**0.79**	0.46	0.30	0.60	−0.48	−0.27
7-7	0.16	0.65	0.55	0.22	0.49	−0.65	−0.20
1-2	**0.70**	−0.53	0.05	0.49	−0.35	−0.25	0.27
1-3	**0.73**	−0.54	0.27	0.69	−0.53	−0.01	−0.35
1-4	**0.86**	−0.44	0.03	**0.75**	−0.57	0.02	0.04
1-5	**0.91**	−0.36	−0.10	**0.89**	−0.39	0.05	0.10
1-6	**0.93**	−0.24	−0.16	**0.92**	−0.29	0.07	0.16
A-O	**0.92**	−0.18	−0.21	**0.94**	−0.19	0.10	0.08
I1	**0.78**	0.22	0.04	**0.73**	0.16	0.44	0.03
I2	**0.72**	0.01	−0.11	**0.70**	0.32	0.13	0.20
C	**0.72**	0.20	0.00	**0.74**	0.02	−0.13	0.05
P1	**0.73**	0.24	−0.12	**0.77**	0.21	−0.12	0.14
P2	**0.77**	0.16	−0.15	**0.75**	0.14	−0.13	0.23
M1	0.60	0.22	0.03	0.64	0.10	−0.28	−0.09
M2	0.54	0.21	−0.22	0.59	−0.14	−0.46	0.03
C_R-A-C_L	−0.56	**0.72**	−0.36	−0.45	**0.73**	0.06	0.38
I2-C-P1	0.13	−0.26	**0.79**	0.05	−0.09	0.13	**−0.88**

At an integration level of 14.68, the maxilla was classified into four clusters (Fig. 2). First, cluster 2, which exhibited the only negative value in component 1, was separated from clusters 1, 3, and 4. Thereafter, cluster 4 exhibited a negative value in component 2 and was separated from clusters 1 and 3. In cluster 3, the mean PCS values for all principal components were at the maximum level. The maximum was 25 cases in cluster 2, and the minimum was 5 cases in cluster 3 (Table 4).

On the other hand, at an integration level of 13.01, the mandible was classified into four clusters (Fig. 3). First, cluster 2, which exhibited the only negative value in component 1, was separated from the clusters 1, 3, and 4. Thereafter, cluster 1 showed a prominent value in component 2 and was separated from clusters 3 and 4. Cluster 3 exhibited the negative and minimum value in component 2, whereas cluster 4 showed a positive value. Cluster 2 exhibited the minimum values in all components excluding component 2 (Table 4). The maximum was 22 cases in cluster 1, and the minimum was 5 cases in cluster 4.

In both the maxilla and mandible, minor differences were observed in the means of PCS values between each

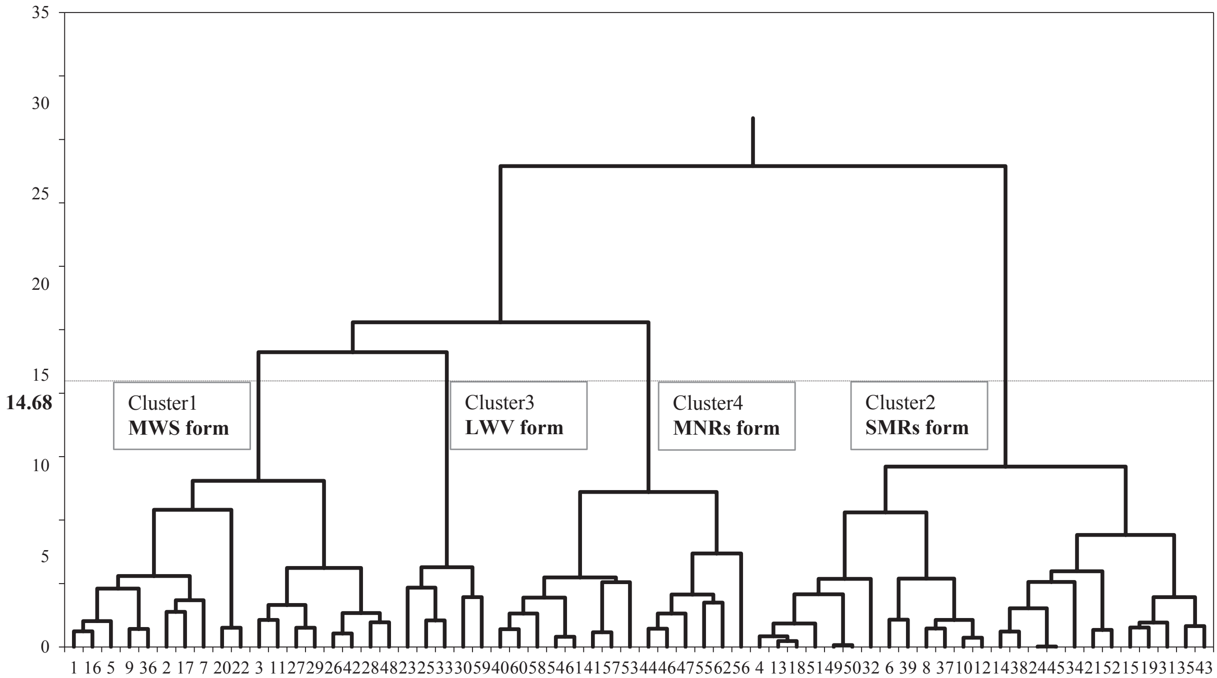

Fig. 2. Dendrogram (maxilla) of cluster analysis (with principal components scores (PCS)).
Four clusters were classified on the basis of each PCS of the maxillary dental arches.
Abbreviations: Arch length: long (L), middle (M), and short (S); intermolar distance: wide (W), middle (M), and narrow (N); shape: square (S), round V (V), round square (Rs). For example, cluster 1 has the MWS form: middle arch length, wide intermolar distance, and square shape.

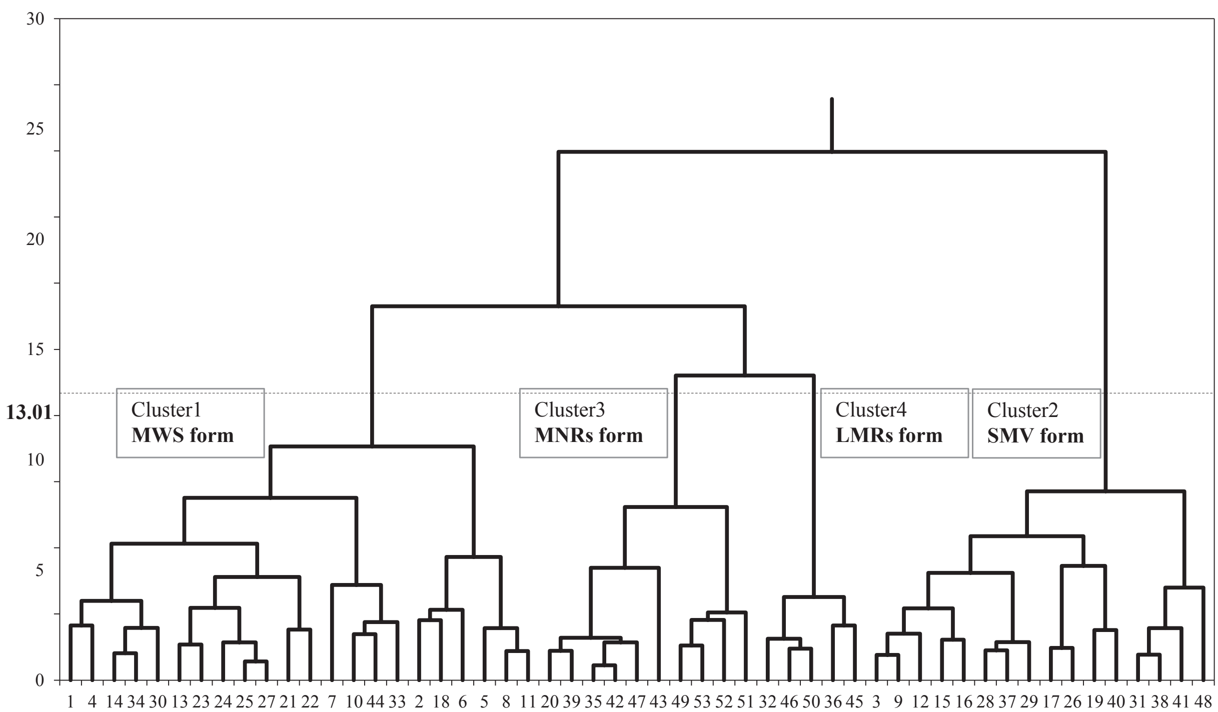

Fig. 3. Dendrogram (mandible) of cluster analysis (with PCS).
Four clusters were classified on the basis of each PCS of the mandibular dental arches.

Table 4. Case and mean PCS of each cluster (upper: maxilla, lower: mandible).

		Cases	Mean			
			Component 1	Component 2	Component 3	Component 4
Maxilla	Cluster1	18	0.75	1.38	*−0.47*	
	Cluster2	25	*−2.89*	0.07	0.22	
	Cluster3	5	**6.38**	**2.27**	**0.65**	
	Cluster4	14	1.92	*−2.71*	−0.01	
Mandible	Cluster1	22	0.45	**1.31**	0.20	**0.46**
	Cluster2	16	*−3.48*	−0.27	*−0.48*	*−0.35*
	Cluster3	10	1.53	*−2.57*	**0.29**	−0.32
	Cluster4	5	**6.10**	0.22	0.06	−0.28

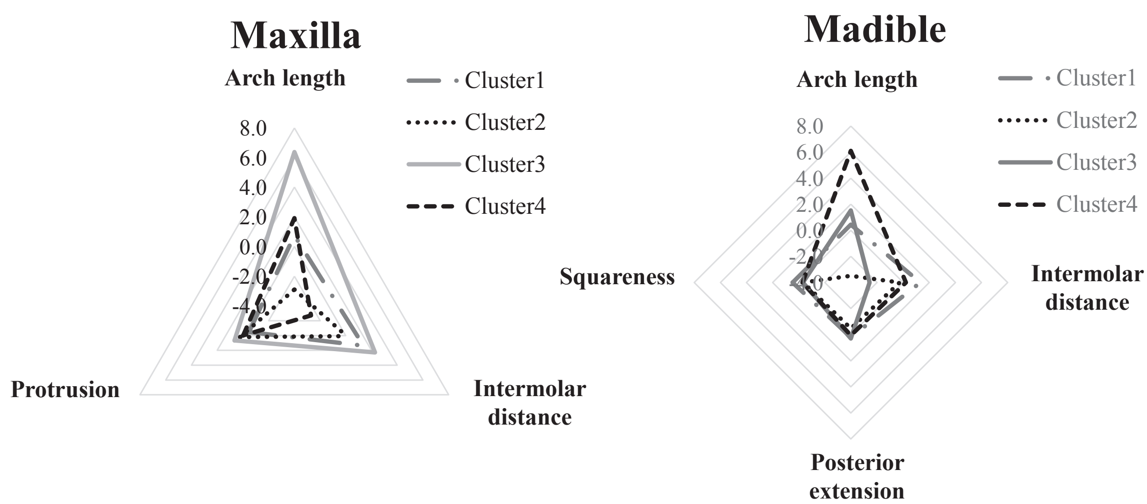

Fig. 4. Radar charts (left: maxilla, right: mandible).
These radar charts indicated the means of the PCS of each cluster.

cluster in component 3 and component 4. However, differences in means were greater in component 1 and component 2.

The area of the radar chart was at the maximum level in cluster 3 in the maxilla and in cluster 4 in the mandible (Fig. 4).

4. Evaluation of the validity of clustering using the Rand index (Ri)

The results of post-PCA cluster analysis for the maxillary and mandibular dental arches and the pre-PCA cluster analysis items were evaluated using the Ri (Table 5).

In the maxilla, the results using the data of pre-PCA cluster analysis were 25 cases of cluster 1, 20 cases of cluster 2, 12 cases of cluster 3, and 5 cases of cluster 4. Comparison of the mean PCS values from cluster to cluster revealed a tendency that cluster 1 in the pre-PCA was similar to cluster 2 in the post-PCA cluster analysis, cluster 2 in the pre-PCA was similar to post-PCA cluster 1, cluster 3 in the pre-PCA was similar to post-PCA cluster 4, and cluster 4 in the pre-PCA was similar to post-PCA cluster 3. The total number of datasets was 1891, including 312 of the same cluster in both cluster analyses and 1067 of different clusters in both cluster analyses. The Ri was 0.73, indicating a result that is closer to 1 (Table 5).

In the mandible, the results using the data of pre-PCA cluster analysis were 21 cases of cluster 1, 14 cases of cluster 2, 13 cases of cluster 3, and 5 cases of cluster 4. Comparison of the mean PCS values from cluster to cluster revealed a tendency that cluster 1 in the pre-PCA was similar to cluster 1 in post-PCA cluster analysis, cluster 2 in the pre-PCA was similar to cluster 2, cluster 3 in the pre-PCA was similar to cluster 3, and cluster 4 in the pre-PCA was similar to cluster 4. The total number of datasets was 1378, including 303 of the same clusters in both cluster analyses and 872 of different clusters in both cluster analyses. The Ri was 0.85, which was closer to 1

Table 5. Rand index (Ri).

		Cases		M	a11	a00	Ri
		post-PCA	pre-PCA				
Maxilla	Cluster1	18	25	1891	312	1067	0.73
	Cluster2	25	20				
	Cluster3	5	12				
	Cluster4	14	5				
Mandible	Cluster1	22	21	1378	303	872	0.85
	Cluster2	16	14				
	Cluster3	10	13				
	Cluster4	5	5				

Abbreviations: Post-principal component analysis (PCA): the data were obtained by PCA, pre-PCA: raw data; M: the number of pairs; a11: the number of pairs that were in the same cluster for both clustering results; a00: the number of pairs that were in different clusters for both clustering results

Rand index = (a11 + a00)/M.

than the result obtained for the maxilla (Table 5).

Discussion

1. Regarding this study

To analyze dental arch forms, 23 measurement items obtained from the dental arches and body height were condensed using PCA into three maxillary and four mandibular principal components. Thereafter, cluster analysis was performed using PCS, and the dental arch forms were classified into four types based on morphological characteristics. Furthermore, cluster analysis was performed using pre-PCA data, and the information was compared with the condensed analytical results (post-PCA data). Using the Ri, the validity of the clustering was verified[36]. This verification demonstrated that condensing the 23 datasets obtained from the dental arches and body height into 4 principal components is valid. Validity was higher in the mandible than in the maxilla. However, the growth of the mandibular bone is reportedly associated with the growth of body height and tongue and maxillofacial muscles[37–41]. Further research is required to explore factors involved in the morphology of mandibular arch forms in detail.

We photographed plaster dental casts and analyzed data measured on two-dimensional surfaces because this was also a comparative study in relation to previous studies. Sekikawa[19] has compared photography data with caliper-based actual measurements and concluded that measurement point errors are negligible. Al-Khatib et al.[42] have analyzed three-dimensional image data of dental casts and concluded that errors are negligible after comparing 3D image data and caliper-based actual measurements.

2. Correlation coefficient between respective items

Results 1 suggest that the bilateral intercentral incisor distance, the mesiodistal crown width of central incisors, and arch length mutually affect each other in both the maxilla and mandible. Al-Khatib et al. have performed PCA for the dental arches of Malay individuals and reported similar results[42]. However, almost no correlation was observed between the bilateral inter-central incisor distance and bilateral intermolar distance for either the maxilla or mandible, indicating that these factors do not have a mutual effect on each other. Furthermore, in the maxilla, the bilateral inter-central incisor distance showed hardly any correlation with factors other than the bilateral inter-lateral incisor width. Therefore, although the bilateral inter-central incisor distance affects the arch length, it scarcely influences the arch width. Conversely, the lateral inter-central incisor distance affects the arch length and the bilateral inter-anterior teeth width in the mandible. This suggests that the bilateral inter-central incisor distance affects the morphology of the anterior teeth in the mandible. In both the maxilla and mandible, the bilateral inter-lateral incisor width may affect the arch length in a manner similar to the central incisors.

The bilateral intercanine width exhibited strong positive correlation with 2-2, 4-4, and the mesiodistal crown widths of incisors, canines, and premolars in both the maxilla and mandible. The correlation coefficient for arch length was smaller in the maxilla than in the mandible. However, a moderate positive correlation was observed in the mandible. Similar to the incisors in the mandible, the intercanine width showed more correlation with arch length in the mandible than the maxilla. Although the canines typically erupt after the premolars in the maxilla, they usually erupt after the lateral incisor in the mandible, which could be the reason for the results obtained. Al-Khatib et al.[42] have reported that the bilateral intercanine width, dental arch length, and mesiodistal crown width between the anterior teeth constitute component 2 of dental arch forms. Additionally, Yoshida et al.[43] have measured the dental arches of adult female Philippines and observed a correlation between the bilateral intercanine width and dental arch length.

The bilateral intermolar distance typically has a tendency to be similar in both the maxilla and mandible.

The distances between the incisors and other teeth and the mesiodistal crown width tended to be essentially similar in both the maxilla and mandible, with both factors typically affecting each other. In particular, the distance between the central incisor and the posterior molar region is influenced by the mesiodistal crown widths of the incisors, canines, and premolars. Moreover, Kanazawa et al.[20], Harris et al.[30], Al-Khatib et al.[42], and Yamada[44] have all reported that mesiodistal crown width correlated with dental arch length, which is consistent with the results of the present study.

Dental arch length is significantly affected by the second premolars in the maxilla. In the mandible, strong positive correlation was observed in the canines in addition to the second premolars. The findings suggest that the influence of the canines should be considered. These results were almost consistent with those of Nakajima who reported that the mesiodistal crown widths of the canines and second premolars in the mandible of women are correlated with the mandibular dental arch length. Al-Khatib et al.[42] have reported that the mesiodistal crown distance of the premolars and dental arch perimeters constituted component 3 of the dental arch forms in PCA. Saitoh et al.[45] have stated that the mandibular second premolars were correlated with the mandibular condyle length, which was closely related to the growth of the maxillary and mandibular bones. Furthermore, second premolars are predisposed to degeneration in the remnants of animal evolution. It is also speculated that the difference in appearance of the degeneration tendency affects the length of the dental arch. However, Sekikawa[19] have stated that the size of the dental arches is represented by the canines and first molars.

The C_R-A-C_L exhibited strong negative correlation with anterior dental arch length, in particular, in both the maxilla and mandible, thereby suggesting that it represents the degree of curvature in the anterior teeth. This result is consistent with those of the previous studies[21, 22]. The I2-C-P1 signifies the angle of the transition part from the anterior teeth to molars, i.e., the morphology of the transition part from the anterior teeth to molars[21, 22]. In the maxilla, although a moderate negative correlation with the C_R-A-C_L was observed, the correlation was weak in the mandible. This may have been because in the mandible, teeth develop in a linguoclination, thereby affecting the tooth alignment.

In the maxilla, the degree of curvature of the anterior teeth affects the angle of the transition part, but the influence in the mandible is not as strong as that in the maxilla. Therefore, these two elements should be separately examined.

3. Influence of body height on dental arch forms

The present study analyzed body height, either. Result 1 showed that the correlation coefficient between body height and M2 was 0.21 in the maxilla and 0.50 in the mandible ($p < 0.01$). Regarding correlation between body height and other items, although a weak positive correlation was observed between body height and 6-6, and 7-7 in the maxilla, correlations were weak with the remaining items. Meanwhile, except M2, there was a moderate positive correlation between body height and 1-3, 1-4 and a weak positive correlation between body height and 7-7, 1-2, 1-5, 1-6, C, and C_R-A-C_L in the mandible.

Results 2 showed that component 3 was positively correlated with 2-2 and negatively correlated with body height and 7-7, with a contribution ratio of 10.19% in the mandible. In contrast, a weak correlation was observed from component 1 to component 3 in the maxilla.

Matsumoto[46] have reported that allometry coefficients are high between body height and mandibular ramus height, and mandibular body length. Ryokawa[47] have reported that the skeletal maturity score is highly correlated with body height and mandibular bone length. Moreover, Seno[48] have reported that maxillofacial width growth starts earlier than body height growth in Japanese individuals. In the mandible, the most protruded part of the mentum grows forward, and the bilateral mandibular angle grows downward, corresponding to the growth of body height. Moreover, both pubescent boys and girls exhibited relatively significant growth in maxillofacial depth, particularly for the most protruded part of the mentum. Clinically, mandibular morphology also changes during puberty; therefore, caution is required during this period[48]. Moreover, Sato et al.[49] have reported that body height strongly correlates with mandibular bone length.

Previous studies have reported that the size of the dental arches is primarily dependent on the mesiodistal crown widths of teeth and teeth movement[17, 18]. Another report[50] has documented that the dental arches exhibit growth patterns that are completely different in nature than the other parts of the facial cranium. Based on these reports, our previous study was excluded body height from the items of factor analysis[26]. The maxillary dental arch exists in the maxillary bone of the facial cranium. Sato[49] has stated that body height is not significantly correlated with the maxillary bone length. These reports all support the results of the present study. Therefore, it appears that body height is not a critical chief component for the discussion of maxillary dental arch forms.

The above results indicate that although body height is not particularly correlated with dental arch forms in the maxilla, there exists a correlation in the mandible. In particular, the distance between the central incisors and canines, and between the central incisors first premolars, and the bilateral second intermolar distance strongly correlate with the mandibular bone growth.

4. Principal component analysis (PCA)

From Results 2, 23 items were condensed into 3 components in the maxilla and four components in the mandible.

In both maxilla and mandible, according to PCL, component 1 was positively correlated with the dental arch length (distance between the central incisors and molars) and the width of each anterior tooth or premolar tooth, which accounted for 40% overall. Moreover, the PCL value of the bilateral inter-anterior tooth width was high in both the maxilla and mandible. Therefore, component 1 signifies "arch length". Component 1 of PCA typically represents comprehensive strength[19, 34, 35], suggesting that dental arch length and mesiodistal crown width are critical determinant factors for the size of the dental arches. Moreover, Sekikawa[19], Harris et al.[30], and Yamada[44] have reported a correlation between mesiodistal crown width and tooth row length, thus corroborating the present study. Additionally, the bilateral inter-anterior tooth width affects the determination of the size of the dental arches. The C_R-A-C_L shows a negative value, and therefore, in the case of dental arch forms where component 1 is strongly manifested, the dental arches exhibit a tendency to be long and the anterior teeth exhibit a tendency to be curved. However, dental arch width is weakly correlated with component 1, so it is suggested that the size of dental arch is not particularly affected dental arch width.

In both the maxilla and mandible, component 2 exhibited a strong positive correlation with the bilateral corresponding intermolar distance, particularly the widths of the canines, premolars and the first molars in the maxilla. In the mandible, a strong positive correlation was observed with inter-premolar distance. Thus component 2 indicates the "intermolar distance". Additionally, in both the maxilla and mandible, the C_R-A-C_L showed a strong positive correlation and the anterior teeth exhibited a negative correlation with the dental arch length. Therefore, a morphology where the dental arch width is large and the curvature of the anterior teeth is shallow is inferred. The contribution rate was approximately 22% in the dental arch form determination in the maxilla and approximately 17% in the mandible. Compared with dental arch width, the dental arch length is a more crucial factor that determines the size of the dental arches. In both the maxilla and mandible, all items indicating dental arch length exhibited negative PCL values. In dental arch forms where component 2 is strongly manifested, the dental arches are short, the bilateral intermolar distance is wide, and the curvature of the anterior teeth is shallow. This suggests that there is little anterior protrusion and that there is a tendency for square-shaped morphology.

From Results 2, component 3 is strongly correlated with the 7-7 and I2-C-P1 in the maxilla and is negatively correlated with the bilateral intercanine width and C_R-A-C_L. This results in a curvature of the anterior teeth ("protrusion") where the width gets narrower from the posterior to anterior teeth. On the other hand, in the mandible, strong positive correlation with the inter-incisor width and a strong negative correlation with the 7-7 were observed. Therefore, bilateral corresponding tooth width tended to become shorter toward the distal of the dental arches, thus signifying "posterior extension." In the mandible, a negative correlation with body height was observed. On considering Discussion 3 too, body height growth is correlated with the mandibular bone growth and dental arch width increase. Moreover, Nakajima et al. have reported that when the mandibular angle is large, the anterior teeth are shaped in a pointed curve, and the posterior teeth are narrow in width. When the mandibular angle is small, the anterior teeth are flat, and the posterior teeth are shaped in a wide square shape[50]. The present study did not investigate data on mandibular angle, and further examination of this topic is required.

In the maxilla, the cumulative contribution ratio exceeded 70% by component 3. Therefore, three components are sufficient to explain dental arch form.

Component 4 was examined in the mandible. A weak negative correlation with the I2-C-P1, weak positive correlation with the C_R-A-C_L, and weak negative correlation with the 1-3 were observed. Therefore, it represents "squareness" with shallow and flat anterior teeth.

As mentioned above, the most crucial chief component in determining dental arch forms is arch length, followed by intermolar distance, and shapes (maxilla: protrusion, mandible: posterior extension, squareness).

These differences in the morphologies of the maxilla and mandible are validated from the previous studies reporting on the growth of the mandibular bone and maxillofacial and general growth[46–49]. However, the ratio of component 4 was approximately 7% overall in the mandible, indicating that it exhibited little effect on morphology.

In the present study, the mesiodistal crown width was strongly correlated with the dental arch length in component 1. Sekikawa[19] has reported that mesiodistal crown width shows no correlation with dental arch forms. Kanazawa et al.[20] have reported that environmental factors are more influential than genetic factors on mesiodistal crown width, dental arch forms, and mandibular bone forms, in this order. In the present study, arch length, intermolar distance and shape were found to be independent chief components; these results are consistent with those of Sekikawa[19] and Kanazawa et al.[20].

Regarding the tooth axis slope affecting the dental arch, Eguchi et al.[31, 51] have stated that the buccal–lingual tooth axis slope in the mandibular molars is strongly affected by genetics; however, the influence of environmental factors gradually increases. Moreover, the masticatory function, an environmental factor, may affect dental arch width. These reports suggest that arch widths may different greater between individuals on the ground of individual dietary habits and preferences, and behavioral habits. In addition, these reports explains the huge gap in the contribution rates of component 1 “arch length” and component 2 “intermolar distance.”

5. Cluster Analysis

From Results 3, both the maxilla and mandible were classified into four clusters.

In the maxilla, cluster 2, which exhibited the only negative value in component 1, was separated from clusters 1, 3, and 4. Therefore, the 25 dental arch cases belonging to cluster 2 may be shorter in length compared with the cases belonging to clusters 1, 3, and 4. Additionally, component 3 exhibited the second value among the four clusters, suggesting that the anterior teeth tended to be slightly curved. The radar chart area was at the minimum level, suggesting that the dental arch length and width were both small populations.

Subsequently, for component 2, the minimum negative value was observed in cluster 4, which was separated from clusters 1 and 3. The dental arches in cluster 4 were not small but tended to have narrower width. In cluster 3, all components exhibited the maximum values, and the radar chart area was the maximum. Therefore, it is suggested that the arches in cluster 3 are large.

Although dental arch length was moderate in cluster 1 among the four clusters in component 1, the component 2 value was positive. In this population, it is suggested that the arch length was not long, the arch width was large and the anterior teeth tended to be shallow square shape.

Considering Discussion 4 and using Thompson’s classification[1, 21], the most widely used dental arch form classification method, we found that maxilla could be morphologically classified into the following types: Cluster 1: arch length (middle)–intermolar distance (wide)–square shape[1, 21] (square shape): MWS form population. Cluster 2: Because the radar chart area was the minimum, arch length (short)–intermolar distance (middle)–round square shape[1, 21]: signifying SMRs form. Cluster 3: arch length (long)–intermolar distance (wide)–round V shape[1, 21]: signifying LWV form. Cluster 4: arch length (middle)–intermolar distance (narrow)–round square shape[1, 21]: signifying MNRs form.

In a previous study[26], factor analysis has been performed, and the maxillary dental arches were classified into the following three types: “anterior-curving posterior-narrowing type”, “anterior-linear short arch type”, and “anterior-linear long arch type”. Compared with the previous studies, the present study managed to classify arch length and width in a more detailed manner.

Moreover, in the mandible, cluster 2, which exhibited the only negative value in component 1, was separated from clusters 1, 3, and 4. The 16 dental arch cases belonging to cluster 2 were shorter in arch length than those belonging to clusters 1, 3, and 4. Components 3 and 4 exhibited the minimum values. This results in a dental arch form, where the bending of the anterior teeth was strong and approximate to a V-shape. In addition, though the interpremolar distance is narrow, the intermolar distance is wide. Thus, the radar chart area was the minimum and arch length was short in this population overall.

Cluster 1 showed the maximum value in component 2 and was separated from clusters 3 and 4. In cluster 1, component 4 exhibited the maximum value. Although the interpremolar distance was large, there was no widening toward the molars. It tended to be a square shape with small anterior protrusion. In cluster 3, component 2 exhibited the lowest value among all clusters, whereas component 3 showed the maximum value among all clusters. The dental arches and inter-anterior tooth width were slightly long, but the intermolar distance was short. It could possibly have a dental arch form with a slightly strong curvature of the anterior teeth. In cluster 4, component 1 had the maximum value among all clusters, and the radar chart area was the largest. However, component 2 was not the maximum value. Overall, it appeared that the dental arch group could possibly be large but slightly narrow.

Similar to in the maxilla, the mandible was morphologically classified in accordance with Thompson’s classification[1, 22]: Cluster 1: arch length (middle)–intermolar distance (wide)–square shape[1, 22]: MWS form dental arch population. Cluster 2: arch length (short)–intermolar distance (middle)–round V shape[1, 22]: SMV form. Cluster 3: arch length (middle)–intermolar distance (narrow)–round square shape[1, 22]: MNRs form. Cluster 4: arch length (long)–intermolar distance (middle)–round square shape[1, 22]: LMRs form.

In a previous study[26], mandibular dental arches were morphologically classified into the following three types using factor analysis: “small, molar non-opening dental arches”, “anterior-curving, molar opening dental arches”, and “small, trapezoid-like dental arches”. In the present study, similar to the maxilla, the size and width of the dental arches were classified in a more detailed manner.

In both the maxilla and mandible, differences in the mean PCS values were small for components 3 and 4 among clusters. However, differences in means were large in components 1 and 2. This indicates that dental arch forms are divided into dental arch length and width. Sekikawa[19] and Mikami et al.[24] have performed Fourier analysis on dental arch forms, and their results were consistent with ours.

In the maxilla, the interincisor width, and the mesiodistal crown widths of the central incisors and second premolars affected the determination of dental arch length. It was classified into four morphologies. In the mandible, the interincisor distance, and the mesiodistal crown widths of the central incisors, canines, and second premolars affected the determination of dental arch length. It was classified into four morphologies. In both the maxilla and mandible, dental arch length was not mutually affected by the widths between bilateral corresponding teeth (canines and molars). The placement of adjacent teeth affects the width between bilateral corresponding teeth. This in turn affects the intermolar distance. Furthermore, it appears that second molars are affected by body height in the mandible.

Nakajima et al.[28, 50] have examined mandibular dental arch forms and found negative correlations with mandibular angle and the bilateral inter-second molar width. Therefore, both these factors as well as intercanine width should be considered. Furthermore, Sekikawa[19] has revealed a strong correlation between the mesiodistal crown widths of canines and first molar, and the size of the entire dental arches in both the maxilla and mandible. In the present study, the canines were found to be more involved in determining the arch length in the mandible than in the maxilla. In the maxilla, it is possible that the mesiodistal crown width of the incisors and second premolars was more influential on the arch length than the canines. These findings resulted in our presenting a differing conclusion to that of Sekikawa[19].

The impact of this study results on clinical practice are described here. The results may be applicable when selecting arch forms in orthodontic treatment. An arch form shows the external shape of the dental arch[28]. Meanwhile, several studies[19, 30, 44], including the present one, have suggested that the mesiodistal crown width influences the arch length; thus, the mesiodistal crown width may be informative when selecting ready-made arch forms. However, in making an assessment, it is not always necessary to consider all the teeth, and the incisors and second premolars should be considered in particular. For the mandible, the primary consideration should be the mesiodistal crown width of the incisors, second premolars and canines. Including these in the preliminary assessment makes it possible to roughly estimate the length and size of the dental arch.

In this study, the bilateral interpremolar distance and the anterior curve of the dental arch were also found to have a great impact on the arch width. Moreover, between the distance of bilateral interanterior teeth and the distance of bilateral interposterior teeth was found to not mutually impact each other. This information may be useful in both orthodontic treatment and predicting the growth of pediatric dental arches.

The most notable finding is that the bilateral inter-central incisor distance had an impact not only on the arch length and anterior curve but also on the depth of the arch from the central incisor to the premolar. In particular, the morphology of the anterior arch of the maxilla may depend on the inter-central incisor distance. This should be considered not only in orthodontic treatment but also in designing dentures and implants. Till date, there has been a dearth of detailed studies on the impact of the central incisors on arch forms. Further investigation is needed, including studies on the impact of tooth axis inclination.

Conclusions

1) Three components (arch length, intermolar distance, and protrusion) are involved in determining maxillary dental arch forms. Four components (arch length, intermolar distance, posterior extension, and squareness) are involved in determining mandibular dental arch forms. Both of these can be clustered into four morphologies.
2) Dental arch length is a crucial index representing the size of the dental arches. In both maxilla and mandible, bilateral interincisor distance, and mesiodistal crown width of the incisors and premolars greatly affect dental arch length. Moreover, in the mandible, the mesiodistal crown width of the canines affects dental arch length.
3) Dental arch width is involved in determining the morphology of the dental arches. The bilateral corresponding tooth distances of the canines, premolars, and first molars, and anterior curvature affect dental arch width. In particular, bilateral interpremolar distance and anterior curvature are major factors. Anterior tooth width and posterior tooth width are mutually independent and do not affect each other.
4) In both the maxilla and mandible, bilateral intercanine width is influenced by bilateral interlateral incisor width, bilateral first interpremolar distance, and mesiodistal crown width of the incisors, canines, and premolars.
5) Posterior extension is affected by the curvature of the anterior teeth and squareness.
6) The curvature of the anterior teeth is affected by bilateral inter-central incisor distance in the maxilla. In both the maxilla and mandible, this affects arch length from the incisors to premolars.
7) In the mandible, the growth of the mandibular bone and body height affects anterior tooth length, mesiodistal crown width of the second molars, and intermolar distance of the bilateral second molars.

Acknowledgement

The authors declare no conflicts of interest associated with this manuscript.

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