

下顎牙弓形態的分類—主要及相關組成要素之分析

本研究從396個年齡介於18至26歲的樣本中（男生257位，女生139位）選出53個（男生29位，女生24位）具有理想咬合及齒列的樣本來進行牙弓型態的評估。下顎的齒列依照傳統牙弓型態的描述標準，我們預先將之分為以下幾類：方形（square），圓方形（round-square），圓形（round），圓V形（round V-shaped）。另外，在解剖位置上我們亦選擇了以下幾處做為參考點，包括：門齒切端中點（ $I1_R$ ， $I1_L$ ， $I2R$ ， $I2_L$ ），犬齒尖端（ C_R ， C_L ），小白齒之頰側咬頭（ $P1_R$ ， $P1_L$ ， $P2_R$ ， $P2_L$ ），第一及第二大臼齒之近心頰側咬頭（ $M1_R$ ， $M1_L$ ， $M2_R$ ， $M2_L$ ）， $I1_R$ - $I1_L$ 連線之中點（A），經由A並垂直 $M2_R$ - $M2_L$ 連線之交叉點B以及A-B連線與 C_R - C_L 連線交點E。藉由以上參考點所量得數值，我們分析以下項目：（1）量測 $\angle R$ （ $I2_R$ - C_R - $P1_R$ 三點所形成之角度）+ $\angle L$ （ $I2_L$ - C_L - $P1_L$ 三點所形成之角度）來評估犬齒之前凸情形。（2）計算 $(A-B)/(C_R-C_L) \cdot 180^\circ - \angle(C_R-A-C_L) \cdot (A-E)/(C_R-C_L)$ 來評估前牙的曲度（curvature）。（3）計算 $(A-B)/(M2_R-M2_L)$ 來評估牙弓長度與寬度的比值。（4）計算 $(r\theta_5 - r\theta_4)_R + (r\theta_5 - r\theta_4)_L$ 來評估下顎牙弓呈現圓形的程度。（5）分析牙弓兩側外型及折線P1-P2-M1-M2(i)與P1-M2(i i)位置的關係，來區別type I與type II的圓方形（round-square）牙弓。

上述所得資料我們將之進一步標準化並統整成三個主要部分：（1）前牙的曲度。（2）牙弓外型的曲線。（3）牙弓長度與寬度的比例。結果顯示（1）36

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個下顎齒列樣本(67.9%)呈現出圓方形(round-square)的牙弓形狀, 11個下顎齒列樣本(20.8%)為方形牙弓形狀, 6個樣本(11.3%)則呈現出圓V形(round V-shaped)的牙弓形狀, 在本實驗中並無發現呈現圓形的下顎牙弓形狀。(2)在不同的下顎牙弓中 $180^\circ - \angle(C_R-A-C_L)$ 、 $(A-E)/(C_R-C_L)$ 、 $(r\theta_5 - r\theta_4)_R + (r\theta_5 - r\theta_4)_L$, 此三項數值在統計上呈現出顯著之差異。(3)藉由檢測上述提及之三個主要部分, 我們可以發現在圓V形(round V-shaped)、方形及圓方形(round-square)下顎牙弓中, $(A-B)/(M2_R-M2_L)$ 此數值在統計上亦呈現出顯著之差異。由上可知本研究顯示出下顎的牙弓型態是由下列兩項因素所決定: 一為呈現出前牙曲度(curvature)的參數——由 $(A-B)/(C_R-C_L)$ 、 $180^\circ - \angle(C_R-A-C_L)$ 、 $(A-E)/(C_R-C_L)$ 所組成, 另一為由 $(r\theta_5 - r\theta_4)_R + (r\theta_5 - r\theta_4)_L$ 組成, 來決定下顎牙弓圓形程度的參數。

關鍵字: 人類下顎、牙弓型態分析

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受文日期: 民國九十三年七月一日

接受刊載: 民國九十三年九月十一日

Classification of Mandibular Dental Arches by Correlation and Principal Component Analyses

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To evaluate the morphology of dental arches, 53 (male: 29, female: 24) paired casts having normal dentitions and occlusion were selected from 396 (age: 18 to 26 years old; male: 257, female: 139) sets of dental study models. The mandibular dentitions were preliminarily classified as square, round-square, round and round V-shaped arches based on the conventional morphological descriptions. Midpoints of the incisor edge (I_{1R} , I_{1L} , I_{2R} , & I_{2L}), summits of the cuspids (C_R & C_L), buccal cusps of the premolars (P_{1R} , P_{1L} , P_{2R} , & P_{2L}), mesial buccal cusps of the first and second molars (M_{1R} , M_{1L} , M_{2R} , & M_{2L}), and the midpoint (A) of line I_{1R} - I_{1L} were designated as reference points. From A , let a vertical line intersected line M_{2R} - M_{2L} at reference point B . The line A - B intersected C_R - C_L at reference point E . We evaluated 1) the protrusion of the cuspids by ① angle I_{2R} - C_R - P_{1R} ($\angle R$) + angle I_{2L} - C_L - P_{1L} ($\angle L$); 2) the curvature of the anterior teeth by ② $(A-B)/(C_R-C_L)$, ③ $180^\circ - \angle(C_R-A-C_L)$, and ④ $(A-E)/(C_R-C_L)$; 3) the length to width ratio of the dental arch by ⑤ $(A-B)/(M_{2R}-M_{2L})$; 4) the degree of roundness of the mandibular arch by estimation of ⑥ $(r\theta_5 - r\theta_4)R + (r\theta_5 - r\theta_4)L$; and 5) an item ⑦ for the differentiation of type I and type II round-square arches by relating the bilateral contour and position of break line P_1 - P_2 - M_1 - M_2 (i) to line P_1 - M_2 (ii). The data of items ①, ②, ③, ④, ⑤ and ⑥ were further standardized and summarized into three essential principal components: 1) the curvature of the anterior teeth, 2) the curvilinear contour of the dental arch, and 3) the length-to-width ratio of the dental arch. The results indicated that: 1) 36 cases (67.9%) of the mandibular dentitions were round-square arches which showed no prominent principal component. 11 cases (20.8%) were square arches and 6 cases (11.3%) were round V-shaped arches; no round arches was found in mandibular dentitions. 2) Statistical analysis indicated significant differences of items ③, ④ and ⑥ in various mandibular arches (Student's t-test). 3) By examination of the three

principal components, significant differences of item ⑤ between the round V-shaped arches and square and round-square mandibular arches were evident (Student's t-test). The present study elucidated that morphology of the mandibular arch was determined by a parameters representing the curvature of anterior teeth (composed of items ②, ③ and ④), and another parameter (item ⑥) representing roundness of the mandibular arch.

Key words: principal component analysis, dental arch, mandible, human, morphology

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Submitted: July, 1, 2004

Accepted: September, 11, 2004

Introduction

It is important to conduct a detailed oral examination in planning an individual treatment program for each dental patient. For instance, we usually study dental casts to provide essential information in daily oral rehabilitation and orthodontic treatments. Clinically, dentitions are expediently classified as square, round-square, round, and round V-shaped arches according to previous classic studies.^(1,2) There have also been some descriptive morphological studies differentiating *upsilon*, *elliptique*, *parabolique* and *hyperbolique* dentitions.⁽³⁾ Nevertheless, the conventional methods seem lacking mathematical evidence but are composed of subjective factors which always lead to a different understanding, because they mainly depend on personal visual examination.⁽¹⁻³⁾ On the other hand, many quantitative studies using mathematical evaluation involving measuring distances between certain reference points and analysing various algebraical functions (e.g., expressions concerning the dental arch curvature) have defined 4 to 5 types of dental arch form.⁽⁴⁻²¹⁾ However, these methods develop voluminous data requiring complicated calibration with specific equipments.

The present study was undertaken with an aim to find objective criteria, for a quick and communicative chair-side morphological evaluation of dental arches, by the correlation and principal component analyses of items

between established reference points designated on standard mandibular plaster casts.

Materials and Methods

1. Materials

In the study, 396 sets of maxillary and mandibular dental casts of young adult students (18 to 26 years old; male: 257, female: 139) at Osaka Dental University were studied. The paired casts were prepared to have a total height of 60 mm with the occlusal plane adjusted to be at a height of 30 mm from the mandibular cast base. From the 396-paired casts, we selected 53 sets (male: 29, female: 24) with normal dentitions and occlusion. They had 1) complete permanent teeth; 2) no prominent tooth crowding nor positional versions; 3) no missing or supernumerary teeth or restorations affecting the arch form (the present study did not count the third molars); 4) definite incisal edges and clear cuspal summits; 5) never undergone any orthodontic treatments; 6) no tooth morphological anomalies (e.g., dwarf tooth, peg tooth); 7) Angle's class I occlusion without open bite or cross bite; and 8) no spacing dentitions.⁽²²⁾

2. Methods

The mandibular arches of the selected 53 cases were preliminarily classified as square, round-square, round and round-V shaped arches with reference to the Thompson's morphological descriptions (Fig. 1).^(1, 2, 22)

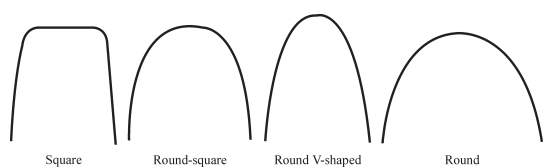


Fig 1. Thompson's classification of dental arches

- (1) Square arch: a dental arch had protruded canines with the anterior teeth in an almost linear arrangement. The bilateral premolars and molars were also linearly arranged in that they were parallel showing little divergence towards the distal ends of the arch.
- (2) Round-square arch: a dental arch with little canine protrusion resulting in a curved anterior teeth line, while the posterior teeth were linearly aligned. The bilateral linearly aligned posterior teeth were nearly parallel in appearance. In the present study, we studied contour lines of the posterior teeth and defined two sub-types of round-square arches.
 - Type I: a round-square arch characterized by approximation of the bilateral last molars that showed a tendency towards distal convergence of the dental arch.
 - Type II: a round-square arch showing a tendency towards distal divergence of the arch.
- (3) Round arch: a semicircle dental arch showing no canine protrusion.
- (4) Round V-shaped arch: a long dentition showing a definite V-shaped anterior teeth

arrangement.

Reference Points and Lines for Examination

In the present study, we designated the midpoints of the incisor edge (I_{1R} , I_{1L} , I_{2R} & I_{2L}), the summits of the cuspids (C_R & C_L), the buccal cusps of premolars (P_{1R} , P_{1L} , P_{2R} & P_{2L}) and the mesial buccal cusps of the first and second molars (M_{1R} , M_{1L} , M_{2R} & M_{2L}) to be the main reference points; however, we did not count third molars in the evaluation.^(22, 23) We then defined the midpoint of line I_{1R} - I_{1L} as reference point A. From A, let a vertical line intersected line (M_{2R} - M_{2L}) at reference point B. The line(A-B) intersected line (C_R - C_L) at reference point E. Point O (origin, pole) was the reference midpoint at the line (M_{2R} - M_{2L}) (original line) and was designated to study the relationships between right and left radius vectors $r \theta n$ ($n=1, \dots, 7$) by developing a spherical (polar) coordinate system (Fig. 2).^(22, 23)

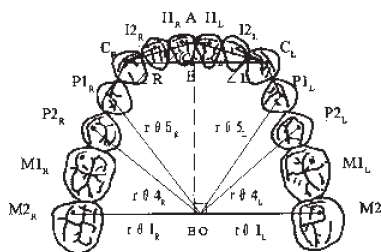


Fig 2. Reference points, lines and angles

The contour of the posterior teeth was represented by connecting P1, P2, M1, and M2 (breaking line P1-P2-M1-M2; line i). The

position of line *i* was then related to the line P1-M2 (line *ii*). Round-square arches having a contour line *i* lateral to line *ii* were defined to be type I round-square arches. On the contrary, those showing line *ii* lateral to line *i* were classified to be type II round-square arches (Figs. 3 & 4).⁽²²⁾

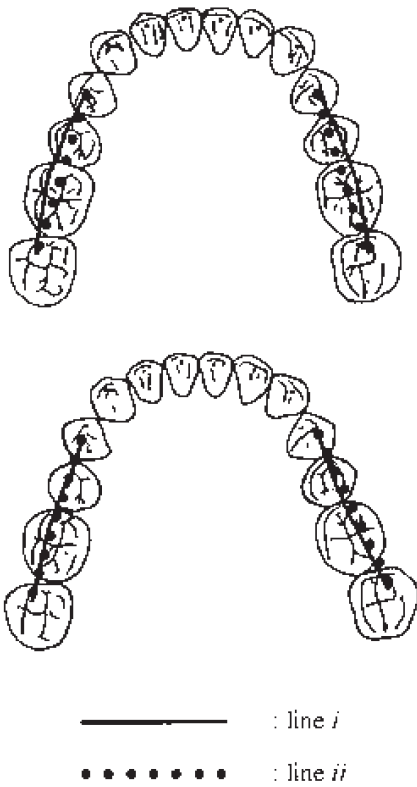


Fig 3. Type I Round-square arch

Fig 4. Type II Round-square arch

Photography of the Dental Casts

AD100 digital camera fitted with an AF MICRO Nikkor 70-180 mm, 1:4.5-5.6 D lens (Nikon, Tokyo, Japan) was set up on a King L4 Copy Stand (Asanuma, Tokyo, Japan).

The axis of the lens was aligned vertically to the occlusal plane—the standard plane—of the mandibular casts (focusing distance= 70 mm, $f= 29$), and the distance between the lens and standard plane was adjusted to 310 mm so that the photographs could be kept in equal proportion with the casts. The digital data were processed with Adobe Photoshop CS (Adobe Systems; Cal., USA) and Adobe Page Maker (ver. 6.5J, Adobe Systems) on a DELL Optiplex GX200 computer (OS: Microsoft Windows XP professional; DELL Japan, Kanagawa, Japan), and the equal-proportional images of studied maxillary casts were printed out using an Epson LP-8300C colour printer (Epson, Nagano, Japan).⁽²²⁾

Establishment and Development of Reference Items

Fourteen reference points ($I1_R, I1_L, I2_R, I2_L, C_R, C_L, P1_R, P1_L, P2_R, P2_L, M1_R, M1_L, M2_R, M2_L$) were plotted on the photographs (Fig. 2). Items $\angle R$ and $\angle L$ represented the angles $\angle I2_R-C_R-P1_R$ and $\angle I2_L-C_L-P1_L$, respectively. Items radius vectors $(r \theta_{1-7})_R$ and $(r \theta_{1-7})_L$ represented the angles between the reference points and the reference point O ($r \theta_1=0^\circ$). We developed seven selected items, and the data of the items were measured using Digimatic Caliper (0.01 mm precision; Mitutoyo, Tokyo, Japan) and common semi-circular protractors. The following seven items were analysed taking the following reason into consideration (Figs. 2-4).⁽²²⁾

- ① $\angle R + \angle L$: prominent protrusion of the cuspids gave a small value (Fig. 2).
- ② $(A-B) / (C_R - C_L)$: prominent protrusion of the cuspids resulted a large $C_R - C_L$ leading to a small $A-B/C_R - C_L$ value (Fig. 2).
- ③ $180^\circ - \angle (C_R - A - C_L)$: an arch having intensive anterior teeth curvature showed a large value (Fig. 2).
- ④ $(A-E) / (C_R - C_L)$: an arch with a large anterior teeth curvature gave a large value (Fig. 2).
- ⑤ $(A-B) / (M2_R - M2_L)$: this was a modification of the conventional Dental Arch Index = arch width/arch length $\times 100$.^(21, 22) A longer arch showed a larger value (Fig. 2).
- ⑥ $(r \theta_5 - r \theta_4)_R + (r \theta_5 - r \theta_4)_L$: round arches demonstrated small values (Fig. 2).
- ⑦ The arrangement and relationship between the P1-P2-M1-M2 (breaking line i) and the P1-M2 (line ii) were inspected to differentiate between type I and type II round-square maxillary arches (Figs. 3 & 4).

Statistical Analysis

(1) Internal estimation and test

Items were analysed using mean value, standard deviation, estimation of population mean with 95% confidence interval, and the Student's t- test with the levels of significance set at $\alpha = 0.01$ and $\alpha = 0.05$.^(22, 24, 25) The following formulae were used:

1. Interval estimation (estimation of population mean)

$$\bar{x} - t_{0.05} \times (\hat{\sigma} / \sqrt{n-1}) \leq \mu \leq \bar{x} + t_{0.05} (\hat{\sigma} / \sqrt{n-1})$$

(n : size of sample, \bar{x} : arithmetic mean, $\hat{\sigma}$: unbiased estimation of standard deviation, μ : population mean)

2. Student's t-test (two-tailed test; $\alpha = 0.01$, $\alpha = 0.05$)

$$t = (\bar{x} - \bar{x}') / SE$$

$$SE = \sqrt{\frac{(n-1)V + (n'-1)V'}{n + n' - 2}} \times \sqrt{\left(\frac{1}{n} + \frac{1}{n'}\right)}$$

(n, n' : size of sample, \bar{x}, \bar{x}' : arithmetic mean, SE : standard error, V, V' : unbiased estimation of population variance)

- (2) Correlation analysis of items with 1% level of significance (two-tailed test; $\alpha = 0.01$)⁽²²⁾

$$r = \frac{\sum xy - n\bar{x}\bar{y}}{\sqrt{\sum x^2 - n\bar{x}^2} \times \sqrt{\sum y^2 - n\bar{y}^2}}$$

(r : correlation coefficient, x : independent variable, y : dependent variable, n : size of sample)

- (3) Principal component (multivariate) analysis

The principal component analysis is an effective method for establishing synthetic indices by standardizing and summarizing multivariate data with the least loss of original data in the differentiation of samples.^(25, 26) The present principal component analysis, using Excel Statistics 2000 for Windows (Community Information Services, Tokyo, Japan), removed the variance of units, and then standardized and summarized ① $\angle R + \angle L$,

② $(A-B) / (C_R-C_L)$, ③ $180^\circ - \angle (C_R-A-C_L)$, ④ $(A-E) / (C_R-C_L)$, ⑤ $(A-B) / (M2_R-M2_L)$ and ⑥ $(r\theta_5 - r\theta_4)_{R+} (r\theta_5 - r\theta_4)_L$ multivariate data into new variables based on the proportion of variance (in descending order of value). The items were analysed with reference to the correlation matrix of the variables.^(22, 26, 27)

Results

Differentiation of Mandibular Casts by Visual Examination

The 53 mandibular arches (male: 29, female: 24) were arbitrarily classified following the Thompson's definition as follows (Table 1):

- (1) Square arches: 11 (male: 2, female: 9) cases, 20.8% of the 53 dentitions.
- (2) Round-square arches: 36 (male: 21, female: 15) cases, 67.9% of the 53 cases were identified as round-square arches. The classification contained 11 type I (male: 4, female: 7; totally 20.7% of the 53 casts) and 25 type II (male: 17, female: 8; totally 47.2% of the 53 casts) round-square arches.
- (3) Round arches: not found (0.0%) in the inspected 53 cases.
- (4) Round V-shaped arches: 6 (male: 6, female: 0) cases, 11.3% of the 53 casts.

The Character of the Examined Specimens

1. Evaluation of the developed items

1-1) The population mean of items ①, ②, ③,

④, ⑤, and ⑥ were estimated with the confidence interval of 95% and Student's t-test; the upper and lower limits are listed in Tables 1-3.

- ① $\angle R + \angle L$: the square arch had the smallest upper and lower limits (Table 1). We did not observe significant differences (t test, $p \geq 0.05$) between the three types of arch (Tables 1 & 2).
- ② $(A-B) / (C_R-C_L)$: the round V-shaped arch had the largest upper and lower limits, and showed its lower limit larger than the upper limit of the other (square, and type I & II round-square) arch types (Table 1). No significant difference (t test, $p < 0.05$) between the square and round-square (types I & II) arches was observed (Tables 1 & 2). In the present study, we defined type I and type II round-square arches, and observed significant differences between the round V-shaped and type I round-square arches (t test, $p < 0.01$), and between round V-shaped and type II round-square arches (t test, $p < 0.05$).
- ③ $180^\circ - \angle (C_R-A-C_L)$: we observed significant differences between square, round-square and round V-shaped arches (t test, $p < 0.01$). The round V-shaped arch had the largest upper and lower limits, and the square arch had the smallest upper limit. A 20° upper limit difference of the round V-shaped arch and square arch was demonstrated (Table 1). We defined type I

and type II round-square arches showing significant differences (t test, $p < 0.01$) with other arch types. Significant differences (t test, $p < 0.01$) between square arches and type II round-square and round V-shaped arches, and round V-shaped arches and type I and type II round-square arches were demonstrated, too (Table 2).

④ $(A-E) / (C_R - C_L)$: the round V-shaped arch had the largest upper value, and showed its lower limit larger than the upper limit of the square and types I and II round-square arches (Table 1). Significant differences between the type I round-square arch, and square arch (t test, $p < 0.05$) and type II round-square arch (t test, $p < 0.01$) were found (Table 2). We observed significant differences between square arch and type II round-square and round V-shaped arches (t test, $p < 0.01$), round V-shaped arch and square and types I and II round-square arches (t test, $p < 0.01$).

⑤ $(A-B) / (M2_R - M2_L)$: we identified that round V-shaped arches showed the largest upper and lower limits (Table 1); the dentition showed significant differences (t test, $p \geq 0.05$) in comparison with other arch types (Table 2).

⑥ $(r \theta_5 - r \theta_4)_R + (r \theta_5 - r \theta_4)_L$: the round V-shaped arch showed the largest upper limit values, and had the lower limit values larger than the upper limit values

of square and round-square (both types I and II) arches (Table 1). Significant differences (t test, $p < 0.01$) were evident between round V-shaped and other arches; the round V-shaped arch did not show prominent transition of the alignment of anterior and posterior teeth (Tables 2 & 5).

1-2) Parameter representing the essential alignment of molars.

⑦ Comparison of relationship between line i and line ii: in the 36 (male: 21, female: 15) cases of round-square arches, we further differentiated 11 type I (30.6% of 36 cases) and 25 type II (69.4% of 36 cases) round-square arches. Under classification by gender, we identified 4 males (19.0% of 21 males) and 7 females (46.7% of 15 females) to have type I round-square arches, and 17 males (80.9% of 21 males) and 8 females (53.3% of 15 females) to have type II round-square arches (Table 1; Figs. 3 & 4).

Analysis of the items ①, ②, ③, ④, ⑤, ⑥ and ⑦ in particular demonstrated significant differences (t test, $p < 0.05$) of the types I and II round-square arches by items ③ and ④ (Table 2). We analysed the mean value of the elements composing the items, and observed that $\angle (CR-A-CL)$ and $(A-E)$ were essentials significantly (t test, $p < 0.05$) affecting items ③ and ④ (Table 3).

Table 1
Confidence limits for the six items evaluated ($\alpha=0.05$)

Item	Arch form		
	Square	Round-square	Round V-shaped
	Cases (M/F)		
	11 (2/9)	36 (21/15)	6 (6/0)
		I 11 (4/7)	
		II 25 (17/8)	
① (degrees)	290-317	310-322	307-326
		I 304-326	
		II 309-324	
② (ratio)	1.23-1.29	1.27-1.32	1.36-1.49
		I 1.21-1.32	
		II 1.27-1.34	
③ (degrees)	33-37	39-44	52-57
		I 35-41	
		II 40-46	
④ (ratio)	0.14-0.16	0.18-0.20	0.24-0.26
		I 0.16-0.19	
		II 0.18-0.20	
⑤ (ratio)	0.65-0.74	0.67-0.71	0.69-0.77
		I 0.64-0.71	
		II 0.68-0.73	
⑥ (mm)	4.70-7.26	5.76-7.18	8.04-9.90
		I 4.13-7.41	
		II 6.07-7.49	

- ① Protrusion of canines ($\angle R + \angle L$)
 ② Curvature of anterior teeth I ($((A-B) / (C_R - C_L))$)
 ③ Curvature of anterior teeth II ($180^\circ - \angle (C_R - A - C_L)$)
 ④ Curvature of anterior teeth III ($((A-E) / (C_R - C_L))$)
 ⑤ Length-to-width ratio of the dental arch ($((A-B) / (M2_R - M2_L))$)
 ⑥ Degree of roundness of the arch ($(r\theta 5 - r\theta 4)_{R+} (r\theta 5 - r\theta 4)_L$)

Table 2
 Student's *t* test of differences of mean values between arch forms (1)

①				④			
Arch form	Square	R-s I	R-s II	Arch form	Square	R-s I	R-s II
Round-square I				Round-square I			
DF	20			DF	20		
<i>t</i>	-1.273			<i>t</i>	-2.498*		
Round-square II				Round-square II			
DF	34	34		DF	34	34	
<i>t</i>	-1.867	-0.312		<i>t</i>	-4.758 **	-2.249*	
Round V-shaped				Round V-shaped			
DF	15	15	29	DF	15	15	29
<i>t</i>	-1.307	-0.211	0.039	<i>t</i>	-11.434 **	-7.402**	-4.721**
②				⑤			
Arch form	Square	R-s I	R-s II	Arch form	Square	R-s I	R-s II
Round-square I				Round-square I			
DF	20			DF	20		
<i>t</i>	-0.366			<i>t</i>	0.750		
Round-square II				Round-square II			
DF	34	34		DF	34	34	
<i>t</i>	-1.699	-1.108		<i>t</i>	-0.240	-1.174	
Round V-shaped				Round V-shaped			
DF	15	15	29	DF	15	15	29
<i>t</i>	-5.299 **	-3.404 **	-3.141*	<i>t</i>	-1.027	-1.858	-0.980
③				⑥			
Arch form	Square	R-s I	R-s II	Arch form	Square	R-s I	R-s II
Round-square I				Round-square I			
DF	20			DF	20		
<i>t</i>	-1.733			<i>t</i>	0.203		
Round-square II				Round-square II			
DF	34	34		DF	34	34	
<i>t</i>	-3.653 **	-2.198*		<i>t</i>	-1.140	-1.301	
Round V-shaped				Round V-shaped			
DF	15	15	29	DF	15	15	29
<i>t</i>	-11.485**	-7.840 **	-3.975**	<i>t</i>	-3.110**	-2.664*	-2.794**

The difference was significant by a 2-tailed test for nonpaired samples. Blanks are overlapping data.

* $p < 0.05$ ** $p < 0.01$

Table 3
Student's *t* test of differences of mean values between arch forms (2)

$\angle(C_R-A-C_L)$				(A-B)			
Arch form	Square	R-s I	R-s II	Arch form	Square	R-s I	R-s II
Round-square I				Round-square I			
DF	20			DF	20		
<i>t</i>	1.733			<i>t</i>	1.548		
Round-square II				Round-square II			
DF	34	34		DF	34	34	
<i>t</i>	3.653**	2.198*		<i>t</i>	-0.498	-1.864	
Round V-shaped				Round V-shaped			
DF	15	15	29	DF	15	15	29
<i>t</i>	11.485**	7.839**	3.975**	<i>t</i>	-2.009	-3.941**	-1.337
(A-E)				(M2 _R -M2 _L)			
Arch form	Square	R-s I	R-s II	Arch form	Square	R-s I	R-s II
Round-square I				Round-square I			
DF	20			DF	20		
<i>t</i>	-1.607			<i>t</i>	0.160		
Round-square II				Round-square II			
DF	34	34		DF	34	34	
<i>t</i>	-4.043**	-2.627*		<i>t</i>	-0.114	-0.328	
Round V-shaped				Round V-shaped			
DF	15	15	29	DF	15	15	29
<i>t</i>	-7.648**	-6.958**	-3.639**	<i>t</i>	-0.242	-0.414	0.202
(C _R -C _L)							
Arch form	Square	R-s I	R-s II				
Round-square I							
DF	20						
<i>t</i>	1.665						
Round-square II							
DF	34	34					
<i>t</i>	1.153	-0.845					
Round V-shaped							
DF	15	15	29				
<i>t</i>	2.127	0.592	1.436				

The difference was significant by a 2-tailed test for nonpaired samples. Blanks are overlapping data.

* $p < 0.05$ ** $p < 0.01$

2. Correlation analysis

Distinct positive relationships (t test; $p < 0.01$) between ② (A-B) / (C_R-C_L) and ③ $180^\circ - \angle (C_R-A-C_L)$, ② (A-B) / (C_R-C_L) and ④ (A-E) / (C_R-C_L), and ③ $180^\circ - \angle (C_R-A-C_L)$ with ④ (A-E) / (C_R-C_L) were found (Table 4). Weak positive relationships between ② (A-B) / (C_R-C_L) and ⑤ (A-B) / (M2_R-M2_L), ② (A-B) / (C_R-C_L) and ⑥ (r θ₅ - r θ₄)_R+ (r θ₅ - r θ₄)_L, and ⑤ (A-B) / (M2_R-M2_L) and ⑥ (r θ₅ - r θ₄)_R+ (r θ₅ - r θ₄)_L. Also the analysis demonstrated a negative relationship between ① $\angle R + \angle L$ and ⑥ (r θ₅ - r θ₄)_R+ (r θ₅ - r θ₄)_L was evident (Table 4).

3. Principal component analysis of the items ①, ②, ③, ④, ⑤, and ⑥

The six items were summarized into three principal components according to eigenvectors (characteristic vectors) of the items in

descending order of value (Fig. 5). The mean values of the principal component scores for various arch types were then correlated and demonstrated three-dimensionally with reference to the (0, 0, 0) point three-dimensionally (Fig. 6).

The loading of the first principal component distinctly showed positive relationships between items ② (A-B) / (C_R-C_L), ③ $180^\circ - \angle (C_R-A-C_L)$ and ④ (A-E) / (C_R-C_L). The first principal component (expressed in mean score) of square and type I round-square arches was negative in value, while that of type II round-square and round V-shaped arches were positive in value (Figs. 5 & 6). The second principal component was positively related with ⑤ $\angle R + \angle L$, but distinctly negatively related with ⑥ (r θ₅ - r θ₄)_R+ (r θ₅ - r θ₄)_L (Figs. 5 & 6). Both the types I and II round-square arches, and round V-shaped mandibular arches had scores approxi-

Table 4
 Correlation coefficient between items

Item	①	②	③	④	⑤
②	0.2262				
③	0.3755	0.7442 *			
④	0.3864	0.7618 *	0.9137 *		
⑤	0.0375	0.6665	0.4691	0.4922	
⑥	-0.4793	0.5680	0.4001	0.3888	0.501

Blanks are overlapping data.

* Distinct positive relationship

** $p < 0.01$

Table 5
Student's *t* test of differences of mean values between arch forms(3)

Rr04				Lr04			
Arch form	Square	R-s I	R-s II	Arch form	Square	R-s I	R-s II
Round-square I				Round-square I			
DF	20			DF	20		
<i>t</i>	2.909**			<i>t</i>	0.561		
Round-square II				Round-square II			
DF	34	34		DF	34	34	
<i>t</i>	1.951	-0.633		<i>t</i>	0.737	0.244	
Round V-shaped				Round V-shaped			
DF	15	15	29	DF	15	15	29
<i>t</i>	2.584*	1.214	1.486	<i>t</i>	1.029	0.786	0.394
Rr05				Lr05			
Arch form	Square	R-s I	R-s II	Arch form	Square	R-s I	R-s II
Round-square I				Round-square I			
DF	20			DF	20		
<i>t</i>	1.599			<i>t</i>	1.693		
Round-square II				Round-square II			
DF	34	34		DF	34	34	
<i>t</i>	0.903	-0.592		<i>t</i>	0.489	-0.916	
Round V-shaped				Round V-shaped			
DF	15	15	29	DF	15	15	29
<i>t</i>	1.077	-0.196	0.275	<i>t</i>	-0.284	-1.916	-0.620
R(r05—r04)				L(r05—r04)			
Arch form	Square	R-s I	R-s II	Arch form	Square	R-s I	R-s II
Round-square I				Round-square I			
DF	20			DF	20		
<i>t</i>	-0.777			<i>t</i>	1.505		
Round-square II				Round-square II			
DF	34	34		DF	34	34	
<i>t</i>	-1.471	-0.200		<i>t</i>	-0.509	-2.577*	
Round V-shaped				Round V-shaped			
DF	15	15	29	DF	15	15	29
<i>t</i>	-3.076**	-1.543	-2.299**	<i>t</i>	-2.403*	-3.808**	-2.684*

The difference was significant by a 2-tailed test for nonpaired samples. Blanks are overlapping data.

* $p < 0.05$ ** $p < 0.01$

R: Right L: Left

ating to the 0 (0, 0, 0) point (Fig. 6). The third principal component analysis showed a coefficient strongly positively correlated with ⑤ $(A-B) / (M2_R - M2_L)$, but negatively correlated with items ③ $180^\circ - \angle (C_R - A - C_L)$ and ④ $(A-E) / (C_R - C_L)$ (Fig. 5). We elucidated that square dental arches had a positive score, types I and II round-square arches had scores nearby the 0 point, and round V-shaped arches had a negative score in the third principal component (Fig. 6). The first component analysis showed mean scores of the various dental arch types were distributed between -1.32 and +2.88 (Fig. 6). Both the second and third component analysis demonstrated scores distributing between -1.00 and +0.50, which is an area smaller than that of the first component analysis (Fig. 6). The results were strongly indicative that analysis of the three principal components successfully combined most of the characteristics of mandibular dental arches in that they contributed 92.55% to the proportion of variances.

Discussion

1. Classification of mandibular casts by visual examination

Most mandibular arches were described to be elliptical in shape by connecting incisal edges of the anterior teeth and buccal cusps of the posterior teeth.^(2, 11, 18) A study in the literature defines ovoid and elliptical arches with certain intermediate forms.⁽³⁾

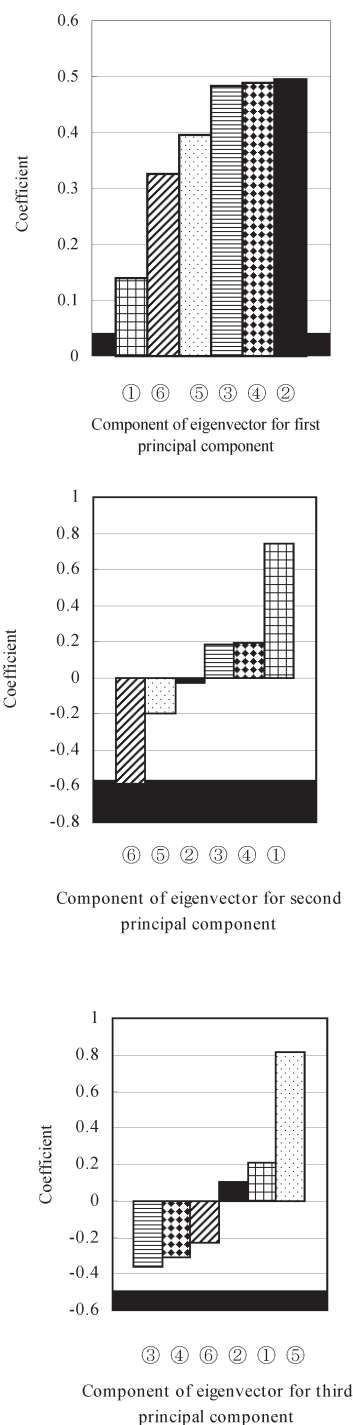


Fig 5. Eigenvectors of the principal components developed by analysis of each item.

In the present study, we differentiate type I and type II round-square arches and then elucidated that most the mandibular arches were elliptical in shape; it was in accordance with the previous studies.^(2,11, 18, 22)

2.Evaluation of parameters by internal estimation and test

Items ① $\angle R + \angle L$, ② $(A-B) / (C_R - C_L)$, ③ $180^\circ - \angle (C_R - A - C_L)$, ④ $(A-E) / (C_R - C_L)$, ⑤ $(A-B) / (M2_R - M2_L)$ and ⑥ $(r\theta_5 - r\theta_4)_R + (r\theta_5 - r\theta_4)_L$ were estimated and analysed. The item ⑦ the position of line i to line ii was in particular compared to differentiate type I and type II round-square arches. The results were concluded as followings:

(1) Protrusion of cuspids: ① $\angle R + \angle L$

No significant differences between the square, round-square and round V-shaped

arches were found for classification of mandibular arches (Table 2).

(2) Items for estimation of the curvature of anterior teeth:

The parameter was composed of items ② $(A-B) / (C_R - C_L)$, ③ $180^\circ - \angle (C_R - A - C_L)$ and ④ $(A-E) / (C_R - C_L)$. Items ③ $180^\circ - \angle (C_R - A - C_L)$ and ④ $(A-E) / (C_R - C_L)$ were significantly different in square, round-square and round V-shaped arches, while estimation of the item ② $(A-B) / (C_R - C_L)$ was in particular effective in identifying round V-shaped arches from square and round-square arches (Table 2). Significant differences of ③ $180^\circ - \angle (C_R - A - C_L)$ and ④ $(A-E) / (C_R - C_L)$ were found in type I and type II round V-shaped arches, too (Table 2). By evaluation of elements composing the analysing items for differentiation of dentition types, no sig-

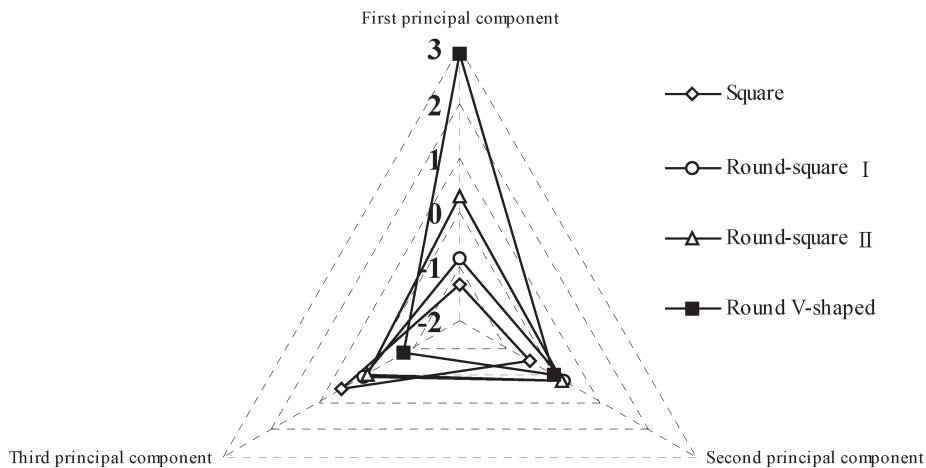


Fig 6. Principal Component Analysis

nificant difference of (C_R-C_L) was observed (Table 3). Instead, we found significant difference of the (A-E) mean values between square and type II round-square, and between round V-shaped and other (square, and types I and II round-square) arch types of arches. The results indicated that ③ and ④ were essential for the anterior teeth curvature, but the significance did not only depend on the (A-E) differences.

The arrangement of mandibular anterior teeth has been described being pointed-, curvy- or U-shaped in arrangement.^(15, 18, 21) In the present study, we differentiated square, round-square and round V-shaped dentitions by analysis of items ②, ③, and ④ (Tables 2 & 3).

(3) Length-to-width ratio of the dental arch

The item ⑤ ($A-B$) / ($M2_R-M2_L$) did not show significant differences between square, round-square and round V-shaped arches (Table 2). By analysing (A-B) and ($M2_R-M2_L$), we found significant differences of (A-B) between type I round-square and round V-shaped arches (Table 3). However, ($M2_R-M2_L$) which had no significant differences between various arch types eventually led to no significant difference in item ⑤ of various types of the mandibular dentition (Tables 2 & 3).

(4) Degree of roundness of the arch

Item ⑥ ($r\theta_5 - r\theta_4$) R+ ($r\theta_5 - r\theta_4$)_L was a significantly essential parameter to differentiate round V-shaped dental

arches from other dental arches (Table 2). Analysis of bilateral $r\theta_5$, $r\theta_4$ and ($r\theta_5 - r\theta_4$) demonstrated significant differences between round V-shaped arches and other types of arches (Table 5). The result indicated that round V-shaped dental arches had a tendency of direct and linear transition of the alignment of anterior segment towards posterior segment. (5) Alignment of posterior teeth

In the present study, we identified 38.1% males and 20.0% females had type I round-square mandibular arch; the female mandibular arch had less curvature. Through comparison of type I and type II round-square mandibular arches, analysis indicated significant differences of items ③ and ④ (Table 2). By examining of the character of types I and II round-square mandibular arches with mean values of the principal components and interval estimation of the upper and lower limits of items ①, ②, ③, ④, ⑤ and ⑥, we found that the type II round-square arch had an acute anterior teeth curvature than other arch types (Table 1, Fig. 6). Differences of (A-E) were significantly developed by comparison of \angle (C_R-A-C_L), (A-E) and (C_R-C_L) of various mandibular types; the element (A-E) was directly related to the curvature differences of molar teeth alignment (Table 3). We elucidated that type II round-square arches had more roundness than type I arches, which showed mild anterior teeth curvature with its characteristic alignment of the posterior teeth (Figs.

3 & 4).

3. Relationships between items ①, ②, ③, ④, ⑤, and ⑥

Correlation analysis indicated that items ② $(A-B)/(C_R-C_L)$, ③ $180^\circ - \angle(C_R-A-C_L)$ and ④ $(A-E)/(C_R-C_L)$ were essential for evaluation of the parameter (2) curvature of anterior teeth (Table 4). Also the analysis indicated that items ③ $180^\circ - \angle C_R-A-C_L$ and ④ $A-E/C_R-C_L$ in particular correlated to each other (Table 4).

4. The principal component analysis

In the present study, we conducted analysis of items ① $\angle R + \angle L$, ② $(A-B)/(C_R-C_L)$, ③ $180^\circ - \angle(C_R-A-C_L)$, ④ $(A-E)/(C_R-C_L)$, ⑤ $(A-B)/(M2_R-M2_L)$, and ⑥ $(r\theta_5 - r\theta_4)_R + (r\theta_5 - r\theta_4)_L$ to standardize and summarize the dental arch form to be represented by three principal components. The character of mandibular arches were represented by mean values of scores of the principal components, and demonstrated that the first principal component was the parameter (2) curvature of anterior teeth, which was strongly affected by parameters ② $(A-B)/(C_R-C_L)$, ③ $180^\circ - \angle(C_R-A-C_L)$, and ④ $(A-E)/(C_R-C_L)$. The $(A-E)$ value was the most important factor affecting the parameter (2). The second principal component, representing the curvilinear contour of the dental arch, was mainly composed of the parameter (1) protrusion of cuspids (① $\angle R + \angle L$) and parameter (4) degree of roundness of the

arch (⑥ $(r\theta_5 - r\theta_4)_R + (r\theta_5 - r\theta_4)_L$). Positive scores of the second principal component was indicative for a gradual transition, while negative values was indicative for a stiff transition of the alignment of anterior and posterior segment. The third principal component was the parameter (3) the length-to-width ratio of the dentition affected by the item ⑤ $(A-B)/(M2_R-M2_L)$; large eigenvector was indicative for a narrow and long mandibular arch. However, eigenvectors of both ③ $180^\circ - \angle(C_R-A-C_L)$ and ④ $(A-E)/(C_R-C_L)$ were corresponding with scores of the third principal component of various dental arch types. The results elucidated that various mandibular arches showed indistinct differences of item ⑤ $(A-B)/(M2_R-M2_L)$ between each other (Tables 3-5, Figs. 5 & 6).

The present study elucidates that morphological differences of the mandibular dental arch form are essentially manifested in the incidence differences of the first (mainly affected by $(A-E)$ values) and second (mainly affected by $(r\theta_5 - r\theta_4)$ differences) principal components of dental arches (Tables 3-5). On the other hand, the third principal component was not determinant for differentiation of arch types, in that mandibular dentitions had small $(A-B)$ and $(M2_R-M2_L)$ differences.

Conclusion

We observed that most of mandibular dental arches were round-square (67.9%) in

shape. It was followed with a descending grade distribution of square (20.8%) and round V-shaped (11.3%) arches; no round arch was identified. We evaluated certain items and elucidated that analysis of ① $\angle R + \angle L$, ② $(A-B) / (C_R - C_L)$, ③ $180^\circ - \angle (C_R - A - C_L)$, ④ $(A-E) / (C_R - C_L)$, ⑤ $(A-B) / (M2_R - M2_L)$, ⑥ $(r\theta_5 - r\theta_4)_R + (r\theta_5 - r\theta_4)_L$ and ⑦ the position of line i to line ii was effective in establishment an objective criteria for the differentiation of mandibular dental arch forms. By analysis of the seven items, we observed that the square arch was characteristic by a small anterior segment curvature having a stiff transition with the buccal segment. In contrast, the round-square arch was characteristically had the seven items on average values. Types I and II round-square arches showed significant differences of the anterior segment curvature having the buccal segment curvaceously (30.6%) or linearly (69.4%) aligned; the curvaceous buccal segment was usually accompanied with an anterior-teeth curvature of different degrees. The study in particular summarized items ①, ②, ③, ④, ⑤, and ⑥ into the first principal component (parameter (2) the curvature of the anterior teeth composed of items ②, ③, and ④), the second principal component representing the curvilinear contour of the dental arch (composed of parameters (1) and (4): items ① and ⑥), and the third principal component developed from parameter (3) length-

to-width ratio -item ⑤ $(A-B) / (M2_R - M2_L)$ - of the dental arch. By analysis and objective evaluation of the three principal components, we elucidated that the first and second principal components were essentially characteristic in various mandibular dentition forms.

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