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A three-dimensional analysis of the perceived proportions of maxillary anterior teeth

SEUNG-PYO LEE[1], SHIN-JAE LEE[2], KAZUO HAYASHI[3] & YOUNG-SEOK PARK[1]

[1]*Department of Oral Anatomy,* [2]*Department of Orthodontics, Dental Research Institute and School of Dentistry, Seoul National University, Seoul, Korea, and* [3]*Division of Orthodontics and Dentofacial Orthopedics, Department of Oral Growth and Development, School of Dentistry, Health Sciences University of Hokkaido, Hokkaido, Japan*

Abstract

Objective. The proportions of the anterior dentition, which is important for excellent esthetics, have been extensively studied, but there have been no 3-dimensional interpretations. This study was conducted to compare real tooth sizes and perceived tooth sizes between different genders and populations and to analyze the effects of 3-dimensional tooth position and alignment. ***Materials and methods.*** Complete dental stone casts were prepared for a total of 139 subjects (50 males and 44 females from Korea and 46 females from Japan). Using 3-dimensional scanning and reconstructions, virtual models were constructed and the widths, lengths and rotations of maxillary anterior teeth were measured. Parameters related to the arch form were measured orthographically. Descriptive statistics and ANOVA were performed to determine the differences among the three groups. A regression model was created to interpret the values of 2-dimensional perceived widths with 3-dimensional measurements and other parameters. ***Results.*** This study observed differences in the average mesiodistal perceived and real dimensions of the maxillary central incisors between Japanese and Korean females, as well as differences in lateral incisor/central incisor ratios and canine/lateral incisor ratios in the perceived 2-dimensional measurements. There were no differences in individual tooth rotations between groups. The r^2 values of the regression model decreased from the central incisors to the canine. ***Conclusions.*** Several differences were found between Japanese and Korean females and the regression models that used real dimensions, rotations and arch form parameters as independent factors were not sufficient to explain the perceived widths of anterior teeth in the study samples.

Key Words: *3-dimensional, anterior teeth, esthetics, proportions, virtual model*

Introduction

Although esthetically pleasing results are not the only goal of dental treatments such as orthodontics and esthetic prosthodontics, it is impossible to overestimate the importance of appearance as a treatment outcome, especially in that the dental patients want it very strongly nowadays much more than before [1]. The development of new dental materials and techniques has led to a greater number of treatment options that maximize the likelihood of esthetically pleasing outcomes [2]. The proportions of the anterior dentition play a major role in determining esthetic outcomes [3] and as a result, appropriate tooth shape, size and alignment relationships are critical [4].

The orthodontic literature includes numerous studies reporting tooth size ratios in various populations [5–8] and most of these studies attest to the importance of tooth size relationships as essential orthodontic diagnostic tools [9]. The Bolton tooth size ratio [10,11] is one of the most widely used analyses in orthodontic treatment planning, even though there are some controversies about the uniform application of this ratio without considering population-level or individual differences [12,13].

From an esthetic point of view, anterior tooth dimensions measured in a frontal view are more important than the actual size of the tooth. Since the dental arch forms a curve rather than a straight line, mesiodistal tooth dimensions that are perceived in frontal views are generally smaller than actual mesiodistal sizes. Prosthodontists have noted the influences of tooth dimensions on esthetics in terms of relative proportion [14], since the relative

Correspondence: Professor Young-Seok Park, Prosthodontist, Department of Oral Anatomy, Dental Research Institute and School of Dentistry, Seoul National University,28 Yeongun Dong Chongro Gu, Seoul, Korea. Tel: +82-2-740-8744. E-mail: ayoayo7@snu.ac.kr

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proportions of teeth are among the most objective dental criteria and can be easily controlled [15]. The identification of ideal tooth dimensions or proportions, however, remains a difficult task due to individual variation and proximal/incisal tooth wear.

Several studies intended to help design better esthetic dental restorations have advocated using geometric or mathematic proportions to aid in establishing tooth forms [16]. The 'golden proportion' has been proposed, taking into account classic elements of art and architecture [17,18]. Levin [19], Rufenacht [20] and Shoemaker and Nestor [21] have advocated the use of the 'golden proportion' and devised tools for this purpose such as grids and calipers. However, Lombardi [22] stated that the strict application of the 'golden proportion' is too rigid for dentistry and Preston [16] confirmed the unrealistic nature of adhering to the 'golden proportion', finding that the 'golden proportion' of perceived width between maxillary central incisors and lateral incisors was found in only 17% of cases and was never found between lateral incisors and canines. Rosenstiel and colleagues [23,24] conducted a web-based survey and found that the 'golden proportion' was preferred by dentists only in smiles with tall teeth. Several other proportions [22,25–28] have been suggested and tested.

Proposed proportions between anterior tooth sizes usually focused on the perceived mesiodistal dimensions, although some studies have dealt with tooth inciso-cervical length as a related factor. In addition, most studies were performed using only two-dimensional photographs (2D). Therefore, three-dimensional (3D) positional effects such as individual tooth rotation and the overall anterior dental arch curvature were not considered, although these factors evidently affect the perceived dimensions of teeth.

Recently, 3D scanners have been introduced to dentistry for various applications with reconstructed virtual models. Studies of 3D reconstructions have reported accurate and reliable techniques for restorative procedures and for facial analyses to aid clinicians in planning more effective treatments [29–32]. In addition, 3D scanners make orthographic measurements possible, which eliminates parallax errors.

The purpose of this study was to compare real tooth sizes and perceived tooth sizes between different genders and populations and to analyze the effects of 3D tooth position in the dental arch using 3D reconstructed virtual models and specialized software programs.

Materials and methods

Complete dental stone (Neoplumstone; Mutsumi Chemical Industry Co. Ltd., Japan) cast sets were prepared for 200 first-year students of the School of Dentistry, Seoul National University, Korea. The same procedure was performed for 100 first year students of the School of Dentistry, Health Sciences University of Hokkaido, Japan. A total of 140 maxillary casts (50 male and 44 female from Korea and 46 female from Japan) were selected for further analyses. Casts missing teeth other than the third molar or having over 3 mm of crowding or arch length discrepancies were excluded. The ages of the students ranged from 23–26 years with a mean age of 24.3 years. All subjects provided written informed consent. This study was approved by the institutional review boards of the College of Dentistry, Seoul National University and School of Dentistry, Health Sciences University of Hokkaido.

The selected casts were scanned by a 3D scanner (optoTOP-HE; Breckmann GMBH, Meersburg, Germany). The scanner has a point accuracy of ± 0.001 mm and a resolution of 0.040 mm in the X and Y directions and 0.002 mm in the Z directions. Each cast was scanned from 10 or more different views that were combined and rendered into 3D using specialized software (Rapidform XO; ver 2,0,1,0., INUS Technology, Seoul, South Korea) (Figure 1). The virtual 3D models were measured and analyzed using specialized software (Rapidform 2004; ver PP2, INUS Technology). Measurements of each cast were made three separate times by a single observer over a 3-week period.

All measurement values were the sum of the right and left tooth dimensions divided by 2. The lengths and the widths of the six maxillary anterior teeth were measured on the reconstructed 3D virtual casts. To compare with 3D measurements, 2D measurements were done after the virtual model's front view was captured and saved as a jpeg file using a specialized add-in program and align view command. Prior to these measurements, a reference plane was established for each virtual cast from a tripod of points. The detailed procedures that we used to identify the reference plane and obtain orthographic measurements are described in a previous study [30]. When performing 2D measurements, the frontal view was defined as the view perpendicular to one of the plane perpendicular to the reference plane which has a line

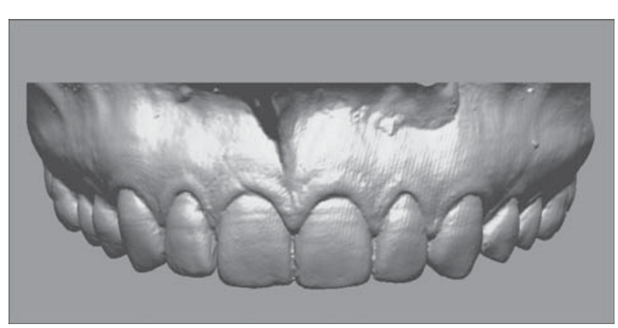

Figure 1. Virtual model made by 3D scanning and software reconstruction.

defined by two foot of perpendicular from canine tip to the reference plane as a line of intersection with the reference plane (Figure 2).

The lengths and widths were measured from the 2D figure acquired using the procedure described above. All values measured in the 3D setting are denoted with a '3' as the last character of the measurement name and the values in the 2D setting are denoted with a '2'. For example, CNTW3 represents the 3D central incisor width, while CUSW2 represents the 2D cuspid width. We calculated lateral incisor width to central incisor and cuspid to central incisor ratios for further assessment. To determine the effects of overall tooth size on perceived dimensions, we quantified individual tooth proportions by dividing width by length.

In order to evaluate the effects of 3D positions and alignments on the perceived dimensions of individual teeth, measurements of tooth rotation and dental arch form were performed. First, individual tooth rotation was quantified according to the angle formed between a line between the mesial incisal tip and the distal incisal tip of the six anterior teeth and a line defined by two foots of perpendicular from canine tip to the reference plane (Figure 3). Second, to determine the effects of arch shape, we performed a number of measurements including ICR (incisor to canine radius), ICA (incisor to canine angle), IMA (incisor to molar angle), ICW (intercanine width), IMW (intermolar width) and IIC (incisor to intercanine line), which were defined in detail in a previous study (Figure 4) [30]. All measurements were obtained orthographically on a single reference plane to preclude any parallax error introduced by different angulations of traditional measuring devices [29,30].

Statistical analyses were performed using SPSS 12.0 software (SPSS Inc., Chicago, IL). Descriptive statistics and ANOVA were performed to compare the mean values of all measurements among three groups: Korean males, Korean females and Japanese females. Scheffe's *post hoc* test was applied to detect differences between Korean and Japanese females and between Korean males and females. We did not perform comparisons between Korean males and Japanese females. Confidence levels of 95% and 99% were applied to all the measurements. To interpret the value of 2D perceived width, a regression analysis was performed using 3D measured widths, rotations and arch shape parameters. All arch shape parameters were used sequentially by a trial and error method to determine the most powerful factors.

Results

Descriptive statistics for all the measurements and summarized ANOVA results with *post hoc* tests are presented in Table I. Box plots of 2D and 3D width of anterior teeth are depicted in Figure 5.

The 3D measured average widths of the central incisors (CNTW3), lateral incisors (LATW3) and canines (CUPW3) were 8.564 ± 0.497 mm, 6.895 ± 0.661 mm and 7.824 ± 0.427 mm, respectively. The 2D measured average perceived widths of the central incisors (CNTW2), lateral incisors (LATW2) and canines (CUPW2) were 8.432 ± 0.461 mm, 6.030 ± 0.674 mm and 5.422 ± 0.645 mm, respectively. Measurements that were significantly different among the three groups were CNTW3 (p = 0.032), CNTW2 (p = 0.002), LATW3 (p = 0.048) and CUSW2 (p = 0.034). According to the *post hoc* test results, there were significant differences between Korean males and females in CNTW3 (p = 0.032) and CNTW2 (p = 0.005) and significant differences between Korean females and Japanese females in CNTW2 (p = 0.022). In other words, Korean females had significantly narrower central incisors than Japanese females in the perceived frontal view.

The 3D measured average ratios of lateral incisors to central incisors (LATW3/CNTW3) and canines to

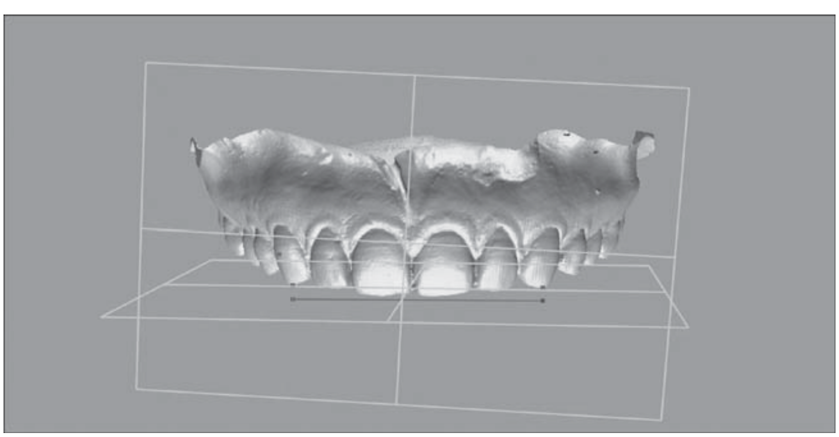

Figure 2. Procedure of defining the frontal view. First, normal vectors were projected from the bilateral canine tips to the reference plane. The two points were connected as a line. The new plane was created as it had the line as a line of intersection with and was perpendicular to the reference plane.

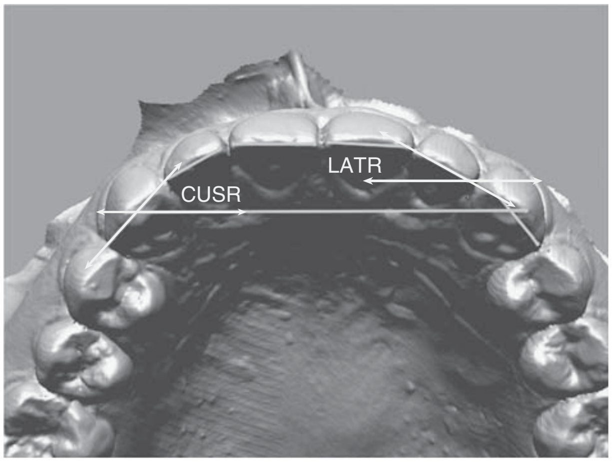

Figure 3. Measurements of the rotation of individual tooth.

lateral incisors (CUPW3/LATW3) were 0.805 ± 0.065 and 1.145 ± 0.125, respectively. The value of LATW3/CNTW3 was significantly different among the three groups (p = 0.034).

The 2D measured perceived average ratios of lateral incisors to central incisors (LATW2/CNTW2) and canines to lateral incisors (CUPW2/LATW2) were 0.716 ± 0.077 and 0.917 ± 0.204, respectively. There were significant differences among the three groups in both ratios (p = 0.009 and p = 0.003) and significant differences were found between Korean females and Japanese females for both ratios (p = 0.010 and p = 0.005, respectively) in *post hoc* tests.

The average rotation values of central incisors (CNTR), lateral incisors (LATR) and canines (CUPR) were 8.038 ± 5.218°, 25.998 ± 9.446° and 55.988 ± 8.776°, respectively. These values were not significantly different between groups.

The average ICW, ICA, ICR, IMW, IMA and IIC values (SD) (attributes arch form) were 35.809 ± 2.103 mm, 129.606 ± 7.772°, 23.820 ± 3.651 mm, 42.296 ± 2.642 mm, 67.231 ± 5.325° and 8.458 ± 1.517 mm, respectively. There were significant differences among the three groups in the values of IMW (p = 0.000) and IMA (p = 0.001). Interestingly, significant differences were found between Korean and Japanese females in the values of IMW (p = 0.000) and IMA (p = 0.002) in Scheffe's *post hoc* tests. These findings indicate that the width or divergence in the first molar area of Korean females was wider than that of Japanese females. Significant differences were also found between the IIC values of Korean males and females (p = 0.015).

Individual tooth proportions, defined as ratios of width to length, were calculated 2D and 3D. Except for CUSP2 (2D canine proportions), no significant differences were found between groups.

In regression analyses to interpret the 2D perceived widths in the context of 3D real widths, rotation and arch form parameters, ICW was found to be the most

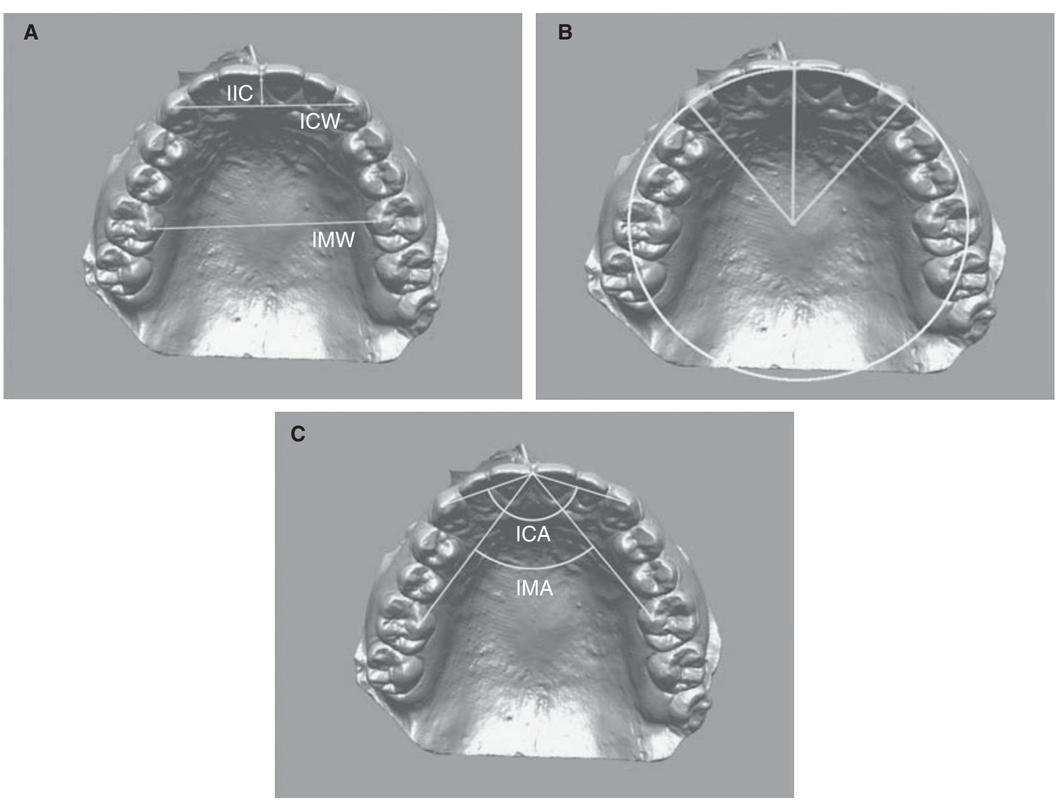

Figure 4. Illustration of measurements related to arch form. (A) ICW (inter-canine width), IMW (inter-molar width) and IIC (incisor to inter-canine line), (B) ICR (incisor-to-canine radius), (C) ICA (incisor-to-canine angle) and IMA (incisor-to-molar angle).

Table I. Descriptive statistics for all measurements and summarized ANOVA result with post-hoc tests.

		Korean male (n = 50)		Korean female (n = 44)		Japanese female (n = 45)		Total (n = 139)	
		M	SD	*M*	SD	*M*	SD	*M*	SD
CNTW3 (mm)*	¶	8.685	0.461	8.416	0.497	8.574	0.497	8.564	0.497
CNTW2 (mm)**	¶¶†	8.543	0.540	8.237	0.469	8.501	0.480	8.432	0.461
CNTR(°)		7.848	5.341	6.881	4.220	9.380	5.743	8.038	5.218
LATW3 (mm)*		7.063	0.576	6.872	0.508	6.731	0.661	6.895	0.661
LATW2 (mm)		6.147	0.498	6.070	0.507	5.861	0.923	6.030	0.674
LATR(°)		26.867	9.610	25.900	8.112	25.127	10.540	25.998	9.446
CUSW3 (mm)		7.898	0.367	7.857	0.391	7.711	0.427	7.824	0.427
CUSW2 (mm)*		5.276	0.495	5.391	0.540	5.615	0.831	5.422	0.645
CUSR(°)		57.028	7.296	56.082	8.401	54.740	10.510	55.988	8.776
LATW3/CNTW3*		0.814	0.059	0.817	0.046	0.785	0.083	0.805	0.065
CUPW3/LATW3		1.123	0.076	1.148	0.084	1.165	0.187	1.145	0.125
LATW2/CNTW2**	†	0.720	0.056	0.738	0.062	0.689	0.100	0.716	0.077
CUPW2/LATW2**	††	0.864	0.109	0.894	0.120	1.000	0.304	0.917	0.204
ICW (mm)		36.316	2.077	35.515	1.749	35.534	2.103	35.809	2.103
ICA(°)		127.904	6.930	131.729	6.871	129.422	7.772	129.606	7.772
ICR (mm)		23.420	2.902	24.219	2.677	23.874	3.651	23.820	3.651
IMW (mm)**	††	43.273	2.632	42.730	2.028	40.788	2.642	42.296	2.642
IMA (mm)**	††	67.623	4.743	69.028	5.029	65.040	5.325	67.231	5.325
IIC (mm)*	¶	8.899	1.369	7.996	1.375	8.419	1.517	8.458	1.517
CNTP3		0.852	0.084	0.853	0.075	0.841	0.076	0.848	0.078
CNTP2		0.841	0.078	0.859	0.077	0.835	0.074	0.845	0.077
LATP3		0.801	0.084	0.815	0.100	0.826	0.118	0.814	0.101
LATP2		0.704	0.077	0.723	0.089	0.718	0.107	0.715	0.091
CUSP3		0.818	0.099	0.829	0.084	0.855	0.091	0.833	0.093
CUSP2**	†	0.557	0.074	0.574	0.075	0.626	0.094	0.585	0.086

* denotes significant difference among the three groups ($p < 0.05$); ** denotes significant difference between the three groups ($p < 0.01$); ¶ denotes significant difference between Korean male and female in the post-hoc test ($p < 0.05$); ¶¶ denotes significant difference between Korean male and female in the post-hoc test ($p < 0.01$); † denotes significant difference between Korean and Japanese female in the post-hoc test ($p < 0.05$); †† denotes significant difference between Korean and Japanese female in the post-hoc test ($p < 0.01$).
CNTW3: Central Incisor 3D Width; CNTW2: Central Incisor 2D Width; CNTR: Central Incisor Rotation; LATW3: Lateral Incisor 3D Width; LATW2: Lateral Incisor 2D Width; LATR: Lateral Incisor Rotation; CUSW3: Canine 3D Width; CUSW2: Canine 2D Width; CUSR: Canine Rotation; ICW: Intercanine Width; ICA: Incisor-Canine Angle; ICR: Incisor-Canine Radius; IMW: Incisor-1st Molar Width; IMA: Incisor-1st Molar Angle; IIC: Incisor-Intercanine Line; CNTP3: Central Incisor 3D Width/Length; LATP3: Lateral Incisor 3D Width/Length; CUSP3: Canines 3D Width/Length; CNTP2: Central Incisor 2 Width/Length; LATP2: Lateral Incisor 2D Width/Length; CUSP2: Canines 2D Width/Length.

powerful factor to fit the regression model among other attributes of arch form. However, the r^2 value of the regression model plummeted from the central incisors to the canines, 0.886, 0.678 and 0.365, respectively (Table II).

Discussion

The concept of the 'golden proportion' was first used in ancient Greek architecture and its basic premise is that for two related objects to appear natural and harmonious, the relationship between the larger and smaller object should form a ratio of 1.618:1 [33]. This concept was described mathematically by Leonardo de Pisa, by Fibonacci, has been used in the design of such classic edifices as the Parthenon and appears frequently in Leonardo da Vinci's sketches [16]; it is also frequently cited in the orthodontic literature [17,18]. The 'golden proportion', however, is not the only esthetic criterion used in restorative dentistry. Lombardi [22] states that the existing proportions between the widths of the central and lateral incisors should remain consistent, progressing anteriorly to posteriorly in the mouth, and refers to this pattern as the 'repeated ratio'. Snow [26] proposed the 'golden mean' theory, which states that the widths of the maxillary central incisor, lateral incisor and canine should comprise 25%, 15% and 10% of the

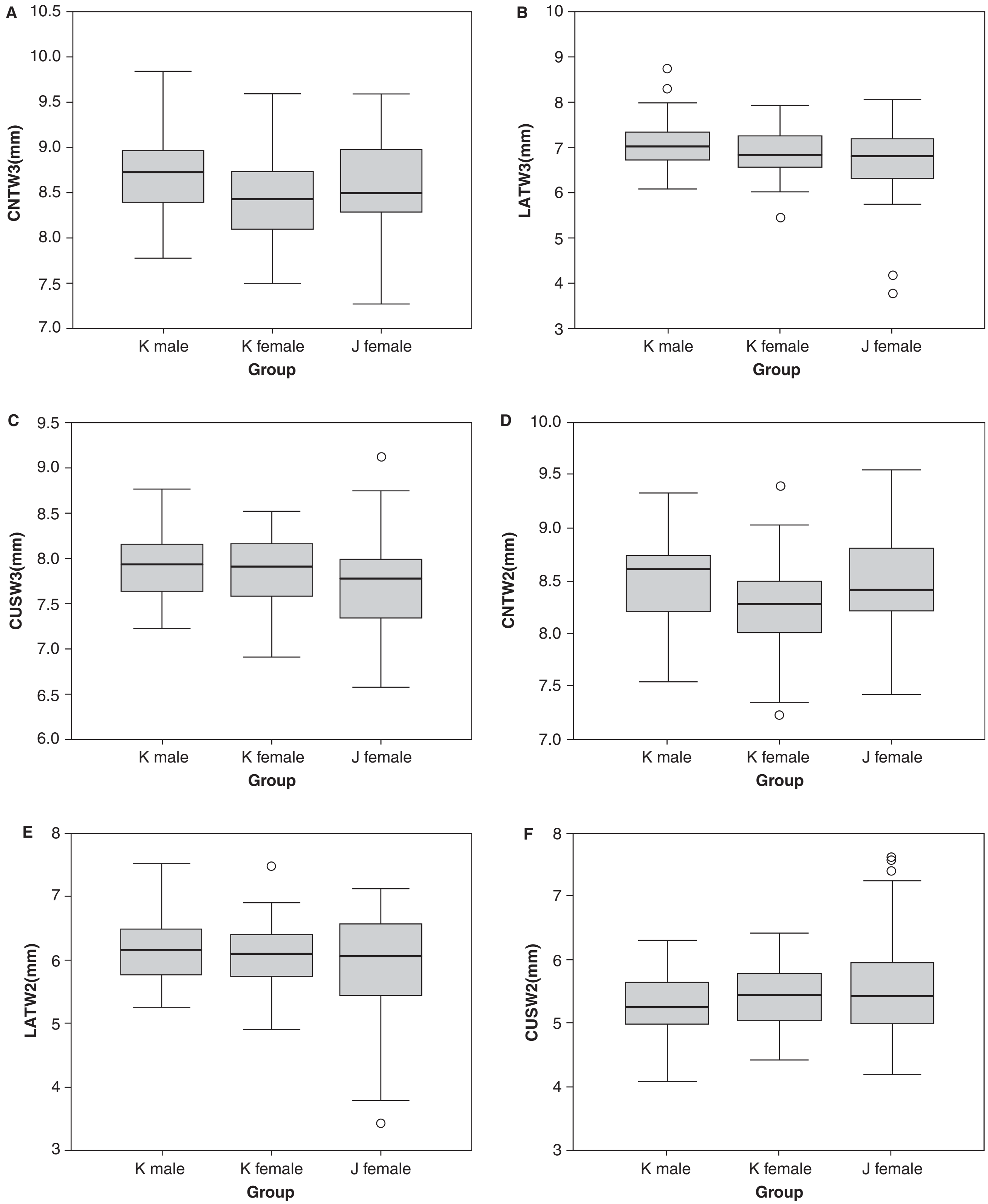

Figure 5. Box plots of 2D and 3D width of anterior teeth. (A) CNTW3, (B) LATW3, (C) CUSW3, (D) CNTW2, (E) LATW2, (F) CUSW2.

total frontal view from the distal aspect of the maxillary canine on one side to the distal aspect of the contralateral maxillary canine. The 'recurring dental esthetic (RED)' proportion proposed by Ward [27] states that the proportions of the successive widths of the maxillary teeth, as viewed from the front, should remain constant, progressing mesiodistally. Preston's [16] report, based on a North American sample, has been occasionally used to represent 'naturally existing proportion'.

Table II. The result of regression analysis.

Model summary					ANOVA					
Teeth	Dependent variable	Predictors	*R*	R^2		Sum of squares	df	Mean square	*F*	Sig
Central incisors	CNTW2	(constant) CNTW3 CNTR ICW	0.886	0.786	Regression	23.001	3	7.667	164.846	0.000
					Residual	6.279	135	0.047		
					Total	29.28	138			
Lateral incisors	LATW2	(constant) LATW3 LATR ICW	0.678	0.460	Regression	28.833	3	9.611	38.294	0.000
					Residual	33.882	135	0.251		
					Total	62.715	138			
Canines	CUPW2	(constant) CUPW3 CUPR ICW	0.365	0.133	Regression	7.641	3	2.547	6.907	0.000
					Residual	49.78	135	0.369		
					Total	57.422	138			

df: degree of freedom.

Based on the average values of the total sample used in the present study, the widths of the lateral incisors are ~ 71.6% of the widths of the central incisors and the widths of the canines are ~ 91.7% of the widths of the lateral incisors. These results partly agree with the findings of previous studies [34–36] including Preston [16], which state that naturally existing dentitions rarely exhibit 'golden' proportions. Another point of agreement with previous studies is that the canine-to-lateral incisor ratio is farther from the 'golden proportion' than are other ratios. However, mean LATW2/CNTW2 value of 71.6% and mean CUPW2/LATW2 value of 91.7% are higher than those of Preston [16] (66% and 84%, respectively). Population characteristics related to the differing geographical origins of the subjects used in the present and past studies may explain these discrepancies. On the other hand, a 71.6% ratio between the central and lateral incisors complies with the esthetic proportions suggested by Ward [25], although the average width/height ratio (0.848) of the central incisors in our sample is larger than Ward's original suggestion (0.75–0.78). This width/height ratio corresponds to the very short (0.80) or short (0.90) height groups defined by Rosenstiel et al. [23], who also reported that the 80% RED proportion was judged best based on the survey results. Disregarding esthetic preferences, it is inferred that the perceived widths of canines in natural dentitions tend to be wider than the ideal values according to the 'golden proportion' or RED. This trait is more evident in the subject of the present study. For example, we observed a 1:1 canine-to-lateral incisor ratio in Japanese females.

In the present study, the average perceived mesiodistal dimensions of the central incisors of Japanese females were significantly larger than those of Korean females. Conversely, the average perceived mesiodistal dimensions of the lateral incisors of Japanese females were smaller than those of Korean females, although the difference was not significantly different. Therefore, the lateral incisor-to-central incisor ratio is significantly smaller in Japanese females than Korean females, indicating that Japanese females have more prominent central incisors in comparison to their lateral incisors than Korean females. There were no significant differences in the width/height ratios of individual teeth among the three study groups, indicating that the differences observed in tooth widths simply reflect overall tooth size.

The perceived frontal view of the anterior dentition plays a key role in dental esthetics [37]. Therefore, the widths or proportions of the anterior dentition are considered important in restorative dentistry. However, as Magne et al. [15] pointed out, crown width/length ratios, transition line angles and other aspects of tooth form are likely to influence the perception of symmetry, dominance and proportion. In the present study, we observed no significant differences in individual tooth rotations. Among parameters related to arch form, significant differences between Korean and Japanese females were observed only in IMW and IMA.

Meanwhile, in regression analyses meant to interpret the 2D perceived widths in the context of 3D real widths, rotation and arch form parameters, ICW was the most powerful factor to fit the regression model among ICW, ICA, ICR, IMW, IMA and IIC. However, the r^2 value of the regression model plummeted mesiodistally from the central incisors to the canines. This indicates that real values for teeth width, rotation and the inter-canine width are not sufficient to explain perceived width, especially in the canine area. Several other factors might affect perceived width, but the detection of all relevant factors is beyond the scope of this study. One of the factors that we can easily infer is the labial convexity of individual teeth. This measurement can be divided into mesial and distal aspects, especially for the canines and sudden decreases of perceived width occur when the rotation of the tooth became above a certain extent.

There is a saying goes 'Beauty is in the eye of the beholder', and the multiplicity of criteria determine differences in esthetic preferences between cultures. However, the perceived harmony between adjacent structures is just as important as more or less esoteric esthetic preferences. Therefore, the proportions of the anterior dentition are a matter of consequence in restorative dentistry. To achieve excellent esthetics when restoring or replacing maxillary anterior teeth, it is necessary to understand the effects of 3D positioning and alignment of individual teeth. Further studies are warranted for a better understanding of 3D positioning and alignment of individual teeth to inform potential applications in restorative dentistry.

Within the limit of the present study, there were significant differences in the average mesiodistal perceived and real dimensions of central incisors between Japanese and Korean females, as well as between the lateral incisor/central incisor and canine/lateral incisor ratios in the perceived 2D measurements between these groups. We did not observe any differences between groups in individual tooth rotations. A regression model that included real dimensions, rotations and arch form parameters as independent factors was not sufficient to explain the perceived widths of the lateral incisors and canines in any of the groups in our study.

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References

[1] Van Der Geld P, Oosterveld P, Berge SJ, Kuijpers-Jagtman AM. Tooth display and lip position during spontaneous and posed smiling in adults.Acta Odontol Scand 2008; 66:207–13.
[2] Hasanreisoglu U, Bersksun S, Aras K, Arslan I. An analysis of maxillary anterior teeth: facial and dental proportions. J Prosthet Dent 2005;94:530–8.
[3] Ahmad I. Geometric considerations in anterior dental aesthetics: restorative principles. Pract Periodontics Aesthet Dent 1998;10:813–22.
[4] Raj V, Heymann HO, Hershey HG, Ritter AV, Casko JS. The apparent contact dimension and covariates among orthodontically treated and nontreated subjects. J Esthet Restor Dent 2009;21:96–111.
[5] Nie Q, Lin J. Comparison of intermaxillary tooth size discrepancies among different malocclusion groups. Am J Orthod and Dentofacial Orthop 1999;116:539–44.
[6] Basaran G, Selek M, Hamamci O, Akkus Z. Intermaxillary Bolton tooth size discrepancies among different malocclusion groups. Angle Orthod 2006;76:26–30.
[7] Crosby DR, Alexander CG. The occurrence of tooth size discrepancies among different malocclusion groups. Am J Orthod Dentofacial Orthop 1989;95:457–61.
[8] Uysal T, Sari Z. Intermaxillary tooth size discrepancy and mesiodistal crown dimensions for a Turkish population. Am J Orthod Dentofacial Orthop 2005;128:226–30.
[9] Lee SJ, Ahn SJ, Lim WH, Lee S, Lim J, Park HJ. Variation of the intermaxillary tooth size relationship in normal occlusion. Eur J Orthod 2011;33:9–14.
[10] Bolton WA. Disharmony in tooth size and its relation to the analysis and treatment of malocclusion. Angle Orthod 1958; 28:113–30.
[11] Bolton WA. The clinical application of a tooth size analysis. Am J Orthod 1962;48:504–29.
[12] Alkofide E, Hashim H. Intermaxillary tooth size discrepancies among different malocclusion classes: a comparative study. J Pediat Dent 2002;26:383–7.
[13] Araujo E, Souki M. Bolton anterior tooth size discrepancies among different malocclusion groups. Angle Orthod 2003;73: 307–13.
[14] Belser UC. Esthetics checklist for the fixed prosthesis. Part II: biscuit-bake try-in. In: Schärer P, Rinn LA, Kopp FR, editors. Esthetic guidelines for restorative dentistry. Chicago, IL: Quintessence; 1982. p 188–92.
[15] Magne P, Gallucci GO, Belser UC. Anatomic crown width/ length ratios of unworn and worn maxillary teeth in white subjects. J Prosthet Dent 2003;89:453–61.
[16] Preston JD. The golden proportion revisited. J Esthet Dent 1993;5:247–51.
[17] Ricketts RE. The divine proportion in facial esthetics. Clin Plast Surg 1982;9:401–22.
[18] Ricketts RE. The biologic significance of the divine proportion. Am J Orthod 1982;81:351–70.
[19] Levin EL. Dental esthetics and the golden proportion. J Prosthet Dent 1978;40:244–52.
[20] Rufenacht C. Fundamentals of esthetics. Berlin: Quintessence; 1990.
[21] Shoemaker WA, Jr, Nestor J. A time to recognize the science in the art of healing. Florida Dent J 1981;52:22–3,46–7.
[22] Lombardi R. The principles of visual perception and their clinical application to dental esthetics. J Prosthet Dent 1973;9: 358–81.
[23] Rosenstiel SF, Ward DH, Rashid RG. Dentists' preferences of anterior tooth proportion–a web-based study. J Prosthodont 2000;9:123–36.
[24] Rosenstiel SF, Rashid RG. Public preferences for anterior tooth variations: a web-based study. J Esthet Restor Dent 2002;14:97–106.
[25] Ward DH. A study of dentists' preferred maxillary anterior tooth width proportions: comparing the recurring esthetic dental proportion to other mathematical and naturally occurring proportions. J Esthet Restor Dent 2007;19:324–37; discussion 338–9.
[26] Snow SR. Esthetic smile analysis of anterior tooth width: the golden percentage. J Esthet Dent 1999;11:177–84.
[27] Ward DH. Proportional smile design using the RED proportion. Dent Clin North Am 2001;45:143–54.
[28] Albers HA. Esthetic treatment planning. Adept Report 1992; 3:45–52.
[29] DeLong R, Heinzen M, Hodges JS, Ko CC, Douglas WH. Accuracy of a system for creating 3D computer models of Dental Arches. J Dent Res 2003;82:438–42.
[30] Park YS, Lee SP, Paik KS. The three dimensional relationship on a virtual model between the maxillary anterior teeth and incisive papilla. J Prosthet Dent 2007;98:312–8.
[31] Lee SP, Delong R, Hodges JS, Hayashi K, Lee JB. Predicting first molar width using virtual models of dental arches. Clin Anat 2008;21:27–32.

[32] Cheon SH, Park YH, Paik KS, Ahn SJ, Hayashi K, Yi WJ, et al. Relationship between the curve of Spee and dentofacial morphology evaluated with a 3-dimensional reconstruction method in Korean adults. Am J Orthod Dentofacial Orthop 2008;133:640.e7–14.

[33] Huntley HE. The divine proportion. New York: Dover Publications; 1970.

[34] Gillen RJ, Schwartz RS, Hilton TJ, Evans DB. An analysis of selected normative tooth proportions. Int J Prosthodont 1994; 7:410–7.

[35] Mahshid M, Khoshvaghti A, Varshosaz M, Vallaei N. Evaluation of "golden proportion" in individuals with esthetic smile. J Esthet Restor Dent 2004;16:185–92.

[36] Basting RT, Trindade RS, Flório FM. Comparative study of smile analysis by subjective and computerized methods. Oper Dent 2006;31:652–9.

[37] Sterrett JD, Oliver T, Robinson F, Fortson W, Knaak B, Russell CM. Width/length ratios of normal clinical crowns of the maxillary anterior dentition in man. J Clin Periodontol 1999;26:153–7.