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New clinical classification of dental arch form using facial axis points derived from three-dimensional models

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Introduction: The purpose of the present study was to use facial axis (FA) points to classify dental arch form generated from an analysis of 3-D virtual models of a sample of normal occlusions . A secondary aim was to introduce a new arch form template based on this classification for clinical application.
Methods: One hundred and twenty five plaster models of Class I occlusions were 3-D scanned (Orapix Co., Ltd, Seoul, Korea) and FA points digitized on the virtual models using Rapidform 2006 software (INUS Technology Inc., Seoul, Korea). Following intercanine and intermolar arch width and depth measurements, K-means cluster analysis was applied on 77 cases (Dataset 1) to classify the sample into arch form types. A curve of best fit of the mean arch form of each type was generated. The remaining 48 cases (Dataset 2) were mapped into the clusters and a multivariate test was performed to assess the differences among the clusters.
Results: Classification into five clusters demonstrated maximum inter-cluster distance in the arch parameters and produced the most homogeneous cluster size. The differences between the 5 cluster types were statistically but not clinically significant and so they were recombined to form three clusters representing 'narrow', 'moderate' and 'wide' arch forms.
Conclusions: A template with three arch form types based on anterior and posterior dimensions has been proposed through 3-D analysis of FA points for more accurate arch form identification and arch wire selection.
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Introduction

The shape of a mandibular dental arch is considered an important reference in orthodontic diagnosis and treatment planning. Since arch form configuration is a key element in treatment stability, the correct identification of arch form during the diagnostic phase has become essential, especially given the popular use of superelastic arch wires.[1-4]

Several studies have indicated that a single ideal dental arch shape will not meet all treatment goals due to the inevitable variation among individuals.[5] Additional research has analysed mandibular arch form with various mathematical models to determine classifications with statistical and clinical significance.[6-14] Raberin et al. attempted to classify mandibular arches into five ideal arch forms by a non-hierarchical K-means clustering method which questioned group characteristics.[15] However, most investigators based landmark selection on cusp tips and incisal edges, which may not be an appropriate representation of clinical bracket points. More recently, Trivino et al. developed a classification method using glass beads placed on casts to simulate ideal bracket positions. The methodology was limited to two dimensions and the resultant classification was based on visual identification of arch form characteristics which, unfortunately, did not convey high reliability and accuracy.[16]

With the advent of 3-dimensional (3-D) imaging technology, the accuracy and versatility of virtual models has been confirmed by several studies.[17-20] Although Kim et al. recently reported that substantial mis-identification and overlap existed in the classification of mandibular arch form,[22] few studies using 3-D technology have evaluated arch dimensions.[19,21,22] However, Camporesi et al.[23] used 3-D derived, clinically-relevant, facial axis (FA) points to examine average dental arch forms, but failed to produce an arch form classification based on these points.

Currently, many different arch type classification systems exist, but not all are clinically applicable since most focus on incisal edges and cusp tips. It is therefore suggested that a revised template system, which uses facial axis (FA) points as key landmarks, may be more appropriate when considering clinical bracket positions and therefore provide a more accurate fit of superelastic arch wires.

Therefore, the purpose of the present study was to classify dental arch form types based on FA points by an analysis of 3-D virtual models of a sample of normal occlusions. Based on this classification, an additional aim was to introduce a new arch form template for clinical application.

Materials and methods

The samples consisted of 125 young adults with normal occlusion (76 males and 49 females) selected from a database of 15,621 Korean subjects. The subjects' ages ranged from 20 to 30 years with a mean of 23.5 years. The inclusion criteria identified:

Angle's Class I molar and canine relationships.

ANB > 0 degrees and < 4 degrees.

Normal overbite and overjet (> 0 mm, < 4 mm).

Minor arch length discrepancy (< 3 mm of crowding, < 1 mm of spacing).

Flat or slight curve of Spee (< 2 mm).

Absence of crossbite or deviations in the dental midline.

Permanent dentition with normal tooth size and shape, except third molars.

No history of previous orthodontic treatment.

No restorations extending to contact areas, cusp tips, incisal edge or facial surface.

Mandibular and maxillary casts were placed in their occlusal relationship and scanned with an Orapix KOD-300 3-D laser scanner (Orapix Co., Ltd, Seoul, Korea) at 20 micrometer unit resolution. The FA points[24] were digitised on each tooth of the virtual models, using Rapidform 2006 software (INUS Technology Inc., Seoul, Korea) (Figure 1).

The transverse direction was set as the X-axis; the antero-posterior direction, the Y-axis and the line perpendicular to the X and Y planes, the Z-axis. The FA point on the maxillary right second molar was set as the origin of the X and Y axes. The Z-axis values were nullified.

Four linear and two ratio variables were measured and calculated for each arch form (Table I and Figure 2). Digitization and measurements were performed by one investigator (MB) experienced in the 3-D technology. Ten randomly selected cases were reprocessed two weeks later by the same operator in order to evaluate intra-operator variability. An intra-class correlation (ICC) test revealed high reliability between the two assessments (ICC > 0.8).

The 125 casts were divided randomly into two datasets. The first consisted of 77 cases and was utilised to create arch form clusters, while Dataset 2 contained 48 cases used to examine the differences between clusters for validation purposes. A K-means Cluster test was used in SPSS (SPSS 16.0.2.1, SPSS Inc., Chicago, IL, USA) to classify Dataset 1 into groups according to differences in the selected parameters. Mandibular intercanine and intermolar widths and lower intercanine width/depth ratio were selected as the variables on which the clustering was based. These parameters were selected due to their importance in relation to arch stability and as a representation of the curvature of the anterior segment of the arch. The classification into the various groups was run through

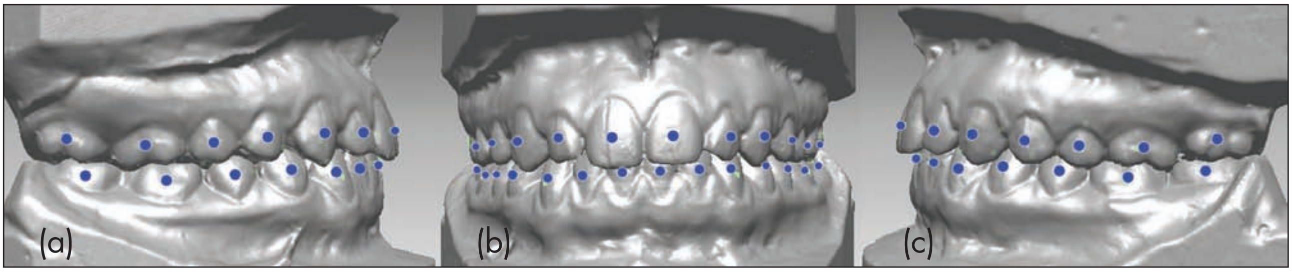

Figure 1. The facial axis (FA) points marked on the three-dimensional (3-D) virtual models. (a), right buccal view; (b), front view; (c), left buccal view.

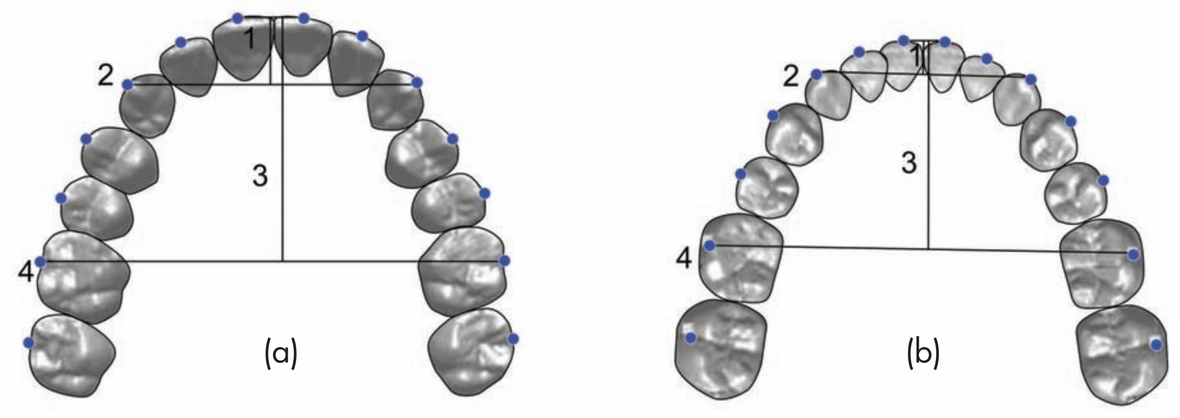

Figure 2. (a) and (b). Arch dimension variables measured from the FA points. 1, intercanine depth; 2, intercanine width; 3, intermolar depth; 4, intermolar width.

the software programme and the distributions within each classification and the homogeneity of group sizes were analysed. The classification which demonstrated highly significant differences between the groups in the three parameters and, at the same time, had the most homogeneous group size, was selected. A Chi-square test was applied to evaluate the frequency distribution of the clusters and the association between clusters and gender. Pearson correlation coefficients were calculated among the maxillary and mandibular arch dimensions.

The mean arch form of each cluster was calculated from the X and Y coordinates of FA points for each subject in the group. The mean coordinates of each point were downloaded into a mathematical software program (MATLAB 7.5 (R2007b), The MathWorks Inc., MA, USA) and the best fit curve representing mean arch form was drawn using the fourth degree polynomial equation ($f(x) = ax^4+bx^3+cx^2+dx+e$).[2,8,9,13,14]

After superimposition of the mandibular arch forms on the midpoints of the arches using Adobe® Photoshop® CS4 (Adobe systems Inc., San Jose, CA, USA), the differences between the arch forms were evaluated for clinical significance and application. Preliminary results indicated that considerable similarity existed between some clusters and therefore these were recombined to produce a three-group template.

Subsequently, Dataset 2 was mapped into the same space and assigned to the three groups already constructed. A multivariate test with Bonferroni correction for multiple comparisons was run to validate the clustering performed on Dataset 1. MATLAB was used to draw the arch forms of the new groups following the same procedure outlined above.

Results

A K-means cluster analysis was repeated seven times to classify the sample into several sub-groups. The classification into five clusters demonstrated maximum inter-cluster distance in the three parameters and produced the most homogeneous cluster size. Table II shows the clusters classified according to their arch form dimensions. The even frequency distribution of the subjects among the clusters was verified by a Chi square test ($p = 0.045$). In addition, the association between gender and clusters was not significant ($p = 0.119$).

Table I. Definitions of the arch dimension variables.

Arch dimension variables	Definition
Intercanine width (mm)	The distance between the FA points of the right and left canines.
Intermolar width (mm)	The distance between the FA points of the right and left first molars.
Intercanine depth (mm)	The shortest distance from a line connecting the FA points of the right and left canines to the midpoint between the FA points of the right and left central incisors.
Intermolar depth (mm)	The shortest distance from a line connecting the FA points of the right and left first molars to the midpoint between the FA points of the two central incisors.
Intercanine W/D ratio	Ratio between Intercanine width and depth.
Intermolar W/D ratio	Ratio between Intermolar width and depth.

Table II. Cluster centres and frequency distribution of the five arch forms of Dataset 1.

Cluster	Lower canine width (mm)	Lower molar width (mm)	Lower canine width/depth	Frequency N (%F)	*p* value
1	28.90	55.44	6.43	20 (26.0)	0.049
2	31.47	57.16	7.01	12 (15.6)	
3	27.32	51.28	7.35	7 (9.1)	
4	28.17	50.66	5.27	16 (20.8)	
5	29.67	53.13	5.86	22 (28.5)	

K-means cluster analysis and Chi-square test

Table III. Comparison of arch dimensions among the three arch form groups of Dataset 2.

		Narrow N = 12		Moderate N = 16		Wide N = 20		*p* value	Multiple comparison
		Mean	SD	Mean	SD	Mean	SD		
Upper	Intercanine width (mm)	37.06	1.13	38.34	1.57	40.08	1.66	< 0.001	W > M > N
	Intermolar width (mm)	55.29	1.21	58.21	1.64	61.37	2.68	< 0.001	W > M > N
	Intercanine depth (mm)	8.59	0.93	8.33	0.78	8.87	0.84	0.177	
	Intermolar depth (mm)	30.47	1.61	30.45	1.72	31.76	1.39	0.025	W > M, N
	Intercanine width/depth	4.36	0.45	4.64	0.47	4.56	0.44	0.266	
	Intermolar width/depth	1.82	0.09	1.92	0.12	1.94	0.12	0.021	W, M > N
Lower	Intercanine width (mm)	28.39	0.94	28.87	1.36	31.00	1.46	< 0.001	W > M, N
	Intermolar width (mm)	49.98	1.17	52.88	1.26	56.55	2.01	< 0.001	W > M > N
	Intercanine depth (mm)	5.12	0.88	4.41	0.94	5.13	0.64	0.023	W, N > M
	Intermolar depth (mm)	26.07	1.45	25.98	1.85	27.43	1.76	0.026	W > M, N
	Intercanine width/depth	5.67	0.87	6.89	1.77	6.14	0.84	0.039	M > W, N
	Intermolar width/depth	1.92	0.11	2.05	0.15	2.07	0.14	0.015	W, M > N

Multivariate analysis with Bonferroni multiple comparison. N, narrow; M, Moderate; W, Wide.

Strong correlations were found between the maxillary and mandibular intermolar widths and depths (r = 0.92 and 0.84, respectively), while the correlations between the maxillary and mandibular canine widths and depths were moderate (r = 0.63 and 0.48, respectively).

Superimposition of the mandibular arch form of the five clusters revealed a great deal of similarity between clusters 1 and 2, as well as between clusters 3 and 5 (Figure 3). Therefore, clusters 1 and 2 were combined to form the 'wide' group, while clusters 3 and 5 were joined to make the 'moderate group'. Cluster 4 became the 'narrow' group. The maxillary and mandibular arch forms of the three groups were drawn and presented in Figure 4.

For validation and comparison between the three groups, Dataset 2 was assigned into the three groups. Table III compares the arch dimensions among the 'narrow', 'moderate', and 'wide' groups. Groups differed significantly in the maxillary and mandibular intermolar and intercanine widths ($p < 0.001$). The 'wide' group showed significantly larger widths than the 'moderate', which in turn was larger than the 'narrow' group. However, the mandibular intercanine width showed no significant difference between the 'narrow' and 'moderate' groups. The 'wide' group demonstrated significantly larger maxillary and mandibular intermolar depths compared to the 'narrow' and 'moderate' groups. Also, the 'narrow' group had a significantly smaller mandibular intercanine depth than the other two groups. However, there were no significant differences between the three groups regarding the maxillary intercanine depth. Furthermore, the intermolar width/depth ratio was significantly smaller in both arches of the 'narrow' group compared with the other groups.

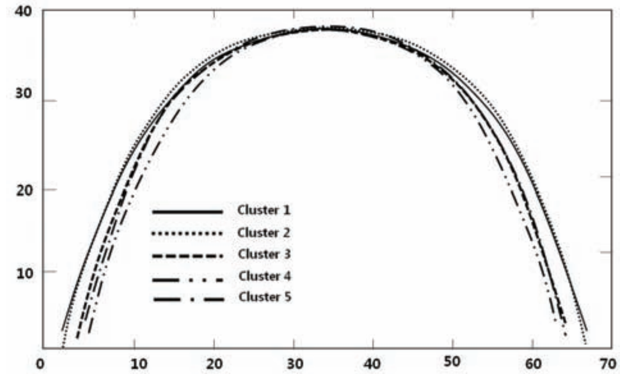

Figure 3. Superimposition of the mandibular arches of the five clusters.

Discussion

Arch form classification and templates derived from FA points using a 3-D assessment for clinical application have not been previously reported. Therefore, the aim of this study was to introduce a new classification system of arch form based on bracket points and intended to improve the clinical application of preformed arch wires.

A 3M OrthoForm template (3M Unitek, Monrovia, CA, USA) has been previously used to analyse arch form and considerable overlap between the various forms has been reported.[22] Although this and other current templates such as Pentamorphic arch template (RMO, Denver, CO, USA), Tru-Arch (Ormco, Sybron Dental Specialties, Orange, CA, USA), Brader (American Orthodontics, Sheboygan, WI, USA) were used in several arch form investigations,[23,25,26] they are mostly based on incisal edge and cusp tip landmarks, and are also influenced by the subjective clinical experience or preferred arch form of clinicians/companies. Therefore, doubts over the current classification and template systems remain and it would be advantageous to introduce an alternative template system based on and for, clinical bracket positions.

Raberin et al. grouped arch forms depending on the ratios of their transverse and sagittal dimensions without a consideration of the dimensions themselves.[15] Although this method of mathematically applying a polynomial equation of each form to different dimensions is versatile, it is not as clinically practical as using a template. The present study attempted to overcome this problem by including intercanine and intermolar arch widths as classification parameters and also by the use of FA points. These are known to be more relevant to clinical application than incisal edges and cusp tips points used in past research.

In 2008, a new classification method was developed by Trivino et al. using FA points as landmarks in order to improve clinical efficiency.[16] Landmark identification was addressed by the attachment of glass beads to dental casts and two-dimensionally scanning and creating mirror-images of each half of the scanned arches. This may have introduced larger errors when compared with measurements on 3-D virtual

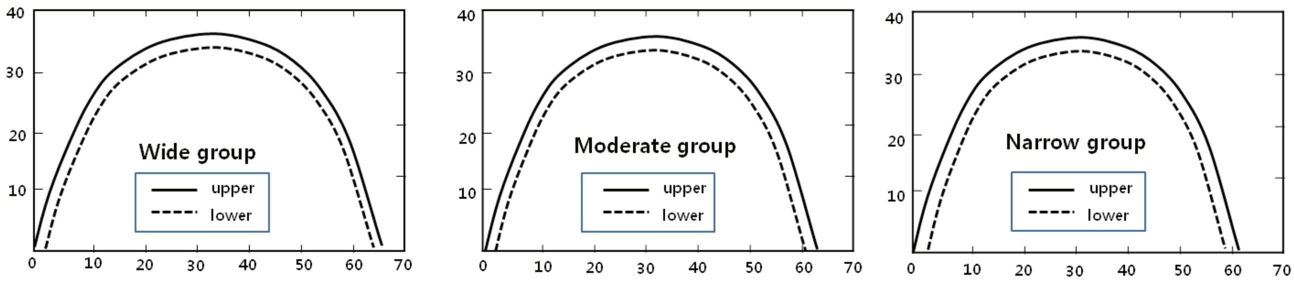

Figure 4. Maxillary and mandibular templates of the three groups: narrow, moderate and wide derived from 3-D analysis of FA points.

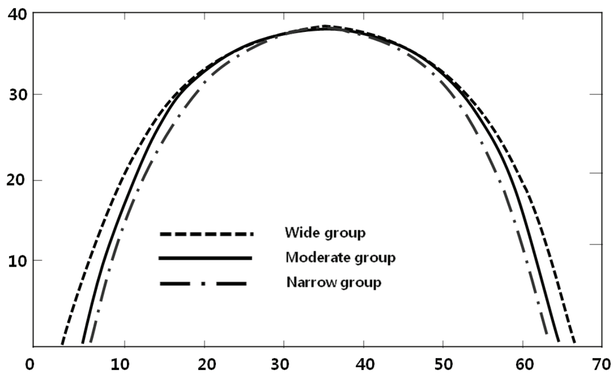

Figure 5. Superimposition of the mandibular arches of the three groups derived for clinical application from the five clusters.

models. In addition, the sample was grouped by visual identification which incorporated subjectivity and lacked accuracy and precision.

In the present study, the classification procedure was based on mandibular intercanine width/depth ratio which represented the curvature of the anterior segment of the arch. The classification was also based on the mandibular intercanine and intermolar widths which were reported to be highly related to treatment stability.[1-3] To test the validity of the three selected parameters, several pilot studies were performed by adding more variables both collectively and separately. This resulted in no significant changes in the clustering categories or homogeneity. However, removing any one of the three variables led to different results. Also, the significant strong and moderate correlations found between the maxillary and mandibular parameters supported the use of the mandibular parameters as the only grouping factors. Hence, this new classification considered both the shape and the size of the dental arch.

The current results supported previous findings that denied the existence of a single, ideal arch form appropriate for all patients.[2,15,16] The 24 different arch forms introduced by Trivino et al.[16] are clinically impractical and create inventory concerns. Therefore, the 5-cluster classification initially developed in the present study was considered to be more practical.

Despite the statistically significant differences, superimposition of the mandibular arch forms of the five clusters indicated that the differences between some groups were not clinically significant. Therefore, to simplify the application of the proposed template system based on these data, the differences between groups were increased to a clinical level. This was achieved by recombining clusters 1 and 2 and clusters 3 and 5 to form the new 'wide' and 'moderate' groups, respectively. Although cluster 4 included only 16 cases, it represented the 'narrow' group as it was both clinically and statistically different from the other clusters. This relatively low frequency of the 'narrow' arch form has been also reported in other populations with normal occlusions.[27]

Figure 5 shows the superimposition of the arch forms from the three groups. The 'narrow' group was characterised by the narrowest intercanine and intermolar widths in both arches. The width/depth ratios of this group were similar to those of the narrow cluster reported by Raberin et al.[15] In addition, the intercanine and intermolar arch depths and width/depth ratios of the 'moderate' group were comparable to previously reported results.[21] However, the 'wide' group intermolar depth was larger than detailed in earlier studies.[15,16,21] The three groups of the present study possessed larger arch widths and ratios but had smaller intercanine depth and similar intermolar depth than all arch forms described by Raberin et al.[15] and Trivinio et al.[16] These differences may be due to the different ethnic samples and research methods.

There was no significant association between gender and arch form. Gender homogeneity in the present study was consistent with the groups reported by Raberin et al.[15] and most of the groups classified by Trivinio et al.[16]

Several previous reports have described the shape of the human dental arch using geometrical and mathematical methods[1,8,23,26,28] and the polynomial equation was considered the best representation of the human dental arch. Hechter[29] supported the second degree polynomial, several authors[9,13,30] advocated the fourth, while Noroozi et al.[28] promoted the sixth degree. Accordingly, several polynomial functions were applied in a pilot study, and the fourth degree was selected as it more accurately represented the human arch form and produced smoother curves with no wave-like properties compared with other formulae.

The main clinical application of the present study is the transference of the arch forms onto clear 1:1 scaled templates. The clinician has the ability to overlay these templates onto a patient's casts and visually select the form of best fit. Although some teeth may be out of alignment due to the malocclusion, the general shape of the arch form would still be recognizable. Therefore, choosing the appropriate arch form and archwire would be facilitated in most cases.

Conclusions

Based on a 3-D analysis of FA points, the present results showed that no single, ideal arch form exists that is suitable for all patients. It was demonstrated that, although five clusters may be statistically verifiable, their clinical use was likely impractical, and so a 3-group classification that considered both anterior and posterior mandibular dimensions was developed for more efficient identification of patients' arch forms. It is expected that this 3-type template would be more practical for the selection of superelastic wires.

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