Original Article

Variation in form of mandibular, light, round, preformed NiTi archwires

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ABSTRACT

Objective: To evaluate the variation in form of nickel-titanium (NiTi) archwires by comparing them with the dental arch form of normal Japanese subjects before and after placing them in the first molar tubes.

Materials and Methods: The mandibular dental casts of 30 normal subjects were scanned, and the dental arch depths and widths from the canine to the first molar were measured. Standardized images of 34 types of 0.016-inch preformed NiTi archwires were also taken in a 37°C environment, and the widths were measured and then classified by cluster analysis. Images of these archwires placed in a custom jig with brackets attached at the mean locations of the normal mandibular central incisors and first molar were additionally taken. The widths of the pooled and classified archwires were then compared with the normal dental arch widths before and after placement in the jig and among the groups ($P < .05$).

Results: The archwires were classified into three groups: small, medium, and large. The archwire widths in the small and medium groups were narrower than those at all examined tooth widths, except in the case of the premolars of the medium group. After placement in the jig, the pooled archwire widths were found to be significantly narrower and wider at the canine and second premolar, respectively, than at the dental arch, but not in the individual comparisons between groups.

Conclusion: The variation observed in the mandibular NiTi archwire forms significantly decreased following fitting into the normal positions of the first molars. (*Angle Orthod.* 2016;86:796–803.)

KEY WORDS: Dental arch form; Nickel-titanium (NiTi); archwires

INTRODUCTION

Although the cause of relapse after orthodontic treatment is known to be multifactorial, studies have indicated that maintaining the initial mandibular dental arch form of each patient is a key element in achieving stable results.[1,2] In the early stage of developing edgewise appliances, the importance of modifying the archwire form for each patient's individual dental arch form was recognized.[3] However, during the 1970s, after the straight-wire appliance was developed by Andrews,[4] Roth designed an arch form that was based mainly on his clinical experience[5]; this subsequently became the standard arch form for the new system. Because introduction of the Roth arch form occurred before publication of articles referencing nickel-titanium (NiTi) archwires,[6,7] adjustment of each preformed stainless steel archwire to fit the individual patient's dental arch form originally adhered to a general procedure called "blanks."[8]

Today, preformed NiTi archwires are available in a wide variety of arch forms and are often prepared in a set of three types by several orthodontic manufacturers, with variations in canine arch width.[9] However, few published studies have explored the relationship between dental arch form and archwire form,[10–13] and agreement on this topic has not been reached.

Currently, most orthodontists use preformed NiTi archwires in the initial stages of orthodontic treatment, without consideration of arch form,[14] because it is believed that changes in the transverse dimension of the dental arch do not occur when using these light

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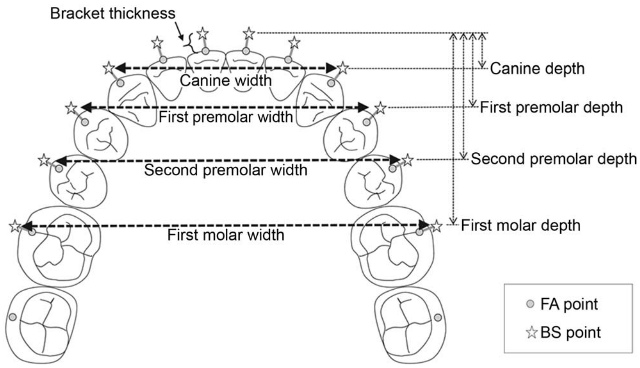

Figure 1. Definition of the depths and widths of the normal dental arch, as calculated based on BS points.

archwires.[9] However, recent randomized clinical trials (RCTs) that evaluated changes in mandibular dental arch form found significant arch expansion in the early stages of orthodontic treatment, despite the bracket type or archwire form.[15–17] Certain authors have stated that the reason for the dimensional change during the alignment phase is the inconsistency between the manufactured archwire forms and the natural diversity of the human dental arch form. Results of the mentioned RCTs[15–17] indicated the necessity of investigating arch form variation among light, round, preformed NiTi archwires.

Cluster analysis is a mathematical method of classifying an item consisting of a number of variables based on the similarity between the variables.[18,19] Hierarchical cluster analysis links and clusters the variables that are close to each other in sequence and expresses the results in a dendrogram. Cluster analysis has been applied to objective classifications of dental arch forms,[20] but not to archwire forms.

The purpose of the present study was to evaluate the variation in form of mandibular light, round, preformed NiTi archwires based on objective classification via cluster analysis compared with the dental arch form of Japanese subjects with normal occlusion.

MATERIALS AND METHODS

Ethical approval (NDU-T2014-06) was obtained from the ethics committee of Nippon Dental University.

Table 1. The 34 Types of 0.016-inch, Preformed Nickel-Titanium Archwires From 12 Manufacturers

Product Number	Archwire Name	Brand/Manufacturer
1	Ortho Form I	3M Unitek Orthodontic Products, Monrovia, Calif
2	Ortho Form II	3M Unitek
3	Ortho Form III	3M Unitek
4	Natural Arch Form I	American Orthodontics, Sheboygan, Wisc
5	Natural Arch Form II	American Orthodontics
6	Natural Arch Form III	American Orthodontics
7	Tynilloy small	Dentsply Sankin, Tochigi, Japan
8	Tynilloy large	Dentsply Sankin
9	Straight-Arch-Form	Forestadent, Pforzheim, Germany
10	Truform I	G & H Wire Company, Franklin, Ind
11	Europa Form I	G & H Wire Co
12	Europa Form II	G & H Wire Co
13	VIA wires—Ovoid	Opal Orthodontics, South Jordan, Utah
14	VIA wires—Tapered	Opal Orthodontics
15	VIA wires—Square	Opal Orthodontics
16	Orthos Arch Form Small	Ormco Corporation, Glendora, Calif
17	Orthos Arch Form Large	Ormco
18	Broad Arch Form Small	Ormco
19	Broad Arch Form Large	Ormco
20	Tru-Arch Form Small	Ormco
21	Tru-Arch Form Large	Ormco
22	Damon Arch Form	Ormco
23	Pro Form	Ortho Organizers Inc, Carlsbad, Calif
24	Natural Arch	Rocky Mountain Orthodontics, Denver, Colo
25	S arch form	Shofu, Kyoto, Japan
26	Accu Form	Tomy International, Tokyo, Japan
27	Standard	Tomy International
28	Bio-Arch I	TP Orthodontics Inc, La Porte, Ind
29	Bio-Arch II	TP Orthodontics
30	Bio-Arch III	TP Orthodontics
31	Bio-Arch IV	TP Orthodontics
32	Bio-Arch V	TP Orthodontics
33	Straight Arch Form	TP Orthodontics
34	Straight Arch II Form	TP Orthodontics

Table 2. Comparison of Medians and Semi-Interquartile Ranges (SIQRs) Between the Mandibular Dental Arch Width of Subjects With Normal Occlusion and Archwire Width at the Arch Depth of the Canine, First and Second Premolar, and First Molar (mm)

	Normal Occlusion (n = 30)				Pooled Archwires (n = 34)			
Tooth	Median	SIQR	Mean	SD	Median	SIQR	Mean	SD
Canine	30.18	0.73	30.19	1.33	28.53	0.93	28.14	1.63
First premolar	40.90	1.43	41.07	1.82	39.63	1.35	39.23	2.10
Second premolar	47.87	1.16	47.99	2.58	46.71	1.10	46.71	2.34
First molar	55.34	1.83	55.73	2.66	51.66	1.66	51.66	3.05

* $P < .05$; ** $P < .01$; Results of comparing dental arch widths of normal occlusion group and the pooled archwire widths using the Mann-Whitney *U* test.

[a] $P < .05$; Results of comparing dental arch widths of normal occlusion group and the archwire widths of medium group using post-hoc tests with Bonferroni correction.

[b] $P < .01$; Results of comparing dental arch widths of normal occlusion group and the archwire widths of small group using post-hoc tests with Bonferroni correction.

[c] $P < .05$; Results of comparing medium and small groups using post-hoc tests with Bonferroni correction.

[d] $P < .01$; Results of comparing medium and large groups using post-hoc tests with Bonferroni correction.

[e] $P < .01$; Results of comparing small and large groups using post-hoc tests with Bonferroni correction.

The mandibular dental casts of 30 subjects (15 men, 15 women; mean age, 23 years 2 months) with the most ideal occlusions, who were selected from a total population of approximately 3500 students at Nippon Dental University and assessed in a study referenced earlier, were used in the present study.[12] To minimize the possibility of further growth, subjects aged 18 years or older were selected. The mandibular arch was analyzed because therapeutic possibilities in the mandible are more limited than in the maxilla. Additionally, maintenance of the mandibular dental arch form is essential for achieving stable results.

According to the method developed by Oda et al.,[12] bracket thicknesses of a set of mandibular brackets for the central and lateral incisors, canines, first and second premolars, and first molars (Damon Q, Ormco Corp, Glendora, Calif), measured with a modified digital caliper (Digimatic Caliper, NTD12-15C, Mitutoyo, Kawasaki, Japan), were 1.11, 1.12, 0.79, 0.96, 1.09, and 0.97 mm, respectively. One reason for selecting this bracket set was the necessity of using commercial brackets with thicknesses close to the mean of the thicknesses used in the previous study,[12] and a second reason was that the passive self-ligation bracket could help avoid the seating force of tying in the archwire with elastic modules.[21]

The mandibular dental casts were then scanned and analyzed using a laser scanner (Surflacer VMS-100F, UNISN, Osaka, Japan).[12] The bracket slot point (BS point),[12] representing the position of the center of the base of the bracket slot in relation to each tooth, was established as the thickest portion of the bracket at the corresponding facial axis point (FA point)[4] of the 14 teeth from the central incisors to the second molars. The means and standard deviations (SDs) of the depths for the canine, first and second premolars, and first molar of the 30 normal subjects, measured from the midpoint between the BS points for the central incisors, were 4.84 ± 0.70 mm, 10.94 ± 0.87 mm, 17.81 ± 1.23 mm, and 26.66 ± 1.57 mm, respectively. The distances between the bilateral BS points for each tooth type were then calculated as the dental arch widths for the canines, first and second premolars, and first molars (Figure 1).

A total of 34 types of 0.016-inch mandibular, round, preformed NiTi archwire from 12 manufacturers were selected (Table 1). Next, a digital camera (EOS Kiss X7, Canon, Tokyo, Japan) with a macro lens (90 mm, F/2.8 Macro, Tamron, Saitama, Japan) was placed above a chamber maintained at 37°C by a heater, and

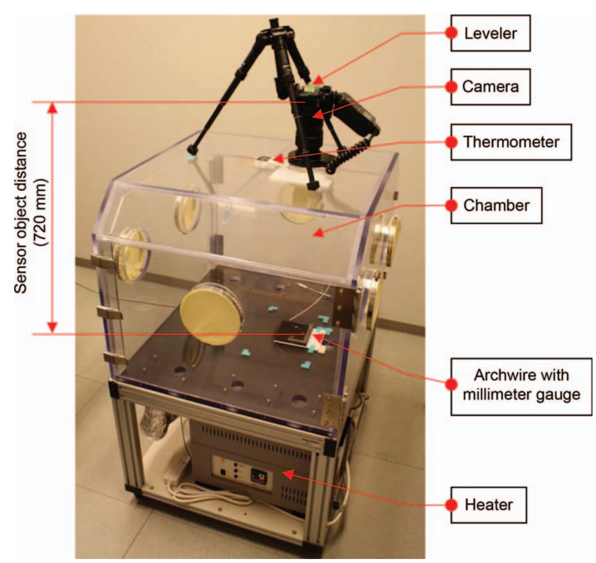

Figure 2. A camera with a macro lens was fixed at a sensor-object distance of 720 mm perpendicular to the archwire, using a leveler to obtain standardized images of the archwires. A millimeter gauge was included in the chamber, which was maintained at 37°C, as monitored by a thermometer.

Table 2. Extended

Tooth	Archwire Group: Medium (n = 15) Median	SIQR	Small (n = 9) Median	SIQR	Large (n = 10) Median	SIQR	Statistical Comparison
Canine	28.99	0.55	26.82	0.94	28.62	0.87	**, a, b, c, and e
First premolar	40.44	0.66	36.77	1.59	40.20	0.83	**, b, c, and e
Second premolar	46.81	0.50	43.53	1.02	47.88	1.15	*, b, c, and e
First molar	51.64	0.17	48.78	0.52	54.96	0.90	**, a, b, c, d, and e

each archwire was placed in the chamber with a millimeter gauge and without fixation. A standardized image was then taken at 5216 × 3504 pixels (Figure 2).

Each archwire was placed in a custom jig, with brackets for the central incisors and tubes for the first molars at locations simulating the mean first molar depth and width at the BS points of normal subjects; a millimeter gauge was also placed in the chamber. Standardized images of the 34 archwires were then taken, and a total of 68 images were analyzed using image analysis software (ImageJ, version 1.48, National Institutes of Health, Bethesda, Md), with 37.20 pixels/mm resolution (Figure 3). The widths of each archwire at the canine, first and second premolars, and first molar were measured as archwire widths at the mean corresponding depths for the normal subjects. The same measurements were performed twice with more than 2-week intervals, and the mean values were used for analysis.

The medians and semi-interquartile ranges (SIQRs) and the means ± SDs for the dental arch width and the pooled archwire widths for the 34 archwires at the canine, first and second premolars, and first molar were calculated. The dental arch widths and the pooled archwire widths were compared for each tooth using the Mann-Whitney *U* test.

The archwires were then classified into three groups by cluster analysis (Ward method) using the archwire width at the first molar.[18,19] For each group, the medians and SIQRs of the archwire widths at the canine, first and second premolars, and first molar were calculated. The archwire widths for each group were then compared with the dental arch widths and were also compared among the groups using the Kruskal-Wallis test and a post-hoc test with Bonferroni correction. Additionally, the pooled and classified archwire widths at each tooth were compared before and after placement in the jig using Wilcoxon signed-rank tests.

Moreover, the medians and SIQRs of the pooled archwire widths after placement in the jig were calculated and compared with those of the dental arch widths at the canine and the first and second premolars using the Mann-Whitney *U* test. For the three groups, the medians and SIQRs of the archwire widths after placement in the jig at the canine and the first and second premolars were also calculated. The archwire widths for each group were then compared with the dental arch widths and also compared among

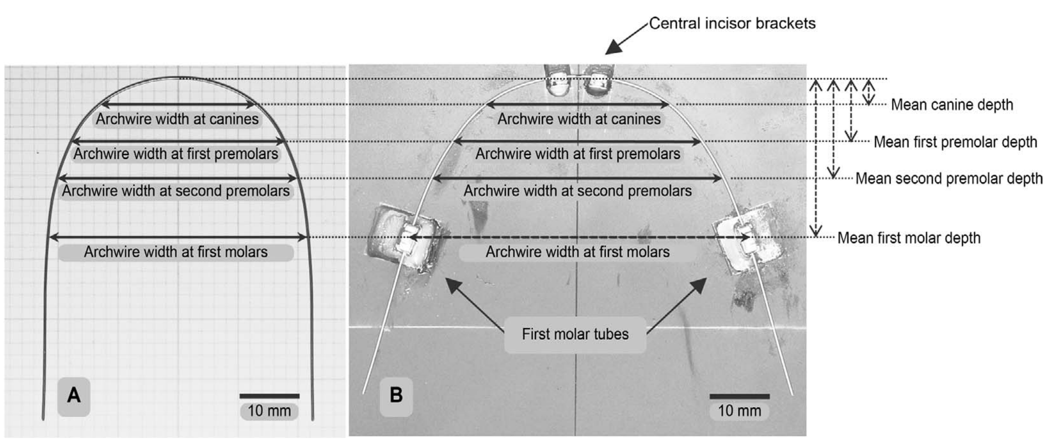

Figure 3. Measurement of archwire widths before and after placement in the custom jig (example: Broad Arch Form Small, archwire ID: B9, product No. 18). (A) Each archwire was placed on graph paper without fixation. (B) Each archwire was placed in the jig with brackets for the central incisors and tubes for the first molars on a thick plastic plate at locations simulating the mean dental arch depth and width at the BS points of normal subjects.

Table 3. Comparison of the Medians and Semi-Interquartile Ranges (SIQRS) Between the Mandibular Dental Arch Width of Subjects With Normal Occlusion and Archwire Width After Placement in the Jig at the Arch Depth of the Canine and First and Second Premolar (mm)

	Normal Occlusion (n = 30)				Pooled Archwires After Placement in the Jig (n = 34)			
Tooth	Median	SIQR	Min	Max	Median	SIQR	Min	Max
Canine	30.18	0.73	26.71	32.85	29.91	1.18	25.18	31.44
First premolar	40.90	1.43	38.25	44.54	41.23	1.26	36.92	42.90
Second premolar	47.87	1.16	43.64	53.99	48.89	0.71	46.61	49.94

* $P < .05$; Results of comparing dental arch widths of normal occlusion group and pooled archwire widths at the canine using the Mann-Whitney *U* test.

** $P < .01$; Results of comparing dental arch widths of normal occlusion group and pooled archwire widths at the second premolar using the Mann-Whitney *U* test.

[a] Results of comparing four groups (dental arch widths of normal occlusion group and archwire widths of the three archwire groups) for each tooth category using the Kruskal-Wallis test.

the groups using the Kruskal-Wallis test and a post-hoc test with Bonferroni correction. *P* values of less than 0.05 were considered significant for all statistical tests.

The measurement errors for the archwire widths before and after placement in the jig were evaluated using Dahlberg's formula.[22] One examiner repeated the measurement for 10 randomly selected archwires at the canine and premolars with more than 2-week intervals to evaluate intraexaminer reliability. The same measurement was performed by another examiner to evaluate interexaminer reliability. Intra- and interexaminer errors ranged from 0.05 to 0.08 mm and from 0.03 to 0.09 mm, respectively.

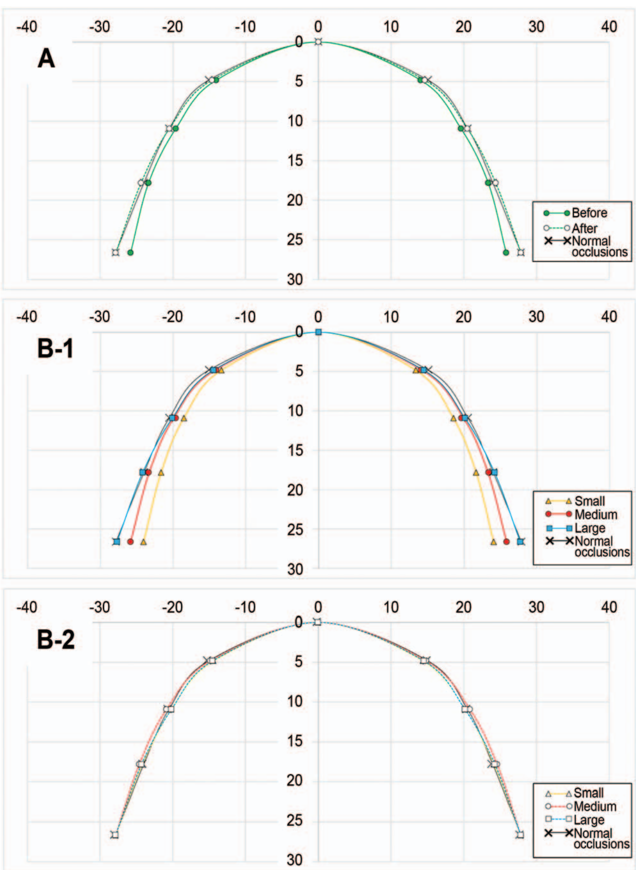

Figure 4. (A) Changes in the medians of the pooled archwires before and after placement in the first molar tubes compared with the mean of the dental arch width. (B-1) Comparison of medians among the three groups in their original shape, without fixation. (B-2) Comparison of medians among the three groups after insertion into the first molar tubes.

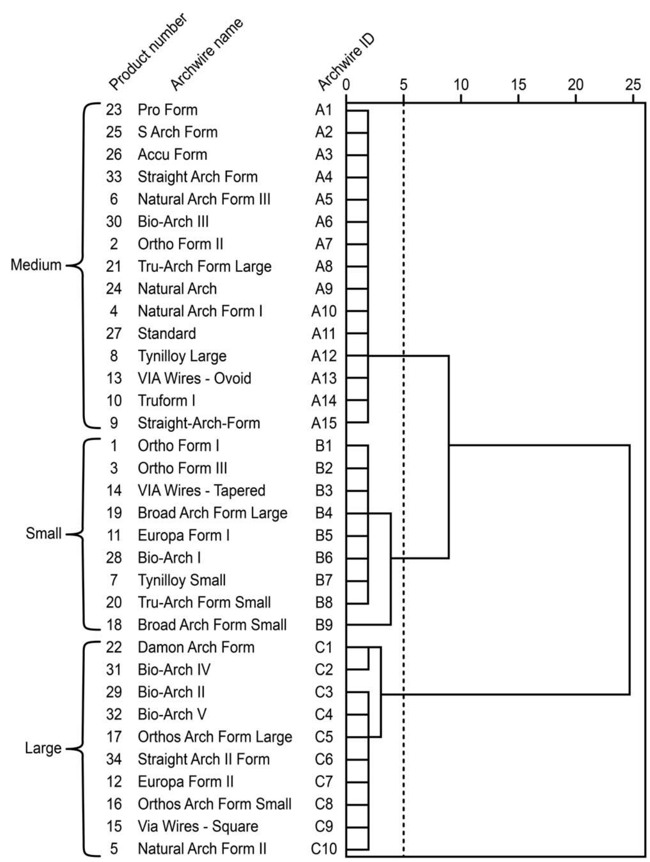

Figure 5. Dendrogram for hierarchical clustering of archwire widths at the first molars for 34 archwires. The archwire ID was determined for the classification groups by cluster analysis.

Table 3. Extended

	Archwire Group After Placement in the Jig						
	Medium (n = 15)		Small (n = 9)		Large (n = 10)		
Tooth	Median	SIQR	Median	SIQR	Median	SIQR	Statistical Comparison
Canine	30.33	0.60	29.46	1.17	28.90	0.94	*
First premolar	42.55	0.68	40.82	1.02	40.55	0.98	–
Second premolar	49.56	0.37	48.38	0.47	48.63	0.81	** and a

RESULTS

The pooled archwire widths were significantly narrower than the dental arch widths at each tooth ($P < .05$) (Table 2; Figure 4A). The archwires were classified into three groups, sequentially defined as small, medium, and large (Figure 5). Individual variations in the 30 dental arch forms and variations in the manufactured archwires are graphically depicted for the widths at the canine and first molar in Figure 6. The distributions show that only four archwires (all in the large group) were within the normal ranges for both the canine and first molar widths.

The archwire widths in the small and medium groups were significantly narrower than the dental arch widths at each tooth, except in the case of the premolars of the medium group ($P < .05$) (Table 2; Figure 4B-1). When the three groups were compared, the small group had significantly narrower archwire widths than did the medium or large groups at each tooth ($P < .05$). The medium group also had significantly narrower archwire widths than did the large group at the first molar ($P < .01$) (Table 2; Figure 4B-1).

After placement in the jig, the pooled archwire widths and the archwire widths in the medium and small groups were significantly increased at each tooth ($P < .01$) (Figure 7). The pooled archwire widths after placement in the jig were significantly narrower at the canine and wider at the second premolar than were the dental arch widths ($P < .05$) (Table 3; Figure 4A).

Finally, a significant difference was observed between the dental arch and the three archwire groups after placement in the jig at the second premolar width ($P < .05$) (Table 3; Figure 4B-2).

DISCUSSION

Relatively wide variations were observed between the 34 preformed NiTi archwires examined and the 30 dental arch forms of the adult subjects with normal occlusion (Figure 6). In the past, variation in dental arch form has been classified into three categories for research purposes,[20] but archwire form variation has not yet been classified in the literature. To analyze this variation, we conducted this, the first study to classify preformed archwires using cluster analysis. We objectively classified the 34 types of archwires into three groups based on archwire widths at the first molars, which showed wider variation than that at the other teeth. However, in orthodontics, a subjective method of categorizing dental arch forms using a

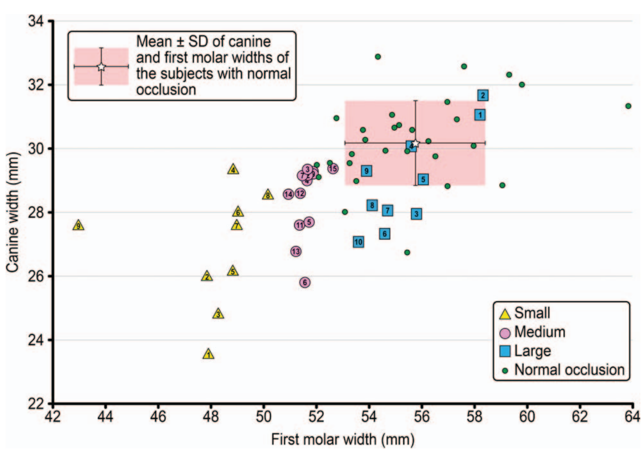

Figure 6. Comparison between means and SDs of the dental arch widths of 30 normal subjects and distribution of 34 archwire widths, along with the group name and archwire ID at the canine and first molar.

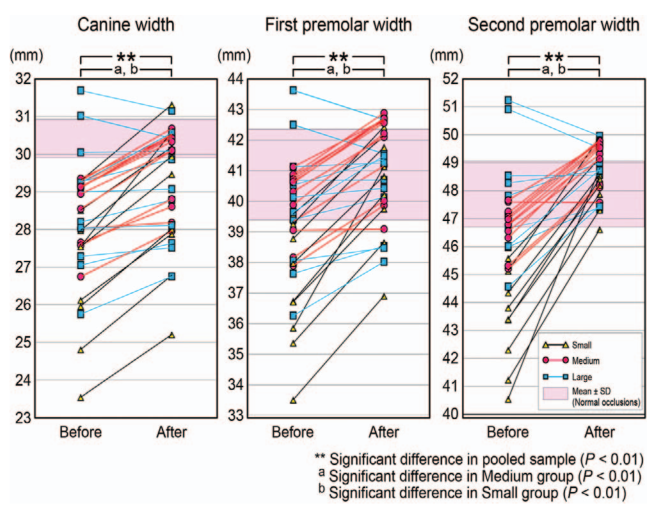

Figure 7. Comparison of archwire widths before and after placement in the jig.

set of three types of arch form templates, such as square, ovoid, and tapered, has been commonly used to account for patients' dental arch form variation, mainly in terms of canine width.[9] Therefore, further, larger-sample studies on classifying archwire and dental arch forms based on the canine width or the overall arch form, including ratios, using cluster analysis, may be required to confirm our results.

The present study obtained archwire widths that were significantly narrower than normal dental arch forms when pooled archwires were examined, supporting the result of a previous study conducted in Japan[12] and contradicting studies from other countries.[11,13] One of the reasons for these disagreements may be ethnic differences in dental arch widths of the sampled populations.[23] However, significant differences were not observed between archwire widths of the large group and dental arch widths. Therefore, the large group may be the most suitable for the Japanese population. Nevertheless, the Damon arch form has been known as an expanded archwire designed as a single arch form for both maxillary and mandibular arches.[24] As one previous study suggested,[16] this archwire may cause excessive expansion of the mandibular dental arch. In contrast, the significantly narrower archwire widths found in the small group indicated possible suitability, on average, for patients of other ethnic groups, such as white patients.[23] Clinically, however, the individual variation in each patient should be independently evaluated during the diagnostic process, and appropriate individual archwire selection and careful adjustments should be performed.

The greatest number of archwires were classified into the medium group, which showed significantly narrower archwire widths than the dental arch widths only at the canine and first molar, indicating convex curvature from canine to molar. In addition, this group showed the smallest SIQRs for all teeth compared with the other groups. In particular, eight archwires available from different companies showed similar designs (within approximately 0.35 mm and 0.43 mm for the canine and first molar widths, respectively) (Figure 6). These popular archwire designs may be imitations of the Roth arch form, which was basically designed for extraction cases.[5,12]

The pooled archwire widths after placement in the jig were significantly narrower at the canine and wider at the second premolar than were the dental arch widths. These results suggest the necessity of modifying the bracket thicknesses to be slightly thinner for canines and thicker for second premolars or of making appropriate archwire adjustments. Although a significant difference was observed between the dental arch and the three archwire groups after placement in the jig at the second premolar, no significant differences were observed when using the post-hoc test for comparison. If canines and premolars are assumed to move by orthodontic force exerted by archwires during alignment, with the first molar as anchorage, these archwires might not provide the built-in variations at the canine and premolars that are expected. The custom jig used in the present study fixed the archwire at the mean first molar depth and width because the results of RCTs showed a non-significant or absent change at the first molar during alignment.[15,17] However, further methods of locating the first molar tubes should be considered in future studies.

CONCLUSIONS

- The pooled archwire widths were significantly narrower than the dental arch widths.
- The archwire forms could be objectively classified into three groups by cluster analysis.
- When the archwires were placed in the custom jig simulating the mean first molar width, there were fewer archwire variations.

REFERENCES

1. Shapiro PA. Mandibular dental arch form and dimension. Treatment and postretention changes. *Am J Orthod*. 1974; 66:58–70.
2. Little RM, Wallen TR, Riedel RA. Stability and relapse of mandibular anterior alignment—first premolar extraction cases treated by traditional edgewise orthodontics. *Am J Orthod*. 1981;80:349–365.
3. Chuck GC. Ideal arch form. *Angle Orthod*. 1934;4:312–327.
4. Andrews LF. *Straight Wire: The Concept and Appliance*. San Diego, CA: LA Wells Co; 1989.
5. Roth RH. The straight-wire appliance 17 years later. *J Clin Orthod*. 1987;21:632–642.
6. Burstone CJ, Qin B, Morton JY. Chinese NiTi wire—a new orthodontic alloy. *Am J Orthod*. 1985;87:445–452.
7. Miura F, Mogi M, Ohura Y, Hamanaka H. The super-elastic property of the Japanese NiTi alloy wire for use in orthodontics. *Am J Orthod Dentofacial Orthop*. 1986;90: 1–10.
8. Proffit WR, Fields HW Jr, Sarver DM. *Contemporary Orthodontics*. 5th ed. St Louis, MO: Mosby; 2014.
9. McLaughlin RP, Bennett JC. Arch form considerations for stability and esthetics. *Rev Esp Orthod*. 1999;29:46–63.
10. Felton JM, Sinclair PM, Jones DL, Alexander RG. A computerized analysis of the shape and stability of mandibular arch form. *Am J Orthod Dentofacial Orthop*. 1987;92:478–483.
11. Braun S, Hnat WP, Leschinsky R, Legan HL. An evaluation of the shape of some popular nickel titanium alloy preformed arch wires. *Am J Orthod Dentofacial Orthop*. 1999;116: 1–12.

12. Oda S, Arai K, Nakahara R. Commercially available archwire forms compared with normal dental arch forms in a Japanese population. *Am J Orthod Dentofacial Orthop*. 2010;137:520–527.
13. Bhowmik SG, Hazare PV, Bhowmik H. Correlation of the arch forms of male and female subjects with those of preformed rectangular nickel-titanium archwires. *Am J Orthod Dentofacial Orthop*. 2012;142:364–373.
14. McNamara C, Drage KJ, Sandy JR, Ireland AJ. An evaluation of clinicians' choices when selecting archwires. *Eur J Orthod*. 2010;32:54–59.
15. Fleming PS, DiBiase AT, Sarri G, Lee RT. Comparison of mandibular arch changes during alignment and leveling with 2 preadjusted edgewise appliances. *Am J Orthod Dentofacial Orthop*. 2009;136:340–347.
16. Pandis N, Polychronopoulou A, Makou M, Eliades T. Mandibular dental arch changes associated with treatment of crowding using self-ligating and conventional brackets. *Eur J Orthod*. 2010;32:248–253.
17. Celikoglu M, Bayram M, Nur M, Kilkis D. Mandibular changes during initial alignment with SmartClip self-ligating and conventional brackets: A single-center prospective randomized controlled clinical trial. *Korean J Orthod*. 2015; 45:89–94.
18. Ward Jr JH. Hierarchical grouping to optimize an objective function. *J Am Stat Assoc*. 1963;58:236–244.
19. Lance GN, Williams WT. A general theory of classificatory sorting strategies II. Clustering systems. *Comput J*. 1967; 10:271–277.
20. Lee S-J, Lee S, Lim J, Park H-J, Wheeler TT. Method to classify dental arch forms. *Am J Orthod Dentofacial Orthop*. 2011;140:87–96.
21. Matarese G, Nucera R, Militi A, et al. Evaluation of frictional forces during dental alignment: an experimental model with 3 nonleveled brackets. *Am J Orthod Dentofacial Orthop*. 2008;133:708–715.
22. Dahlberg G. *Statistical Methods for Medical and Biological Students*. London: George Allen and Unwin Ltd; 1940.
23. Nojima K, McLaughlin RP, Isshiki Y, Sinclair PM. A comparative study of Caucasian and Japanese mandibular clinical arch forms. *Angle Orthod*. 2001;71:195–200.
24. Damon DH. Treatment of the face with biocompatible orthodontics. In: Graber TM, Vanarsdall RL, Vig KW, eds. *Orthodontics: Current Principles and Techniques*. 4th ed. St Louis, MO: Mosby; 2005:753–831.