Original Article

Dental archforms in dentoalveolar Class I, II and III

Martina Slaj[a]; Stjepan Spalj[b]; Dubravko Pavlin[c]; Davor Illes[d]; Mladen Slaj[e]

ABSTRACT

Objective: To test the hypothesis that no differences exist in dental arch dimensions between dentoalveolar Classes I, II, and III, and between male and female subjects, as measured on virtual three-dimensional (3D) models.

Materials and Methods: Samples included randomly selected plaster dental casts of 137 white patients (43 Class I, 50 Class II, and 44 Class III) from the Department of Orthodontics, School of Dental Medicine, University of Zagreb, Croatia. Dental models were scanned and digitized using ATOS II SO (''Small Objects'') scanning technology (GOM mbH, Braunschweig, Germany). Eight linear and two proportional measurements were calculated for both upper and lower dental arches.

Results: In men, a significant difference in the upper dental arch was present in the incisor region, and in the lower dental arch, differences were found in intercanine and intermolar widths ($P < .05$). Significant differences were noted between male groups in the upper molar depth dimension ($P = .022$) and in the lower molar and canine depth dimensions ($P < .05$). Class III males had the greatest lower molar and canine width/depth ratios and the smallest lower canine depth/molar depth ratio. Class III women had wider and shorter mandibular arches when compared with Class I and Class II females.

Conclusion: The hypothesis was rejected. The dimensions of the dental arches are related to gender and to dentoalveolar class. Class I and II subjects have similar dimensions of maxillary dental arch, but Class II subjects have a transverse deficit in the mandible. In Class III subjects, the maxillary dental arch is insufficient in transverse and sagittal dimensions, and the mandibular arch dominates in the transverse but not in the sagittal dimension. (*Angle Orthod.* 2010;80:919–924.)

KEY WORDS: Archform; Three-dimensional model

INTRODUCTION

Many studies have reported on dental archform, and a number of researchers have tried to establish the form unique to certain malocclusions, ethnic groups, and genders.[1–3] Descriptions of dental archforms vary from geometric forms (ellipse, parabolic curve) to mathematical functions.[4–6]

Clinically, it is important that archform does not change during orthodontic treatment because occlusal stability depends on preservation of the patient's original archform.[7,8] Preformed archwires have been used frequently, although many reports have brought up the fact that application of the same archwire in all cases can negatively affect posttreatment occlusal stability.[9–11]

Most studies measured the transverse dimensions of the dental arches and investigated the differences between Class I normal occlusion and different malocclusions.[11–23] According to these studies, in both males and females, mean maxillary and mandibular intercanine widths showed small variations in Class I normal occlusions, and in Class I, II/1, II/2, and III malocclusions. The main differences were seen in the premolar and molar areas. Maxillary intercanine width tended to be similar in Class III and similar or larger in Class I malocclusion, Class II/1, and Class II/2.

[a] Assistant Professor, Department of Orthodontics, School of Dental Medicine, University of Zagreb, Zagreb, Croatia.

[b] Assistant Professor, Department of Paediatric Dentistry and Orthodontics, School of Medicine, University of Rijeka, Rijeka, Croatia.

[c] Associate Professor, Department of Orthodontics, Dental School, San Antonio Health Science Center, University of Texas, San Antonio, United States.

[d] Assistant Professor, Department of Prosthodontics, School of Dental Medicine, University of Zagreb, Zagreb, Croatia.

[e] Professor and Department Chair, Department of Orthodontics, School of Dental Medicine, University of Zagreb, Zagreb, Croatia.

Corresponding author: Dr Martina Slaj, Department of Orthodontics, School of Dental Medicine, University of Zagreb, Gunduliceva 5, Zagreb, 10000 Croatia (e-mail: mslaj@sfzg.hr).

Accepted: February 2010. Submitted: November 2009.

Compared with Class I normal occlusions, mandibular intercanine width was similar or narrower in Class I malocclusion, similar or larger in both Class II subdivisions, and similar or narrower in Class III subjects.[12,18–22] Class I malocclusions have mean maxillary and mandibular intermolar and alveolar arch widths smaller than those of Class I normal occlusion.[19] Maxillary intermolar width is deficient in Class III, and mandible intermolar width is similar in Class I normal occlusions and Class III, or is increased in Class III.[19–21] Class II/2 cases appear to have maxillary arch widths smaller than those of normal Class I occlusions, but larger than the Class II/1 group. Mandibular intermolar width in Class II was smaller than with normal occlusions.[18,20,22] Some studies, however, did not find major differences in dental arch width in subjects with and without malocclusion.[13,17]

The traditional odontometric tools were the sliding calipers, but recently three-dimensional (3D) scanners and specialized software have been developed to provide accurate digital models of dental structures that allow us to do sophisticated and more precise measurements.[24] Therefore, the aim of this study was to investigate arch dimensions defined on virtual 3D dental arches in dentoalveolar Class I, II, and III, and the differences between male and female subjects. The hypothesis was that no differences exist between dentoalveolar classes or in gender dimorphism.

MATERIALS AND METHODS

Samples included randomly selected plaster dental casts of 137 white subjects (43 Class I [19 males and 24 females], 50 Class II [22 males and 28 females], and 44 Class III [25 males and 19 females]) referred to the Department of Orthodontics, School of Dental Medicine, University of Zagreb, for consultation and/or treatment. The casts corresponded to 71 female and 66 male subjects between 15 and 18 years old. Sample inclusion criteria were as follows: (1) Angle's bilateral dentoalveolar Class I, II, and III, present on molars; (2) permanent dentition without mesiodistal extended restorations; and (3) overjet of not more than 4 mm. Class I malocclusions had mild or moderate crowding (mean, 2.1 $\pm$ 1.4 mm; range, 0.5–4 mm). Both Class II/1 and II/2 were included, but cases with overjet of more than 4 mm were excluded.

Dental models were scanned and digitized using ATOS II SO (''Small Objects'') scanning technology (GOM mbH, Braunschweig, Germany), and 3D virtual models were created. The scanner has point spacing in the 0.02–0.17 mm range, a measuring area of 30 $\times$ 24–250 $\times$ 200 mm^2, and 1,400,000 measured points. Fringe patterns were projected onto the object's surface with a white light projection and recorded by

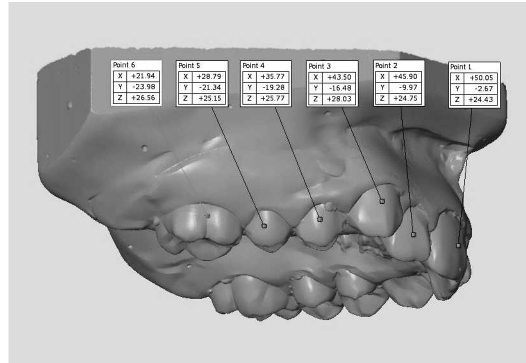

Figure 1. Virtual 3D model.

two cameras. The system self-dependently checked its calibration and the influence of the ambient conditions. The 3D coordinates for each camera pixel were calculated, and a polygon mesh of the surface of the object surface was generated. With ATOS Viewer version 6.0.2 software, 12 points on the most prominent labial tooth surfaces were digitally marked on each model (upper and lower). These points were picked to represent the clinical bracket points (midpoint of the facial axis of the clinical crown). Each point was automatically defined by software in a 3D coordinate system with associated values (x, y, z) (Figure 1). All landmarks of the points were made by a senior investigator and checked by another investigator to verify the accuracy of landmark placement. From these landmarks, eight linear and two proportional measurements were calculated for both upper and lower dental arches:

- Central interincisor width: the distance between central incisor clinical bracket points
- Lateral interincisor width: the distance between lateral incisor clinical bracket points
- Intercanine width: the distance between canine clinical bracket points
- First interpremolar width: the distance between first premolar clinical bracket points
- Second interpremolar width: the distance between second premolar clinical bracket points
- Intermolar width: the distance between first molar clinical bracket points
- Canine depth: the distance from a line connecting canine clinical bracket points to the origin between central incisors
- Molar depth: the distance from a line connecting first molar clinical bracket points to the origin between central incisors
- Canine W/D ratio: the ratio of the intercanine width and the canine depth
- Molar W/D ratio: the ratio of the intermolar width and the molar depth.

All data were analyzed using STATISTICA 7.1 statistical software (StatSoft Inc, Tulsa, Okla). Because dental arch dimensions (widths, depths, and ratios) were normally distributed, one- and two-way analysis of variance (ANOVA) with post hoc Bonferroni tests was used to test the significance of differences between Angle's dentoalveolar classes and genders. Measurement error and intraobserver agreement were calculated on the basis of double landmark placements and linear measurements performed on 30 randomly selected casts with a 1-month interval from the first analysis. Intraobserver agreement was assessed by means of intraclass correlation coefficient (ICC), and measurement error was calculated by the square root of the residual mean square from the ANOVA table. An alpha level of .05 was considered statistically significant.

Intraobserver agreement in locating points on 3D models and measurements was excellent (ICC $\geq$ 0.94), and measurement error was small and acceptable ($\leq$0.23 mm in locating the points and $\leq$0.26 mm for linear measurements). Biological variation of every measurement was assessed as a standard deviation and was always higher ($\geq$0.42 mm) than measurement error.

RESULTS

Because two-way ANOVA showed a significant effect of gender, dental arch dimensions (widths, depths, and ratios) were analyzed separately for males and females. The results are shown in Tables 1 through 4.

In men, a statistically significant difference in upper dental arch was found only in the incisor region and in the lower dental arch, where we found differences in intercanine and intermolar widths (Table 1, $P < .05$). Men in the Class III group had wider lower dental arches than those in the Class I and Class II groups. Significant differences were observed between the male groups in upper molar depth dimension ($P = .022$) and in lower molar and canine depth dimensions ($P < .05$). The Class I group had the longest upper and lower dental arches, and the Class III group the shortest (Table 1). Significant differences were found in lower molar width/depth ratio, lower canine width/depth ratio, and lower canine depth/molar depth ratio (Table 2). Class III males had the biggest lower molar and canine width/depth ratios and the smallest lower canine depth/molar depth ratios.

Class III women basically had somewhat wider and shorter mandibular arches than did Class I and II females, but the difference was statistically significant only in the lower second premolar width ($P = .012$) and lower molar width/depth ratios (Tables 3 and 4).

Table 1. Main Differences in Arch Widths and Depths According to Dentoalveolar Classes in Male Subjects—Results of ANOVA and Bonferroni Post Hoc Test[a]

Variable	Class	N[b]	$\bar{x}$[c]	s[d]	F[e]	df1/df2[f]	P
Maxillary	I	19	56.22	3.17	0.52	2/63	.595
intermolar	II	22	55.26	3.46			
width	III	25	56.07	3.31			
Maxillary	I	19	37.51	2.37	0.68	2/63	.510
intercanine	II	22	36.77	2.67			
width	III	25	36.62	2.70			
Mandibular	I	19	52.32[g]	3.26	3.91	2/63	**.025**
intermolar	II	22	53.08[gh]	2.79			
width	III	25	54.93[h]	3.50			
Mandibular	I	19	29.97[gh]	1.62	3.43	2/63	**.039**
intercanine	II	22	29.01[g]	2.28			
width	III	25	30.41[h]	1.54			
Upper	I	19	32.48[g]	1.86	4.05	2/63	**.022**
intermolar	II	22	31.07[gh]	2.70			
depth	III	25	30.50[h]	2.21			
Upper	I	19	9.50	1.12	2.37	2/63	.102
intercanine	II	22	8.39	1.99			
depth	III	25	8.84	1.62			
Lower	I	19	27.67[g]	2.00	3.96	2/63	**.024**
intermolar	II	22	26.84[gh]	2.68			
depth	III	25	25.69[h]	2.22			
Lower	I	19	5.28[gh]	1.31	5.27	2/63	**.008**
intercanine	II	22	5.50[g]	1.23			
depth	III	25	4.28[h]	1.47			

[a] Means that do not share superscripts differ at $P < .05$ according to results of the Bonferroni post hoc test.

[b] Number of cases; [c] mean; [d] deviation; [e] F statistic; [f] degrees of freedom, [g] paired differences results of Bonferroni post hoc test, [h] paired differences results of Bonferroni post hoc test.

Visual analysis of approximation of measurement points showed that the maxillary dental arch in Class III is insufficient in transverse and sagittal dimension compared with those in Class I and Class II for both genders (Figure 2). The mandibular dental arch in Class III dominated in the transverse but not in the sagittal dimension for both genders (Figure 3).

DISCUSSION

Preformed archwires that meet the needs for treatment of a specific group of malocclusions can enhance orthodontic therapy and guarantee posttreatment stability and the absence of relapse. Studies that are focused on assessing the characteristics of dental arch dimensions, in particular dentoalveolar classes, aim to meet this goal. Measurements were taken in the permanent dentition at ages 15 to 18 years, when future transverse growth changes can hardly be expected.[16,25]

The advantage of this method is the use of points representing the clinical bracket slot on labial tooth surfaces instead of on incisal edges and on tips of the buccal cusps. Points defined in this manner represent the actual clinical orthodontic archform and simulation

Table 2. Differences in Arch Width/Depth Ratios According to Dentoalveolar Classes in Male Subjects—Results of ANOVA and Bonferroni Post Hoc Test[a]

Variable	Class	N[b]	$\bar{x}$[c]	s[d]	F[e]	df1/df2[f]	P
Upper molar width/depth ratio	I	19	1.74	0.13	2.30	2/63	.109
	II	22	1.79	0.19			
	III	25	1.85	0.17			
Upper canine width/depth ratio	I	19	4.00	0.51	2.61	2/63	.081
	II	22	4.67	1.33			
	III	25	4.26	0.78			
Lower molar width/depth ratio	I	19	1.90[g]	0.15	9.26	2/63	**< .001**
	II	22	1.99[gh]	0.21			
	III	25	2.16[h]	0.23			
Lower canine width/depth ratio	I	19	6.02[g]	1.64	8.41	2/63	**.001**
	II	22	5.51[g]	1.25			
	III	25	8.00[h]	2.97			
Upper canine depth/molar depth ratio	I	19	0.29	0.03	2.27	2/63	.112
	II	22	0.27	0.05			
	III	25	0.29	0.05			
Lower canine depth/molar depth ratio	I	19	0.19[g]	0.04	4.23	2/63	**.019**
	II	22	0.20[g]	0.04			
	III	25	0.17[h]	0.05			

[a] Means columns that do not share superscripts differ at $P < .05$ according to results of the Bonferroni post hoc test.
[b] Number of cases; [c] mean; [d] deviation; [e] F statistic; [f] degrees of freedom, [g] paired differences results of Bonferroni post hoc test, [h] paired differences results of Bonferroni post hoc test.

of the effects of archwire form used in orthodontic therapy.

Most conventional odontometric studies and biometric analyses of archform were done with measurements taken directly by sliding calipers on plaster casts.[12,18,19] Such studies often are not repeatable, and some material defects, like little holes or damage, can cause mistakes. Methods based on photographing and photocopying plaster cast have major shortcomings because of the omission of the third dimension. In this study, we used 3D digital models and software to automatically very precisely calculate distances between defined points. In this way, our model database is always available and models are kept.

This study provides evidence that the dimensions of the maxillary and mandibular dental arches could be related to Angle's Class and gender. Differences in archform and dimension are more pronounced in Class III males and correspond to dentoalveolar compensation mechanisms. When analyzing approximation of measurement points, one can see that the upper dental arch in Class III is insufficient in the transverse and sagittal dimensions compared with Class I and Class II for both genders (Figure 2). The upper dental arch in Class I and Class II is longer and narrower in both the male and female groups. The Class II group was between Class I and Class III, presenting a shape that appears more like Class I in the frontal segment, but wider in the posterior segment of the upper dental arch. In Figure 3, which represents the approximation of measurement points of the mandibular dental arch, Class III dominates in the transverse but surprisingly not in the sagittal dimension. A longer and, in front, narrower dental arch represented the Class I groups for both genders. As can be expected, according to approximations, the shortest and the narrowest mandibular dental arch

Table 3. Main Differences in Arch Widths and Depths According to Dentoalveolar Classes in Female Subjects—Results of ANOVA

Variable	Class	N[a]	$\bar{x}$[b]	s[c]	F[d]	df1/df2[e]	P
Maxillary	I	24	54.37	2.58	2.95	2/68	.059
intermolar	II	28	52.55	3.05			
width	III	19	54.27	3.17			
Maxillary	I	24	36.38	1.62	2.30	2/68	.108
intercanine	II	28	35.73	1.91			
width	III	19	35.11	2.21			
Mandibular	I	24	51.10	2.27	2.90	2/68	.062
intermolar	II	28	50.64	3.20			
width	III	19	52.64	2.51			
Mandibular	I	24	28.20	1.44	2.53	2/68	.088
intercanine	II	28	28.56	1.37			
width	III	19	29.19	1.51			
Upper	I	24	30.96	1.48	0.23	2/68	.792
intermolar	II	28	30.79	2.77			
depth	III	19	30.46	2.48			
Upper	I	24	8.59	0.69	0.03	2/68	.973
intercanine	II	28	8.63	2.19			
depth	III	19	8.70	1.02			
Lower	I	24	25.97	1.83	0.90	2/68	.411
intermolar	II	28	26.10	1.47			
depth	III	19	25.36	2.33			
Lower	I	24	4.82	1.04	0.83	2/68	.439
intercanine	II	28	5.05	.99			
depth	III	19	4.66	1.13			

[a] Number of cases; [b] mean; [c] deviation; [d] F statistic; [e] degrees of freedom.

Table 4. Differences in Arch Width/Depth Ratios According to Dentoalveolar Classes in Female Subjects—Results of ANOVA and Bonferroni Post Hoc Test[a]

Variable	Class	N[b]	$\bar{x}$[c]	s[d]	F[e]	df1/df2[f]	*P*
Upper molar width/depth ratio	I	24	1.76	0.10	1.16	2/68	.321
	II	28	1.72	0.18			
	III	19	1.79	0.16			
Upper canine width/depth ratio	I	24	4.26	0.37	0.86	2/68	.429
	II	28	4.44	1.29			
	III	19	4.09	0.54			
Lower molar width/depth ratio	I	24	1.98[gh]	0.17	3.32	2/68	**.042**
	II	28	1.95[g]	0.15			
	III	19	2.09[h]	0.23			
Lower canine width/depth ratio	I	24	6.21	1.92	1.35	2/68	.268
	II	28	5.87	1.21			
	III	19	6.73	2.14			
Upper canine depth/molar depth ratio	I	24	0.28	0.02	0.14	2/68	.871
	II	28	0.28	0.05			
	III	19	0.28	0.03			
Lower canine depth/molar depth ratio	I	24	0.18	0.03	0.56	2/68	.571
	II	28	0.19	0.03			
	III	19	0.18	0.05			

[a] Means that do not share superscripts differ at $P < .05$ according to results of the Bonferroni post hoc test.

[b] Number of cases; [c] mean; [d] deviation; [e] F statistic; [f] degrees of freedom, [g] paired differences results of Bonferroni post hoc test, [h] paired differences results of Bonferroni post hoc test.

corresponded to Class II subjects, both males and females.

Wider mandibular arches and narrower maxillary arches were found in Class III subjects compared with Class I subjects in some other studies.[21] Clinicians speculate that the reason may be nasal obstruction, low tongue position in the mandibular space, or habits such as thumb sucking. Other opinions have been expressed as well. Braun et al.[5] found that the upper dental arches in the Class III group are 5.1 mm wider than those in the Class I group. Other authors described this finding as surprising. In this study, we found that both male and female mandibular dental arches are wider in the Class III group than in Class II and Class I groups. Specific mesiodistal dimensions[21]of mandibular teeth may provide a possible explanation. Sperry et al.[26] reported that Class III patients often have wider lower teeth than Class I and II subjects. Other authors had a similar finding.[27–29] A shorter and larger mandibular arch in subjects with

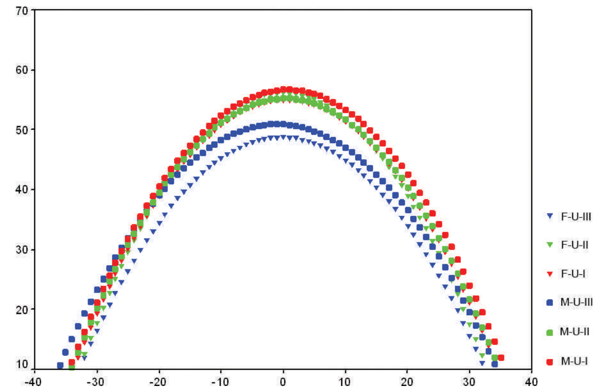

Figure 2. Approximation of measurement points in the upper (U) dental arch in Class I, II, and III in males (M) and females (F).

Class III could be a consequence of dental compensation in that patients with that malocclusion tend to have the mandibular incisors inclined to the lingual, and the lateral teeth inclined to the buccal. This has been attributed to restriction of maxillary growth and development.[18]

According to Nojima et al.,[30] dental arch dimensions could be ethnically related, but the archforms are not related to a specific ethnic group or to Angle's dental Class. This finding concerning Angle's Classes is contrary to results seen in our data. Nevertheless, according to our findings, it seems reasonable to use different shapes and sizes of preformed archwires, according to the patient's original archform. Because the differences are most obvious in Class III cases, it would be wise to use squared archwires, which are wider in posterior segment, in the treatment of Class III malocclusions. Special attention must be taken to not expand the posterior segment of the mandibular dental arch in Class III patients for stability reasons, but in Class II subjects it would be advisable to use preformed archwires in the mandible to expand the posterior segment.

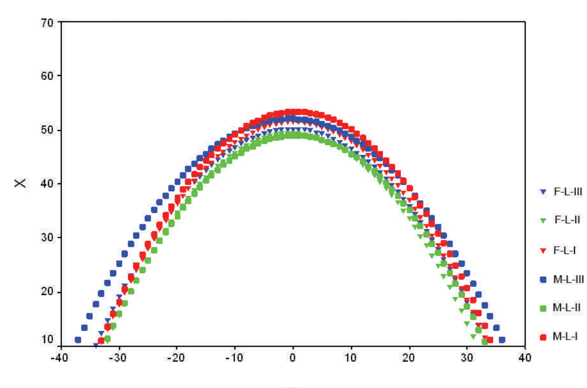

Figure 3. Approximation of measurement points in the lower (L) dental arch in Class I, II, and III in males (M) and females (F).

Additional multivariate analyses are needed to discern how many archforms could be related to a particular dentoalveolar class, what the most common forms are, and what percentage of variability could be presented in the most common forms.

CONCLUSIONS

- Dimensions of the dental arches are related to gender and to dentoalveolar class.
- All dimensions are more pronounced in males than in females.
- It would be wise to use preformed archwires for reasons of stability.

REFERENCES

1. Pepe SH. Polynomial and catenary curve fits to human dental arches. *J Dent Res*. 1975;54:1124–1132.
2. Ferrario VF, Sforza C, Miani A Jr, Tartaglia G. Human dental arch shape evaluated by Euclidean-distance matrix analysis. *Am J Phys Anthropol*. 1993;90:445–453.
3. Cassidy KM, Harris EF, Tolley EA, Keim RG. Genetic influence on dental arch form in orthodontic patients. *Angle Orthod*. 1998;68:445–454.
4. Ferrario VF, Sforza C, Miani A Jr, Tartaglia G. Mathematical definition of the shape of dental arches in human permanent healthy dentitions. *Eur J Orthod*. 1994;16:287–294.
5. Braun S, Hnat WP, Fender DE, Legan HL. The form of the human dental arch. *Angle Orthod*. 1998;68:29–36.
6. Noroozi H. Re: the form of human arch. *Angle Orthod*. 2000;70:271–275.
7. Felton MJ, Sinclair PM, Jones DL, Alexander RG. A computerized analysis of the shape and stability of mandibular arch form. *Am J Orthod*. 1987;92:478–483.
8. De La Cruz AR, Sampson P, Little RM, Artun J, Shapiro PA. Long term changes in arch form after orthodontic treatment and retention. *Am J Orthod*. 1995;107:518–530.
9. Strang RHW. Factors of influence in producing a stable result in treatment of malocclusions. *Am J Orthod*. 1946;32:313–332.
10. Strang RHW. The fallacy of denture expansion as a treatment procedure. *Angle Orthod*. 1949;19:12–17.
11. Gardner SD. Posttreatment and postretention changes following orthodontic therapy. *Angle Orthod*. 1976;46:151–161.
12. Sayin MO, Turkkahraman H. Comparison of dental arch and alveolar widths of patients with Class II division 1 malocclusion and subjects with Class I ideal occlusion. *Angle Orthod*. 2004;74:356–360.
13. Staley RN, Stuntz WR, Peterson LC. A comparison of arch widths in adults with normal occlusion and adults with Class II division 1 malocclusion. *Am J Orthod*. 1985;88:163–169.
14. Enlow DH, Hans MG. *Essentials of Facial Growth*. Philadelphia, Pa: WB Saunders; 1996.
15. Buschang PH, Stroud J, Alexander RG. Differences in dental arch morphology among adult females with untreated Class I and Class II malocclusion. *Eur J Orthod*. 1994;16:47–52.
16. Moorrees CFA, Gron AM, Lebret LML, Yen PKJ, Frohlich FJ. Growth studies of the dentition: a review. *Am J Orthod*. 1969;55:600–616.
17. Walkow TM, Peck S. Dental arch width in Class II division 2 deep-bite malocclusion. *Am J Orthod Dentofacial Orthop*. 2002;122:608–613.
18. Uysal T, Memili B, Usumez S, Sari Z. Dental and alveolar arch widths in normal occlusion, Class II division 1 and Class II division 2. *Angle Orthod*. 2005;75:756–762.
19. Kuntz TR, Staley RN, Bigelow HF, Kremenak CR, Kohout FJ, Jakobsen JR. Arch widths in adults with Class I crowded and Class III malocclusions compared with normal occlusions. *Angle Orthod*. 2008;78:597–603.
20. Al-Khateeb SN, Abu Alhaija ESJ. Tooth size discrepancies and arch parameters among different malocclusions in a Jordanian sample. *Angle Orthod*. 2006;76:459–465.
21. Uysal T, Usumez S, Memili B, Sari Z. Dental and alveolar arch widths in normal occlusion and Class III malocclusion. *Angle Orthod*. 2005;75:809–813.
22. Huth J, Staley RN, Jacobs R, Bigelow H, Jakobsen J. Arch widths in Class II-2 adults compared to adults with Class II-1 and normal occlusion. *Angle Orthod*. 2007;77:837–844.
23. Ling JYK, Wong RWK. Dental arch widths of southern Chinese. *Angle Orthod*. 2009;79:54–63.
24. 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.
25. Bishara SE, Jakobsen RJ, Treder J, Nowak A. Arch width changes from 6 weeks to 45 years of age. *Am J Orthod Dentofacial Orthop*. 1997;111:401–409.
26. Sperry TP, Worms FW, Isaacson RJ, Speidel TM. Tooth-size discrepancy in mandibular prognathism. *Am J Orthod*. 1977;72:183–190.
27. Lavelle CLB. Maxillary and mandibular tooth size in different racial groups and in different occlusion categories. *Am J Orthod*. 1972;6:29–37.
28. Nie Q, Lin J. Comparison of intermaxillary tooth size discrepancies among different malocclusion groups. *Am J Orthod Dentofacial Orthop*. 1999;116:539–544.
29. Hnat WP, Braun S, Chinhara A, Legan HL. The relationship of arch length to alterations in dental arch width. *Am J Orthod Dentofacial Orthop*. 2000;118:184–188.
30. Nojima K, McLaughlin RP, Isshiki Y, Sinclair PM. A comparative study of White and Japanese mandibular clinical arch forms. *Angle Orthod*. 2001;71:195–200.