Overjet at the Anterior and Posterior Segments: Three-Dimensional Analysis of Arch Coordination

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ABSTRACT

Objectives: To compare the amounts of anatomical overjet measured from facial axis (FA) points with the amounts of bracket overjet measured from bracket slot center (BSC) points.

Materials and Methods: The samples consisted of 27 subjects with normal occlusion whose models were fabricated with a three-dimensional (3D) scanner and the 3Txer program (Orapix Co Ltd, Seoul, Korea). 3D virtual brackets (0.022″ Slot, MBT setup, 3M Unitek, Monrovia, Calif) constructed with a 3D-CAD program were placed on an FA point with the 3Txer program. The arch dimension and the amounts of overjet from FA and BSC points were measured. Paired *t*-tests and analysis of variance (ANOVA) tests were used for statistical analysis.

Results: No significant difference in arch width and depth was observed between FA and BSC points. Although the amounts of overjet measured from FA points showed homogenous distribution, a tendency to decrease from the anterior segment (2.3 mm) to the posterior one (2.0 mm) was noted. However, the amounts of overjet measured from BSC points were variable, especially in the premolar and molar areas. Significant discrepancies in the amounts of overjet in most of the areas between FA and BSC points (more than $P < .05$), except the lower second premolar and second molar areas, were reported, even though insets and offsets are part of the prescription for the base of straight-wire appliance (SWA) brackets.

Conclusions: The hypotheses that the amount of overjet measured from BSC points was 3 mm through the whole segments and that distribution of the amounts of overjet from BSC points was the same as that from FA points were rejected. (*Angle Orthod.* 2009;79:495–501.)

KEY WORDS: Overjet; Arch coordination; Facial axis point; Bracket slot center point

INTRODUCTION

Results of orthodontic treatment might fall short of clinicians' expectations for several reasons, including inaccurate bracket placement, variations in tooth surface anatomy and maxillary/mandibular relationships, tissue rebound, and biomechanical inefficiency of the orthodontic appliances.[1]

The individualized prescription of the preadjusted appliance, which could change the orientation of the bracket slot relative to the labial or buccal surface of each tooth, and the customized and coordinated arch form might facilitate attainment of treatment goals and increase the chance that stability will be improved.[1,2]

Coordination between the upper and lower arches is one of the most important aspects of achieving stable functional and esthetic results during orthodontic treatment. Because a transverse discrepancy could induce an adverse periodontal response, unstable dental camouflage, and functional and esthetic problems,[3–6] maintenance of an adequate overjet during treatment is essential.

Different and diverse landmarks such as the incisal edge and cusp tip,[7–11] centers of gravity (centroids) of the occlusal surfaces,[12] contact points, and clinical bracket points based on mandibular tooth thickness data[13,14] have been used for measurement of arch form

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and dimension. However, these landmarks did not represent the real alignment of the brackets and eventually of the archwires.

With rapid advances in three-dimensional (3D) virtual technology, most parameters of the 3D virtual models could be measured as reliably and accurately as those of the plaster models.[15,16] Moreover, 3D software programs currently on the market, such as Invisalign (Align Technology Inc, Santa Clara, Calif),[17] SureSmile (OraMetrix Inc, Dallas, Tex),[18] and 3Txer (Orapix Co Ltd, Seoul, Korea), can define the facial axis (FA) point[19] and perform virtual setup and bracket placement on 3D virtual models. However, for precise arch coordination, alignment of the bracket slots on the teeth rather than alignment of FA points is needed. Also, accurate positioning of the bracket slot center (BSC) point may be possible in the 3D virtual study rather than in the plaster models.

McLaughlin et al[20] proposed that the upper archwire should be coordinated with the lower one and should be 3 mm wider than the lower one based on imprints of brackets in the wax bite. Although Braun et al[21] used the spatial coordinates of the labial and buccal dental/bracket interfacing surfaces in the upper and lower arches, information about arch coordination with ''3 mm'' overjet through whole areas between the upper and lower bracket slots is lacking.

The purposes of this study were to compare the amounts of overjet measured from the FA points with amounts measured from the BSC points in 3D virtual models, and to provide a guideline for proper arch coordination. Therefore, two null hypotheses were postulated: the amount of overjet measured from BSC points was 3 mm through the whole segments, and distribution of the amounts of overjet from BSC points was the same as from FA points.

MATERIALS AND METHODS

The samples consisted of Korean young adults with normal occlusion (N = 27; 15 male and 12 female; mean age, 23 years 5 months; age range, 20 to 25 years), to avoid the influence of growth- and malocclusion type–related bias. Inclusion criteria were as follows:

- Angle's Class I canine and molar relationships
- ANB >0° and <4°
- 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 deviations in the dental midline and buccal crossbite
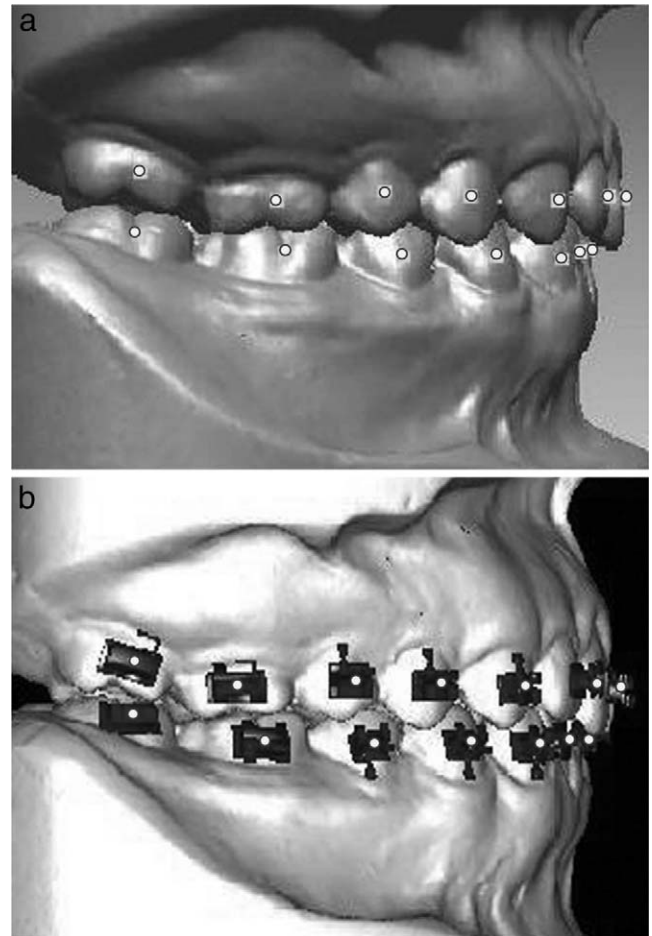- Permanent dentition with normal tooth size and shape, except third molars

Figure 1. (A) The right side view of the facial axis (FA) points marked on three-dimensional (3D) virtual models. (B) The right side views of the bracket slot center (BSC) points in 3D virtual brackets and tubes (0.022″ Slot, MBT setup, 3M Unitek Co, Monrovia, Calif) placed on the FA points of 3D virtual models. The FA point is the facial axis point, which is defined as the point on the facial axis that separates the gingival half of the clinical crown from the occlusal half. The BSC point is defined as the junction of the midtransverse, midsagittal, and midfrontal planes of the bracket slot.

- No history of previous orthodontic treatment
- No restorations extending to the contact areas, cusp tips, or incisal edges

The 3D virtual maxillary and mandibular models were fabricated with a 3D scanner (Orapix; 20 μm units resolution) and the 3Txer program, version 1.9.6 (Orapix). FA points[19] were marked on the whole dentition in both arches with the 3Txer program (Orapix) (Figure 1A,B).

The 3D virtual straight wire appliance brackets (0.022″ Slot, MBT setup, 3M Unitek, Monrovia, Calif), which were fabricated by a 3D-CAD program (Solid Edge, version 15, Siemens PLM Software, Plano, Tex) according to the manufacturer's prescription and measurement by digital Vernier calipers (500-18-20, Mitutoyo, Tokyo, Japan; accuracy, 0.01 mm), were placed

Table 1. Definition of Arch Dimension Variables[a]

Arch Dimension Variables		Definition
Intercanine width, mm	FA	Distance between the FA points of the right and left lower canines
	BSC	Distance between the BSC points of the right and left lower canines
Inter-first premolar width, mm	FA	Distance between the FA points of the right and left lower first premolars
	BSC	Distance between the BSC points of the right and left lower first premolars
Inter-first molar width, mm	FA	Distance between the FA points of the right and left lower first molars
	BSC	Distance between the BSC points of the right and left lower first molars
Canine depth, mm	FA	Shortest distance from a line connecting the FA points of the right and left lower canines to the midpoint between the FA points of the right and left lower central incisors
	BSC	Shortest distance from a line connecting the BSC points of the right and left lower canines to the midpoint between the BSC points of the right and left lower central incisors
Molar depth, mm	FA	Shortest distance from a line connecting the FA points of the right and left lower first molars to the midpoint between the FA points of the right and left lower central incisors
	BSC	Shortest distance from a line connecting the BSC points of the right and left lower first molars to the midpoint between the BSC points of the right and left lower central incisors
Canine width/depth ratio	FA	Ratio between lower canine width and depth from measurement using FA points
	BSC	Ratio between lower canine width and depth from measurement using BSC points
Molar width/depth ratio	FA	Ratio between lower first molar width and depth from measurement using FA points
	BSC	Ratio between lower first molar width and depth from measurement using BSC points

[a] FA indicates facial axis; BSC, bracket slot center.

on the FA point with use of the BSC point and the 3Txer program (Orapix) by one investigator (B.M.), who had adequate experience in 3D technology (Figure 1C,D). To guarantee precise placement of the 3D virtual brackets on the tooth surface, bracket movement was begun at the level of 0.1 mm and under check of the collision test to prevent unnecessary premature contact between the bracket and the tooth surface. In addition, each 3D virtual cast was checked from the inside to verify the position of the bracket in relation to the tooth surface.

The transverse direction was set as the x-axis, the anteroposterior direction the y-axis, and the vertical line perpendicular to the x and y planes, the z-axis. The xy plane was formed from the FA point or the BSC point of the lower right central incisor and the FA points or the BSC points of the lower right and left first molars.

Arch dimensions, including arch width and depth, were measured with use of the FA and BSC points as follows:

• The FA point on the upper right second molar was set as the origin of the x and y axes.
• Five linear and two ratio variables for the arch dimension were measured and calculated (Table 1 and Figure 2).

Amounts of overjet at the anterior and posterior segments were measured with use of the FA and BSC points as follows:

• The x and y coordinates for FA points or BSC points of each case were inputted into a mathematical software program (MATLAB 7.5 [R2007b], The MathWorks Inc, Natick, Mass) to draw the best fitting curve that represents the arch, in accordance with the fourth-degree polynomial equation ($f(x) = ax^4 + bx^3 + cx^2 + dx + e$) (Figure 3).[2,11,12,22]
• Overjet variables, which were defined as the tangent and the shortest distance from the FA points or from the BSC points of the lower teeth to the upper arch, were measured with the 3Txer program, version 1.9.6 (Orapix) (Figure 3).

Measurements were taken by a single operator to eliminate interoperator variability. All variables of the five cases were reassessed after 2 weeks by the same operator, so intraoperator variability could be evaluated. Because the Wilcoxon signed rank test revealed no statistically significant difference between the two assessments ($P > .05$), the first set of measurements was used.

Because no statistically significant difference was seen in the arch dimensions and the overjet between right and left sides and between male and female subjects, the data were combined.

Paired t-tests were done to compare arch dimension variables and amounts of overjet at the anterior and posterior segments between the FA points and the BSC points. A one-way analysis of variance (ANOVA) test was performed to assess the differences in amounts of overjet among these areas according to FA and BSC points, respectively; data were verified with Tukey's post hoc test.

RESULTS

For arch dimension variables, no significant difference was observed between the FA points and the BSC points in both upper and lower arches (Table 2).
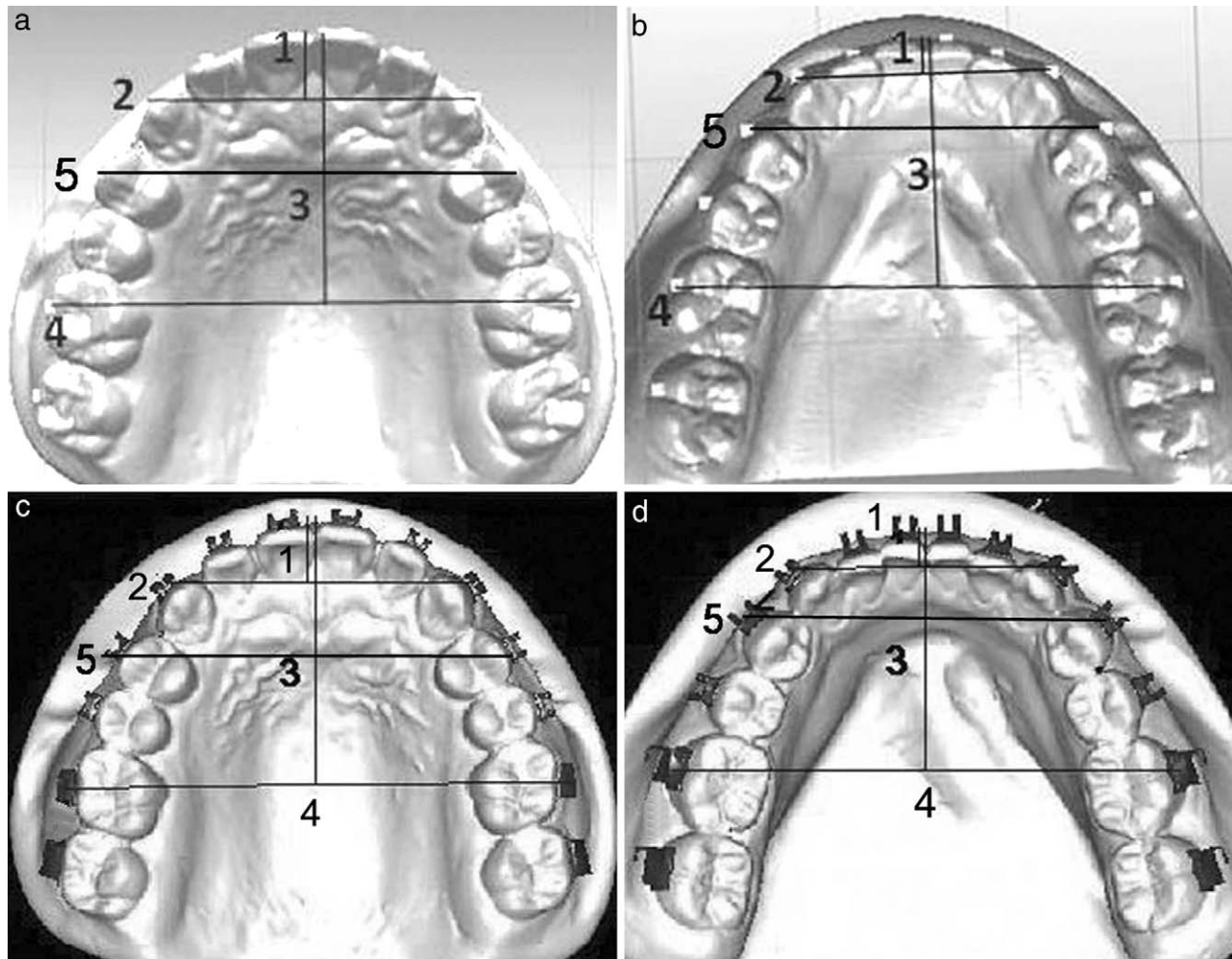
Figure 2. (A and B) Arch dimension variables measured from the facial axis (FA) points *(the upper row)*. (C and D) Arch dimension variables measured from the bracket slot center (BSC) points *(the lower row)*. 1 indicates canine depth; 2, intercanine width; 3, molar depth; 4, inter-first molar width; and 5, inter-first premolar width.

In overjet measurement based on FA points, the amounts of overjet showed homogenous distribution according to ANOVA and Duncan tests (Table 3). However, a tendency to decrease from the anterior segment (~2.3 mm) to the posterior one (~2.0 mm) was noted (Table 3 and Figure 4). Amounts of overjet measured from the BSC points showed a tendency toward greater variation through the whole dentition than was seen with the FA points, and differences between the lower first premolar and second premolar areas and between the lower second premolar and first molar areas were reported (1.6 mm vs 2.1 mm; 2.1 mm vs 1.5 mm, respectively; Table 3 and Figure 4). Therefore, the hypothesis that the amount of overjet measured from BSC points was 3 mm through the whole segments was rejected.

Significant discrepancies in amounts of overjet in most areas between FA and BSC points were noted ($P < .05$ in the lower central incisor area, lower lateral incisor area, lower canine area, and lower first premolar area; $P < .01$ in the lower first molar area; Table 3 and Figure 4), even though insets and offsets are part of the prescription for the base of straight-wire appliance (SWA) brackets. Therefore, the hypothesis that the distribution of amounts of overjet from BSC points was the same as from FA points was rejected.

DISCUSSION

In addition to arch coordination, amounts of overjet in the anterior and posterior segments of the dental arches could be related to torque, labiolingual or buccolingual offset, marginal ridge relationships, and occlusal function such as incisal guidance and working and nonworking side interference.

Cordato[23,24] reported on a mathematical model that could calculate the overjet of the anterior segment according to the sum of tooth widths in each arch, spac-
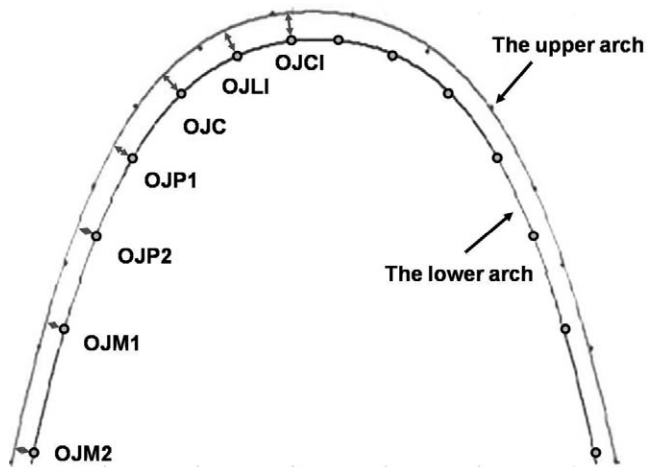
Figure 3. Overjet variables were defined as the tangent and the shortest distance from the facial axis (FA) points or from the bracket slot center (BSC) points of the lower teeth to the upper arch. The best fitting curves of the upper and lower arches were established by the fourth-degree polynomial quation $f(x) = ax^4 + bx^3 + cx^2 + dx + e$. OJCI means overjet at the lower central incisor area; OJLI, overjet at the lower lateral incisor area; OJC, overjet at the lower canine area; OJP1, overjet at the lower first premolar area; OJP2, overjet at the lower second premolar area; OJM1, overjet at the lower first molar area; and OJM2, overjet at the lower second molar area.

ing, crowding, angle of the arc of each arch, and the anteroposterior buccal relation. Cordato[25] insisted that changes in overjet and overbite during and after orthodontic treatment could be predicted on the basis of tooth thickness and angles of the upper teeth. Mutinelli et al[26] showed that different amounts of arch length could be gained through proclination of the anterior teeth (controlled tipping vs uncontrolled tipping) and eventual change of the overjet without modification to the arch width. However, few studies were undertaken to analyze the overjet of the dental arches, especially in the posterior segment.

Investigating the alignment of bracket slots on the teeth seems to be a prerequisite to checking coordination of the upper and lower arches. However, previous studies that have used the incisal edge and the cusp tip,[7–11,26] centers of gravity (centroids) of the occlusal surfaces,[12] and contact points and clinical bracket points based on mandibular tooth thickness data[13,14] might not be related to alignment of the bracket in association with the ''line of occlusion.'' If the landmark on the crown is located at a place far from the FA point, this can influence amounts of overjet in keeping with changes in crown inclination and angulation. Be-

Table 2. Comparison of the Arch Dimension Variables Between the Facial Axis Point and the Bracket Slot Center Point

	Maxilla					Mandible				
	Facial Axis		Bracket Slot Center			Facial Axis		Bracket Slot Center		
	Mean	SD	Mean	SD	Sig.*	Mean	SD	Mean	SD	Sig.*
Intercanine width, mm	38.13	1.54	38.51	2.05	NS	29.1	1.53	29.61	1.78	NS
Inter-first premolar width, mm	47.14	2.01	47.54	2.22	NS	39.43	2.36	39.83	2.28	NS
Inter-first molar width, mm	58.94	2.49	59.95	2.75	NS	53.57	2.26	54.95	2.81	NS
Canine depth, mm	8.39	0.77	8.43	0.66	NS	4.66	0.96	4.88	0.98	NS
Molar depth, mm	30.17	1.52	30.94	1.88	NS	25.89	1.82	26.05	1.75	NS
Canine width/depth ratio	4.58	0.42	4.59	0.4	NS	6.51	1.36	6.31	1.36	NS
Molar width/depth ratio	1.96	0.13	1.94	0.15	NS	2.08	0.17	2.12	0.17	NS

* Paired *t*-tests were performed. Sig. indicates significance; NS, not significant; and SD, standard deviation.

Table 3. Comparison of the Overjet Between the Facial Axis Point and the Bracket Slot Center Point*

Overjet (coordination distance)	Facial Axis Point[a]		Bracket Slot Center Point[b]		
	Mean	SD	Mean	SD	P Value
Lower central incisor area (CI)	2.34	0.89	1.73	0.80	.0112*
Lower lateral incisor area (LI)	2.31	0.72	1.77	0.91	.0155*
Lower canine area (C)	2.19	0.72	1.80	0.86	.0382*
Lower first premolar area (P1)	2.05	0.64	1.61	0.72	.0123*
Lower second premolar area (P2)	2.00	0.48	2.05	0.58	.7577
Lower first molar area (M1)	1.97	0.45	1.50	0.51	.0043**
Lower second molar area (M2)	1.98	0.74	1.86	0.75	.5160
Duncan multiple comparison test	NS		NS		

* Paired *t*-test was performed. $P < .05$; ** $P < .01$; SD indicates standard deviation; NS, not significant.

[a] ANOVA test did not show a significant difference in the amounts of overjet measured from the facial axis point among whole areas ($P = .2062$).

[b] ANOVA test did show significant difference in the amounts of overjet measured from the bracket slot center point among whole areas ($P = .1869$). However, Duncan test showed marginal difference ($P = .0590$) in (M1, P1, CI, LI, C, M2) < (P1, CI, LI, C, M2, P2).
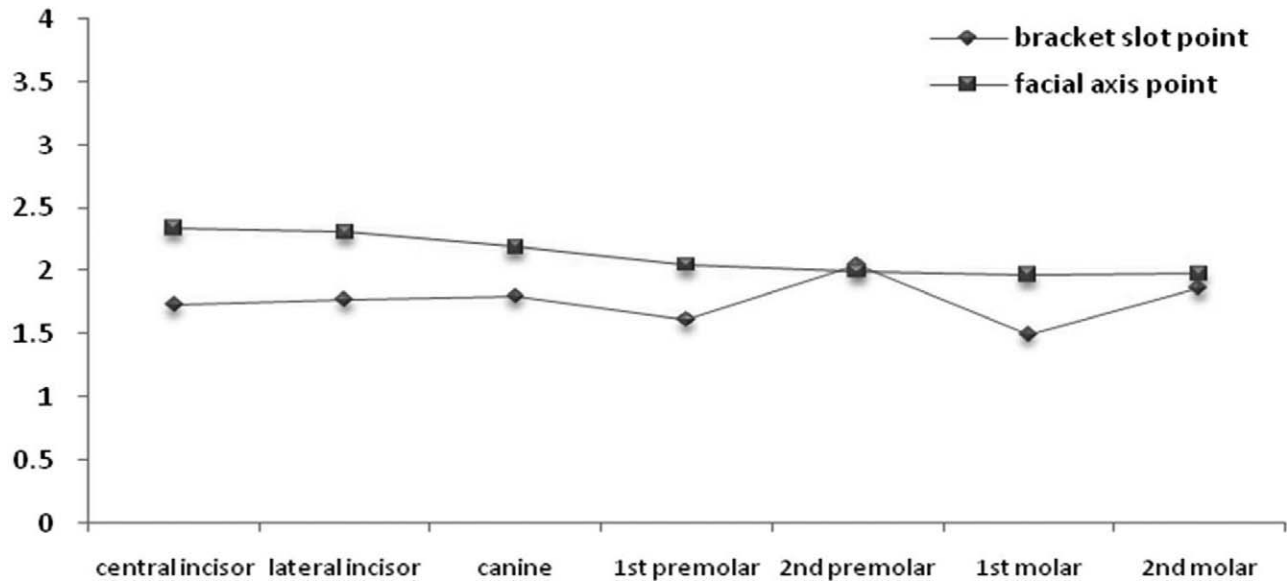
Figure 4. Comparison of the overjet at whole areas between the FA points and the BSC points.

cause the 3D virtual brackets used in the present study were placed on the FA points, the BSC points seemed to be less affected by changes in crown inclination and angulation than other landmarks used in previous studies.[7–14,26]

The finding of a tendency toward a decreased amount of overjet from the anterior segment (~2.3 mm) to the posterior one (~2.0 mm) in the FA points (Table 3 and Figure 4) means that the arc of the posterior segment becomes relatively narrower than the anterior one in the upper arch. This finding is consistent with those of Ferrario et al,[11] who stated that the upper arch showed a "mixed" elliptical (anterior teeth) plus parabolic (postcanine teeth) interpolation of buccal cusp tips (central incisor to second molar).

Because the difference in the amount of overjet between anterior and posterior segments from FA points was 0.3 mm (the value was obtained by subtraction between 2.3 mm of the anterior segment and 2.0 mm of the posterior one; Table 3) and values for the overjet in the anterior segment from BSC points were approximately 1.8 mm (Table 3), the amounts of overjet in the posterior segment from BSC points seemed to be approximately 1.5 mm to achieve arch coordination between upper and lower archwires. Therefore, it might be recommended that the slight amount (around a half millimeter) of the offset bend be added to the second premolar area and second molar area in the archwire to allow proper arch coordination.

The finding that there was a significant difference in the amounts of overjet between FA points and BSC points ($P < .05$ in the lower central incisor area, lower lateral incisor area, lower canine area and lower first premolar area; $P < .01$ in the lower first molar area;

Table 3 and Figure 4) and the finding that there were significant differences in the amount of overjet between the lower first premolar and second premolar areas and between the lower second premolar and first molar areas from BSC points (~0.4 to ~0.5 mm; Table 3 and Figure 4) could affect the amount of overjet in the finishing stage. These differences could be compensated for by wire bending in the finishing stage, by production of new brackets that have an individualized bracket base thickness, or by individualization of resin thickness under the bracket base for indirect bonding.

Too much wire bending and adjustment of stainless steel archwires in the finishing stage to restore a more natural arch form and size and to obtain solid interdigitation of occlusion might result in deleterious tissue effects.[21] Therefore, evaluation of the relationship between the position of 3D virtual brackets and 3D virtual setup models could help clinicians understand the possible "round tripping" movement of teeth in the finishing stage.

Because the present study used a 3D virtual MBT bracket (0.022″ Slot, 3M Unitek), other brackets should be included to provide a guideline regarding amounts of overjet used in future studies. In addition, because racial differences in anatomical variation and dimensions of tooth material and arch may be seen,[9] additional study of ethnic samples from multicenters is recommended.

CONCLUSIONS

- Although the amounts of overjet in the best fitting curve established from the FA points showed ho-

mogenous distribution, a tendency to decrease from the anterior segment (2.3 mm) to the posterior one (2.0 mm) was noted.

- Statistically significant differences were seen in the amounts of overjet in most areas in the best fitting curve between the FA and BSC points (more than $P < .05$), except in the lower second premolar and second molar areas.
- To get proper arch coordination between upper and lower archwires, wire bending in the finishing stage, production of new brackets that have an individualized bracket base thickness, or individualization of resin thickness under the bracket base for indirect bonding might be recommended.

ACKNOWLEDGMENTS

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