Case Report

A Morphometric Study With Setup Models for Bracket Design

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Abstract: This study was designed to obtain basic data on bracket design for the Asian patient. Setup models of 125 Japanese orthodontic patients seeking treatment were measured relative to the occlusal plane by the Andrews' method. A single experienced dental technician fabricated all setup models to provide one-tooth-to-two-teeth occlusal relationship, maximum intercuspation, ABC contacts, flat occlusal planes, canine guidance, and anterior guidance. Means and standard deviations of the crown angulations, inclinations, facial prominence, vertical contour, horizontal contour, and maxillary molar offsets were measured to reach the following conclusions: (1) No difference was observed in crown angulation between groups with one-tooth-to-two-teeth relationships. (2) Crown inclinations of the mandibular central and lateral incisors and canine were greater in the Class II setup group. (3) Maxillary molar offset averaged approximately 7° in the Class II setup group. (4) The data from the Class I setup group showed minor differences from other researchers' data. (*Angle Orthod* 2001;71:499–511.)

Key Words: Preadjusted appliance; Setup model; Bracket design; Asian

INTRODUCTION

Andrews[1,2] measured each tooth in relation to the occlusal plane on the dental models of 120 Caucasian nonorthodontic normal subjects to use as basic data for the fully programmed appliance (FPA) or straight-wire appliance (SWA). Sebata[3] made similar measurements on 41 Japanese nonorthodontic normal subjects. In this study, aimed at obtaining data to be incorporated into the FPA for Japanese orthodontic patients, setup models of 125 patients who had visited orthodontic offices for treatment were fabricated to make various measurements of the crowns. The teeth on the pre-orthodontic models were rearranged into normal occlusion based on the visual treatment objectives (VTO) of Ricketts et al.[4] The following measurements were made using the method of Andrews[5]: crown angulation, crown inclination, crown facial prominence, vertical crown contour, horizontal crown contour, and upper molar offset. The measurements obtained were compared between different treatment plans and with Andrews' and Sebata's data.

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Accepted: May 2001. Submitted: July 2000.

MATERIALS AND METHODS

Materials

Subjects. The study included 125 (26 male and 96 female) young Japanese orthodontic patients with a mean age of 15 years, 3 months, and with Hellman's Dental Age of III C or above. None of the patients revealed severe skeletal discrepancies at the time of initial examinations. Nonanatomical restorations or prostheses and congenitally malformed teeth were excluded from the measurements and subsequent statistical analysis. The number of crowns measured in the 4 quadrants totaled 3061. The breakdown is shown in Table 1.

Setup models. Impressions of the dental arches were taken using an alginate impression material mixed to a standard consistency. Dental stone also was mixed to a standard consistency to pour into the impressions. The completed maxillary and mandibular models were mounted in centric relation on a Panadent PSL articulator Panadent Corporation, Grand Terrace, CA (Figure 1A). The teeth were cut and rearranged in wax into maximum intercuspation according to the treatment plan established for each patient based on the Ricketts VTO.[4] A cusp-embrasure relationship with ABC contacts was established to create the occlusion, which was considered morphologically and functionally ideal as an orthodontic treatment goal (Figure 1B). All the setup models were provided with proper canine and anterior guidance based on the arch form derived from Japanese nonorthodontic normal subjects[3] (Figure 2). The setup models were accurately duplicated with an agar impression material to avoid any distortion caused by wax shrinkage that

TABLE 1. The Number of Measured Crowns

	Tooth							
	1	2	3	4	5	6	7	Total
Upper	248	239	248	83	248	241	181	1488
Lower	249	249	250	146	246	235	198	1573
Total (n)								3061

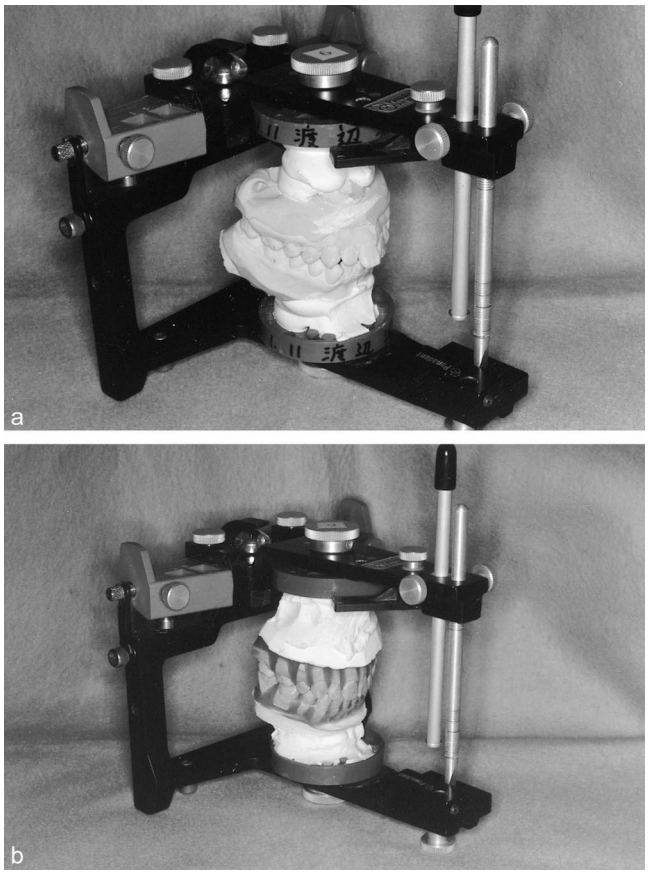

FIGURE 1. (A) The upper and lower models of a Japanese patient with malocclusion mounted on a Panadent PSL articulator in centric relation. (B) The setup model based on treatment objective. A cusp-embrasure relationship with ABC contacts was established to create the occlusion that was considered morphologically and functionally ideal as an orthodontic treatment goal.

would adversely affect the measurements. The duplicates were used to make the actual measurements (Figure 3).

Methods of Measurement

Facial axis of the clinical crown. The facial axis of the clinical crown (FACC) was established by Andrews'[5] method and marked with a pencil on the facial surface of each crown. The FACC line represented the most prominent portion of the facial central lobe for all teeth except molars. The buccal groove was used for the molars. In addition, midpoints of the FACCs of the left and right central incisors and first molars were connected with a continuous line as

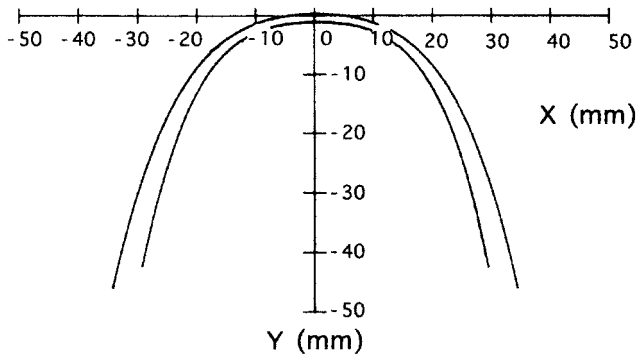

FIGURE 2. All the setup models were provided with the arch form derived from Japanese nonorthodontic normal subjects.

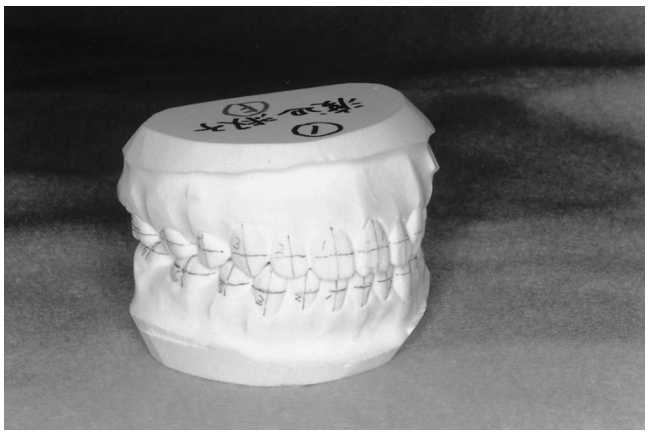

FIGURE 3. The duplicate models prepared to adjust for possible effects of wax shrinkage and other distortions on the measurements.

if a straight orthodontic wire were placed at the end of appliance therapy. The intersection of this line with the FACC of each crown was named a tentative Facial axis (FA) point, which may be slightly more gingival or occlusal to the original FA point, and was used as a convenient reference point for the measurements.

Reference occlusal planes. Two-millimeter-thick, rigid, flat acrylic plates were trimmed to the maxillary and mandibular arch shapes with recessed areas for cuspids as described by Andrews.[5] They were used as reference occlusal planes for the measurements. Each acrylic plate was set over the occlusal surfaces of the respective arch so that it touched the incisal edges of the central incisors as well as the cusp tips of the maxillary and the mandibular terminal molars.

Methods of measurement and equipment. Crown angulation, crown inclination, crown prominence, vertical and horizontal crown contour, and maxillary molar offset were measured in the manner shown in Figures 4 through 8.

Crown angulation. Crown angulation, the mesiodistal angle formed by the FACC and a line perpendicular to the occlusal plane, was measured using the arch-shaped acrylic plate and a stainless steel protractor as shown in Figure 4.

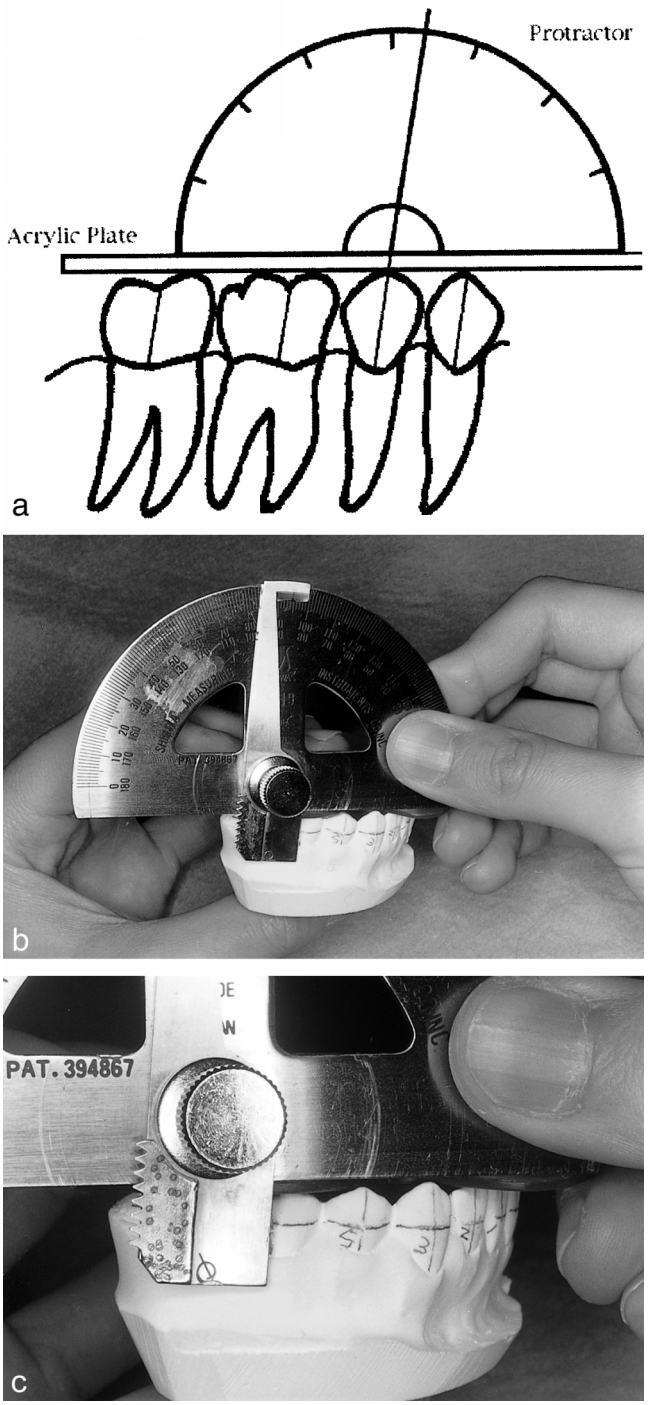

FIGURE 4. (A) Measuring crown angulation (schema). (B) Measurement of the crown angulation. The occlusal plane was established using an acrylic plate to measure crown angulation according to Andrews' method. (C) The magnification of measuring crown angulation.

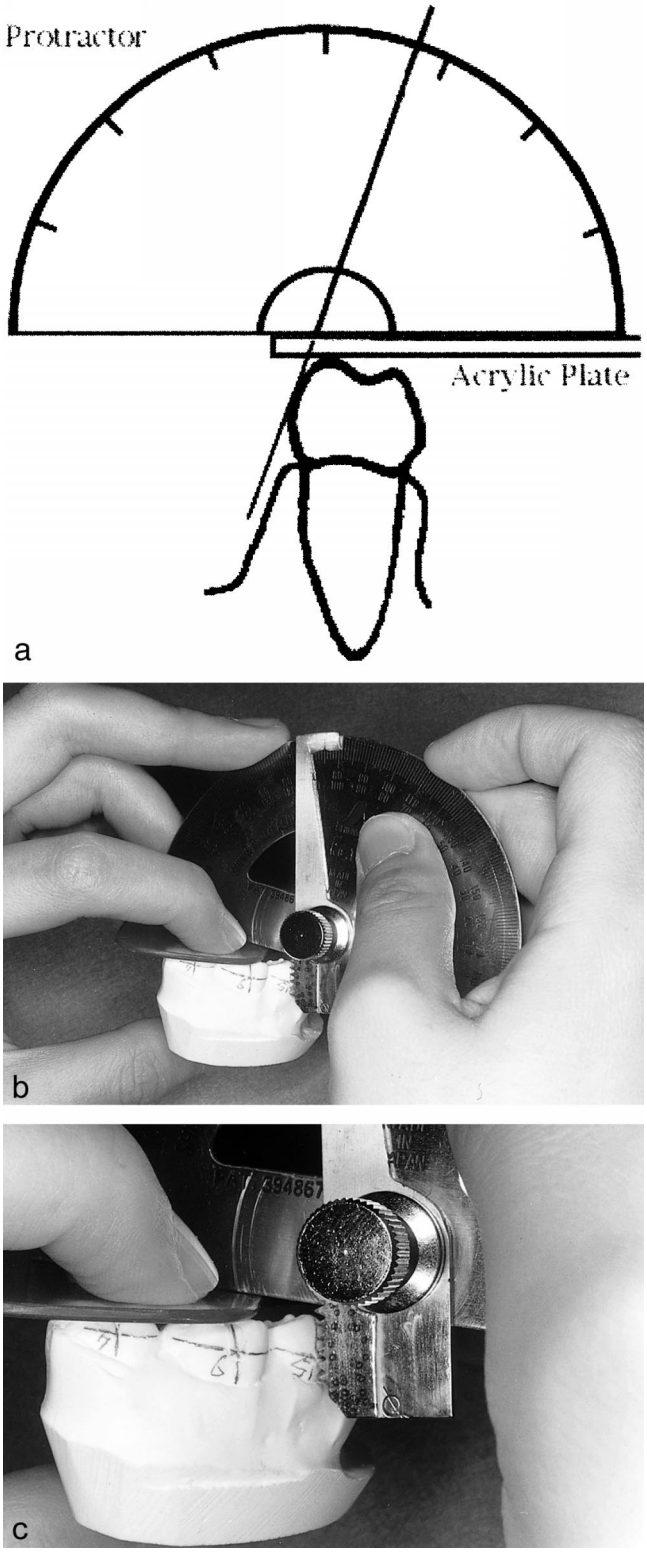

FIGURE 5. (A) Measurement of the crown inclination (schema). (B) Measurement of the crown inclination. The occlusal plane was established in the same manner used for measuring angulation. (C) The magnification of measuring crown inclination. A special protractor was developed to measure the angle formed by the facial axis of the clinical crown and a line perpendicular to the occlusal plane.

Crown inclination. Crown inclination is the labiolingual (buccolingual) angle between a line perpendicular to the occlusal plane and the FACC. A special protractor was developed to measure the angle formed by the FACC and a

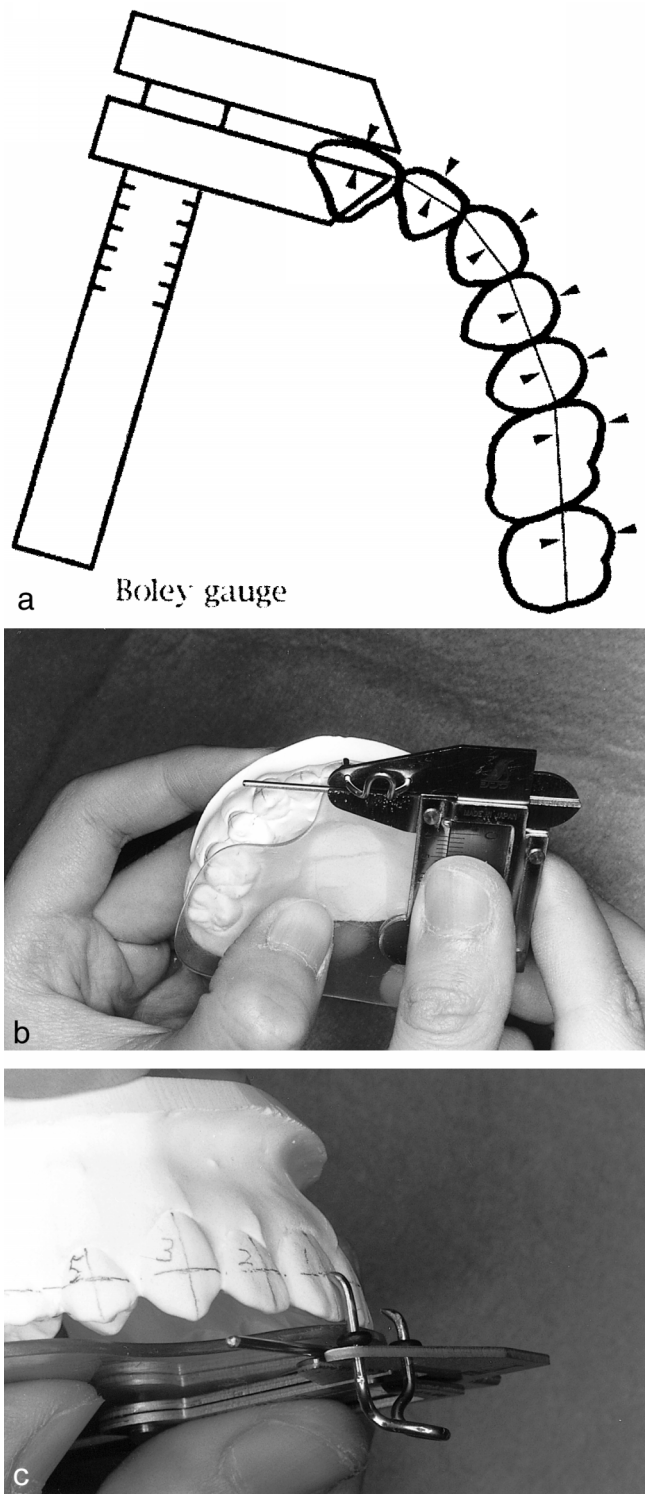

FIGURE 6. (A) Measuring facial prominence of crown (schema). (B) Measurement of the facial prominence of crown. The occlusal plane was established by using an acrylic plate as described previously. (C) The magnification of measuring facial prominence. A modified stainless steel Boley gauge was used as shown in this picture.

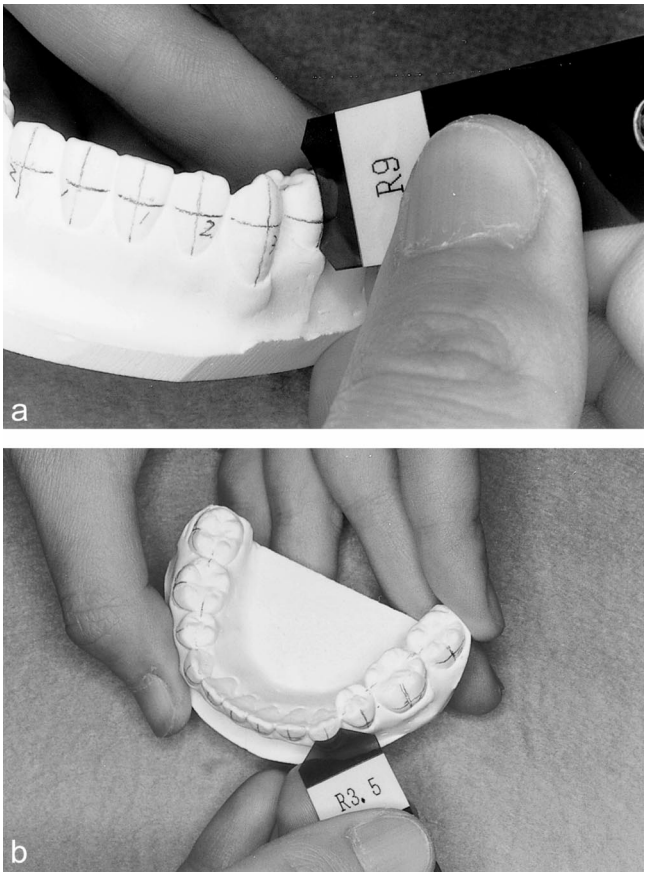

FIGURE 7. (A) The method of measuring vertical crown contour. The vertical crown contour was measured with a modified template of circles. (B) The method of measuring horizontal crown contour. The template of circles was used in measuring horizontal crown contour as well.

line perpendicular to the occlusal plane, as shown in Figures 5A and B.

Crown prominence. Crown prominence is the distance to the tentative FA point from an imaginary line that connects the most facial portions of the contact areas of all teeth except terminal molars. A modified stainless steel Boley gauge was used, as shown in Figures 6A and B.

Vertical crown contour. In order to measure vertical crown contour, one end of each 0.5-mm-thick acrylic strip was cut to the shape of an arc 1 mm to 40 mm in radius to match the respective circle. This acrylic strip could then be used as a guide to determine the radius of the vertical facial curvature of each crown, as shown in Figure 7A.

Horizontal crown contour. The same acrylic strips were used to measure horizontal crown contour by recording the radius of the horizontal facial curvature of each crown, as shown in Figure 7B.

Maxillary molar offset. Maxillary molar offset, the angle formed by the imaginary line that connects the most facial portions of the contact areas and a straight line that connects the mesial and distal buccal cusps of each maxillary molar at the level of the tentative FA point, was measured

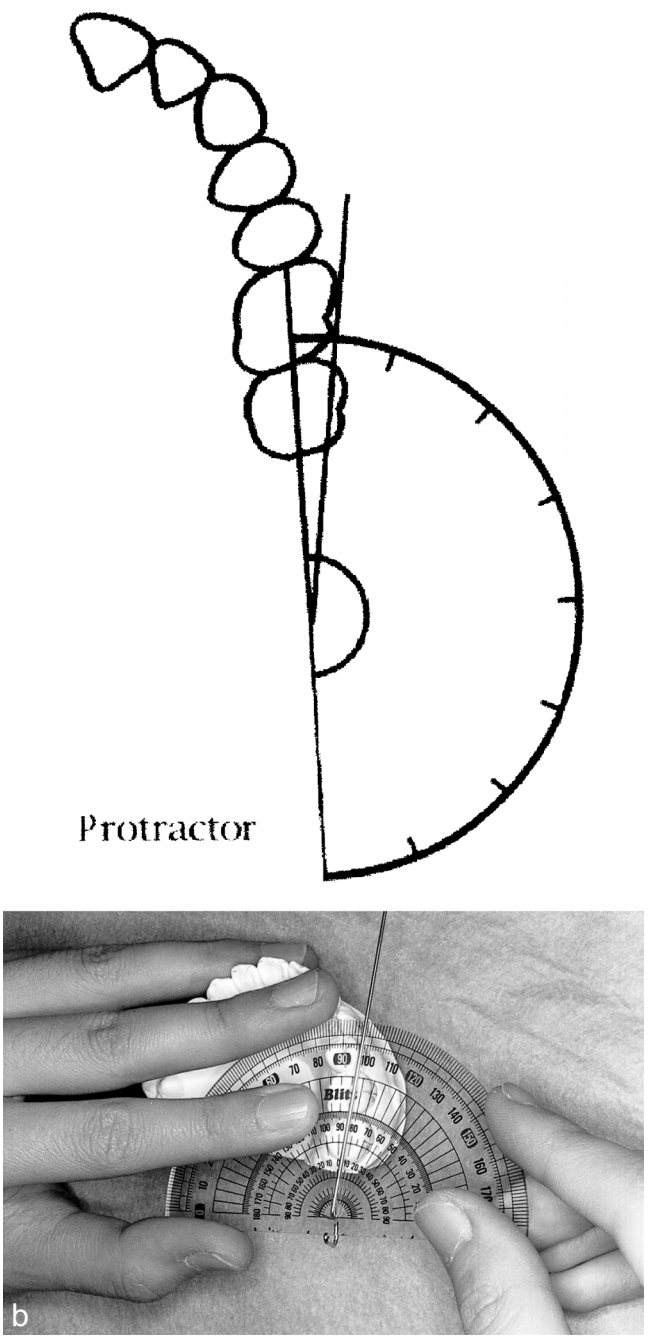

FIGURE 8. (A) Measurement of the upper molar offset (schema). (B) The angle of the upper molar offset was measured by using an acrylic protractor with a readout arm.

using an acrylic protractor with a readout arm, as shown in Figure 8.

Data Processing

All the relevant data and measurements obtained were stored in Excel version 5.0 for the Macintosh (Microsoft, Redmond, Wash). The same software was used for statistical analysis. These data were compared by treatment plan (extraction and nonextraction). The subjects were divided into a nonextraction setup group (33 patients) and 3 extraction setup groups: a group of upper-premolar-only extraction cases with a Class II setup (33 patients), a group of four-first-premolar extraction cases with a Class I setup (47 patients), and a group of unusual extraction cases to be treated by extraction of other teeth (12 patients).

RESULTS

The following measurements were obtained and compared between the groups:

Crown Angulation

Tables 2 and 3 show the maxillary and mandibular crown angulation measurements obtained in each group. The 4 groups showed similar measurements for all teeth. The tooth with the largest difference in the mean value between the groups was the second molar (1.70°) for the maxillary arch and the first premolar (1.37°) for the mandibular teeth.

Crown Inclination

The crown inclination measurements are compared between the groups in Tables 4 and 5. Posterior teeth showed larger differences in mean crown inclination between the groups than anterior teeth in both maxillary and mandibular arches. Particularly, the group with a Class II setup showed greater crown inclinations for the mandibular anterior teeth. The canine (3.03°) showed the largest difference in the mean value between the groups for the maxillary arch and the central incisor (6.37°) for the mandibular arch.

Crown Prominence

The crown prominence measurements of each group are shown in Tables 6 and 7. The measurements for each tooth varied little between the groups. The largest difference in the mean value between the groups was recorded with the second molar (0.25 mm) for the maxillary arch and the lateral incisor (0.27 mm) for the mandibular arch.

Vertical Crown Contour

The vertical crown contour measurements obtained in each group are shown in Tables 8 and 9. In this study, vertical crown contour was determined by superimposing the arcs on the portion of the facial surface from 2 mm above to 2 mm below the tentative FA point along the FACC of each crown until the closest match was found and then recording its radius in millimeters.

There were great similarities in crown vertical contour between the 4 groups for all teeth. The largest difference in mean value between the groups was found with the second premolar (1.46 mm in radius) for the maxillary arch and the canine (1.52 mm in radius) for the mandibular arch.

TABLE 2. Upper Tooth Angulation by Treatment Plan (in Degrees)

	Tooth													
	1		2		3		4		5		6		7	
Treatment Plan, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nonextraction setup, 33	2.97	1.50	3.67	1.53	7.64	2.09	4.67	1.98	4.91	2.30	4.57	2.47	3.09	3.65
Upper-bicuspid-only extraction with class II setup, 33	3.57	1.41	5.10	1.87	7.76	1.86			5.42	1.72	5.47	1.60	3.93	2.58
Four-first-bicuspid extraction with class I setup, 47	3.21	1.50	4.21	1.51	7.79	1.30			5.40	1.42	5.17	1.25	4.68	2.39
Unusual extraction setup, 12	3.50	1.32	4.75	1.48	8.64	2.06	5.15	1.46	4.87	1.62	4.87	1.60	4.79	2.74
Total, 125	3.27	1.48	4.33	1.71	7.81	1.78	4.75	1.91	5.23	1.80	5.07	1.78	4.13	2.91

TABLE 3. Lower Tooth Angulation by Treatment Plan (in Degrees)

	Tooth													
	1		2		3		4		5		6		7	
Treatment Plan, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nonextraction setup, 33	1.88	0.69	2.12	0.77	5.27	2.05	3.80	1.62	4.18	1.78	4.19	1.87	4.30	1.83
Upper-bicuspid-only extraction with class II setup, 33	1.88	0.59	2.15	0.78	4.94	1.79	3.55	1.71	4.06	1.93	4.44	2.17	4.59	1.79
Four-first-bicuspid extraction with class I setup, 47	2.04	0.85	2.38	1.12	5.49	1.69			3.72	1.63	3.34	1.17	3.61	1.70
Unusual extraction setup, 12	2.04	0.81	2.26	1.11	5.17	1.99	4.92	2.06	4.50	2.36	4.58	2.33	4.71	2.41
Total, 125	1.96	0.75	2.24	0.96	5.26	1.86	3.78	1.74	4.01	1.85	3.98	1.86	4.12	1.89

TABLE 4. Upper Tooth Inclination by Treatment Plan (in Degrees)

	Tooth													
	1		2		3		4		5		6		7	
Treatment Plan, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nonextraction setup, 33	13.91	3.42	11.64	3.75	−4.64	4.64	−6.00	5.29	−7.18	5.53	−9.72	4.60	−10.16	5.31
Upper-bicuspid-only extraction with class II setup, 33	12.54	5.22	9.97	4.49	−6.67	3.95			−7.65	4.13	−10.41	3.73	−11.00	4.53
Four-first-bicuspid extraction with class I setup, 47	12.06	3.30	9.45	2.86	−5.74	4.13			−7.18	3.18	−9.77	4.05	−9.21	4.03
Unusual extraction setup, 12	11.42	3.20	11.38	3.50	−3.64	4.31	−7.08	3.45	−7.78	3.18	−10.04	3.47	−11.11	5.36
Total, 125	12.61	4.00	10.32	3.76	−5.51	4.35	−6.18	5.05	−7.36	4.18	−9.95	4.07	−10.05	4.69

TABLE 5. Lower Tooth Inclination by Treatment Plan (in Degrees)

	Tooth													
	1		2		3		4		5		6		7	
Treatment Plan, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nonextraction setup, 33	2.00	3.77	1.67	3.52	−9.27	3.91	−18.38	5.46	−23.38	4.75	−32.60	2.73	−33.75	3.27
Upper-bicuspid-only extraction with class II setup, 33	6.18	5.21	5.91	5.13	−6.39	3.95	−15.67	3.09	−21.97	3.58	−31.38	2.95	−33.34	2.00
Four-first-bicuspid extraction with class I setup, 47	−0.19	4.51	−0.28	4.51	−12.43	5.09			−20.72	4.64	−30.23	4.58	−32.39	4.03
Unusual extraction setup, 12	0.78	7.14	0.43	7.18	−10.50	4.66	−16.46	2.21	−22.42	3.07	−31.42	3.38	−32.90	3.26
Total, 125	2.17	5.47	1.94	5.38	−9.82	5.07	−16.97	4.47	−21.91	4.42	−31.29	3.75	−32.99	3.46

TABLE 6. Facial Prominence of Upper Teeth by Treatment Plan (in Millimeters)

	Tooth													
	1		2		3		4		5		6		7	
Treatment Plan, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nonextraction setup, 33	2.59	0.45	2.52	0.98	3.98	0.36	4.58	0.30	4.53	0.34	5.04	0.30	4.86	0.63
Upper-bicuspid-only extraction with class II setup, 33	2.78	0.35	2.50	0.31	3.92	0.37			4.42	0.29	4.93	0.50	4.98	0.37
Four-first-bicuspid extraction with class I setup, 47	2.72	0.41	2.48	0.35	3.90	0.43			4.47	0.37	5.00	0.56	4.94	0.35
Unusual extraction setup, 12	2.65	0.43	2.44	0.45	3.75	0.42	4.53	0.29	4.42	0.45	4.81	0.37	4.73	0.26
Total, 125	2.70	0.42	2.49	0.59	3.91	0.40	4.57	0.30	4.47	0.35	4.98	0.48	4.91	0.44

TABLE 7. Facial Prominence of Lower Teeth by Treatment Plan (in Millimeters)

	Tooth													
	1		2		3		4		5		6		7	
Treatment Plan, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nonextraction setup, 33	1.92	0.30	1.95	0.27	3.35	0.27	4.11	0.25	4.30	0.27	5.11	0.30	5.02	0.26
Upper-bicuspid-only extraction with class II setup, 33	2.08	0.44	2.15	0.49	3.47	0.40	4.10	0.33	4.25	0.52	5.14	0.35	4.97	0.57
Four-first-bicuspid extraction with class I setup, 47	2.00	0.24	2.01	0.24	3.40	0.38			4.38	0.34	5.24	0.29	5.05	0.43
Unusual extraction setup, 12	1.90	0.22	1.88	0.21	3.32	0.39	3.99	0.46	4.34	0.32	5.28	0.33	5.15	0.31
Total, 125	1.99	0.33	2.02	0.34	3.40	0.36	4.09	0.31	4.32	0.38	5.18	0.32	5.03	0.42

TABLE 8. Vertical Crown Contour of Upper Teeth by Treatment Plan (in Millimeters Radius)

	Tooth													
	1		2		3		4		5		6		7	
Treatment Plan, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nonextraction setup, 33	20.55	5.00	19.97	4.63	18.62	3.97	13.86	4.00	11.03	3.82	9.71	3.42	8.48	2.39
Upper-bicuspid-only extraction with class II setup, 33	20.31	3.58	19.17	2.88	17.64	2.87			9.57	2.20	8.36	1.61	8.13	1.90
Four-first-bicuspid extraction with class I setup, 47	21.06	3.22	19.72	2.83	18.23	2.33			10.07	2.41	8.92	2.58	8.24	1.94
Unusual extraction setup, 12	21.75	3.49	19.13	2.69	17.91	1.98	13.88	3.43	10.83	3.11	8.35	1.17	7.29	1.24
Total, 125	20.80	3.90	19.61	3.44	18.15	2.99	13.87	3.92	10.27	2.93	8.92	2.57	8.17	2.01

TABLE 9. Vertical Crown Contour of Lower Teeth by Treatment Plan (in Millimeters Radius)

	Tooth													
	1		2		3		4		5		6		7	
Treatment Plan, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nonextraction setup, 33	22.24	4.07	22.14	4.09	17.77	1.83	11.63	3.32	8.82	1.88	8.04	1.21	7.97	1.14
Upper-bicuspid-only extraction with class II setup, 33	21.48	3.75	21.36	3.83	16.73	2.77	11.55	3.24	8.98	2.21	8.06	1.37	7.79	1.29
Four-first-bicuspid extraction with class I setup, 47	21.89	3.83	21.70	3.73	18.21	4.21			8.33	1.35	7.42	0.96	7.54	0.97
Unusual extraction setup, 12	21.57	3.91	21.57	3.91	18.25	2.05	11.85	4.69	8.96	2.05	7.50	1.22	7.26	0.88
Total, 125	21.85	3.89	21.71	3.88	17.71	3.22	11.61	3.43	8.69	1.84	7.76	1.21	7.67	1.10

TABLE 10. Horizontal Crown Contour of Upper Teeth by Treatment Plan (in Millimeters Radius)

	Tooth													
	1		2		3		4		5		6		7	
Treatment Plan, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nonextraction setup, 33	24.54	3.59	24.55	3.56	4.65	0.74	3.71	0.41	3.58	0.39	39.34	3.56	38.37	5.14
Upper-bicuspid-only extraction with class II setup, 33	23.31	3.20	23.25	2.70	4.55	0.74			3.52	0.39	40.00	0.00	40.00	0.00
Four-first-bicuspid extraction with class I setup, 47	24.61	6.33	24.35	6.10	4.91	0.90			3.58	0.45	39.57	2.28	39.34	2.61
Unusual extraction setup, 12	23.75	2.98	19.94	6.28	4.73	0.94	3.54	0.41	3.50	0.42	39.13	2.82	38.42	4.60
Total, 125	24.17	4.74	23.82	4.90	4.73	0.84	3.68	0.41	3.56	0.42	39.59	2.46	39.16	3.44

TABLE 11. Horizontal Crown Contour of Lower Teeth by Treatment Plan (in Millimeters Radius)

	Tooth													
	1		2		3		4		5		6		7	
Treatment Plan, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nonextraction setup, 33	24.39	2.04	24.39	2.04	4.13	0.57	3.96	0.41	3.79	0.38	39.68	1.75	38.75	4.62
Upper-bicuspid-only extraction with class II setup, 33	22.73	2.78	22.73	2.78	4.05	0.58	3.89	0.44	3.85	0.54	40.00	0.00	40.00	0.00
Four-first-bicuspid extraction with class I setup, 47	23.50	4.53	23.50	4.53	4.39	0.75			3.70	0.39	38.97	6.02	38.80	6.29
Unusual extraction setup, 12	23.70	2.20	23.91	2.06	4.21	0.56	3.73	0.50	3.75	0.48	39.58	1.38	40.00	0.00
Total, 125	23.55	3.42	23.57	3.42	4.21	0.66	3.91	0.44	3.77	0.45	39.49	3.83	39.16	4.75

Horizontal Crown Contour

Tables 10 and 11 show horizontal crown contour measurements for each group. Horizontal crown contour was determined in a similar manner to vertical crown contour—by finding the arc that most closely approximated the curvature of the crown's facial surface mesial and distal to the tentative FA point. The largest difference in the mean value between the groups was found with the second molar (1.63 mm in radius) for all maxillary teeth except lateral incisors and central and lateral incisors (1.66 mm in radius) for the mandibular teeth. The measurements showed little variation between the groups, although measurements of the maxillary lateral incisors, which may be associated with microdontia or other morphological abnormalities, differed by as much as 4.61 mm between the groups.

Maxillary Molar Offset

Table 12 shows the maxillary molar offset measurements obtained in each group. A difference in mean maxillary molar offset between the highest and lowest groups was 4.04° for the first molars and 4.32° for the second molars. In the upper-first-premolar-only extraction group with a Class II setup, maxillary molar offset averaged 6.71° for the first molars and 7.50° for the second molars.

TABLE 12. Upper Molar Offset by Treatment Plan (in Degrees)

	Tooth			
	6		7	
Treatment plan, n	Mean	SD	Mean	SD
Nonextraction setup, 33	10.75	4.12	10.51	3.94
Upper-bicuspid-only extraction with class II setup, 33	6.71	4.61	7.50	3.99
Four-first-bicuspid extraction with class I setup, 47	9.86	4.21	11.82	3.74
Unusual extraction setup, 12	7.74	3.25	9.53	5.87
Total, 125	9.04	4.52	10.27	4.45

DISCUSSION

Measurements on Setup Models

It was Andrews who most clearly proposed the hypothesis that nonorthodontic normal occlusion (optimal occlusion) could serve as an orthodontic treatment goal.[6–9] The following observations seem to represent the thought process that led him to this hypothesis:

1. The anatomies of natural teeth are highly consistent.
2. This high degree of consistency can be viewed from two standpoints—consistency from the systematic anatomy standpoint and consistency of relative size of the teeth that constitute the maxillary and mandibular arches.

3. Thus, there is a consistent spatial relationship of the teeth to the occlusal plane that can be used as a treatment goal when the dental arches satisfy specific requirements.[1]

Indeed, the FPA (SWA) bracket system was developed based on this hypothesis. A number of cases treated with this system have been reported over the years, suggesting a positive clinical significance of this hypothesis.

On the other hand, even after a malocclusion is orthodontically corrected, the resultant normal occlusion is still composed of the same teeth as the original malocclusion. Therefore, it was considered necessary to conduct similar studies of the measurements made on nonorthodontic normal models by using setup models of malocclusions with teeth rearranged into normal occlusion under a specific set of conditions. These efforts would provide important additional data to be incorporated into the FPA and would validate the hypothesis that nonorthodontic normal occlusion could be used as an orthodontic goal.

In this study, dental models of each subject were mounted on an articulator in centric relation, and teeth were set based on the VTO in such a way that the following requirements were fulfilled:

1. Teeth should be arranged in a one-tooth-to-two-teeth (cusp-embrasure) relationship.
2. Maxillary and mandibular teeth should occlude in maximum intercuspation.
3. Cusps and opposing fossae should establish as many ABC contacts as possible.
4. The arch form should be derived from Japanese nonorthodontic normal subjects.
5. The occlusal plane should be made almost flat, with proper canine and anterior guidance provided on a mean value articulator.

Methods of Measurement

FA points. Andrews defined the FACC as the most prominent ridge on the crown's face as a reference for all teeth except molars. The buccal groove was used as the molar reference. These references or landmarks are relatively easy to find, making it possible to identify the FACC quite accurately. Andrews called the midpoint of the FACC the FA point. He found that when the teeth in an arch are correctly positioned, their FA points fall on the Andrews' plane, which is an almost flat surface closely approximating the occlusal plane.

In 1978, however, Dellinger[10] conducted a study with setup models of 50 subjects with malocclusion. He constructed a plane by connecting left and right midcrown molar points and the clinical crown average of the left and right central incisors to demonstrate that the FA points did not always fall on this plane.

Clinicians may encounter in daily practice the situation where the FA points do not line up on the same plane. McLaughlin and Bennet[11] have recently shown that the FA points do not always constitute a continuous straight line, and although they strongly emphasize the significance of the FA point, there is a consistency in the way the FA points are discontinuous. They have developed the Recommended Bracket Placement Chart for clinical use. Thus, the likelihood of all the FA points being always so continuous as to form a straight line seems to be rather small.

Meanwhile, it is possible to draw a straight line connecting the left and right terminal molars around the arch and passing near the center of each crown on a model of a successfully treated orthodontic patient with an almost flat occlusal plane. Thus, the authors imagined what is called the Bracket Positioning Zone (BPZ; Koga,[12] 1980). This is a zone with a minimum width on each crown's surface, assuming a continuous line drawn through the FA point of each crown that would serve as a reference to represent the BPZ. Thus, an almost straight line was drawn through the FA points of the central incisors and first molars in such a way that the line most closely approximated the original FA points of the rest of the teeth. The junction of this line with each crown's long axis was then used as a tentative FA point to facilitate the measurements.

Methods of measurement. All the measurements were made by the same investigator to minimize errors in locating the crown axes. When crown inclination is measured, it is often difficult to locate by visual means only the FACC that is tangent to the FA point and equidistant from the occlusal and gingival extremities of the crown's facial surface. Therefore, in this study, a stainless steel protractor was modified to measure the angle formed by an imaginary line that connects the two points 0.5 mm above and 0.5 mm below the tentative FA point and a line perpendicular to the occlusal plane in order to standardize the measurement of crown inclination.

Crown prominence is the distance from an imaginary line connecting the most facial portions of the contact areas of all teeth except terminal molars to each crown's FA point. A modified stainless steel Boley gauge was used to measure crown prominence without trimming away occlusal halves of the crowns.

Andrews[2] measured vertical and horizontal crown contours using a template of circles. It is more difficult to measure vertical and horizontal crown contour by superimposing the template of circles on the model, possibly lowering the accuracy. In this study, ends of 0.5-mm-thick acrylic strips were trimmed to match the arcs of the circles on the template of circles ranging from 1 mm to 40 mm in radius. The arc-shaped ends of the acrylic strips were placed on each crown's facial surface until a match was found. The radius was then recorded in millimeters. There has been no report published concerning crown contour measurements to date.

Comparison by treatment plan (between extraction and

TABLE 13. Comparing Upper Tooth Angulation With Previous Data (in Degrees)

	Tooth													
	1		2		3		4		5		6		7	
Researcher, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Andrews,[5] 120	3.59	1.65	8.04	2.80	8.40	2.97	2.65	1.69	2.82	1.52	5.73	1.90	0.39	5.69
Sebata,[3] 41	4.25	1.72	5.74	2.30	7.74	4.10	3.51	4.02	6.18	3.68	5.22	4.03	−0.30	7.31
Our study, 80	3.11	1.50	3.99	1.55	7.73	1.67	4.67	1.98	5.20	1.85	4.94	1.85	4.09	3.02

TABLE 14. Comparing Lower Tooth Angulation With Previous Data (in Degrees)

	Tooth													
	1		2		3		4		5		6		7	
Researcher, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Andrews,[5] 120	0.53	1.29	0.38	1.47	2.48	3.28	1.28	1.90	1.54	1.35	2.03	1.14	2.94	2.05
Sebata,[3] 41	−0.48	2.45	−1.20	2.51	1.48	5.40	2.52	5.24	6.70	4.00	5.74	4.40	7.34	6.70
Our study, 80	1.98	0.79	2.28	1.00	5.40	1.85	3.80	1.62	3.91	1.71	3.70	1.56	3.88	1.78

nonextraction groups). The subjects in the study were divided into a nonextraction group, an upper-premolar-only extraction group with a Class II setup, a four-first-premolar extraction group, and a group with other extraction patterns for comparison. Little difference was found in crown angulation for all the crowns in either arch between the groups, suggesting that each tooth type can be provided with a similar amount of crown angulation when a one-tooth-to-two-teeth (cusp-embrasure) occlusal relationship is established.

The Class II setup group showed larger amounts of crown inclinations for the mandibular incisors and canines, showing a flaring tendency of these teeth. This may be explained by the need for proclining the mandibular anterior teeth in order to correctly set the posterior teeth in Class II molar relationship when only the maxillary first premolars are extracted. Maxillary molar offset averaged approximately 10° in the Class I setup groups and approximately 7° in the Class II setup group. Other measurements showed no major difference between the groups.

Comparison of measurements from the setup models and nonorthodontic normal models. Of 125 patients, those who were to be treated by nonextraction and extraction of 4 first premolars (80 patients) were newly classified as a Class I setup group, so that the results could be compared with data from Andrews'[2] and from Sebata[3] that were obtained from nonorthodontic normal models.

Crown angulation. Comparisons with Andrews' and Sebata's[3] data are shown in Table 13 for maxillary teeth and in Table 14 for mandibular teeth, whereas Figures 9 and 10 show graphs of the same data. In the maxillary arch, the authors' measurements for the lateral incisor were smaller than those obtained by Sebata[3] and Andrews, indicating a tendency of the tooth to be more upright mesiodistally. For the second premolars, Sebata's values were similar to those of the authors, whereas Andrews' values were smaller, with

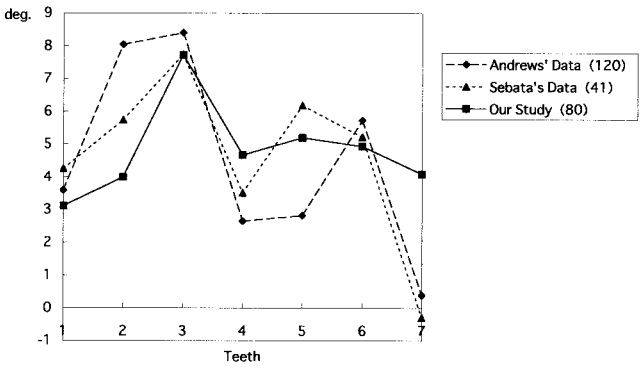

FIGURE 9. The comparison of the mean crown angulation for upper teeth obtained in this study with those of Andrews and Sebata.[3] Our data for the central incisor, canine, and first molar showed almost the same values as those of Andrews and Sebata, whereas the lateral incisor and premolars showed different values.

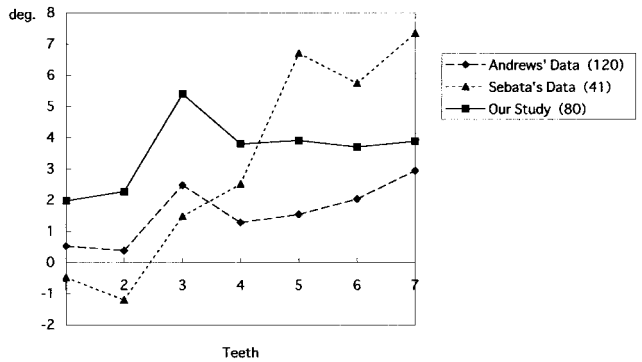

FIGURE 10. The comparison of the mean crown angulation for lower teeth obtained in this study with those of Andrews and Sebata.[3] Although our measurements differed from those of Andrews' by 1° to 3° in general, the overall tendency was the same. Our values were slightly larger. Sebata's measurements tended to be smaller in the anterior and larger in the posterior area than ours.

TABLE 15. Comparing Upper Tooth Inclination With Previous Data (in Degrees)

	Tooth													
	1		2		3		4		5		6		7	
Researcher, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Andrews,[5] 120	6.11	3.97	4.42	4.38	−7.25	4.21	−8.47	4.02	−8.78	4.13	−11.53	3.91	−8.10	5.63
Sebata,[3] 41	9.42	4.88	7.48	4.80	0.67	4.42	−6.46	6.49	−6.64	6.90	−1.73	7.66	−2.97	8.03
Our study, 80	12.82	3.47	10.35	3.43	−5.29	4.39	−6.00	5.29	−7.18	4.31	−9.75	4.27	−9.55	4.56

TABLE 16. Comparing Lower Tooth Inclination With Previous Data (in Degrees)

	Tooth													
	1		2		3		4		5		6		7	
Researcher, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Andrews,[5] 120	−1.71	5.79	−3.24	5.37	−12.73	4.65	−18.95	4.96	−23.63	5.58	−30.67	5.90	−36.03	6.57
Sebata,[3] 41	3.55	6.46	1.66	5.77	−4.73	6.17	−14.80	6.76	−22.57	6.62	−26.17	6.14	−31.03	8.66
Our study, 80	0.71	4.36	0.53	4.24	−11.13	4.89	−18.38	5.46	−21.81	4.87	−31.23	4.08	−32.90	3.82

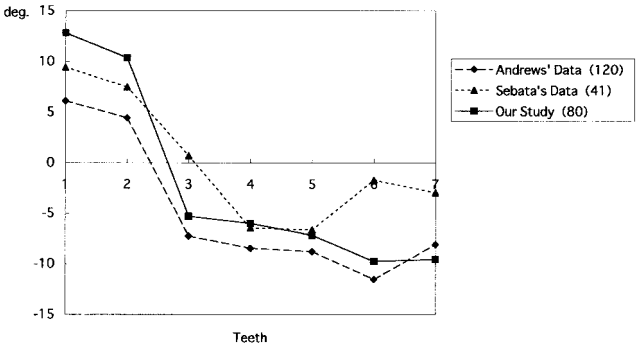

FIGURE 11. The comparison of our mean crown inclination for upper teeth with those of Andrews and of Sebata.[3] Our measurements for the canine and for the teeth distal to it were almost equal to those of Andrews', but measurements for the central and lateral incisors were 6° larger than those of Andrews'. Sebata's data were almost the same as ours in the premolar area.

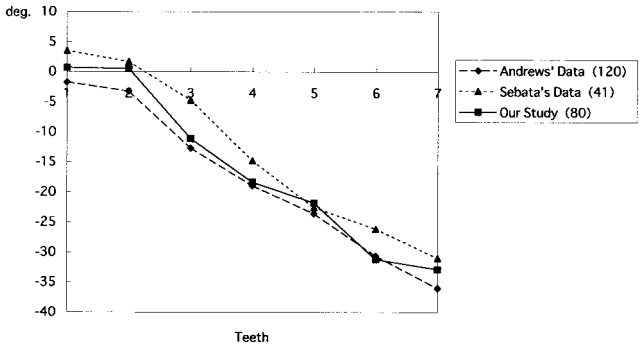

FIGURE 12. The comparison of our mean crown inclination for lower teeth with those of Andrews and of Sebata.[3] Our measurements were in between Andrews' and Sebata's data. The overall tendency was almost the same.

the teeth tending to be more upright. For the second molars, Andrews' and Sebata's results were very close, whereas the authors' values were higher, with the teeth more mesially angulated. In the mandibular arch, the authors' and Andrews' data were close, ranging between 1° and 3°. Sebata[3] showed distal inclinations of anterior teeth, and posterior teeth were more mesially inclined in Sebata's sample than in those of Andrews or of the authors.

Crown inclination. The authors' values were compared with those of Andrews and those of Sebata[3] in Tables 15 and 16 and in Figures 11 and 12. The results obtained in this study showed crown inclination similar to Andrews' data for the maxillary canines and posterior teeth, though the authors' values were larger by 6° for the maxillary central and lateral incisors. Sebata's values fell between those of the authors' and those of Andrews' for the maxillary anterior teeth and were larger than those of the authors or of Andrews for the maxillary molars. The authors' values were intermediate between Andrews' and Sebata's for all mandibular teeth.

Crown facial prominence. Crown facial prominence was measured as described earlier. Sebata,[3] on the other hand, calculated the distance from her FA points on the radiographic films of each crown to a line perpendicular to the arch form, so-called In/Out values. Therefore, a comparison was made with only Andrews' data, the results of which are shown in Tables 17 and 18 and in Figures 13 and 14. Similar values for crown prominence were found in this study for both maxillary and mandibular anterior teeth. They were generally larger than Andrews' values, especially for posterior teeth.

Because Andrews trimmed away occlusal halves of the clinical crowns to measure crown prominence, the imaginary line he used as a reference may not coincide with that of the authors. However, because crown facial prominence values are closely associated with bracket base configurations, it is more important to consider the pattern of changes in crown facial prominence from one tooth to another rather

TABLE 17. Comparing Prominence of Upper Teeth With Previous Data (in Millimeters)

	Tooth													
	1		2		3		4		5		6		7	
Researcher, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Andrews,[5] 120	2.01	0.32	1.84	0.30	2.67	0.39	2.54	0.35	2.48	0.36	2.88	0.40	3.00	0.51
Our study, 80	2.67	0.43	2.49	0.68	3.93	0.41	4.58	0.30	4.50	0.36	5.02	0.47	4.92	0.47

TABLE 18. Comparing Prominence of Lower Teeth With Previous Data (in Millimeters)

	Tooth													
	1		2		3		4		5		6		7	
Researcher, n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Andrews,[5] 120	1.59	0.27	1.64	0.32	2.37	0.40	2.72	0.43	2.60	0.34	3.02	0.40	2.79	0.47
Our study, 80	1.97	0.27	1.99	0.25	3.38	0.34	4.11	0.25	4.34	0.31	5.18	0.30	5.04	0.38

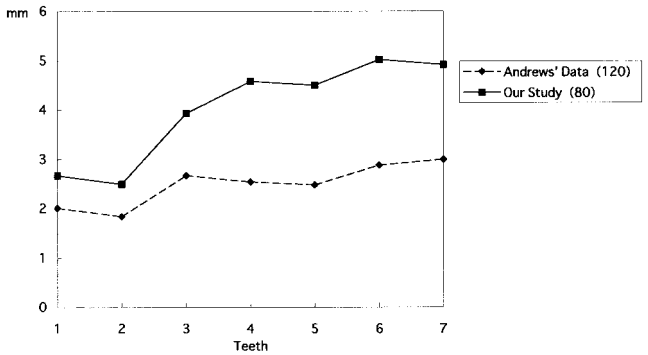

FIGURE 13. Our mean facial prominence of crown for upper teeth was compared with Andrews' data. Although our measurements differed from those of Andrews' by 1 mm to 2 mm in general, the overall tendency was the same. Our values were slightly larger.

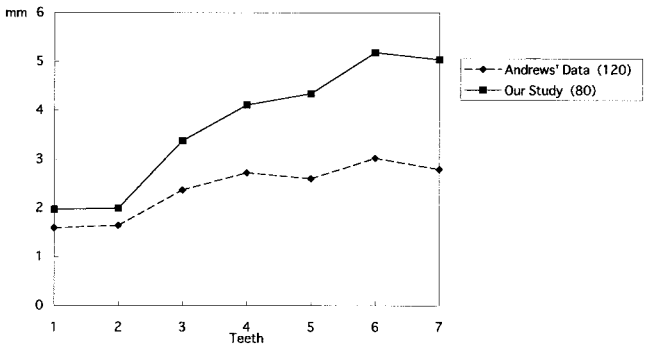

FIGURE 14. The comparison of our mean facial prominence of crown for lower teeth with Andrews' measurements. Ours were similar to those of Andrews in both upper and lower anterior areas, although our values were slightly larger overall and especially in the molar area.

than the absolute value. The results of this study suggested that the changes in crown facial prominence from the anterior to the posterior teeth might be greater in Japanese than in Caucasian subjects.

The differences observed between this study using setup models of patients with malocclusion and Andrews' and Sebata's[3] studies using nonorthodontic normal models need to be further examined concerning the following aspects in the future:

1. Morphological characteristics of Japanese and Caucasian teeth.
2. Morphological characteristics of the maxillary and mandibular bones of Japanese and Caucasian subjects.
3. Morphological characteristics of setup models and nonorthodontic normal models when teeth occlude in maximum intercuspation.
4. Differences due to the methods of measurement.

SUMMARY AND CONCLUSIONS

The authors measured crown angulation, crown inclination, crown facial prominence, vertical crown contour, horizontal crown contour, and maxillary molar offset on setup models of 125 Japanese patients with malocclusion according to Andrews' method.

The results were first compared between the nonextraction and different extraction groups, leading to the following findings:

1. No difference was found in crown angulation regardless of treatment plan as long as a one-tooth-to-two-teeth (cusp-embrasure) occlusal relationship was established.
2. The mandibular incisors and canines showed larger crown inclinations and hence a flaring tendency in the Class II setup group.
3. Crown facial prominence and vertical and horizontal crown contour measurements were similar regardless of the treatment plan.
4. Maxillary molar offset averaged approximately 10° in the Class I setup group and approximately 7° in the Class II setup group.

The measurements obtained from the Class I setup groups were compared with Andrews' and Sebata's[3] data. Differences were observed in some measurements, which may be due to differences in morphological characteristics between the races, differences between setup models and nonorthodontic models, and differences in method of measurement.

ACKNOWLEDGMENT

The authors would like to express their gratitude to Dr L.F. Andrews and Dr R.P. McLaughlin for their valuable advice, Dr N. Shirasuka of Kashiwa Orthodontic Clinic for providing valuable materials, and Mr T. Omura of Japan Oral Arts for his cooperation in constructing the setup models. The authors would also like to thank Dr S. Miyama and the staff of the Department of Orthodontics, Tokyo Dental College, for their cooperation in conducting the study.

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