ORIGINAL ARTICLE

Sagittal, vertical, and transverse changes consequent to maxillary molar distalization with the pendulum appliance

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Introduction: The purpose of this study was to evaluate the skeletal and dental changes in patients who underwent distalization of their maxillary molars with pendulum appliances. **Methods:** The sample consisted of 31 patients (initial mean age, 14.58 years) with Angle Class II molar relationships and all permanent teeth up to the second molars. The maxillary molars were distalized with pendulum appliances for a mean period of 5.87 months. Lateral cephalograms, 45° oblique radiographs, and dental casts were obtained before and after distalization. Changes produced by the pendulum appliance were analyzed with paired *t* tests. **Results:** Maxillary first molar distalization accounted for 63.5% of the space opening; mesial movement of the maxillary first premolars contributed 36.5% of the space. The mean space opening on lateral cephalograms was 7.25 mm, and the rate of molar movement was 1.23 mm per month. The mean distalization of the maxillary molars was 4.6 mm, with a mean distal crown tipping of 18.5° The maxillary molars experienced expansion, with a smaller effect on the first molars than on the second molars. The pendulum appliance produced symmetrical expansion, with a rate of 1.04 mm per month on the right and 1.10 mm per month on the left. **Conclusions:** The pendulum appliance is effective for distalization of the maxillary molars and the establishment of a Class I molar relationship in a relatively short time. However, caution is needed to control collateral effects, including mesial movement of the first premolars and distal tipping of the molar crowns.
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Moyers et al[1] classified Class II malocclusions into 6 subgroups according to the skeletal and dental involvement. Type A malocclusions are characterized by the absence of skeletal involvement, requiring distalization of the maxillary teeth for normal molar and incisor relationships, without changing the favorable skeletal relationship.

Headgear has been the most frequently used appliance for maxillary molar distalization. However, according to Clemmer and Hayes,[2] patients wore their cervical headgears for an average of 55.8% of the hours recommended by their orthodontists. Because of clinically unsatisfactory patient compliance,[2,3] several distalizing appliances have been suggested in the literature: repelling magnets,[4-7] nickel-titanium coils,[8] modified Nance appliance,[9,10] Jones jig appliance,[11-13] distal jet appliance,[14,15] and pendulum appliance.[16-21] The pendulum appliance was introduced by Hilgers in 1992.[16] It is a tooth-tissue-borne appliance that includes a Nance button on the palate for intraoral anchorage and titanium-molybdenum coils that deliver a mild and continuous force to the maxillary molars.

However, few studies in the literature have analyzed the appliance's sagittal, vertical, and transverse skeletal and dental changes simultaneously with cephalograms and dental casts.[21-23] Additionally, maxillary molar distalization on each side has not been separately investigated. Therefore, the aim of this study was to evaluate the skeletal and dental changes in patients receiving distalization of their maxillary molars with pendulum appliances, by using lateral cephalograms, 45° oblique radiographs, and dental casts.

MATERIAL AND METHODS

The sample comprised 31 subjects (22 female, 9 male), with a mean age of 14.58 years (range, 11.16-17 years). All patients met the following inclusion criteria:

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Fig 1. A, Occlusal view before distalization with pendulum appliance; **B,** pendulum appliance in place, after distalization of maxillary molars.

Angle Class II molar relationship (21 patients had full-cusp Class II molar relationship, 10 had half-cusp Class II molar relationships) and all permanent teeth up to the second molars. Sample selection was based exclusively on the initial molar anteroposterior relationship, regardless of any other dentoalveolar or skeletal characteristic.

Maxillary molars were distalized with pendulum appliances, as described by Hilgers.[16] Each appliance was anchored to the first premolars with bands and to the second premolars with wires bonded to the occlusal surface (Fig 1). The pendulum springs were activated parallel to the palatal midline, with a mean force of about 250 g, following the activation scheme suggested by Hilgers.[16] The mean treatment time was 5.87 months, until an overcorrected Class I molar relationship was obtained.

Cephalometric analysis

Lateral cephalograms, 45° oblique radiographs, and dental casts of these patients were obtained before and after distalization of the maxillary molars. The lateral cephalograms were taken conventionally in the same x-ray machine (magnification factor, 6%), and only the 45° oblique radiographs were obtained in 3 x-ray machines, with magnification factors of 1.4%, 1.2%, and 0.45%.[24]

The cephalometric tracings and landmark identifications were performed on acetate paper by 1 investigator (A.F.) and digitized (Numonics AccuGrid XNT, model A30TL.F, Numonics Corporation, Montgomeryville, Pa) (Figs 2 and 3). These data were stored on a computer and analyzed with Dentofacial Planner 7.02 (Dentofacial Planner Software, Toronto, Ontario, Canada), which corrected the image magnification factors. The analyzed variables of the lateral cephalograms and the 45° oblique radiographs are shown in Tables I and II, respectively. All dental measurements on the cephalometric analysis of the 45° oblique radiograph had the palatal plane as a reference.

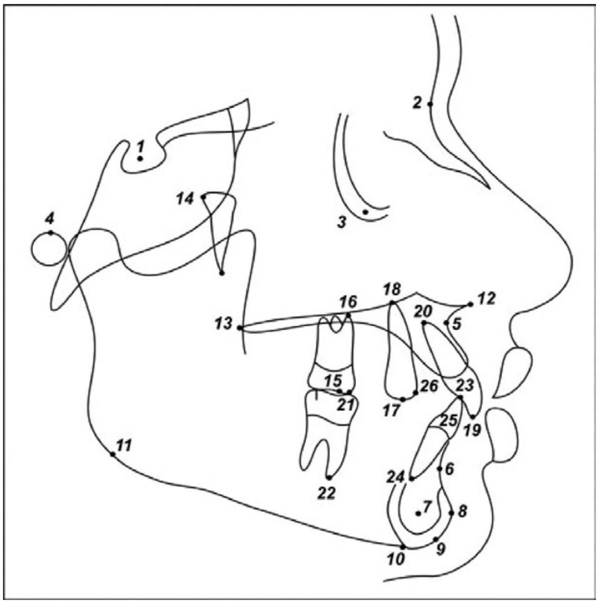

Fig 2. Lateral cephalometric tracing with landmarks: *1,* sella (S); *2,* nasion (N); *3,* orbitale (O); *4,* porion (Po); *5,* subspinale (A); *6,* supramentale (B); *7,* D-point; *8,* pogonion (Pog); *9,* gnathion (Gn); *10,* menton (Me); *11,* gonion (Go); *12,* anterior nasal spine (ANS); *13,* posterior nasal spine (PNS); *14,* CF-point; *15,* mesiobuccal cusp of maxillary first molar; *16,* mesiobuccal root apex of maxillary first molar; *17,* buccal cusp of maxillary first premolar; *18,* buccal root apex of maxillary first premolar; *19,* incisal border of maxillary central incisor; *20,* root apex of maxillary central incisor; *21,* mesiobuccal cusp of mandibular first molar; *22,* mesiobuccal root apex of mandibular first molar; *23,* incisal border of mandibular central incisor; *24,* root apex of mandibular central incisor; *25,* AO-point; *26,* BO-point. *D-point*, Midpoint of the internal mandibular symphysis; *CF-point*, most posterior and superior point of the pterygopalatine fissure; *AO-point*, perpendicular projection of A point on the functional occlusal plane; *BO-point*, perpendicular projection of B point on the functional occlusal plane.

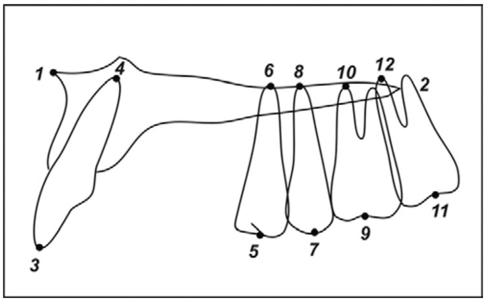

Fig 3. Cephalometric tracing of 45° oblique radiograph and landmarks: *1,* anterior nasal spine; *2,* posterior nasal spine; *3,* incisal border of maxillary central incisor; *4,* root apex of maxillary central incisor; *5,* midpoint between buccal and lingual cusps of maxillary first premolar; *6,* root apex of maxillary first premolar; *7,* midpoint between buccal and lingual cusps of maxillary second premolar; *8,* root apex of maxillary second premolar; *9,* midpoint between buccal cusps of maxillary first molar; *10.* mesiobuccal root apex of maxillary first molar; *11,* midpoint between buccal cusps of maxillary second molar; *12,* mesiobuccal root apex of maxillary second molar.

Table I. Variables of lateral cephalograms

Variables	*Description*
Frank.Ocl	Angle between Frankfort and occlusal planes
Frank.Pal	Angle between Frankfort and palatal planes
Frank.GoGn	Angle between Frankfort and GoGn planes
CI-AV	Distance from incisal border of maxillary central incisor to Aperp line
Frank.4	Angle between Frankfort plane and long axis of maxillary first premolar
Frank.6	Angle between Frankfort plane and long axis of maxillary first molar
CI-PTV	Distance from incisal border of maxillary central incisor to PTV line
First PM-PTV	Distance from buccal cusp of maxillary first premolar to PTV line
First M-PTV	Distance from mesiobuccal cusp of maxillary first molar to PTV line

Aperp, Perpendicular line to Frankfort plane through A point; *PTV*, perpendicular line Frankfort plane through CF point.

Moreover, the rate of monthly distalization was calculated by application of the mathematical formula of the amount of space opening according to the mean total time of distalization.

Dental cast analysis

The initial and final maxillary dental casts were positioned with their occlusal aspects facing down and centered on the scanner, followed by image capture. After the filtering processes, the images were printed on white paper, and the reference points were delineated according to Bailey et al,[25] as shown in Figure 4. The reference points were digitized and analyzed with Dentofacial Planner software. A horizontal reference line, passing through the lateral ends of the third palatal rugae,[25] and a vertical reference line, passing through the incisive papilla and the midpalatal suture, were used. Measurements were obtained as perpendicular distances between the reference points on the teeth and the horizontal and vertical reference lines to evaluate the anteroposterior and transverse dental changes. Distances to structures located mesially to the horizontal reference line had positive values (maxillary incisors, canines, and first premolars), and distances to structures located distally to the horizontal reference line had negative values (maxillary second premolars, first and second molars).

Table II. Variables of 45° oblique radiographs

Variables	*Description*
1.Pal	Angle between long axis of maxillary central incisor and palatal plane
4.Pal	Angle between long axis of maxillary first premolar and palatal plane
5.Pal	Angle between long axis of maxillary second premolar and palatal plane
6.Pal	Angle between long axis of maxillary first molar and palatal plane
7.Pal	Angle between long axis of maxillary second molar and palatal plane
1-Pal	Distance from incisal border of maxillary central incisor to palatal plane
4-Pal	Distance from buccal cusp of maxillary first premolar to palatal plane
5-Pal	Distance from buccal cusp of maxillary second premolar to palatal plane
6-Pal	Distance from mesiobuccal cusp of maxillary first molar to palatal plane
7-Pal	Distance from mesiobuccal cusp of maxillary second molar to palatal plane

Error study

Cephalograms and dental casts of 20 randomly selected patients were retraced, redigitized, and remeasured by the same examiner 15 days after the first evaluation. The systematic error was evaluated with dependent *t* tests, at $P < .05$.

Statistical analysis

The changes produced by distalization of the maxillary molars by the pendulum appliance were evaluated with paired *t* tests at $P < .05$. The statistical analyses were made with software (Statistica for Windows 6.0; Statsoft, Tulsa, Okla).

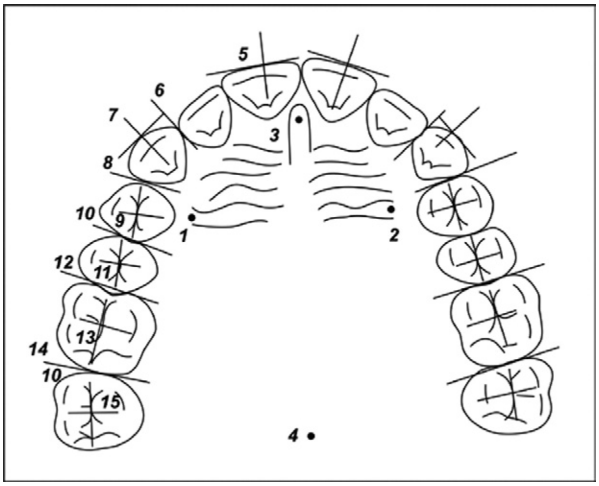

Fig 4. Maxillary dental cast with reference landmarks: *1,* lateral ends of third palatal rugae (right side); *2,* lateral ends of third palatal rugae (left side); *3,* incisive papilla; *4,* distal point on midpalatal suture at level of second molar distal surface; *5,* midpoint of buccal surface of maxillary central incisor; *6,* mesial of maxillary canine; *7,* midpoint of buccal surface of maxillary canine; *8,* mesial of maxillary first premolar; *9,* midpoint of maxillary first premolar central sulcus; *10,* mesial of maxillary second premolar; *11,* midpoint of maxillary second premolar central sulcus; *12,* mesial of maxillary first molar; *13,* midpoint of maxillary first molar central sulcus; *14,* mesial of maxillary second molar; *15,* midpoint of maxillary second molar central sulcus.

RESULTS

There were 1 systematic error in the 45° oblique radiograph and 6 systematic errors in the dental casts variables.

Tables III, IV, and V show the results of the lateral headfilms and the 45° oblique radiographs, and Table VI illustrates the results on the dental casts.

According to the lateral cephalograms, distalization of the maxillary first molars accounted for 63.5% of the space opening, and 36.5% was due to mesialization of the maxillary first premolars. Because the mean space opening on the lateral cephalograms was 7.25 mm and the mean distalization time was 5.87 months, the monthly rate of molar movement was 1.23 mm.

On the dental casts, the mean space openings on the right and left sides were 6.12 and 6.5 mm, respectively, resulting in monthly rates of molar movement of 1.04 and 1.10 mm for the right and left sides, respectively.

DISCUSSION

This prospective study of 31 patients of both sexes was statistically satisfactory and treated by 1 operator; this reduced the variability that would have been introduced by several operators. Studies of the effects of the pendulum appliance usually do not use a control group because the observation period is short (5.87 months in this study) for normal growth changes to play a significant role in the changes.[4,6,7,12,17-23,26,27] The age range of the sample, 11.16 to 17 years, might be criticized for including nongrowing patients, but only 2 patients were 17 years old, and the others were 11.16 to 15.58 years of age.

Skeletal changes

No statistically significant changes were observed in the sagittal positioning of the maxilla and the mandible with the pendulum appliance, thus corroborating other studies (Table III).[6,7,12,19,20,22,28] However, the Pg-Nperp distance had a statistically significant reduction of 1.17 mm (see Tables for definitions of abbreviations). This decrease in the Pg-Nperp distance can be explained by the clockwise rotation of the mandibular plane, as previously observed.[18-21,29] Mandibular rotation secondary to distalization of the maxillary molars is a consequence of the distal tipping of the molar crowns, also observed in our study.

Clockwise mandibular rotation was demonstrated by the statistically significant increases in LAFH, SN.GoGn, FMA, Frank.GoGn, and SN.Gn, agreeing with previous findings.[16,18] Moreover, a significant counterclockwise inclination of $-0.62°$ of the palatal plane was observed, different from the mandibular plane, which had clockwise rotations of 0.91°, confirming previous observations and the tendency toward bite opening.[18] Consequently, there was a statistically significant change in the maxillomandibular relationship in the Wits appraisal. Probably, there was a statistically significant difference in the Wits distance and not in ANB angle, because the Wits distance depends on the occlusal plane that had a nonsignificant clockwise change. Furthermore, on the lateral cephalograms, there was a mild increase in overjet, indicating the change in maxillomandibular relationship and the protrusion and labial tipping of the maxillary incisors.

Dental effects

The statistically significant change in the first M-PTV distance showed that the mean distalization of the maxillary molars was 4.6 mm in 5.87 months (Table III). However, this distalization was achieved with a mean distal tipping of the crown of 18.5° The amount of distalization of the maxillary molars observed in this study was similar to that found by Hilgers,[16] yet greater than other studies.[19-23] Even greater distalization amounts were

Table III. Lateral cephalogram treatment changes (paired *t* test)

	Initial (n = 31)		*Final (n = 31)*					
	Mean	*SD*	*Mean*	*SD*	*Difference*	t	P	*Significance*
Maxillary skeletal								
SNA (°)	81.77	3.25	81.99	3.21	0.22	−1.07	0.292445	NS
A-NPerp (mm)	0.28	2.98	0.22	2.64	−0.06	0.24	0.805609	NS
Mandibular skeletal								
SNB (°)	77.72	2.87	77.58	2.96	−0.14	0.88	0.381565	NS
SND (°)	74.95	2.42	74.9	2.58	−0.05	0.34	0.729045	NS
Pg-Nperp (mm)	−4.16	3.83	−5.33	4.36	−1.17	2.82	0.008312	*
Maxillomandibular relationship								
ANB (°)	4.05	1.68	4.40	1.63	0.35	−1.99	0.055469	NS
Wits (mm)	3.2	2.45	3.84	2.34	0.64	−2.11	0.042398	*
Overbite (mm)	5.17	1.50	4.15	1.70	−1.02	5.79	0.000002	*
Overjet (mm)	5.36	1.90	6.92	2.23	1.56	−9.33	0.000000	*
1.1 (°)	123.82	8.83	119.96	8.39	−3.86	5.63	0.000004	*
Vertical skeletal								
LAFH (mm)	65.98	4.37	67.92	4.80	1.94	−6.52	0.000000	*
SN.GoGn (°)	30.70	4.85	31.17	5.25	0.47	−2.34	0.025674	*
FMA (°)	24.51	4.32	25.50	4.74	0.99	−3.57	0.001218	*
Frank.Ocl (°)	5.14	2.96	5.59	3.03	0.45	−0.90	0.370590	NS
Frank.Pal (°)	1.23	2.53	0.61	2.66	−0.62	−2.31	0.027747	*
Frank.GoGn (°)	22.24	4.14	23.15	4.59	0.91	−3.26	0.002726	*
SN.OclPl (°)	13.66	3.78	13.62	3.46	−0.04	0.11	0.908444	NS
SN.Gn (°)	67.17	3.03	67.63	3.27	0.46	−2.58	0.014842	*
Maxillary dentoalveolar								
1.NA (°)	22.91	7.07	26.31	7.93	3.4	−5.98	0.000001	*
1-NA (mm)	4.85	2.47	5.96	2.83	1.11	−5.003	0.000023	*
CI-AV (mm)	4.89	2.29	5.97	2.64	1.08	−5.37	0.000008	*
Frank.4 (°)	88.38	4.51	85.88	6.55	−2.50	2.35	0.025433	*
Frank.6 (°)	93.23	3.55	111.73	5.18	18.5	−3.03	0.004920	*
CI-PTV (mm)	60.51	3.54	62.02	3.72	1.51	−4.41	0.000121	*
First PM-PTV (mm)	41.88	3.16	44.53	3.18	2.65	−8.83	0.000000	*
First M-PTV (mm)	27.63	3.07	23.03	2.70	−4.6	11.18	0.000000	*

*Statistically significant at $P < .05$.
NS, Not significant.
Nperp, Perpendicular line to Frankfort plane through N point; *LAFH*, lower anterior face height; *SN.GoGn*, angle between SN line and mandibular plane; *SN.OclPl*, angle between SN line and occlusal plane; *NA*, line that connects A and N points.

observed in other studies with the pendulum appliance, but this might have been due to the absence of erupted maxillary second molars in part of their samples.[18,29]

Intraoral distalizing appliances act on the dental crowns at a certain distance from the center of resistance of the molars, and therefore distal tipping of the crowns is expected on distal movement. This tipping is similar to that produced by cervical headgear.[27] Most studies evaluated sagittal and angular molar changes by means of conventional lateral cephalograms. Evaluation of the 45° oblique radiographs in our study provided individualized analysis of the angular changes affecting the maxillary first and second molars separately (Tables IV and V). These results were similar to previous findings on lateral cephalograms.[18,19,21,29]

Anchorage loss

Association of the space opening between first molars and premolars, directly measured on the lateral cephalograms, and the proportional changes of these teeth showed that the percentages of space opening consequent to movement were 63.5% for the first molars and 36.5% for the premolars. As we observed on lateral cephalograms, the amount of premolar anchorage loss was greater than reported in other investigations.[18,19,21,23]

Anchorage loss is also demonstrated by increased labial tipping and protrusion of the maxillary incisors.[16,18] The maxillary incisors had 3.4° of labial tipping and 1.11 mm of protrusion, as demonstrated by 1.NA and 1-NA (Table III). Protrusion of the incisors was also demonstrated by variations in CI-AV and

Table IV. 45° oblique radiograph treatment changes (paired *t* test, right side)

	Initial (n = 31)		*Final (n = 31)*					
	Mean	*SD*	*Mean*	*SD*	*Difference*	t	P	*Significance*
Angular changes								
1.Pal	107.44	4.40	111.04	5.18	3.60	5.30	0.000010	*
4.Pal	86.3	4.14	90.36	5.04	4.06	5.46	0.000006	*
5.Pal	81.52	4.18	83.93	5.85	2.41	2.49	0.018249	*
6.Pal	83.08	5.22	71.72	7.56	−11.36	8.74	0.000000	*
7.Pal	66.43	6.57	52.41	7.35	−14.02	15.13	0.000000	*
Vertical changes								
1-Pal	27.32	3.03	28.46	3.36	1.14	2.92	0.006511	*
4-Pal	23.35	2.72	25.06	3.51	1.71	3.38	0.001994	*
5-Pal	22.73	2.57	24.34	3.06	1.61	3.51	0.001427	*
6-Pal	20.42	2.37	20.69	2.89	0.27	0.69	0.493948	NS
7-Pal	16.65	2.79	15.48	3.30	−1.17	2.93	0.006267	*

*Statistically significant at $P < .05$.
NS, Not significant.

Table V. 45° oblique radiograph treatment changes (paired *t* test, left side)

	Initial (n = 31)		*Final (n = 31)*					
	Mean	*SD*	*Mean*	*SD*	*Difference*	t	P	*Significance*
Angular changes								
1.Pal	106.58	4.51	111.10	4.78	4.51	6.59	0.000000	*
4.Pal	89.93	4.40	90.26	5.74	0.33	0.33	0.737564	NS
5.Pal	85.31	4.53	84.62	6.24	−0.69	0.64	0.522769	NS
6.Pal	80.98	4.99	67.01	6.49	−13.96	12.61	0.000000	*
7.Pal	67.61	6.35	49.18	6.51	−18.42	17.58	0.000000	*
Vertical changes								
1-Pal	28.58	3.09	29.03	2.90	0.45	1.44	0.158635	NS
4-Pal	24.25	3.46	25.72	3.48	1.47	3.66	0.000960	*
5-Pal	23.65	3.42	25.01	3.54	1.35	3.18	0.003361	*
6-Pal	21.14	3.04	20.74	3.42	−0.4	0.96	0.342717	NS
7-Pal	17.17	3.13	15.25	3.39	−1.91	5.12	0.000016	*

*Statistically significant at $P < .05$.
NS, Not significant.

CI-PTV of 1.08 and 1.51 mm, respectively. There was also an increase of 1.56 mm in overjet as a direct effect of labial tipping of the maxillary incisors. Similar values were found in other studies,[19,21-23,29] but anchorage loss was greater in subjects with erupted second molars.[5,16,22,26]

Vertical dental changes

Distalization and distal tipping of the maxillary molars can lead to intrusion of these teeth in relation to the palatal plane. Analysis of our 45° oblique radiographs showed that the right and left second molars had 1.17 and 1.91 mm of intrusion (Tables IV and V), similar to a previous report.[19] Probably the use of the 15° antitipping bend led to less intrusion than if it had not been used, because of its extrusive effect.[20]

The premolars were extruded, with mean extrusions of 1.71 and 1.47 mm for the right and left first premolars, respectively. The right and left second premolars had mean extrusions of 1.61 and 1.35 mm, similar to another study,[21] but greater than others.[18,19] The extrusion of the premolars is explained by the fact that the Nance button is supported by the premolars, and activation of the appliance produces a vertical force component that leads to extrusion of the premolars and intrusion of the molars. This extrusion is more evident when antitipping bends are used simultaneously with horizontal activation of the coils. This intensifies the extrusion of premolars because of the vertical reactive component of the uprighting bend.[20] Perhaps adding occlusal stops at the first premolars could minimize these extrusive effects.

The maxillary incisors were extruded in relation to

Table VI. Dental cast treatment changes (paired *t* test)

	Initial (n = 31)		*Final (n = 31)*					
	Mean	*SD*	*Mean*	*SD*	*Difference*	t	P	*Significance*
Sagittal changes								
Sag11	18.14	1.69	18.51	2.01	0.36	−1.86	0.071503	NS
Sag13	11.25	2.12	13.01	2.49	1.76	−7.27	0.000000	*
Sag14	4.28	2.06	6.36	2.59	2.07	−7.94	0.000000	*
Sag15	−2.09	2.23	−0.41	2.75	1.68	−5.86	0.000002	*
Sag16	−8.47	2.40	−12.91	3.67	−4.44	11.25	0.000000	*
Sag17	−18.78	2.72	−23	3.79	−4.22	11.04	0.000000	*
Sag21	17.95	1.78	18.2	2.37	0.24	−1.06	0.295777	NS
Sag23	10.3	2.28	11.68	2.83	1.38	−4.22	0.000205	*
Sag24	2.76	2.30	4.42	2.79	1.66	−5.63	0.000004	*
Sag25	−4.03	2.44	−2.75	2.80	1.28	−3.7	0.000857	*
Sag26	−10.55	2.54	−15.77	3.30	−5.22	13.16	0.000000	*
Sag27	−20.97	2.70	−26.25	3.28	−5.28	13.36	0.000000	*
Transverse changes								
Trans13	−17.62	1.07	−17.54	1.03	−0.07	−0.56	0.575322	NS
Trans14	−17.76	1.14	−17.86	1.44	0.10	0.66	0.513469	NS
Trans15	−20.56	1.37	−20.76	1.57	0.2	1.84	0.074623	NS
Trans16	−17.62	1.07	−17.54	1.03	−0.07	−0.56	0.575322	NS
Trans17	−25.47	1.42	−27.13	2.06	1.66	6.46	0.000000	*
Trans23	17.74	1.29	17.62	1.44	−0.11	0.84	0.404723	NS
Trans24	17.64	1.47	17.77	1.55	0.13	−0.93	0.359024	NS
Trans25	20.49	1.52	20.62	1.57	0.13	−1.09	0.280490	NS
Trans26	22.92	1.72	24.43	1.80	1.51	−7.02	0.000000	*
Trans27	25.21	1.79	26.75	1.93	1.53	−8.29	0.000000	*

Sag*(tooth number),* Sagittal distance of tooth surface to horizontal reference line.
Trans(tooth number), Transverse distance of tooth midpoint to vertical reference line.
*Statistically significant at $P < .05$.
NS, Not significant.

the palatal plane, with mean extrusions of 1.14 and 0.45 mm for the right and left maxillary central incisors, respectively, yet the latter was not statistically significant, corroborating other studies.[20,21]

The vertical changes led to a reduction in overbite, similar to previous studies.[16,18-21,29] The decrease in overbite was consequent to the effect of the occlusal rests and the second premolar bonding, which could have acted as a selective bite plate, allowing vertical development of the molars, associated with the clockwise mandibular rotation.[18]

Transverse dental changes

Distalizing coils act lingually at the center of resistance of the molars, and thus there is a tendency toward distopalatal rotation,[21-23] possibly leading to molar crossbite.[16] Similar to the forces producing transverse changes in the molars, there will probably be reciprocal effects on the premolars, because of the connection of the appliance to these teeth. In this study, the transverse changes measured on the dental casts showed a nonstatistically significant contraction of 0.07 mm for the right first molars and a statistically significant expansion of 1.51 mm on the left side (Table VI). The maxillary right and left second molars had 1.66 and 1.53 mm of expansion, respectively, with a mean of 1.59 mm. The smaller expansion in the first molars than the second molars usually occurs because of the lingual action of the coils on the first molars; this causes a tendency toward constriction, whereas the second molars show partial responses to the sagittal forces with buccal displacement. These transverse changes have already been mentioned.[16,21] Kinzinger et al[22] found mesiobuccal rotation of the second molars but also buccal drift of the unbanded second molars. According to these authors, a possible factor for buccal drift might be molar morphology and the contact point regions, the relative position of the molars to each other, or the anatomically fixed position of the spongiosa groove.

Despite the tendency toward expansion of the maxillary premolars and canines,[16,20] no statistically significant transverse changes were found in the maxillary first premolars, second premolars, and canines.

Rate of monthly distalization

Distalizing appliances are options for applying mild and continuous forces to the maxillary molars. The pendulum appliance provides monthly rates of distalization of molars from 0.62 to 1.50 mm,[16,18,19,22,23,29] or even 1.20 mm for the crowns and 1.01 mm for the root apices.[20] In our study, the mean space opening was 7.25 mm on lateral cephalograms, resulting in a monthly distalization rate of the maxillary molars of 1.23 mm, similar to another study[16] and to the findings of Byloff et al,[20] who also used the 15° antitipping bend on the coils. However, even though it is called the monthly rate of distalization in the literature,[16,18,19,22,29] this is in fact the monthly rate of space opening because it includes mesialization of the premolars. Therefore, the actual monthly distalization rate of the molars on the lateral cephalograms in this study was 0.78 mm.

The results on the dental casts were similar to those of the lateral cephalograms and the 45° oblique radiographs, although with smaller magnitudes probably because of the different measuring media (Table VI). One factor that might have accounted for the smaller magnitudes in the dental casts is the tendency of moved teeth to rebound to their original positions in the short time between appliance removal and impression taking to make the casts. Therefore, the monthly distalization rates for the right and left sides were 1.04 and 1.10 mm, respectively. Similar to the cephalograms, the actual monthly distalization rates of the right and left first molars were 0.75 and 0.88 mm, respectively.

CONCLUSIONS

Our results suggest that the pendulum appliance is effective for the distalization of maxillary molars and the establishment of a Class I molar relationship in a relatively short time—5.87 months. Effects of the pendulum appliance were symmetrical, with rates of monthly space opening of 1.04 and 1.10 mm for the right and left sides, respectively. Molar distalization accounted for 63.5% of the space opening, and 36.5% was due to maxillary second premolar mesialization. Therefore, caution is required to control this collateral effect. Proper control of distal tipping of molar crowns is advisable, because this side effect also occurred. The use of antitipping bends is recommended, as well as overcorrection, because some relapse is expected on uprighting of the molars. The anchorage unit can be controlled with Class II elastics or even sequential molar distalization.

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