Dentoalveolar and skeletal changes associated with the pendulum appliance

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The purpose of the study was to examine the dentoalveolar and skeletal effects of the pendulum appliance in Class II patients at varying stages of dental development and with varying facial patterns (high, neutral, and low mandibular plane angles). Specifically, the amount and nature of the "distalization" of the maxillary first molars and the reciprocal effects on the anchoring maxillary first premolars and incisors were studied, as were skeletal changes in the sagittal and vertical dimensions of the face. Pretreatment and posttreatment cephalometric radiographs obtained from 13 practitioners were used to document the treatment of 101 patients (45 boys and 56 girls). The average maxillary first molar distalization was 5.7 mm, with a distal tipping of 10.6°. The anchoring anterior teeth moved mesially, as indicated by the 1.8-mm anterior movement of the upper first premolars, with a mesial tipping of 1.5°. The maxillary first molars intruded 0.7 mm, and the first premolars extruded 1.0 mm. Lower anterior facial height increased 2.2 mm; there was no significant difference in lower anterior facial height increase between patients of high, neutral, or low mandibular plane angles. In patients with erupted maxillary second molars, there was a slightly greater increase in lower anterior face height and in the mandibular plane angle and a slightly greater decrease in overbite in comparison to patients with unerupted second molars. Similar findings were observed in patients with second premolar anchorage versus those with second deciduous molar anchorage. The results of this study suggest that the pendulum appliance is effective in moving maxillary molars posteriorly during orthodontic treatment. For maximum maxillary first molar distalization with minimal increase in lower anterior facial height, this appliance is used most effectively in patients with deciduous maxillary second molars for anchorage and unerupted permanent maxillary second molars, although significant bite opening was not a concern in any patient in this study. (Am J Orthod Dentofacial Orthop 2000;117:333-43)

The use of so-called "distalization" mechanics to correct Class II malocclusions is a common treatment modality. This type of mechanotherapy typically is used in patients with maxillary skeletal or dentoalveolar protrusion or both. Molar distalization also can be used when extraction of maxillary teeth is not indicated and the mandibular tooth-size/arch-perimeter relationship does not permit mesial movement of the lower molars. In a recent survey by Sinclair,[1] all responding orthodontists reported using molar distalization, and nearly all indicated that patient cooperation was the most significant problem encountered in distalizing maxillary molars.

Most traditional approaches to molar distalization, including extraoral traction, Wilson distalizing arches, removable spring appliances, and intermaxillary elastics with sliding jigs, require considerable patient compliance to be successful. More recently, the subjectivity and problems of predicting patient behavior have led many clinicians to devise appliances that minimized reliance on the patient and that are under the control of the clinician.[2-4] Relying on the patient's willingness to wear an appliance consistently may result in increased treatment time, a change of treatment plan, or both.

A number of treatment protocols that minimize the need for patient compliance have been suggested in recent years, including repelling magnets combined with a Nance anchorage appliance.[5-11] These magnetic forces unquestionably can produce tooth movement; the use of this approach, however, has not gained wide acceptance because the magnets tend to be expensive and bulky, their force dissipates rapidly with increasing intermagnet distance, and their biologic systemic effects still are a subject of speculation. Because of

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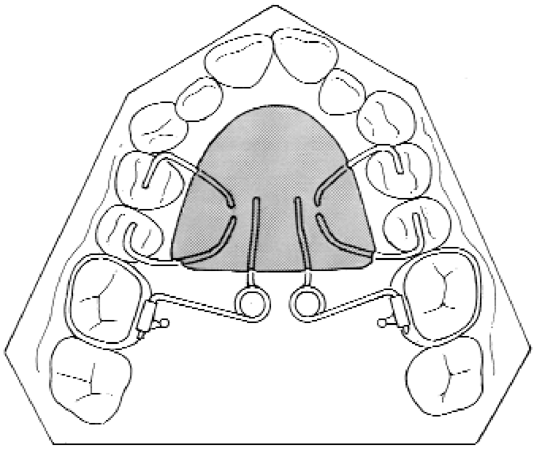

Fig 1. Typical design of the pendulum appliance of Hilgers. Acrylic palatal button is bonded to the occlusal surfaces of the upper first premolars and bands are placed on the upper first molars.

these drawbacks, along with the necessity of frequent recall reactivation, Darendeliler[12] has concluded that magnets offer no advantage over conventional systems in molar distalization.

Springs made from compressed stainless steel or nickel titanium also have been used in conjunction with various non–cooperation-based appliances to produce maxillary molar movement.[13-18] Gianelly et al[13] described the use of 100 g superelastic nickel titanium coils developed by Miura et al[19] to move maxillary molars distally.

The deflection of straight wires, not coils, has also been used to produce distal molar movement. Gianelly et al[20,21] have demonstrated distalization of maxillary molars with a 100 g nickel titanium wire compressed between the maxillary first premolars and maxillary first molars with crimpable stops. A Nance holding arch cemented to the first premolars is used for anchorage. In addition, Kalra[22] has developed a titanium molybdenum alloy (TMA) wire compressed between the maxillary first premolars and maxillary first molars. This design, combined with the anchorage of a Nance button, has been shown to produce similar distalization and anchorage loss as seen with magnets and coil springs.

Another popular method of molar distalization that requires no cooperation is the so-called "pendulum" appliance system. In 1992, Hilgers[23] described the development of 2 hybrid appliances, the pendulum and pendex. Modifications in appliance design and clinical management also have been described by Bennett and Hilgers[24,25] and by Snodgrass.[26]

Hilgers[27] recommends overcorrection of the molars toward a Class III relationship followed by stabilization for 6 to 10 weeks. He maintains the overcorrection with various techniques, including Nance buttons, short-term headgear wear, utility arches, or stopped continuous arch wires.[23,25] Once the molars are in a correct (or slightly overcorrected) position, the stabilization arms to the premolars or deciduous molars are disengaged to allow the transseptal fibers to pull these teeth posteriorly. Hilgers[27] states that it is typical to see approximately 5 mm of distal molar movement in a 3- to 4-month period of time. He has estimated that 20% of the space opening can be ascribed to anterior anchorage loss.

There have been few previous studies of the treatment effects produced by the pendulum/pendex appliance. Ghosh and Nanda[28] evaluated 41 patients treated with the pendulum appliance. Byloff and Darendeliler[29] studied 13 patients in whom a pendex version of the appliance was used. In a companion study, the same group[30] examined another group of 20 patients, 12 of whom wore a pendulum appliance and 8 of whom underwent slow expansion (one turn per week) with the pendex version of the appliance. Each appliance had been modified after molar distalization (after about 16 weeks) by incorporating an uprighting bend into the molar distalizing spring during the second phase of treatment (an additional 11 weeks of treatment) to eliminate excessive distal tipping of the maxillary molars. In comparison to the results of their initial study,[29] the uprighting bends reduced molar tipping with minimal anteroposterior effects, except for a slight increase in the flaring of the upper incisal edge. Treatment time was increased as well. There was no significant difference in anchorage loss between the patients with and without expansion.

Thus, the pendulum appliance is gaining popularity as a means for distalizing maxillary molars in Class II patients; however, to date only case reports[27,31,32] and 3 clinical studies[28-30] have been published that document the pendulum's results and its impact on anchorage. The purpose of the current clinical study, therefore, is to determine the short-term dentoalveolar and skeletal changes associated with rapid molar distalization with the pendulum appliance in a large sample of patients of varying facial types. The study analyzes regional treatment changes produced specifically during the period that the pendulum appliance was used. This investigation will determine the magnitude and direction of maxillary first molar, first premolar, and incisor changes, as well as document the anchorage loss and mesial movement of the maxillary first premolars and incisors. The study also explores the hypothesis that the treatment effects produced by this appliance system vary according to the stage of dental development. The relative effect of erupted maxillary second molars on distalization of the first molar and the effects, if any, of permanent versus deciduous dentition based anchorage on distalization of maxillary molars also will be evaluated. The treatment effects of the pendulum appliance still present at the end of fixed appliance therapy are being investigated in a follow-up study on the same patient sample.

SUBJECTS AND METHODS

A sample of records from 177 patients treated with rapid molar distalization with the pendulum appliance was obtained from 13 practitioners from the United States. The names of the practitioners who used this appliance routinely were obtained from 5 commercial laboratories and from the referral of other orthodontists. The participating practitioners responded to a letter requesting their help in obtaining serial cephalograms of consecutively treated patients in whom the pendulum appliance was used. Study models were not evaluated.

The clinicians were asked to send cephalometric headfilms that had been obtained at pretreatment (T_1) and posttreatment at time of pendulum appliance removal (T_2). Generally, there was a 1- to 2-month period between the pretreatment (T1) cephalogram and the actual start of pendulum treatment. The records of 27 patients from the parent sample were excluded due to poor film quality or incomplete records. An additional 49 patients were excluded because a Class II molar relationship was not present at the start of treatment, because the interval between the T_1 and T_2 films was greater than 1 year, or both. Thus, 101 patients were included in the study sample.

The final sample consisted of 56 females with a mean age of 12 years 1 month (range, 8 years 4 months to 16 years 5 months) and 45 males with a mean age of 12 years 1 month (range, 8 years 3 months to 15 years 9 months). The mean time period between the initial T_1 radiograph and the postpendulum T_2 radiograph was 7 months ± 2 months (range, 3 to 11 months). Gender differences were not considered a factor because of the short duration of pendulum appliance treatment.

Treatment Protocol

Treatment with a pendulum/pendex appliance, similar to the type described by Hilgers,[23,27] was initiated in all patients. No differentiation was made between the pendulum and pendex designs in this 2-dimensional cephalometric study, as a previous cephalometric investigation[30] did not find differences in treatment response between pendulum and pendex appliances. In the present study, the appliances consisted of a large Nance

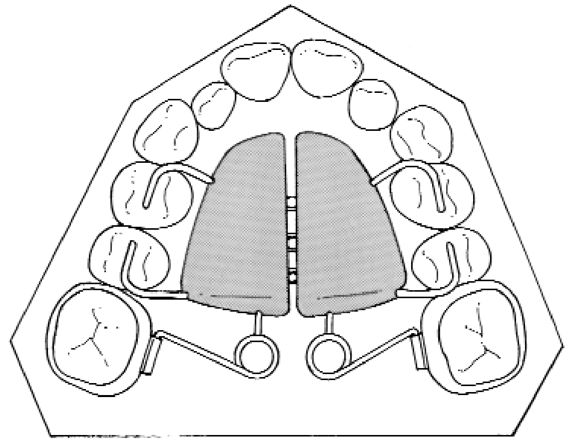

Fig 2. Typical design of the pendex appliance of Hilgers. Midline expansion screw is activated in order to increase palatal width in patients with maxillary constriction.

acrylic button that extended transversely from premolars to premolars (or deciduous first and second molars; Figs 1 and 2). The acrylic button extended from the maxillary first molars anteriorly to just posterior to the lingual papilla. The acrylic was stabilized with 4 wires that were bonded as occlusal rests to the first and second premolars or the first and second deciduous molars.[23] All appliances incorporated 0.032 inch TMA springs that were inserted into 0.036 inch lingual sheaths on the bands attached to the maxillary first molars. The TMA springs exerted 200 to 250 g of force, as the springs were activated 60° to 90°.[27]

Typically, the adjustment loops were activated as needed for an appropriate treatment response in the transverse dimension, thereby allowing the maxillary molars to “derotate” while being driven distally. Generally, the patients were monitored every 3 to 4 weeks, with the total activation time typically 8 to 12 weeks.[27] When the molars achieved near Class III occlusion, the second premolars were released from the anchorage unit and allowed to drift distally. Once the desired molar distalization was achieved, the appliance was removed and the T_2 film was obtained.

Cephalometric Analysis

The lateral cephalograms within each series were traced in random order by one investigator (T.J.B.) with verification of anatomic outlines and landmark position by a second (J.A.M.). In instances of disagreement, the structures in question were retraced to the mutual satisfaction of the two investigators. In instances of bilateral structures (eg, gonial angle, teeth), a single averaged tracing was made. A conventional cephalometric analysis, including measurements and variables from a variety of analyses, was used.[33-37] The cephalograms were digitized in an *x-y* coordinate system by way of a customized digitization package. Fifty-seven angular and linear variables were derived.

For each patient and in all of the tracings, an additional 6 arbitrary fiducial registration points (anterior and posterior cranial base, anterior and posterior maxilla, anterior and posterior mandible) were drafted on the T_1 cephalogram and transferred to the T_2 cephalogram by way of regional superimpositions based on stable internal structures.[38] These registration points or fiducial lines simulated “bony implants” and thus facilitated analysis of tooth movement within each jaw. Dentoalveolar measures were related to the movement of the maxillary and mandibular teeth relative to the fiducial lines (ie, basal bone) or to the Frankfort horizontal or palatal plane for maxillary teeth and the mandibular plane for mandibular teeth. Changes in maxillary and mandibular skeletal position also were computed with the movement of the corresponding registration points relative to cranial base superimposition along the basion-nasion line at the pterygomaxillary suture.[36,39] All linear cephalometric measures were adjusted to a constant 8% enlargement to standardize the data.[37]

To evaluate the treatment response to the stage of dental development, the sample of 101 patients was divided into subgroups: presence (N = 33) or absence (N = 68) of maxillary deciduous second molars and eruption (N = 44) or lack of eruption (N = 57) of maxillary permanent second molars. The final analysis considered differences in the response of patients with differing facial patterns, as indicated by the mandibular plane angle (MPA) relative to the Frankfort horizontal. The patients were divided into 3 subgroups according to their pretreatment MPA (low MPA <21°; neutral MPA, 21° to 26°; high MPA >26°). There were 30, 38, and 33 patients in the low, neutral, and high mandibular plane angle groups, respectively.

Statistical Analysis

Descriptive statistics (mean, standard deviation, and ranges) were calculated for each of the cephalometric measurements at T_1 and T_2. The data were analyzed with a commercial statistical package (SPSS for Macintosh Version 6.1, SPSS, Inc, Chicago, Ill).

Independent-sample *t* tests were used to analyze differences between the paired pretreatment and posttreatment cephalometric variables. Analysis of variance and Tukey’s post hoc test were used to determine significant differences between the mean values of the changes between groups based on the Frankfort plane to mandibular plane angle measurements, whether the maxillary second molars were erupted and whether deciduous teeth were used as anchorage. The error of method has been calculated and described previously.[40]

RESULTS

The descriptive statistics, including mean, standard deviation, and range for observations at T_1, T_2 and changes during the treatment interval ($\Delta T_1–T_2$) as measured from the cephalometric radiographs are found in Table I. Inferential statistics for the T_1 to T_2 group changes, with and without deciduous dentition anchorage, are presented in Table II. Inferential statistics for the T1 to T2 group changes with and without maxillary second molars erupted are presented in Table III.

Analysis of Overall Treatment Effects (Table I)

The pendulum appliance primarily affected the maxillary dentition and to a minor extent the maxilla and mandible. The dentoalveolar treatment effects of the pendulum appliance consisted of an increase in overjet, a decrease in overbite, and correction of the molar relationship toward a Class I relationship (Table I). Overjet increase is attributed primarily to slight mesial movement and flaring of the upper incisors as well as to a slight downward and backward relocation of the lower incisors that occurred as the bite was opened and the mandible rotated downward and backward.

An average change of 6.4 mm occurred in molar relationship, as measured at the mesial aspect of the first molars along the functional occlusal plane. The maxillary molars moved distally, and the maxillary first premolars and incisors reciprocally moved mesially and flared slightly (Fig 3). Distal movement of the maxillary first molars from T_1 to T_2 contributed to the creation of a space mesial to these teeth (Table I), with the mean first molar distalization of –5.7 ± 1.9 mm. In contrast, the first premolar and central incisors moved mesially 1.8 ± 2.0 mm and 0.9 ± 1.2 mm, respectively (Fig 3). The maxillary first molar tipped distally (–10.6° ± 5.6°), whereas the mesial tipping of the first premolar and incisors was less (1.5° ± 4.3° and 3.6° ± 8.4°, respectively). The lower incisors remained relatively stable during treatment, whereas the lower first molar moved slightly mesially (0.3 mm; Table I), an amount that was statistically significant. Increases in dentoalveolar vertical dimensions for the upper incisors and premolars also were observed. The maxillary first molars intruded slightly by an amount that was not statistically significant. In addition, minor vertical increases in both lower molars and lower incisors were observed after pendulum treatment.

Table I. Descriptive statistics of cephalometric measurements at T_1, T_2, and ΔT_1-T_2

	T_1			T_2			ΔT_1-T_2		
Cephalometric measures	*N*	*Mean*	*SD*	*N*	*Mean*	*SD*	*Mean*	*SD*	*Significance*
Anteroposterior skeletal									
SNA angle (°)	101	80.6	3.5	101	80.8	3.5	0.2	0.8	*
SNB angle (°)	101	76.6	3.1	101	76.3	3.3	–0.3	0.9	*
ANB angle (°)	101	4.0	2.0	101	4.4	2.1	0.4	0.8	***
Midfacial length (Condylion–Pt A) (mm)	101	94.3	5.7	101	94.9	5.8	0.6	1.0	***
Mandibular length (Co–Gn) (mm)	101	113.5	7.3	101	115.1	7.4	1.6	1.2	***
Point A to nasion perpendicular (mm)	101	–0.4	3.0	101	–0.2	3.0	–0.2	0.9	*
Pogonion to nasion perpendicular (mm)	101	–6.3	5.1	101	–7.1	5.3	0.8	1.4	***
WITS appraisal (mm)	101	1.6	2.8	101	1.3	3.0	–0.3	1.8	NS
Vertical skeletal									
Anterior nasal spine to menton (mm)	101	65.4	4.7	101	67.6	5.1	2.2	1.4	***
Frankfort horizontal to palatal plane (°)	101	–0.9	2.7	101	–0.9	2.8	0.0	1.2	NS
Frankfort horizontal to occlusal plane (°)	101	8.3	3.5	101	9.4	3.7	1.1	2.3	***
Frankfort horizontal to mandibular plane (°)	101	23.7	4.1	101	24.7	4.3	1.0	1.1	***
Interdental									
Molar relationship (mm)	101	–1.6	1.4	101	4.8	1.7	6.4	1.7	***
Overjet (mm)	101	5.4	2.2	101	6.3	2.6	0.8	1.4	***
Overbite (mm)	101	4.6	1.7	101	3.5	2.0	–1.1	1.7	***
Maxillary Dentoalveolar									
Upper 1 to Point A vertical (mm)	101	5.0	2.0	101	5.8	2.1	0.8	1.0	***
Upper 1 horizontal (mm)	101	56.2	5.1	101	57.6	5.2	1.4	1.5	***
Upper 1 vertical (mm)	101	50.8	4.2	101	51.7	4.2	0.9	1.2	***
Upper 4 horizontal (mm)	76	43.2	4.4	76	45.0	5.2	1.8	2.0	***
Upper 4 vertical (mm)	76	25.2	2.0	76	26.3	2.3	1.1	1.2	**
Upper 6 horizontal (mm)	101	27.0	3.6	101	21.3	4.0	–5.7	1.9	***
Upper 6 vertical (mm)	101	44.8	4.1	101	44.9	4.3	0.1	1.3	NS
Upper 1 to Frankfort (°)	96	111.0	10.1	96	114.6	7.9	3.6	8.4	***
Upper 4 to Frankfort (°)	76	89.9	5.9	76	91.4	5.3	1.5	4.3	**
Upper 6 to Frankfort (°)	96	78.9	4.7	96	68.3	7.3	–10.6	5.6	***
Mandibular dentoalveolar									
Lower 1 to mandibular plane (°)	101	94.7	6.0	100	94.6	5.7	–0.1	4.0	NS
Lower 1 horizontal (mm)	101	8.7	2.8	101	8.7	2.8	0.0	1.2	NS
Lower I vertical (mm)	101	43.9	5.7	100	44.5	4.6	0.6	4.6	NS
Lower 6 horizontal (mm)	101	32.4	2.6	101	32.1	2.7	–0.3	0.7	***
Lower 6 vertical (mm)	101	33.1	3.6	101	34.1	6.0	1.0	5.7	*
Soft tissue									
Upper lip to E plane (mm)	101	–2.0	2.5	100	–1.4	2.5	0.6	1.5	***
Lower lip to E plane (mm)	101	–1.0	2.9	100	0.0	2.8	1.0	1.6	***
Nasolabial angle (°)	101	121.4	8.8	100	118.9	9.5	–2.5	6.8	***
Cant of upper lip (°)	101	4.1	8.0	101	6.1	7.3	2.0	5.6	***

$^*P < .05$; $^{**}P < .01$; $^{***}P < .001$.
1, Central incisor; 4, first premolar; 6, first molar.

The minimal sagittal skeletal effect of pendulum treatment is reflected in the change in the ANB angle, which increased 0.4° from T_1 to T_2. The maxilla moved forward between T_1 and T_2, and midfacial length (Co-Point A) also increased (0.6 mm; Table I). The mandible moved downward and backward during treatment. Mandibular length increased, and there was a slight decrease in the SNB angle and in the distance from nasion perpendicular to pogonion (Table I). Significant increases in the vertical dimension were indicated by a slight opening of the mandibular plane angle relative to the Frankfort horizontal and by an increase in lower anterior facial height (Table I).

Stage of Dental Development

The sample of 101 patients was divided into subgroups according to the stage of dental development, presence or absence of maxillary second deciduous molars, and eruption or lack of eruption of maxillary second permanent molars.

Table II. *t* Tests of cephalometric measures for independent samples of deciduous versus permanent dentition anchorage

	ΔT_1-T_2 E's			ΔT_1-T_2 No E's			
Cephalometrio measures	*N*	*Mean*	*SD*	*N*	*Mean*	*SD*	*Significance*
Anteroposterior skeletal							
SNA angle (°)	33	0.2	0.7	68	0.2	0.8	NS
SNB angle (°)	33	0.0	0.8	68	–0.3	0.9	NS
ANB angle (°)	33	0.2	0.8	68	0.5	0.8	NS
Midfacial length (Condylion–Pt A) (mm)	33	0.5	0.8	68	0.6	1.1	NS
Mandibular length (Co–Gn) (mm)	33	1.6	1.3	68	1.6	1.2	NS
Point A to nasion perpendicular (mm)	33	0.2	0.6	68	0.1	0.9	NS
Pogonion to nasion perpendicular (mm)	33	–0.2	1.2	68	–1.0	1.5	**
WITS appraisal (mm)	33	–0.5	1.5	68	–0.1	1.9	NS
Vertical skeletal							
Anterior nasal spine to menton (mm)	33	1.6	1.5	68	2.4	1.3	**
Frankfort horizontal to occlusal plane (°)	33	1.0	2.0	68	1.1	2.5	NS
Frankfort horizontal to palatal plane (°)	33	–0.1	1.0	68	0.0	1.2	NS
Frankfort horizontal to mandibular plane (°)	33	0.7	1.0	68	1.1	1.1	NS
Interdental							
Overjet (mm)	33	0.6	1.5	68	1.0	1.4	NS
Overbite (mm)	33	–0.3	1.9	68	–1.5	1.4	***
Molar relationship (mm)	33	6.6	1.6	68	6.3	1.7	NS
Maxillary dentoalveolar							
Upper 1 to Point A vertical (mm)	33	0.8	1.2	68	0.8	0.9	NS
Upper 1 horizontal (mm)	33	1.4	1.2	68	1.5	1.6	NS
Upper 1 vertical (mm)	33	1.1	0.8	68	0.8	1.3	NS
Upper 4 horizontal (mm)	11	2.2	1.9	65	1.7	2.1	NS
Upper 4 vertical (mm)	11	1.0	1.5	65	1.1	1.2	NS
Upper 6 horizontal (mm)	33	–5.5	1.7	68	–5.7	1.9	NS
Upper 6 vertical (mm)	33	–0.4	1.1	68	0.2	1.4	*
Upper 1 to Frankfort (°)	31	3.3	9.0	65	3.7	8.2	NS
Upper 4 to Frankfort (°)	11	–0.5	3.8	65	–1.7	4.4	NS
Upper 6 to Frankfort (°)	31	–10.7	5.3	65	–10.6	5.8	NS
Mandibular dentoalveolar							
Lower 1 to mandibular plane (°)	33	–0.6	4.7	67	0.1	3.6	NS
Lower 1 horizontal (mm)	33	0.1	1.5	68	–0.1	1.0	NS
Lower 1 vertical (mm)	33	1.3	3.0	67	0.2	5.2	NS
Lower 6 horizontal (mm)	33	–0.1	0.7	68	–0.4	0.7	*
Lower 6 vertical (mm)	33	0.4	3.2	68	1.2	6.6	NS

*$P < .05$; **$P < .01$; ***$P < .001$.
NS, Not significant.
1, Central incisor; 4, first premolar; 6, first molar.

Second deciduous molars vs second premolar anchorage (Table II). Generally, significant between-group differences were not noted in either the horizontal or vertical movements of the maxillary and mandibular dentitions (Table II). The reduction in overbite at the end of the pendulum phase of treatment was significantly greater in the second premolar group (–1.5 ± 1.4 mm) than in the second deciduous molar group (–0.3 ± 1.9 mm).

Patients with erupted second premolars demonstrated significantly greater increases in lower anterior facial height (2.4 ± 1.3 mm) than did younger patients with second deciduous molars (1.6 ± 1.5 mm). The patients in the second premolar group also demonstrated significantly greater posterior mandibular repositioning and a larger decrease in overbite than did the patients in the second deciduous molar group, changes that are related to a downward and backward rotation of the mandible.

Presence or absence of erupted permanent maxillary second molars (Table III) No differences were observed in the amount of molar correction between patients who had second molars erupted and those who did not. In fact, generally there were no statistically significant differences in the responses of the dentition to treatment

Table III. *t* Tests of cephalometric measures for independent samples for maxillary second molars present versus non-present

	ΔT_1-T_2 7's			ΔT_1-T_2 No 7's			
Cephalometric measures	*N*	*Mean*	*SD*	*N*	*Mean*	*SD*	*Significance*
Anteroposterior skeletal							
SNA angle (°)	57	0.1	0.8	44	0.3	0.7	NS
SNB angle (°)	57	–0.3	0.8	44	–0.1	0.9	NS
ANB angle (°)	57	0.4	0.8	44	0.4	0.8	NS
Midfacial length (Condylion–Pt A) (mm)	57	0.6	1.2	44	0.5	0.8	NS
Mandibular length (Co–Gn) (mm)	57	1.7	1.2	44	1.4	1.2	NS
Point A to nasion perpendicular (mm)	57	0.1	0.9	44	0.3	0.7	NS
Pogonion to nasion perpendicular (mm)	57	–1.1	1.5	44	–0.4	1.2	NS
WITS appraisal (mm)	57	–0.2	1.9	44	–0.3	1.7	NS
Vertical skeletal							
Anterior nasal spine to menton (mm)	57	2.7	1.2	44	1.5	1.4	***
Frankfort horizontal to occlusal plane (°)	57	1.1	2.4	44	1.1	2.2	NS
Frankfort horizontal to palatal plane (°)	57	–0.1	1.1	44	0.1	1.3	NS
Frankfort horizontal to mandibular plane (°)	57	1.2	1.1	44	0.7	0.9	*
Interdental							
Overjet (mm)	57	1.0	1.4	44	0.7	1.5	NS
Overbite (mm)	57	–1.6	1.8	44	–0.4	1.1	***
Molar relationship (mm)	57	6.3	1.7	44	6.5	1.6	NS
Maxillary dentoalveolar							
Upper 1 to Point A vertical (mm)	57	0.9	1.0	44	0.6	1.0	NS
Upper 1 horizontal (mm)	57	1.5	1.6	44	1.4	1.4	NS
Upper 1 vertical (mm)	57	0.8	1.3	44	1.0	0.9	NS
Upper 4 horizontal (mm)	54	1.8	2.1	22	1.6	1.9	NS
Upper 4 vertical (mm)	54	1.2	1.1	22	0.6	1.4	NS
Upper 6 horizontal (mm)	57	5.6	2.0	44	–5.7	1.6	NS
Upper 6 vertical (mm)	57	0.4	1.4	44	–0.5	1.1	**
Upper 1 to Frankfort (°)	55	4.0	8.9	41	3.0	7.8	NS
Upper 4 to Frankfort (°)	54	–1.3	4.2	22	–2.0	4.6	NS
Upper 6 to Frankfort (°)	55	–9.8	5.6	41	–11.7	5.6	NS
Mandibular dentoalveolar							
Lower 1 to mandibular plane (°)	56	0.0	3.6	44	–0.3	4.5	NS
Lower 1 horizontal (mm)	57	0.0	1.0	44	0.0	1.4	NS
Lower 1 vertical (mm)	56	0.5	3.0	44	0.6	6.1	NS
Lower 6 horizontal (mm)	57	–0.4	0.7	44	–0.2	0.8	NS
Lower 6 vertical (mm)	57	1.3	7.2	44	0.5	2.9	NS

P < .05; ***P* < .01; ****P* < .001.
NS, Not significant.
1, Central incisor; 4, first premolar; 6, first molar.

between groups, with the exception of the upper first molar. The upper molars extruded significantly more in the presence of erupted maxillary second molars (eg, upper 6 vertical increased 0.4 ± 1.4 mm in the 7s group, yet decreased –0.5 ± 1.1 mm in the no-7s group; Table III). Overbite reduction was significantly greater (-1.6 ± 1.8 mm) in the erupted second molar group than in the unerupted second molar group (-0.4 ± 1.1 mm).

Significantly greater increases in the vertical dimension were observed in the erupted second molar group. Lower anterior facial height increased 2.7 ± 1.2 mm in the erupted second molar group in comparison with 1.5 ± 1.4 mm in the unerupted second molar group. This difference in response also was evident in the change in the mandibular plane angle during treatment.

Variation in Facial Patterns (Table IV)

The final analysis was an investigation of the possible differences in the response of patients with differing facial patterns, as indicated by the MPA relative to the Frankfort horizontal. The patients were divided into 3 subgroups according to their pretreatment mandibular plane angles. Analysis of variance among these subgroups did not reveal any significant differ-

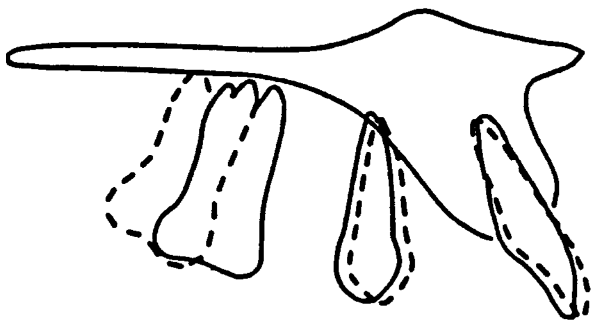

Fig 3. Average treatment effects of the pendulum appliance on the maxillary dentition.

ences among the low, neutral, and high MPA subgroups (Table IV).

DISCUSSION

Overall Treatment Effects of the Pendulum Appliance

The results of this study indicate that the pendulum appliance affects primarily the maxillary dentition; however, there also are less pronounced effects on the craniofacial skeleton and associated soft tissue.

Dentoalveolar effects. The maxillary first permanent molars moved posteriorly and tipped distally in every subject (Table I). The mean molar distalization was 5.7 mm, a change that contributed substantially to the Class II correction. Molar distalization accounted for 76% of the change in sagittal position between the upper first molar and the upper first premolars, whereas 24% was due to reciprocal anterior movement of the upper premolars. The distalization of the first molars in the current study is greater than that found by Byloff and Darendeliler[29] and by Ghosh and Nanda,[28] both groups reporting 3.4 mm. The subjects in the latter study exhibited anchorage loss of 0.75 mm for every 1.0 mm of distalization, whereas in the current study the premolar or deciduous first molar moved mesially only 0.32 mm for every millimeter of distal molar movement.

One of the potential undesirable effects of pendulum appliance treatment is excessive distal tipping of the upper first molars. In the present study, the mean molar distal tipping during treatment was 10.6°. Ghosh and Nanda[28] report similar distal tipping (8.4°), whereas greater tipping of the upper first molars (14.5°) was reported by Byloff and Darendeliler[29] when the original pendex design was evaluated. A companion study by the same group[30] of a pendulum appliance that was modified by adding a bend to upright the molars by moving the roots distally reported a reduction in the average distal tipping of the upper first molars to 6.1°. Byloff and Darendeliler[30] recommend making uprighting bends in the spring by increasing the angle by 10° to 15° between the long arms of the spring and the recurved end of the spring that is engaged into the palatal sheaths located on the upper first molar bands. This modification in the springs is made after the initial distilization of the upper molar is completed in order to encourage an uprighting of the molar roots while the spring remains slightly active to maintain the position of the molar crowns.

Distalization and tipping of the upper first molars can result in molar intrusion relative to the palatal plane. In the present sample, the upper first molar intruded an average of 0.7 mm. Molar intrusion was greater in the Byloff and Darendeliler[29] study of the standard appliance design; slightly less molar intrusion was observed when the modified design was used.[30] In contrast, Ghosh and Nanda[28] noted virtually no intrusion of the upper molar (0.1 mm) after pendulum appliance treatment.

The upper first premolars or deciduous first molars moved anteriorly 1.8 mm, extruded 1.0 mm, and tipped mesially 1.5° in the current investigation. Byloff and Darendeliler[29] reported that the upper second premolars extruded 0.8 mm relative to the palatal plane. Ghosh and Nanda[28] noted 2.6-mm mesial movement of the upper first premolars as well as an extrusion of 1.7 mm.

The mandibular dentition was relatively stable during the treatment period. The mandibular first molar extruded slightly (0.7 mm) and moved mesially 0.2 mm on average, values that have minimal clinical relevance, although the lower molar extrusion was statistically significant. These changes probably occurred primarily as a result of normal growth during the treatment period.[41] It also is possible that some of the extrusion of the molars was due to the effect of the occlusal rests and the bonding on the upper first and second premolars or deciduous molars. The bonded occlusal rests could have acted as a selective bite plate, allowing extrusion of the molars as well as a slight clockwise rotation of the mandible.

Interdental and soft tissue effects. All eight interdental and soft tissue measurements demonstrated highly significant changes from T_1 to T_2. The overbite decreased by 1.7 mm, and the overjet increased by 0.8 mm as a result of the pendulum appliance. The molar relationship demonstrated a 6.4-mm correction from a Class II to a Class I relationship. The upper lip protruded 0.6 mm and the lower lip protruded 1.0 mm relative to the esthetic plane. The nasolabial angle decreased 2.5°, and the cant of the upper lip increased 2.0° during treatment, both values reflecting a slight protrusion of upper lip contour. These findings concerning increased protrusion of the upper lip must be interpreted with some caution as a portion of the lip's protrusion may be due to anterior anchorage loss or also may have resulted from the bracket placement on the incisors in 39 of the patients.

Skeletal effects. The cant of the palatal plane remained unchanged during the treatment period. The occlusal plane opened as the mandibular plane and lower anterior facial height increased significantly. The mandible rotated down and backward 1.0°, and the overbite decreased by 1.7 mm. The increase in the lower anterior facial height can be attributed to a 0.7-mm extrusion of the mandibular molars together with the maxillary molars moving distally into the arc of closure.

Second Deciduous Molars vs Second Premolar Anchorage

The effect of deciduous (ie, second deciduous molar) versus permanent (ie, second premolar) anchorage on the distalization of maxillary molars has not been analyzed previously. The permanent dentition anchorage group demonstrated more maxillary first molar vertical extrusion. This extrusion in turn led to a significant increase in lower anterior facial height (2.4 vs 1.6 mm), upper lip protrusion (0.8 mm), and a decrease in overbite (1.5 mm). The downward and backward rotation of the mandible was increased in the permanent dentition anchorage group as well. The significant decrease in the distance from pogonion to nasion perpendicular also reflects this difference. The negative vertical effects associated with the permanent dentition anchorage group suggest that the optimal anchorage (and treatment timing for molar distalization) is during the late mixed dentition, although this difference in response may not be relevant clinically over the long-term.

Presence or Absence of Erupted Permanent Maxillary Second Molars

No significant mean differences were noted in the anteroposterior movement of the maxillary first molar and sagittal anchorage loss between the 57 patients who had erupted maxillary second molars and the 44 who had not. There were highly significant differences, however, between the groups with regard to vertical anchorage loss. The presence of erupted permanent maxillary second molars was associated with significant increases in the mandibular plane angle and lower anterior facial height, 1.2 mm and 2.7 mm, respectively. This increase in facial height associated with the eruption of the maxillary second molars resulted in a downward and backward positioning of the chin point, exacerbating the Class II clinical appearance.

The erupted maxillary second molar group also had a significant decrease in overbite and an increase in relative extrusion of the maxillary molar when compared with the nonerupted maxillary second molar group. These findings are similar to the results of Ghosh and Nanda[28] and Muse et al[42] who state that distalization of the maxillary first molars and related dentoalveolar changes are not dependent on the stage of eruption of the second molar. These investigators contend that maxillary first molar distalization can be accomplished before or after the eruption of the second molars with no appreciable or significant differences in outcomes. The conclusions of Gianelly et al,[11] Ten-Hoeve,[43] and Jeckel and Rakosi,[44] however, are similar to the results of the current study in this regard, even though these investigators evaluated other distalizing appliance systems.

Variations in Facial Pattern

The patients in the sample were divided into 3 subgroups on the basis of their initial mandibular plane angle (FMA) to determine if molar distalization would affect some subgroups more significantly than others. Statistically significant increases in lower anterior facial height were not evident between patients with high, neutral, or low mandibular plane angles. This finding is in contrast to that of Ghosh and Nanda,[28] who state that increases in lower anterior facial height are greater in patients with higher mandibular plane angle measurements. Part of the difference between studies may have been related to the criteria used to classify the patients according to pretreatment lower anterior facial height.

Other Considerations

It should be stressed that this study considered only the effects of the pendulum appliance when it was used as an active treatment appliance. A subsequent investigation will follow these patients until the end of active treatment, at which time the overall dentoalveolar and skeletal treatment effects can be determined. It appears that the pendulum appliance is effective in moving molars distally. The challenge remaining to the clinician is to retract the anterior teeth while maintaining a Class I molar relationship, a task that often requires adequate patient compliance (eg, headgear, Class II elastics).

Lastly, although the results of this study indicate that the pendulum appliance is effective in moving the maxillary molars distally, the clinician should make sure that this treatment technique is appropriate for the specific patient. It is well known that Class II malocclusion can be due to a number of differing causes.[45] This treatment protocol should be used only in those patients who would benefit from maxillary molar distalization.

Table IV: Analysis of variance for high, medium, and low anterior face heights

	ΔT_1–T_2 High (N = 33)		ΔT_1–T_2 Neutral (N = 38)		ΔT_1–T_2 Low (N = 30)				
Cephalometric measures	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*HN*	*NL*	*LH*
Vertical									
Frankfort hor to occlusal plane (°)	1.0	2.4	1.1	2.3	1.1	2.4	NS	NS	NS
Frankfort hor to palatal plane (°)	–0.1	1.3	0.3	1.2	–0.2	0.9	NS	NS	NS
Frankfort hor to mandibular plane (°)	1.0	1.0	1.0	1.1	0.9	1.1	NS	NS	NS
Ant nasal spine to menton (mm)	2.4	1.3	1.9	1.5	2.3	1.5	NS	NS	NS
Maxillary dentoalveolar									
Upper 6 horizontal (mm)	–5.6	2.0	–5.9	1.7	–5.4	1.9	NS	NS	NS
Upper 6 vertical (mm)	0.3	1.7	–0.2	1.1	–0.0	1.1	NS	NS	NS
Upper 6 Frankfort (°)	–10.4	6.8	–11.6	4.7	–9.8	5.4	NS	NS	NS

H = FMA > 26°
N = FMA 21 – 26°
L = FMA < 21°
HN = High/Neutral
NL = Neutral/Low
LH = Low/High
NS = Not significant
6= First molar.

SUMMARY AND CONCLUSIONS

This study examined the treatment effects of maxillary first molar distalization with the pendulum appliance in a sample treated by 13 practitioners in the United States. Pretreatment (T_1) and posttreatment (T_2) cephalograms were analyzed for 101 (56 female and 45 male) patients. The average pretreatment age was 12 years 1 month. The average time between T_1 and T_2 radiographs was 7.1 months.

The following treatment effects were noted:

1. The pendulum appliance primarily affects the maxillary dentition; however, there are secondary minor effects on the soft tissue and skeletal components.
2. All maxillary molars were driven distally into an overcorrected Class I relationship. There was reciprocal anchorage loss in the premolars and incisors in a mesial direction.
3. The maxillary molar distalization contributed to 76% of the total space opening anterior to the maxillary first molar, whereas 24% was due to reciprocal anchorage loss of the maxillary premolars. The maxillary central incisors proclined slightly during treatment, and the amount of distal tipping of the maxillary molars during treatment was about 10°.
4. Facial height increased slightly during treatment. The occlusal plane tipped upward, and the mandibular plane opened slightly. Significant differences in lower anterior facial height increases between patients of high, medium, or low Frankfort mandibular plane angles were not observed.
5. No difference in the amount of molar distalization was noted between patients with erupted second molars and patients with unerupted second molars; however, significant increases in lower anterior facial height and in the Frankfort mandibular plane angle, and a small decrease in overbite were noted in patients with erupted second molars. The maxillary first molars were extruded as well.
6. The effect of permanent dentition versus deciduous dentition anchorage was significant. Increases in maxillary first molar extrusion and lower anterior facial height and a decrease in overbite were noted in patients with permanent dentition anchorage.

The results of the present study suggest that the pendulum appliance is an effective appliance for distalizing maxillary molars and correcting Class II malocclusions. For maximum maxillary first molar distalization with minimal increase in lower anterior facial height, this appliance appears to be best used on patients with maxillary second deciduous molars for anchorage and the absence of erupted permanent maxillary second molars, although significant bite opening was not of major concern in any patient in the study.

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