ORIGINAL ARTICLE

A comparison of two intraoral molar distalization appliances: Distal jet versus pendulum

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Introduction: This study compared the dentoalveolar and skeletal effects on Class II malocclusions of the distal jet with concurrent full fixed appliances and the pendulum appliance both followed by fixed appliances. **Methods:** The 2 samples each consisted of 32 subjects (19 girls and 13 boys) with mean ages at the start of treatment of 12 years 3 months in the distal jet group and 12 years 6 months in the pendulum group. The durations of the distalization phase of treatment were 10 months in the distal jet group and 7 months in the pendulum group, and the durations of the second phase of treatment with fixed appliances were 18 months in the distal jet group and 24 months in the pendulum group. Lateral cephalograms were analyzed at 3 observation times: before treatment, after distalization, and after orthodontic treatment. **Results:** During molar distalization, the pendulum subjects showed significantly more distal molar movement and significantly less anchorage loss at both the premolars and the maxillary incisors than the distal jet subjects. The distal jet used simultaneously with fixed appliances and the pendulum were equal in their ability to move the molars bodily. Very little change occurred in the inclination of the mandibular plane at the end of the 2-phase treatment (less than 1°) in both groups. At the end of comprehensive treatment, the maxillary first molars were 0.6 mm mesial to their original positions in the distal jet group and 0.5 mm distal in the pendulum group. Nevertheless, total molar correction was identical in the 2 groups (3.0 mm), and both appliances were equally effective in achieving a Class I molar relationship. Simultaneous edgewise orthodontic treatment during molar distalization in the distal jet group shortened the overall treatment time but produced significant flaring of both maxillary and mandibular incisors at the end of treatment. The impact on the soft tissue profile was minimal with both appliances. (Am J Orthod Dentofacial Orthop 2005;128:353-65)

Maxillary molar distalization for nonextraction treatment of Class II patients has become increasingly popular in the last 10 years. Traditional appliances for molar distalization such as extraoral traction,[1-7] Cetlin removable plate,[8,9] and Wilson distalizing arches[10-12] require patient cooperation to achieve molar distal movement. Recently, problems related to patient compliance have led many clinicians to prefer intraoral distalizing systems that minimize reliance on the patient and are under the orthodontist's control.

These intraoral devices consist schematically of an anchorage unit (usually comprising premolars or deciduous molars and an acrylic Nance button) and an active unit. Various force-generating devices for molar distalization have been proposed, including repelling magnets,[13-17] coil springs on continuous archwire,[18,19] superelastic nickel-titanium archwires,[20] coil springs on a sectional archwire (Jones jig,[21-25] distal jet,[26-29] and Keles slider[30,31]), springs in beta titanium alloy (pendulum,[32-38] pendulum with distal screw,[39,40] K-loop,[41] intraoral bodily molar distalizer[42]), and vestibular screws combined with palatal nickel-titanium coil-spring (first class) appliances.[43,44]

The distal jet and the pendulum are 2 of the more commonly used "noncompliance appliances" for molar distalization. Few studies, however, have investigated the dentoalveolar and skeletal postdistalization changes induced by the distal jet[27-29] and the pendulum appliances[33-38] (Table I). Previous studies have indicated that the pendulum appliance produces on average

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Table I. Dentoalveolar effects of pendulum and distal jet appliances

Report	Appliance	N	Treatment duration (mos)	Molar distal movement (mm)	Molar distal tipping (°)	Premolar mesial movement (mm)	Molar distalization %	Anchorage loss %
Ghosh and Nanda[33]	Pendulum	41	6.2	3.4	8.4	2.5	57	43
Byloff and Darendeliler[34]	Pendulum	13	4.1	3.4	14.5	1.6	71	29
Byloff et al[35]	Pendulum*	20	6.8	4.1	6.1	2.2	64	36
Bussick and McNamara[36]	Pendulum	101	7.0	5.7	10.6	1.8	76	24
Joseph and Butchart[37]	Pendulum	7	3.4	5.1	15.7	—	50	50
Chaqués-Asensi and Kalra[38]	Pendulum	26	6.5	5.3	13.1	2.2	71	29
Ngantung et al[27]	Distal jet†	33	6.7	2.1	3.3	2.6	45	55
Nishii et al[28]	Distal jet‡	15	6.4	2.6	1.8	1.5	63	37
Bolla et al[29]	Distal jet‡	20	5.0	3.2	3.1	1.3	71	29

*Pendulum with molar uprighting bends.
†Distal jet with full fixed appliances.
‡Distal jet without full fixed appliances.

greater molar distalization (3.4-5.7 mm) than the distal jet appliance (2.1-3.2 mm). The distalization, however, is associated with greater molar tipping (8.4°-15.7°) that can be reduced substantially (6.1°) when molar uprighting bends are incorporated into the pendulum appliance.[35] The distal jet produces better bodily movement (1.8°-3.3° of molar distal tipping) because the distalizing force is directed close to the level of the maxillary first molar's center of resistance. The amounts of anchorage loss that can be expected as a result of the mesial reciprocal force on the premolars ares similar for both appliances (1.8-2.5 mm for the pendulum; 1.3-2.6 mm for the distal jet; Table I).

Evaluations of the effects of the pendulum and distal jet appliances on vertical skeletal relationships have had conflicting outcomes. According to most studies on the pendulum appliance,[33,35,36,38] significant increases in the vertical dimension must be expected. These vertical changes comprise a slight opening of the mandibular plane angle (about 1°) and an increase in lower anterior facial height (2.2-2.8 mm). Bussick and McNamara[36] found no significant difference in lower anterior facial height increase among patients with high, neutral, or low mandibular plane angles, whereas Ghosh and Nanda[33] reported that the increases in lower anterior facial height are significantly greater in patients with higher pretreatment mandibular plane angles.

Contrary to these reports, both Nishii et al[28] and Bolla et al[29] found that the distal jet appliance without simultaneous edgewise treatment during molar distalization produced no significant change in vertical dimension. The distal jet used in combination with full fixed appliances, however, produced a significant increase in lower anterior facial height.[27] No significant changes in lower anterior facial height among patients with high, neutral, or low mandibular plane angles have been reported for the distal jet without fixed appliances.[29]

There are controversial opinions about the effect of erupted maxillary second molars on distalization of the first molars. All investigators agree that the presence or absence of the second molars does not significantly influence the amount of first molar distalization with either the distal jet [27,29] or the pendulum appliance.[33-38] Bussick and McNamara,[36] who studied the largest sample of subjects treated with the pendulum appliance to date, suggest to start moving the first molars distally before the eruption of the second molars to avoid significant increases in mandibular plane angle and lower anterior facial height. As for the distal jet appliance, Bolla et al[29] found significantly less tipping of the maxillary first molars and significantly less anchorage loss and extrusion at the first premolars in subjects with erupted second molars when compared with subjects with unerupted second molars.

Most studies on treatment effects induced by either the distal jet or the pendulum have been limited to the analysis of postdistalization changes (the period of posterior molar movement) only. To date, there is little information about outcomes after comprehensive orthodontic treatment including a second phase of therapy with fixed appliances. The only exceptions are the studies by Ngantung et al[27] on the distal jet appliance used simultaneously with full fixed appliances and Burkhardt et al,[45] who compared the effects of the pendulum and the Herbst appliances after comprehensive orthodontic treatment.

Carano and Testa,[26] the developers of the distal jet, recommended that this appliance system be used alone during the molar-distalization phase. Further distaliza-

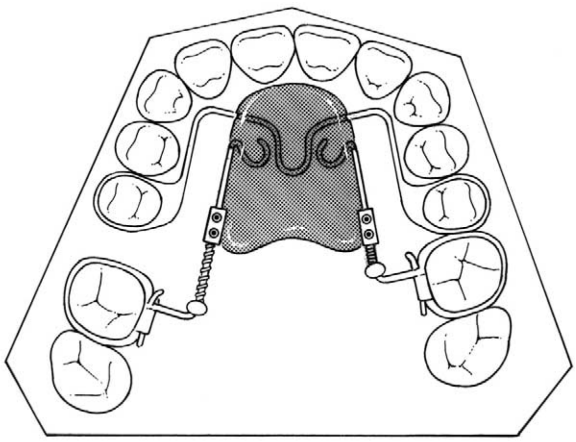

Fig 1. Distal jet appliance.

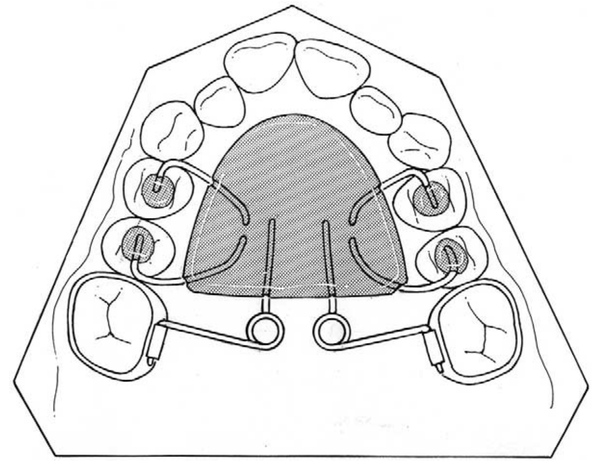

Fig 2. Pendulum appliance.

tion of the anterior dentition is accomplished with fixed appliances. On the other hand, Bowman[46,47] suggested the use of fixed appliances concurrently with distal jet treatment to achieve initial incisal alignment.

The aim of this study was to compare the dentoalveolar and skeletal effects on Class II malocclusions of the distal jet used concurrently with full fixed appliances and the pendulum. Treatment effects were analyzed both at the end of distalization and at the end of comprehensive orthodontic treatment comprising fixed appliance therapy.

SUBJECTS AND METHODS

This retrospective study was designed to evaluate cephalometrically the skeletal and dentoalveolar effects of molar distalization produced by the distal jet (Fig 1) and the pendulum (Fig 2) appliances in subjects with Class II malocclusions. The distal jet group consisted of 32 subjects who received fixed appliance therapy during the molar distalization phase according to Bowman's recommendations.[46,47] The outcome of the distal jet group was compared with that in 32 patients treated with the pendulum appliance. In both groups, the first phase of treatment was designed to achieve a Class I molar relationship with molar distalization; the second phase consisted of fixed appliance therapy to align and detail the dentition. Three serial cephalograms for all patients in both groups were available at 3 observation times: before treatment (T1), after distalization (T2), and after orthodontic treatment (T3).

Table II. Sample selection and exclusionary criteria for distal jet with full fixed appliances

Sample selection	n
Patient sample	94
Primary exclusionary criteria	
1. Poor film quality/magnification problems	6
2. Incomplete records	13
Secondary exclusionary criteria	
1. T1 to T2 interval greater than 12 months	16
2. Non-Class II malocclusion	4
3. Use of other molar distalization methods between T1 and T2	23
Final sample	32

The distal jet group

The distal jet sample was selected from an original group of 94 subjects from 2 private orthodontic practices. To be included in this group, each patient had to meet the following criteria: (1) a pretreatment Class II Division 1 malocclusion, defined by at least an end-to-end molar relationship; (2) no permanent teeth extracted before or during treatment; (3) good-quality radiographs with adequate landmark visualization and minimal or no rotation of the head; and (4) no other molar distalization procedures (eg, headgear) performed between the T1 and T2 cephalograms. The final distal jet sample consisted of 32 subjects (19 girls and 13 boys) (Table II). The mean ages at T1, T2, and T3 and the mean treatment intervals are summarized in Table III.

In the patients in the distal jet group, coil springs were activated every 4 to 6 weeks; most patients received 3 to 5 activations. The forces generated by the

Table III. Demographics of observation periods and observation intervals

Observation period/interval	*Distal jet group (n = 32)*				*Pendulum group (n = 32)*			
	Mean	*SD*	*Min*	*Max*	*Mean*	*SD*	*Min*	*Max*
T1	12y 3mo	1y 4mo	9y 2mo	15y 10mo	12y 6mo	1y 1mo	10y 9mo	15y 10mo
T2	13y 1mo	1y 4mo	10y 2mo	16y 11mo	13y 1mo	1y 1mo	11y 2mo	16y 5mo
T3	14y 7mo	1y 4mo	11y 2mo	18y	15y 1mo	1y 2mo	12y 10mo	18y 6mo
T1-T2	10mo	2mo	6mo	14mo	7mo	2mo	4mo	24mo
T2-T3	18mo	4mo	11mo	29mo	24mo	6mo	15mo	36mo
T1-T3	28mo	5mo	21mo	42mo	31mo	6mo	22mo	44mo

Ni-Ti coils were recommended by Carano and Testa[26] (240 g). The anterior dentitions were aligned during molar distalization with full fixed appliances. Once a "super Class I" molar relationship was achieved, the distal jet was converted to a large Nance holding arch by removing the coil springs. The extension arms to the second premolars were cut and removed to allow the premolars to drift back or be actively retracted. During the postdistalization period, 22 of the 32 patients received Jasper jumpers[48] bilaterally, used passively to stabilize the maxillary molars. The remaining 10 patients received headgear to help hold the molars in position. The Jasper jumpers and the Nance holding arches were removed after maxillary space closure and attainment of a Class I molar relationship. Full fixed appliances were maintained until the completion of treatment.

The pendulum group

The parent sample for the pendulum group consisted of 50 patients from previous pendulum studies.[36,45] The final sample (32 subjects, 19 girls and 13 boys) was selected by matching the subjects to the distal jet sample based on sex and age at the start of treatment. The mean ages at T1, T2, and T3 and the mean treatment intervals for the pendulum group are shown in Table III.

The pendulum/pendex appliance used in this study was similar to that described by Hilgers.[32] With the appliance in place, the 0.032-in TMA springs were placed in the lingual sheaths on maxillary first molar bands. This 60° activation exerted approximately 230 g of distalizing force. The pendulum appliance was removed when a "super Class I" molar relationship was achieved. A Nance holding arch was placed after molar distalization. Typically, the occlusal rests were removed from the second premolars, and the premolars were allowed to drift posteriorly. No archwire was placed in the brackets (if present) on the second premolars during the first few months after molar distalization. Comprehensive fixed appliances followed molar distalization.

In both groups, 9 subjects had unerupted maxillary second molars at the start of treatment, and 23 subjects had either partially or totally erupted second molars.

Cephalometric analysis

Lateral cephalograms of a given series were hand-traced at a single sitting in the same manner. Cephalograms were traced by one investigator (P.P.C.); landmark location was verified by a second investigator (J.A.M.). Disagreements were resolved by retracing the landmark or structure in question to the satisfaction of both.

Lateral cephalograms for each patient at T1, T2, and T3 in both treatment groups were standardized as to magnification factor (8% enlargement) and digitized. A customized digitization regimen based on Dentofacial Planner (version 2.5, Toronto, Ontario, Canada) that included 78 landmarks and 4 fiducial markers was used for the cephalometric evaluation. The cephalometric analysis, containing measurements from the analyses of Jacobson,[49] McNamara,[50] Ricketts,[51] and Steiner,[52] consisted of 31 variables (10 angular and 21 linear) for each tracing.

Fiducial markers were placed in the maxilla and mandible on the T2 tracings and transferred to T1 and T3 tracings in each subject's cephalometric series, based on superimposition of internal maxillary or mandibular structures. Regional superimpositions were done by hand, and the 78 landmarks and the 4 fiducial markers (anterior and posterior maxilla, anterior and posterior mandible) were digitized with Dentofacial Planner. Cranial base superimpositions assessed the movements of the maxilla and mandible relative to the basion-nasion line registered at the posterosuperior aspect of the pterygomaxillary fissure.[50,53] These movements were shown by the direction and magnitude of displacement of the fiducial markers in the maxilla and mandible relative to cranial-base structures.

The maxillae were superimposed along the palatal plane by registering on the bony internal details of the maxilla superior to the incisors and the superior and inferior surfaces of the hard palate. Fiducial markers were placed in the anterior and posterior part of the maxilla along the palatal plane. The movement of the maxillary dentition in the maxilla was determined from this maxillary superimposition. The mandibles were superimposed posteriorly on the outline of the mandibular canal. Anteriorly, they were superimposed on the anterior contour of the chin and the bony structures of the symphysis.[50,53] Fiducial markers were placed in the center of the symphysis and the body of the mandible near the gonial angle. This superimposition facilitated measuring the movement of the mandibular dentition relative to the mandible.

Statistical analysis

Descriptive statistics were calculated for all cephalometric measures at T1 for the 2 groups and for the changes at T2-T1, T3-T2, and T3-T1 in each group. Significant between-group differences were tested with the Hotelling T^2 as an initial exploratory test (MANOVA). When significance was detected, the independent sample Student *t* test was used to identify significant between-group differences for each cephalometric variable. Statistical significance was tested at $P < .05$, $P < .01$, and $P < .001$. All computations were performed with a statistical software package (Statistical Package for the Social Sciences, Version 10.0, SPSS, Chicago, Ill).

The error of the method has been described previously by McNamara et al.[54]

Table IV. Comparison of starting forms†

Cephalometric measures	Distal jet n = 32 Mean	Distal jet SD	Pendulum n = 32 Mean	Pendulum SD
Maxillary skeletal				
SNA (°)	82.0	4.2	80.5	3.7
Pt A to nasion perp (mm)	0.7	3.9	−0.9	3.2
Mandibular skeletal				
SNB (°)	77.8	3.2	76.9	3.5
Pg to nasion perp (mm)	−4.1	5.4	−6.1	5.4
Co-Gn (mm)	114.0	5.7	114.0	7.2
Maxillary/mandibular				
ANB (°)	4.1	2.4	3.6	2.1
Wits (mm)	1.7	2.3	1.4	2.7
Vertical skeletal				
ANS to Me (mm)	63.4	4.4	64.9	4.2
FH to occlusal plane (°)	8.3	4.6	8.2	3.6
FH to palatal plane (°)	1.3	3.0	0.3	2.8
FH to mandibular plane (°)	21.5	6.0	24.4	3.9
Interdental				
Molar relationship (mm)	−1.0	0.9	−1.2	1.3
Overjet (mm)	4.7	1.3	4.8	1.5
Overbite (mm)	4.9	1.8	4.8	1.8
Maxillary dentoalveolar				
U1 to Pt A vert (mm)	4.0	1.6	4.1	2.3
U1 to FH (°)	108.4	6.5	109.4	7.0
U4 to FH (°)	93.4	5.2	90.3	6.0
U6 to FH (°)	82.6	4.1	79.8	4.4
Mandibular dentoalveolar				
L1 to mand plane (°)	97.1	6.7	93.3	6.0
Soft tissue				
UL to E plane (mm)	−2.8	1.8	−2.4	2.5
LL to E plane (mm)	−1.6	1.8	−0.9	3.6

†Hotelling's $T^2 = 0.773$, F = 1.546, $P = .113$; not significant.

RESULTS

Descriptive statistics for the 19 cephalometric measures at T1 for the distal jet and pendulum groups are given in Table IV. Multivariate analysis did not show a significant between-group difference in starting forms for the distal jet group when compared with the pendulum group at T1.

Descriptive and inferential statistics for changes during overall treatment intervals T1-T2, T2-T3, and T1-T3 are summarized in Tables V-VII. Average craniofacial forms for both groups at the 3 observation times and their superimpositions are shown in Figures 3 and 4.

Pretreatment to postdistalization

No significant difference in both sagittal and vertical skeletal changes could be detected between the 2 groups during the distalization phase. The only exception was a slightly more protruded chin in the distal jet sample (Pg to nasion perpendicular, −0.3 mm v −1.1 mm) that was associated with significantly greater increments in total mandibular length (Co-Pg, 2.5 mm v 1.3 mm). In both groups, the mandibular plane angle opened slightly (FH to mandibular plane, 0.7°-1.3°), resulting in a comparable increase in lower anterior facial height (ANS to Me, 2.4-2.5 mm) (Table V).

The pendulum group showed a significantly greater correction of molar relationship (6.4 mm) and a significantly larger amount of molar distalization (U6 horizontal, −6.1 mm) compared with the distal jet group (3.8 and −2.8 mm, respectively). The maxillary first molars in the pendulum group, however, experienced significantly more distal tipping (U6 to FH, −10.7°) than the distal jet group (−5.0°). The maxillary first molars also extruded slightly in both samples (U6 vertical, 0.5-1.0 mm) (Table V).

At the end of the first phase of treatment, the pendulum group showed significantly less anchorage loss measured at the first premolars (U4 horizontal, 1.4 mm mesial movement) than the distal jet group (2.6 mm). The first premolars tended to extrude in both groups (U4 vertical, 1.2-1.3 mm) (Table V).

Table V. Comparison of change during distalization period (T1 to T2)[†]

	Distal jet *n = 32*		*Pendulum* *n = 32*		*Distal jet* vs *pendulum*	
Cephalometric measures	*Mean*	*SD*	*Mean*	*SD*	*t*	*Sig.*
Maxillary skeletal						
SNA (°)	−0.1	1.1	0.2	0.8	−1.190	NS
Pt A to nasion perp (mm)	0.1	1.1	0.1	0.7	−0.132	NS
Mandibular skeletal						
SNB (°)	−0.3	0.8	−0.3	0.8	−0.016	NS
Pg to nasion perp (mm)	−0.3	1.3	−1.1	1.4	2.386	*
Co-Gn (mm)	2.5	1.5	1.3	1.8	2.976	**
Maxillary/mandibular						
ANB (°)	0.2	1.1	0.5	0.8	−1.249	NS
Wits (mm)	1.4	1.6	0.7	1.5	1.967	NS
Vertical skeletal						
ANS to Me (mm)	2.4	1.7	2.5	1.4	−0.333	NS
FH to occlusal plane (°)	0.8	2.6	1.5	2.6	−1.057	NS
FH to palatal plane (°)	−0.1	1.2	−0.2	1.1	0.496	NS
FH to mandibular plane (°)	0.7	0.9	1.3	1.4	−1.845	NS
Interdental						
Molar relationship (mm)	3.8	1.0	6.4	1.9	−7.082	***
Overjet (mm)	2.4	2.1	1.2	1.5	2.695	**
Overbite (mm)	−2.9	1.6	−1.7	1.2	−3.228	**
Maxillary dentoalveolar						
U1 to Pt A vert (mm)	3.8	1.9	1.0	1.2	7.071	***
U1 horizontal (mm)	3.7	1.7	1.1	1.2	6.952	***
U1 vertical (mm)	−1.5	1.6	−0.1	0.9	−4.159	***
U4 horizontal (mm)	2.6	1.1	1.4	1.9	2.964	**
U4 vertical (mm)	1.3	1.2	1.2	1.1	0.236	NS
U6 horizontal (mm)	−2.8	1.1	−6.1	1.8	8.875	***
U6 vertical (mm)	1.0	1.1	0.5	1.1	1.712	NS
U1 to FH (°)	13.7	8.0	3.1	4.1	6.655	***
U4 to FH (°)	0.3	4.9	−1.7	4.7	1.633	NS
U6 to FH (°)	−5.0	3.6	−10.7	5.5	4.817	***
Mandibular dentoalveolar						
L1 to mand plane (°)	6.7	4.9	0.9	3.8	5.295	***
L1 horizontal (mm)	1.2	1.2	0.4	0.7	3.285	**
L1 vertical (mm)	0.7	1.2	0.6	0.7	0.250	NS
L6 horizontal (mm)	0.5	0.7	0.6	0.6	−0.763	NS
L6 vertical (mm)	0.6	1.2	0.5	0.8	0.498	NS
Soft tissue						
UL to E plane (mm)	0.9	1.6	0.3	1.5	1.628	NS
LL to E plane (mm)	2.1	1.4	0.5	1.7	4.055	***

[†]Hotelling's T^2 = 10.302, F = 9.366, P = .000; significant.
*P < .05; **P < .01; ***P < .001.

The maxillary incisors of the distal jet group exhibited significantly more flaring (U1 horizontal, 3.7 v 1.1 mm; U1 to FH, 13.7° v 3.1°) and intrusion (U1 vertical, −1.5 v −0.1 mm) during molar distalization. The mandibular incisors of the distal jet group also were significantly more protruded (L1 to mandibular plane, 6.7°) than those of the pendulum group (0.9°). From T1 to T2, the distal jet group had a significantly greater increase in overjet (2.4 mm) and a significantly greater decrease in overbite (−2.9 mm) than the pendulum group (1.2 and −1.7 mm, respectively) (Table V).

The lower lip in the distal jet group was significantly more protruded (2.1 mm) than it was in the pendulum group (0.5°) (Table V).

Postdistalization to end of orthodontic treatment

Between T2 and T3, the pendulum group showed a 0.7° greater decrease in SNA angle, whereas the distal jet group had a 1.0° greater increase in SNB angle than the pendulum group. The distal jet group experienced 1.8 mm more reduction in the Wits appraisal than the

Table VI. Comparison of change during postdistalization period (fixed appliance therapy) (T2 to T3)†

	Distal jet n = 32		*Pendulum n = 32*		*Distal jet vs pendulum*	
Cephalometric measures	*Mean*	*SD*	*Mean*	*SD*	*t*	*Sig.*
Maxillary skeletal						
SNA (°)	−0.2	1.1	−0.9	1.3	2.249	*
Pt A to nasion perp (mm)	−0.3	1.2	−0.8	1.4	1.565	NS
Mandibular skeletal						
SNB (°)	0.8	1.0	−0.2	1.0	3.942	***
Pg to nasion perp (mm)	1.3	1.6	0.8	2.3	1.148	NS
Co-Gn (mm)	3.1	2.0	4.7	3.3	−2.302	NS
Maxillary/mandibular						
ANB (°)	−1.0	1.3	−0.7	1.1	−0.899	NS
Wits (mm)	−2.9	2.4	−1.1	1.8	−3.444	***
Vertical skeletal						
ANS to Me (mm)	1.5	2.1	1.8	1.9	−0.674	NS
FH to occlusal plane (°)	−0.5	2.9	−1.4	2.7	1.267	NS
FH to palatal plane (°)	−0.1	1.1	−0.3	2.1	0.488	NS
FH to mandibular plane (°)	−0.6	1.3	−0.4	2.2	−0.527	NS
Interdental						
Molar relationship (mm)	−1.0	1.3	−3.5	1.9	6.362	***
Overjet (mm)	−4.2	2.1	−2.6	2.3	−3.003	**
Overbite (mm)	0.4	2.0	−0.2	1.7	1.225	NS
Maxillary dentoalveolar						
U1 to Pt A vert (mm)	−2.3	2.2	−0.8	2.5	−2.472	*
U1 horizontal (mm)	−1.9	2.1	−0.9	2.3	−1.999	*
U1 vertical (mm)	2.1	1.7	1.1	1.3	2.803	**
U4 horizontal (mm)	−2.1	1.1	−1.4	2.0	−1.736	NS
U4 vertical (mm)	0.7	0.9	0.7	1.2	−0.172	NS
U6 horizontal (mm)	3.4	1.4	5.5	1.7	−5.649	***
U6 vertical (mm)	0.7	1.1	1.1	0.9	−1.428	NS
U1 to FH (°)	−7.7	7.8	0.1	8.9	−3.720	***
U4 to FH (°)	−2.7	5.3	−1.6	4.3	−0.892	NS
U6 to FH (°)	7.2	3.1	13.6	6.3	−5.193	***
Mandibular dentoalveolar						
L1 to mand plane (°)	0.1	4.8	3.1	5.0	−2.454	*
L1 horizontal (mm)	0.7	1.0	0.6	1.4	0.544	NS
L1 vertical (mm)	0.1	1.9	1.1	1.8	−2.023	*
L6 horizontal (mm)	1.0	1.0	0.9	0.9	0.513	NS
L6 vertical (mm)	1.4	1.0	2.4	1.6	−3.024	**
Soft tissue						
UL to E plane (mm)	−2.2	1.5	−2.3	1.3	0.145	NS
LL to E plane (mm)	−1.9	1.8	−1.5	1.5	−0.857	NS

†Hotelling's T^2 = 8.125, F = 7.386, P = .000; significant.
*$P < .05$; **$P < .01$; ***$P < .001$.

pendulum group. No statistically significant differences in the changes in vertical skeletal relationships were found between the 2 groups (Table VI).

During the second phase of treatment with full fixed appliances, the maxillary first molars in the pendulum group showed significantly more mesial movement (5.5 mm) and mesial tipping (13.6°) than the distal jet group (3.4 mm and 7.2°, respectively). The greater tendency to relapse in the sagittal position of the maxillary first molar in the pendulum group was shown also by a greater unfavorable change in molar relationships (−3.5 mm v −1.0 mm). The amount of mesial movement of the maxillary first molars in the distal jet group, however, was greater than the amount of distalization achieved during the first phase of treatment (Table VI).

There were no significant differences in the horizontal and vertical movements of the first premolars between the 2 groups during the second phase of treatment. The first premolars tipped distally in the distal jet group (−2.1 mm and −2.7°) and the pendulum group (−1.4 mm and −1.6°) (Table VI).

The maxillary incisors of the distal jet group showed significantly more retraction (−1.9 mm and

Table VII. Comparison of change during overall observation period (T1 to T3)[†]

	Distal jet n = 32		*Pendulum n = 32*		*Distal jet vs pendulum*	
Cephalometric measures	*Mean*	*SD*	*Mean*	*SD*	*t*	*Sig.*
Maxillary skeletal						
SNA (°)	−0.3	1.4	−0.7	1.3	1.204	NS
Pt A to nasion perp (mm)	−0.2	1.1	−0.6	1.3	1.591	NS
Mandibular skeletal						
SNB (°)	0.5	1.0	−0.4	1.0	3.778	***
Pg to nasion perp (mm)	1.1	1.6	−0.3	2.3	2.816	**
Co-Gn (mm)	5.7	2.8	6.0	3.5	−0.399	NS
Maxillary/mandibular						
ANB (°)	−0.8	1.1	−0.3	1.0	−2.099	*
Wits (mm)	−1.5	2.4	−0.4	1.5	−2.171	*
Vertical skeletal						
ANS to Me (mm)	3.9	2.5	4.4	2.7	−0.722	NS
FH to occlusal plane (°)	0.3	2.8	0.1	3.1	0.260	NS
FH to palatal plane (°)	−0.2	1.5	−0.6	2.1	0.757	NS
FH to mandibular plane (°)	0.1	1.5	0.9	2.2	−1.645	NS
Interdental						
Molar relationship (mm)	2.9	1.1	2.9	1.4	−0.319	NS
Overjet (mm)	−1.8	1.3	−1.4	1.6	−1.103	NS
Overbite (mm)	−2.5	1.8	−1.9	1.7	−1.297	NS
Maxillary dentoalveolar						
U1 to Pt A vert (mm)	1.5	1.7	0.2	2.1	2.838	**
U1 horizontal (mm)	1.8	1.8	0.2	1.9	3.355	**
U1 vertical (mm)	0.6	1.6	0.9	1.2	−0.910	NS
U4 horizontal (mm)	0.5	1.2	0.1	1.2	1.442	NS
U4 vertical (mm)	2.0	1.1	2.0	1.5	0.064	NS
U6 horizontal (mm)	0.6	1.2	−0.6	1.4	3.583	**
U6 vertical (mm)	1.7	1.4	1.6	1.2	0.322	NS
U1 to FH (°)	6.0	6.3	3.3	7.7	1.572	NS
U4 to FH (°)	−2.4	4.6	−3.3	4.8	0.758	NS
U6 to FH (°)	2.2	3.2	3.0	4.8	−0.800	NS
Mandibular dentoalveolar						
L1 to mand plane (°)	6.9	4.9	4.0	4.7	2.344	*
L1 horizontal (mm)	2.0	1.2	1.0	1.4	2.971	**
L1 vertical (mm)	0.8	2.1	1.7	1.7	−1.848	NS
L6 horizontal (mm)	1.5	1.1	1.5	0.9	0.010	NS
L6 vertical (mm)	2.0	1.6	2.9	1.4	−2.288	*
Soft tissue						
UL to E plane (mm)	−1.3	1.5	−2.0	1.8	1.649	NS
LL to E plane (mm)	0.2	1.3	−1.0	1.9	2.993	**

[†]Hotelling's T^2 = 2.999, F = 2.726, P = 0.000; significant.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

−7.7° v −0.9 mm and 0.1°) and extrusion (2.1 v 1.1 mm) during the second phase of treatment. The mandibular incisors of the pendulum group proclined 3.0° and extruded 1 mm more than those of the distal jet patients. The overjet was reduced to a greater extent in the distal jet group (−4.2 mm) than in the pendulum group (−2.6 mm); overbite showed minimal changes in both groups (Table VI).

During treatment with fixed appliances, the upper and lower lips tended toward retraction relative to the E plane in both groups (Table VI).

Overall treatment effects

Over the entire treatment period, SNB angle and pogonion-to-nasion perpendicular distance increased significantly in the distal jet group (0.5° and 1.1 mm) with respect to the pendulum group, which showed a slight decrease for both mandibular measures (−0.4° and −0.3 mm). Both the Wits appraisal and ANB angle decreased significantly more in the distal jet group (−1.1 and − 0.5 mm, respectively). No statistically significant differences were found between the 2 groups for any T3-T1 changes in vertical skeletal relationships (Table VII).

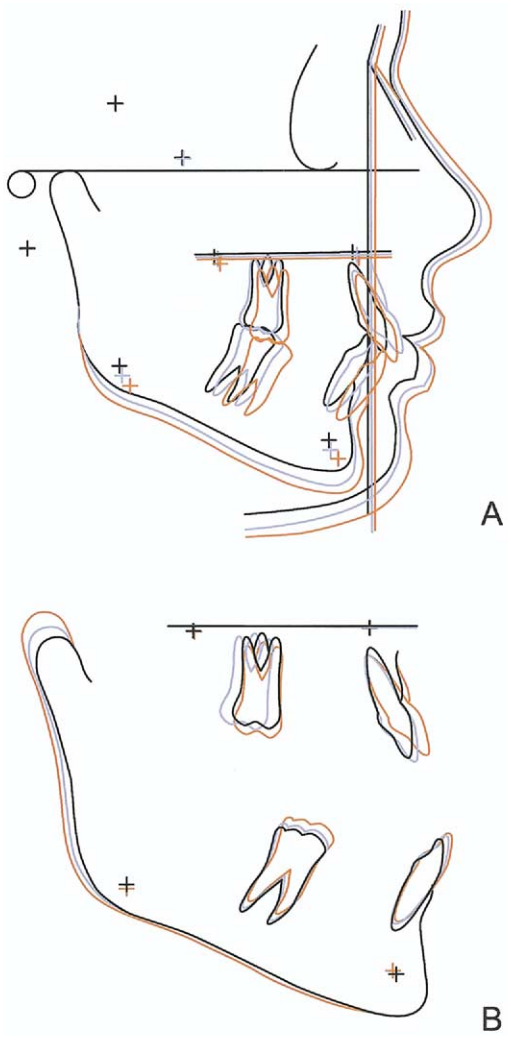

Fig 3. Average craniofacial forms for distal jet group at T1, T2, and T3. **A,** Cranial-base superimposition; **B,** maxillary and mandibular superimpositions. *Black,* T1; *blue,* T2; *red,* T3.

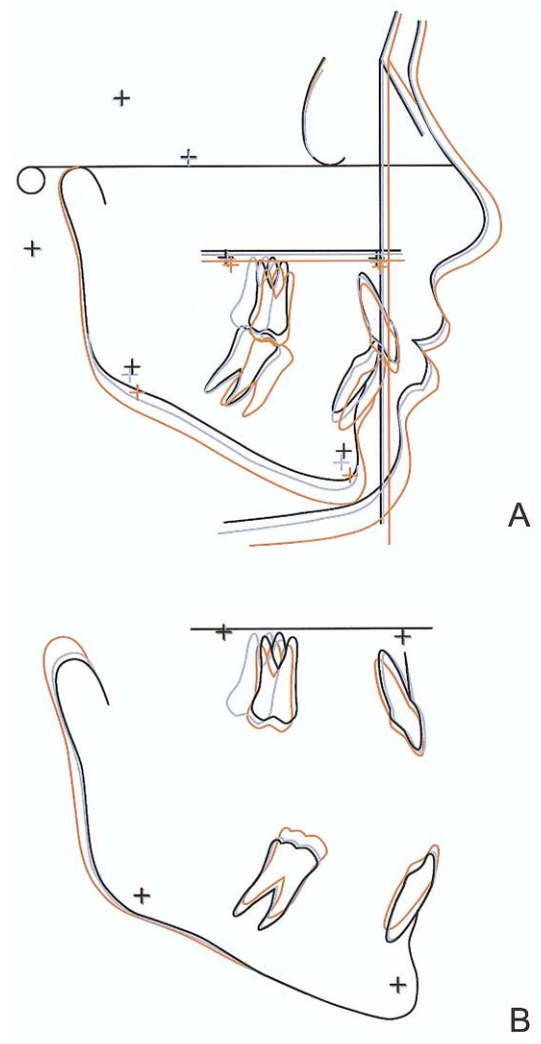

Fig 4. Average craniofacial forms for pendulum group at T1, T2, and T3. **A,** Cranial base superimposition; **B,** maxillary and mandibular superimpositions. *Black,* T1; *blue,* T2; *red,* T3.

At the end of treatment, the pendulum group showed significantly more molar distalization (1.2 mm more than the distal jet group). The maxillary first molars were 0.6 mm distal to their original positions for the pendulum group, whereas they were 0.6 mm mesial for the distal jet group. Both appliances, however, induced the same amount of correction in molar relationships (2.9 mm). From T1 to T3, the maxillary first molars tended to extrude (1.6-1.7 mm) and tip mesially (2.2°-3.0°) in both samples. During overall treatment, the mandibular first molars moved mesially 1.5 mm in both groups, whereas they were 0.9 mm more extruded in the pendulum group (Table VII).

There were no significant differences in horizontal or vertical movements of the first premolars between the 2 groups at the end of treatment (Table VII).

After comprehensive treatment, the maxillary incisors of the distal jet subjects were 1.6 mm more labial than those of the pendulum subjects. The mandibular incisors also were proclined significantly more in the distal jet group (2.0 mm and 6.9°) than those in the pendulum group (1.0 mm and 4.0°). There were no statistically significant differences in overbite and overjet between the 2 groups (Table VII).

At the end of comprehensive treatment, the upper lip showed a tendency toward retraction relative to the E plane in both groups. The lower lip of the distal jet group maintained its original position relative to the E plane, whereas the lower lip of the pendulum group became significantly less protrusive (Table VII).

DISCUSSION

Many intraoral molar distalization appliances have been designed to minimize or eliminate the need for patient cooperation. The pendulum appliance and the distal jet are recent examples of noncooperation appliances. The purpose of this study was to compare the treatment effects of the distal jet and the pendulum appliances for the correction of Class II malocclusions.

The analysis of starting forms showed that the distal jet and pendulum patients generally were not significantly different at the start of treatment (Table IV) and verified that this study has a low susceptibility bias. Susceptibility bias occurs when the groups received different treatment modalities based on the patients' characteristics at the start of treatment.[55,56] One of the best ways to minimize the susceptibility bias is to randomly assign patients to the different treatments. In this study, all patients came from orthodontic practices that were using either the distal jet or the pendulum appliance exclusively, not both appliances. In other words, every patient who was thought to require distalization received the distal jet in 1 practice and the pendulum in the other. Essentially, this study in some respects resembles a randomized trial in that treatment was not rendered based on the patient's pretreatment characteristics.

Skeletal changes

During the distalization phase of treatment, the patients treated with the distal jet showed more mandibular growth that was associated with a more protruded chin (Figs 3 and 4). This difference in mandibular growth can be explained, in part, by the longer duration of treatment (3 months) with the distal jet during a period of accelerated growth for most patients. The mandible also rotated slightly downward and backward in similar amounts for both groups, resulting in comparable increases in lower anterior facial height. The bite opening might have been caused by extrusion of posterior teeth or the maxillary molars being distalized into the arc of closure. The amount of changes in vertical skeletal relationships during molar distalization in the pendulum sample is comparable with those reported in previous studies,[33,36-38] whereas the distal jet produced greater increments in vertical dimensions than those reported by other authors.[27-29]

During the postdistalization phase, distal jet patients had a slightly greater improvement in the Class II skeletal relationship that was reflected in the decreases of both the Wits appraisal and ANB angle when compared with the pendulum patients. The bite opening observed during molar distalization was reversed slightly in both groups. Similar skeletal findings in the postdistalization period were recorded by Ngantung et al[27] for the distal jet used simultaneously with fixed appliances.

Over the entire treatment, the distal jet subjects experienced more mandibular advancement and, as a result, showed a slightly greater improvement in the Class II skeletal relationship (Figs 3 and 4).

Very little change occurred in the inclination of the mandibular plane at the end of the 2-phase treatment (less than 1°) in both groups, whereas the increase in lower anterior facial height was slightly greater than that in normal subjects[57] during the same observation interval (4.0-4.5 v 3.5 mm in normal subjects). The final outcomes of the 2 treatment protocols can be compared with cephalometric composite norms[57] to evaluate the sagittal and vertical intermaxillary skeletal harmony at the end of overall treatment (T2). Although the 2 sagittal components appeared to be in good reciprocal balance (midfacial length, Co-Pt. A, 93 mm for both groups; mandibular length Co-Gn, 120 mm for both groups), the vertical dimension increased slightly in both samples (67 mm in the distal jet group and 69 mm in the pendulum group v 65-66 mm in the composite norms).

Dentoalveolar changes

From T1 to T2, a "super Class I" molar relationship was achieved, on average, in 7 months in the pendulum treatment group and 10 months in the distal jet group. The data suggest that the pendulum appliance was more efficient in distalizing molars than the distal jet. By T2, the molars moved posteriorly 2.8 mm in the distal jet group and 6.1 mm in the pendulum group, which also showed 2.6 mm greater correction in molar relationship (Figs 3 and 4). This difference was statistically and clinically significant. The main objective of molar distalizing therapy is to induce a true bodily distal movement or at least to keep molar distal tipping to a minimum. The amount of molar distal tipping relative to Frankfort horizontal was 5.0° in the distal jet group and 10.7° in the pendulum group (Figs 3 and 4).

At first glance, this finding (T1-T2) seemed to show that the distal jet produced less tipping. However, when the amount of distal movement was considered with the degree of tipping, the result showed that the molars tipped 1.8° per millimeter of distal tooth movement in both groups. In other words, the 2 appliances were equally likely to tip the maxillary molars. The amount of distal tipping per millimeter of distal molar movement in the distal jet group was similar to that reported by Ngantung et al[27] for the distal jet with full fixed appliances (1.6°/mm) and Bussick and McNamara[36] for the pendulum (1.9°/mm), although it is greater than that reported by Bolla et al[29] for the distal jet without full fixed appliances (1.0°/mm).

The anchorage loss (T1-T2) measured at the first premolars during molar distalization was 48% for the distal jet group and 19% for the pendulum group (2.6 and 1.4 mm, respectively) of mesial movement, a clinically and statistically significant difference. The inclusion of 2 premolars in the anchorage unit for the distal jet versus 4 premolars for the pendulum might have contributed to the greater loss of anchorage in the distal jet group than in the pendulum group. For every millimeter the maxillary first molar moved distally, the premolars moved forward 0.9 mm in the distal jet patients and a mere 0.2 mm in the pendulum patients. A similar amount of anchorage loss at the first premolars has been found by Ngantung et al[27] for the distal jet with fixed appliances (55%). The distal jet when used without fixed appliances[28,29] produced less anchorage loss (29%-37%). The percentages of anchorage loss for the pendulum appliance have been reported to be 24%[35] to 43%[32] (Table I).

The patients in the distal jet group also showed a significantly greater anchorage loss measured at the maxillary incisor from T1 to T2. The maxillary incisors were 10.1° more proclined than the pendulum group (Figs 3 and 4). The simultaneous use of full fixed orthodontic appliances to align the anterior teeth contributed greatly to the incisor flaring observed during molar distalization. Ngantung et al[27] reported similar findings for the distal jet with fixed appliances (12.1° of vestibular tipping). When the distal jet was used without fixed appliances,[28] the amount of labial tipping of the maxillary incisor varied from 0.6°[29] to 4.5°[28] during distalization. In our study, the mandibular incisor of the distal jet group also showed greater labial inclination (5.8°) than the pendulum group. The findings of the study showed that incorporating anterior teeth into the anchor unit does not appear to reduce anchorage loss. It confirmed the observation of Melsen and Bosch,[58] who stated that teeth that have been mobilized provide very little, if any, anchorage value.

In general, during the first phase of treatment, the pendulum appeared to be more efficient than the distal jet (combined with fixed appliances), both in distalizing the maxillary molars and in controlling anchorage loss.

The analysis of the changes from T2 to T3 showed that the pendulum group had a greater tendency to rebound in the sagittal position of the maxillary first molars (2.5 mm greater mesial movement than in the distal jet group). About 90% of the molar distalization achieved during the first phase of treatment in the pendulum group was lost during the second phase of treatment. The amount of relapse in the sagittal position of the maxillary first molars in the distal jet group, however, was greater than the amount of distalization achieved during the first phase of treatment (Figs 3 and 4).

As expected, the premolars also experienced positional rebound from T2 to T3. They moved and tipped distally 2.1 mm and 2.7° in the distal jet group and 1.4 mm and 1.6° in the pendulum group. The maxillary incisors, which were flared significantly during phase 1, were retracted and tipped lingually in the distal jet patients (Fig 3). Such "round tripping" of the incisor position might lead to undesirable side effects, such as increased root resorption.[59] For the pendulum patients, edgewise treatment did not flare the maxillary incisors, as was seen in the distal jet patients during molar distalization. An advantage was that the space created from molar distalization could be used to align the anterior segment.

For the distal jet patients from T2 to T3, the maxillary molars were 0.6 mm mesial of their original positions. This surprising result agreed with that of Ngantung et al,[27] who found 1.8 mm net mesial change in maxillary first molar position at the end of treatment. In the pendulum group, the maxillary first molars were 0.5 mm distal of their pretreatment positions at T3 (31 months). However, the total molar corrections were not significantly different between the groups, and, most importantly, both groups achieved and maintained Class I molar relationships.

The forward movement of the maxillary molars after applying a device for distalization must be expected as part of a normal process of dentoalveolar compensation. As the mandible continues to outgrow the maxilla, and through intercuspation of the buccal segment and dentoalveolar compensation, the maxillary molars need to move mesially to maintain the Class I molar relationship.[7]

At T3, the premolars maintained approximately the same positions as at T1 in both groups, whereas both the maxillary and mandibular incisors had more proclination in the distal jet group. Because the maxillary and mandibular incisors moved similarly in each group, however, total overjet and overbite corrections were the same in the groups. Overall, both appliances had minimal impact on soft tissue profiles.

CONCLUSIONS

The distal jet and the pendulum appliances are 2 intraoral molar distalization appliances commonly used in the treatment of Class II malocclusions. This study compared the treatment effects of the distal jet with concurrent full-fixed appliances and the pendulum appliance followed by fixed appliances.

Our findings can be summarized as follows:

1. During molar distalization, the pendulum subjects demonstrated significantly more distal molar movement and significantly less anchorage loss at both the premolars and the maxillary incisors than did the distal jet group.
2. The distal jet used simultaneously with fixed appliances and the pendulum were equal in their abilities to move the molars bodily.
3. At the end of comprehensive treatment, the maxillary first molars were 0.6 mm mesial to their original positions in the distal jet group, and 0.5 mm distal in the pendulum group. Nevertheless, total molar correction was identical in the 2 groups (3.0 mm), and both appliances were equally effective in achieving a Class I molar relationship at the end of treatment.
4. Simultaneous edgewise orthodontic treatment during molar distalization in the distal jet group shortened the overall treatment time but produced significant flaring of both maxillary and mandibular incisors at the end of treatment.

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