Original Article

Evaluation of Maxillary Molar Distalization With the Distal Jet: A Comparison With Other Contemporary Methods

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Abstract: Maxillary molar distalization is an increasingly popular option for the resolution of Class II malocclusions. This communication describes the effects of one particular molar distalizing appliance, the distal jet, in a sample of 20 consecutively treated and growing subjects (11 females, nine males; mean starting age of 13) and compares these effects with those of similar devices. Pre- and postdistalization cephalometric radiographs and dental models were analyzed to determine the dental and skeletal effects. The distal jet appliances were constructed using a biomechanical couple to direct the distalizing force to the level of the maxillary first molar's center of resistance. The distal jet was the only appliance used during the distalization phase of treatment. Examination of the cephalometric tracings demonstrated that the crowns of the maxillary first molars were distalized an average of 3.2 mm into a Class I molar relationship. In the process, the first molars were tipped distally an average of 3.1°, however, the amount of tipping in each case was influenced by the state of eruption of the second molar. In subjects whose second molars had erupted only to the level of the apical third of the first molar roots, distal tipping was almost twice that seen when the second molar had completed their eruption. Anchorage loss measured at the first premolars averaged 1.3 mm, but the crowns tipped 3.1° distally because of the design of the appliance. The maxillary incisors were proclined an average of 0.6° with minimal effect on the mandibular plane angle and lower facial height. This study suggests that the distal jet appliance effectively moves the maxillary molars distally into a Class I molar relationship with minimal distal tipping, however, some loss of anchorage is to be expected during this process. The distal jet appliance compares favorably with other intraoral distalization devices and with mechanics featuring mandibular protraction for the resolution of patients with Class II, despite the fact that these types of mechanics address different jaws. (*Angle Orthod* 2002;72:481–494.)

Key Words: Class II; Molar distalization; Distal jet

INTRODUCTION

Class II malocclusions form a heterogeneous group of patients that represents a significant portion of the patients who typically present for orthodontic treatment. Resolving Class II molar relationships by distalizing maxillary molars may be indicated for patients with maxillary dentoalveolar protrusion or minor skeletal discrepancies (but not for those patients who also exhibit significant dental crowding).

Behrents[1] has stated that patient cooperation is the most important key to any treatment success; however, patient adherence is said to be decreasing[2] and cooperation with prescribed intraoral and extraoral devices (ie, removable functional appliances, intermaxillary elastics, and headgear) is unpredictable.[3–6] Consequently, treatments that reduce dependence on patient compliance may produce more predictable results than those that require cooperation.

Molar distalization

Extraoral traction (ie, headgear) has a long history of use in Class II correction and is designed to push the maxilla and the maxillary dentition posteriorly. Angle,[7] for example, used many forms of extraoral traction, and Kloehn[8] advocated early headgear treatment to guide the growth of the maxilla and to provide a ''gentle force to move the teeth that need to be moved.'' Kloehn's goal was to distalize the maxillary teeth into a correct relationship with the mandibular dentition. Graber[9] noted that when extraoral traction was applied to the maxillary first molar, without the pres-

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Accepted: August 2002. Submitted: January 2002.

ence of the erupted maxillary second molar, the first molar tipped distally rather than exhibiting bodily movement. To help prevent this tipping, Cetlin[10] combined part-time extraoral force with full-time intraoral force (ie, a removable maxillary molar distalizing appliance). The intent of these combined mechanics was to create bodily molar movement: the constant force of the removable appliance is said to tip the crown distally while the headgear controls root position. During distalization, Cetlin argued that the maxillary second molars erupt normally and traction from the transeptal fibers causes the second premolars to move distally along with the first molars.

The effects of another alternative for distalization, Wilson modular mechanics,[11] were studied by Rana and Becher[12] who reported that this appliance system moves the molars posteriorly about one mm with 2° of distal tipping. They also reported a concurrent 3.5° of flaring and 2.7 mm of extrusion of the maxillary anterior teeth. In comparison, Muse et al[13] reported that Wilson mechanics produce a bit more distalization (two mm) but substantially more molar tipping (7.8°). Consequently, Wilson mechanics produce only a limited amount of distal molar movement and, furthermore, may stress mandibular anchorage and are totally dependent upon patient cooperation with intermaxillary elastics.

Unfortunately, the use of extraoral traction, removable appliances, and intermaxillary elastics to generate distally directed forces requires considerable patient compliance for success. Alternative methods have been proposed to diminish the need for patient cooperation.[14–21] Despite the effectiveness of many of these appliances in moving posterior teeth distally, they all produce a certain amount of anterior anchorage loss—mesial movement of anchoring teeth and proclination of maxillary incisors. In addition, they also tend to produce some distal tipping of the maxillary molars, rather than pure bodily movement. These limitations introduce inefficiencies into the Class II correction, specifically, round tripping of the incisors and posterior anchorage loss during the retraction of the other maxillary teeth.

Noncompliance molar distalizers

Many noncompliance fixed appliances have been developed to apply a distal force to the maxillary molars. Ghosh and Nanda[22] evaluated 41 subjects treated with one such device, the pendulum appliance, and found that 57% of the maxillary space created was from molar distalization. The remaining 43% resulted from anchorage loss (mesial movement) measured at the maxillary first premolars and anterior teeth. They also reported an average of 8.4° of first molar distal tipping. This report stands in contrast to the 10.7° of tipping but only 19% anchorage loss described by Chiu.[23] Other studies have reported even more molar tipping (13.1–15.7°) with the pendulum.[24–26] On the balance, it might be concluded that the pendulum produces from 8° to 16° of molar tipping and from 19% to 43% anchorage loss. This substantial distal tipping and a concern for undesirable bite opening led Bussick and McNamara[27] to suggest that the pendulum appliance is used most effectively when the appliance is constructed with anchorage support from maxillary second deciduous molars and when maxillary permanent second molars are unerupted.

Brickman et al[28] examined the results of 72 consecutive subjects treated with another distalizing device, the Jones jig. They found that 55% of the space created between the molar and premolar was from distal movement of the first molar crown, an amount similar to that reported by Ghosh and Nanda[22] for the pendulum appliance. Haydar and Uner[29] reported that the Jones jig produced distalization much like a cervical headgear but with a 55% anchorage loss. Runge et al[30] found 50% of the space was generated from mesial premolar movement, whereas Gulati et al[31] described only 26% anchorage loss with the Jones jig. Therefore, treatment with the Jones jig produces from 26% to 55% anchorage loss, an amount similar to that found with the pendulum.

Distal jet

Among the aforementioned appliances, the distal jet, a lingual distalization appliance, is said to feature several distinct advantages.[21,32] The maxillary molars are distalized with less distal tipping and without the lingual movement that occurs with the pendulum, and the distal jet can be easily converted into a Nance holding arch to maintain the distalized molar position.[33–37]

Patel[35] examined the records of 35 subjects (average starting age of 12 years), 24 of whom were treated with the distal jet in combination with full fixed brackets, and 11 with the distal jet alone. He found two mm of distal molar movement per side with 3.8° of distal tipping. Huerter[34] examined a sample of 28 similar subjects (starting age of 13) and reported 3.1 mm of first molar distalization and 5.6° of tipping during a treatment period of seven months. In addition, a 2.4 mm increase in lower anterior face height but only a 0.8° increase in SN-GoGn was described. Anchorage loss, measured at the second premolars, was 2.1 mm with 1.3° of mesial crown tip. Davis[37] studied 30 similar subjects and reported that the first molar was moved three mm but tipped 6°. Lower anterior face height increased 3.2 mm with a minor 0.4° increase in FMA.

The distal jet with full fixed brackets produces less molar tipping than other intraoral alternatives such as the pendulum, Jones jig, Greenfield molar distalizing appliance[36] and the sagittal appliance.[37] These studies also suggest that mild increases in lower anterior facial height are related to the amount of molar tipping generated during distalization. Perhaps appliances with better control of molar inclination (eg, distal jet) might diminish the risk, however small, of clinically significant vertical changes.

To reduce anchorage loss, Gianelly et al[38] recommended that molar distalization be performed before the eruption of the maxillary second molars. Several investigators, however, have found no difference in distalization and anchorage loss for the pendulum,[22] Jones jig,[28] and distal jet[23,34,35] when second molars were unerupted or erupted. Bussick and McNamara,[27] Huerter,[34] and Chiu[23] discovered a mild increase in the mandibular plane angle during distalization when second molars were erupted. In contrast, Huerter[34] described less anchorage loss when the second molars were completely erupted. The effect of the eruption status of second molars on distalization is inconclusive.

Molar distalization is contraindicated for hyperdivergent patients.[39] This admonition is based on the assumption that, when maxillary molars are distalized into the wedge of the occlusion, they will prop open the bite. This effect, combined with a backward rotation of the mandible, is said to increase the vertical dimension, especially in high angle cases. Ghosh and Nanda[22] reported that such an increase is indeed the case for subjects treated with the Jones jig. Huerter[34] divided a sample of distal jet subjects into three groups on the basis of their pretreatment mandibular plane (SN-GoGn less than 32°; between 32° and 38°; and greater than 38°). Although the samples for each group were small, there were no significant increases in lower anterior face height among any of the three treatment groups, despite some mild extrusion of the first molars (0.5–1.0 mm). Other studies have demonstrated similar findings for other methods of molar distalization. Indeed, some have even reported molar intrusion.[22,25–27,35]

Unfortunately, most of the reports of the effects of the distal jet have examined samples of subjects that were treated with full fixed appliances at the same time,[34,35,37,40] thereby making it difficult to isolate the effects from only the distal jet. Gutierrez[41] evaluated the effects of the distal jet with and without brackets and found that greater distal movement of the maxillary first molar was achieved when the distal jet was used alone (3.7 mm vs 2.6 mm), however, there was greater distal tipping (7.3° vs 4.7°). The most significant finding was dramatically less maxillary incisor flaring when the distal jet was used alone (2.2° vs 12.3°). The majority of this excessive proclination (about 10°) results from the 6–8 month leveling process with preadjusted appliances. Although the incisors were flared labially during distalization with brackets, they recovered to a normal incisal angulation by the completion of treatment.[23,34] Both Chiu[23] and Gutierrez[41] described less incisor tipping without brackets, but Chiu (in contrast to Gutierrez' findings) also reported less molar tipping (3.8° vs 5°) when the distal jet was used alone.

Clearly, the previous findings do not support the notion that incorporating more teeth into anchorage improves resistance to undesirable reactive forces. In fact, there is little anchorage value to mobilized teeth.[23,42] Consequently, the only possible advantages from the placement of maxillary fixed brackets during distalization may be a minor reduction in total treatment time[23,41] or the possibility of adding supplemental forces (eg, elastics or headgear) if desired. The use of only mandibular fixed brackets to facilitate leveling and alignment during maxillary molar distalization may serve as a useful compromise. The remaining maxillary brackets would then be placed after the completion of distalization.

The aim of the present clinical study was to evaluate the nature of maxillary molar movement with the distal jet alone, to determine the extent of mesial movement of the anchorage unit, and to contrast its effects to that of other comparable devices.

MATERIALS AND METHODS

The sample for this retrospective analysis of the distal jet molar distalizing appliance consisted of 20 consecutively treated Class II orthodontic patients (11 females; nine males) obtained from the private practice of two clinicians. The mean age of the sample at the time of the initial records was 12.6 (SD ± 2.3).

The criteria for subject selection included

- Need for nonextraction treatment (ie, mild to moderate crowding);
- Molar distalization achieved only with the distal jet in the first phase of treatment;
- Availability of good quality radiographs and dental models (before treatment and after distalization).

Presence of maxillary second permanent molars

The 20 consecutively treated cases included nine subjects with maxillary second molars not yet emerged into the oral cavity. The second molars were partly erupted in five subjects and completely erupted in the remaining six subjects. No attachments were placed on any second molars during distalization and, therefore, the effects of second molar position on molar distalization could be isolated and examined.

Fabrication of the distal jet

The distal jets used in this study were constructed with two bilateral tubes embedded in a modified acrylic Nance palatal button according to the recommendations of the inventors of the distal jet (Figure 1).[21,32] The position of these tubes is critical for proper functioning and will be discussed later. The Nance buttons were anchored by supporting wires to the first premolars. A bayonet wire was inserted into the lingual sheath of each first molar band and the free end was inserted into the tubes, much like a piston. A nickel-titanium open-coil spring and an activation collar (ie, screw clamp) were placed on each tube. Compressing the coil spring generated a distally directed force. The activation

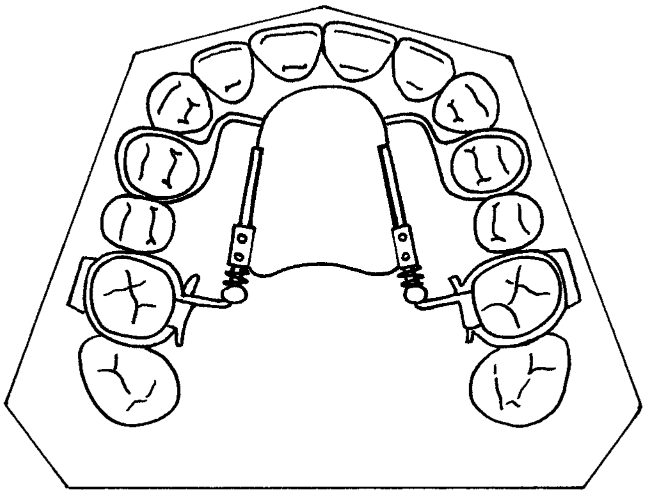

FIGURE 1. The distal jet consists of two bilateral tubes embedded in a modified acrylic Nance palatal button that is anchored to the first premolars. A bayonet wire is inserted into the lingual sheath of the first molar band and the free end is inserted into the tube, much like a piston. A superelastic open-coil spring is compressed along the tube by retracting an activation collar and locking the mesial setscrew in each collar onto the tube to maintain the force to distalize the molars.

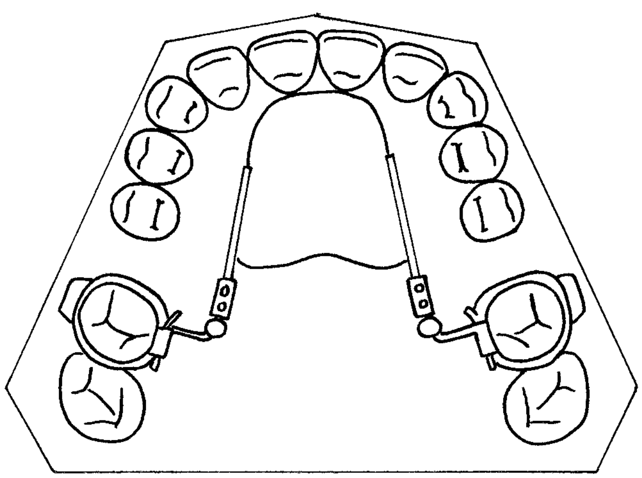

FIGURE 2. Conversion to a Nance holding arch subsequent to completing molar distalization. Both setscrews in the activation collar are locked onto the tube/piston or blocked with light-cured acrylic to create a solid support from the first molars to the modified Nance palatal button. The premolar support arms are removed by sectioning them with a hand piece and bur. The remaining maxillary dentition may be retracted using conventional orthodontic mechanics.

collar was retracted and the mesial setscrew in each collar was locked onto the tube to maintain the force.

Once the first molars had been moved into a Class I (normal) relationship, the distal jet appliance was converted into a modified Nance holding arch by sealing the clamp-spring assemblies with cold cure acrylic[21] or by locking the double screws of the activation collar onto the tube and piston.[43] Subsequently, the supporting wires to the first premolars were cut and removed (Figure 2).

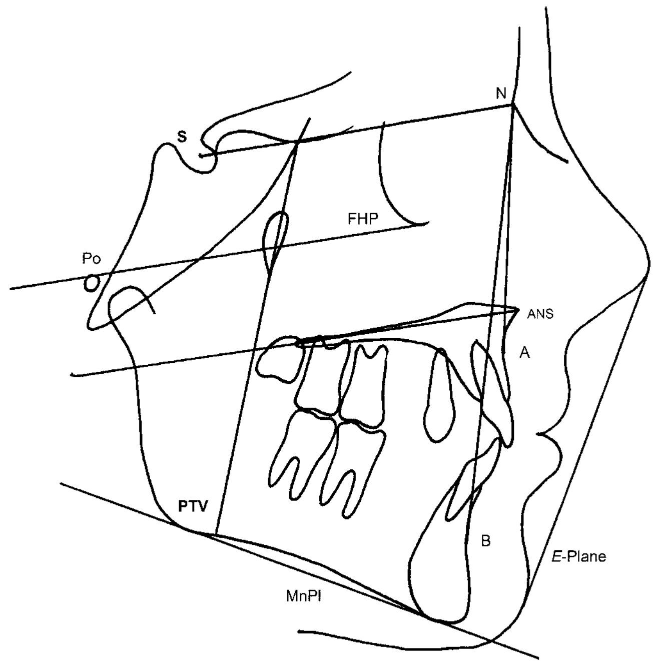

FIGURE 3. Cephalometric measurements used to analyze the effects of the distal jet appliance (after Ghosh and Nanda).[22]

Cephalometric analysis

The methods of cephalometric analysis used here to determine the effects of the distal jet appliance were described by Ghosh and Nanda (Figures 3–5).[22,28,40] This method of cephalometric analysis has been used in several previous studies examining the effects of other devices used to move maxillary molars distally and it was chosen in the hope that the results from this study could be reasonably compared with others using the same analysis. Cephalometric radiographs were obtained on all subjects both before treatment and after complete molar distalization, when the distal jet was converted into a modified Nance button (Figure 2). The average duration between the pretreatment and postdistalization radiograph was about five months (range, 2–6 months). Ten randomly selected cephalograms from the sample were retraced and redigitized by the same examiner. A Student's *t*-test was used to compare the two tracings for these cephalograms and demonstrated no statistically significant measurement errors ($P < .05$).

Dental cast analysis

The dental cast analysis was performed according to the technique of Ghosh and Nanda to determine any maxillary transverse or molar rotational changes.[22] Three sets of casts were missing or distorted and, therefore, for this portion of the study N = 17. The mean Class II cusp relationship measured at the beginning of treatment, was the same on both the right and left for these 17 cases. Transverse measurements were recorded between the buccal cusp tips of the maxillary first and second premolars along with the me-

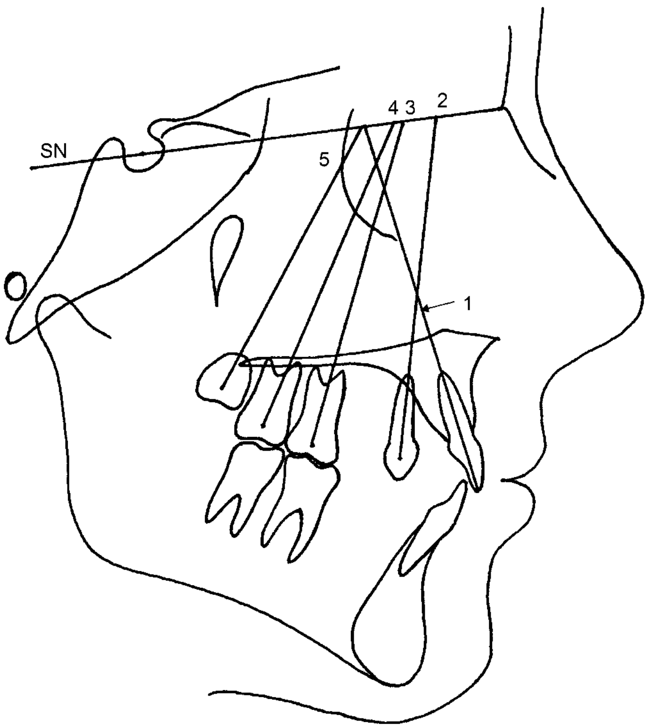

FIGURE 4. Angular cephalometric measurements. 1, SN-maxillary incisor; 2, SN-maxillary first premolar; 3, SN-maxillary first molar; 4, SN-maxillary second molar; 5, SN-maxillary third molar.

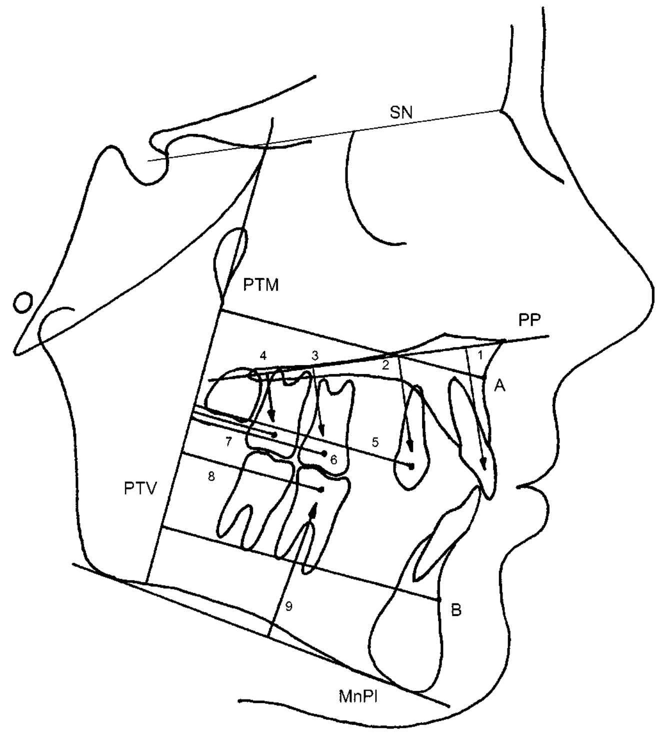

FIGURE 5. Linear cephalometric measurements. 1, PP-maxillary incisor tip; 2, PP-maxillary first premolar centroid; 3, PP- maxillary first molar centroid; 4, PP- maxillary second molar centroid; 5, PTV- maxillary first premolar centroid; 6, PTV- maxillary first molar centroid; 7, PTV- maxillary second molar centroid; 8, PTV-mandibular first molar centroid; 9, MNPl- mandibular first molar centroid.

siobuccal and distobuccal cusp tips of the maxillary first and second molars.

Statistics

Means and the standard deviations for the pre- (T0) and postdistalization (T1) measurements and the changes (T0 to T1) were calculated for the various cephalometric and transverse dental measurements. Student's *t*-tests were used to analyze the differences between pre- and postdistalization cephalometric landmarks measurements for all subjects and also in a comparison of subjects with erupted and without erupted second molars.

RESULTS

Pre- and postdistalization cephalometric data are summarized in Tables 1 and 2, whereas dental-cast measurements and their changes are summarized in Table 3. During the molar distalization phase of treatment, the crowns of the maxillary first molars were distalized an average of 3.2 mm (SD 1.4) and were also tipped distally 3.1° (SD 2.8°; Table 2). In the same treatment phase, the first premolars moved mesially 1.3 mm (SD 1.5) with a distal axial incline of 2.8° (SD 4°). Therefore, the total space created between molars and premolar was about 4.5 mm. In addition, the maxillary first molars extruded 0.5 mm (SD 1.5) and the first premolars extruded 1.1 mm (SD 1.6). The maxillary second molars were also distalized 2.7 mm (SD 1.8), tipped distally 4.9° (SD 4.7°) and extruded 1.1 mm (SD 2.0).

The position of the maxillary incisors and overjet did not change significantly during molar distalization. There was an insignificant increase in lower anterior facial height (0.9 mm) with no significant difference among subjects with high, neutral, or low pretreatment mandibular plane angles. In fact, the pretreatment mandibular plane angle remained about the same during molar distalization.

Examination of the dental casts demonstrated significant maxillary transverse changes during distalization (Table 3). The distal jet produced 2.9 mm of intermolar width expansion, accompanied by a mild distal rotation of the palatal cusps of the first molars.

DISCUSSION

Molar distalization and tipping

During a five-month period, the distal jet moved the crowns of the maxillary first molars distally an average of 3.2 mm/side into a Class I relationship (Table 2). For the present sample of 20 subjects, treated consecutively only with the distal jet, the maxillary first molars were also tipped distally an average of 3.1°. This was a lesser effect than reported by Guiterrez[41] (7.3°) but comparable to that

TABLE 1. Pre- and Posttreatment Cephalometric Measurements (N = 20)

Measure	Pretreatment (T0)				Posttreatment (T1)			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Soft tissue								
UL-*E* plane (mm)	−0.7	2.6	−4.0	6.2	−1.4	2.3	−3.3	5.7
LL-*E* plane (mm)	0.9	2.2	−4.5	4.0	0.4	2.6	−3.8	4.1
Skeletal								
SN-palatal plane (°)	8.7	3.6	2.4	13.0	8.7	3.6	2.4	13.5
SN-occlusal plane (°)	18.2	4.3	16.1	23.6	18.8	4.5	14.9	23.6
FH-mandibular plane (°)	24.3	5.3	17.0	31.7	23.7	6.4	14.2	36.7
PTV-A (mm)	53.2	5.1	42.1	64.3	53.6	4.2	45.5	67.2
PTV-B (mm)	45.8	5.0	37.5	51.5	46.6	4.9	38.1	55.3
ANS-Menton (mm)	66.4	4.4	57.7	72.5	67.4	4.1	58.5	74.1
Dental-angular (°)								
SN-maxillary incisor	100.0	6.9	82.3	104.3	100.9	6.4	95.3	111.2
SN-maxillary first premolar	80.7	6.6	67.7	93.4	77.6	6.2	68.5	90.1
SN-maxillary first molar	67.7	4.6	62.1	76.3	64.5	6.1	57.9	76.2
SN-maxillary second molar	53.1	7.4	44.6	66.7	48.8	9.7	27.3	67.2
SN-maxillary third molar	45.3	6.8	34.6	50.0	41.5	9.2	25.3	49.8
Dental-linear (mm)								
PTV-maxillary first premolar centroid	37.9	3.6	34.5	42.5	38.9	4.2	31.9	42.8
PTV-maxillary first molar centroid	21.7	3.9	17.5	29.6	18.3	4.4	11.5	27.5
PTV-maxillary second molar centroid	12.4	3.3	9.6	19.1	9.7	2.8	5.5	12.3
PTV-maxillary third molar centroid	9.2	2.2	3.2	11.6	7.2	2.8	5.1	12.9
PTV-mandibular first molar centroid	18.6	5.1	12.1	29.4	20.3	4.4	13.2	22.7
PP-maxillary incisor tip	28.3	2.6	24.1	34.0	28.6	2.4	23.6	32.8
PP-maxillary first premolar centroid	20.9	2.1	15.9	23.8	21.3	1.8	17.3	23.5
PP-maxillary first molar centroid	17.1	2.4	12.8	19.6	17.5	2.3	14.3	22.4
PP-maxillary second molar centroid	9.4	4.8	1.9	15.3	10.4	4.0	4.6	15.3
PP-maxillary third molar centroid	−1.3	4.3	−4.6	5.4	−0.9	4.2	−6.8	4.7
MnPl-mandibular first molar centroid	24.8	2.7	21.4	30.8	26.4	2.6	23.6	33.4
Overjet	3.8	1.7	2.7	6.3	3.9	2.2	0.2	7.2
Overbite	3.0	1.8	0.6	6.5	2.9	1.9	0.5	5.4

seen by Chiu[23] (3.8°) in similar evaluations of the distal jet without concurrent use of orthodontic brackets (Table 4). On balance, the distal jet is likely to produce about three mm of molar crown distalization with from 3° to 7° of distal inclination.

Creation of space

During molar distalization with the distal jet, space was created between the maxillary first molar and first premolar, however, this space was not solely due to bodily movement of the molars. The reciprocal forces resulted in a loss of anterior anchorage that was responsible for some of the space that appeared.

In the present sample, distal movement of the molar crown contributed 71% of the 4.5 mm of space created on each side; the remainder—29%—resulted from mesial movement of the anchoring premolars (Table 5). Interestingly enough, a comparable sample of subjects, also treated only with the distal jet,[23] demonstrated molar distalization that contributed 85% of the 5.4 mm of space created on each side vs 15% from anchorage loss. Both these reports demonstrate slightly less anchorage loss when the distal jet is used alone compared with its use combined with full fixed brackets (Table 4).[34–36,40]

Previously, the distal jet has been reported to have generated from 1.9 to 3.7 mm of distalization per side[35,41] and from 0.4 to 3.0 mm of anchorage loss per side (Table 4).[23,35] Therefore, the total amount of space created during distalization ranged from 4.6 to 13.4 mm. These estimates of space are somewhat less than those reported for the pendulum (from 10 to 15 mm).[22,24–27] Yet it must be remembered that most of the evaluations of molar distalization devices have used measurements that were made on intraoral and cephalometric radiographs. Before this study, no estimates of space generated between molars and premolars, measured on study casts, were reported. The effects of possible molar and premolar rotation cannot be measured easily from radiographs. In any event, the distal jet creates spaces that are comparable to other similar devices (eg, Jones jig and pendulum).[22,24–31]

Anchorage loss and tipping of the premolars

The present sample demonstrated slightly less anchorage loss (mesial movement of premolars) than reports by Chiu[23]

TABLE 2. Changes in Cephalometric Measurements from Pretreatment to Postdistalization (N = 20). Where a Difference is Concluded, the Null Hypothesis was Rejected ($P < .05$) by Student's *t*-test

Measure	Mean	SD	Min	Max
Soft tissue				
UL-*E* plane (mm)	−0.4	2.4	−4.3	6.2
LL-*E* plane (mm)	−0.3	3.1	−5.2	5.3
Skeletal				
SN-palatal plane (°)	0.1	1.9	−3.4	3.6
SN-occlusal plane (°)	0.8	1.7	−1.5	4.2
FH-mandibular plane (°)	−0.3	2.2	−5.7	2.9
PTV-A (mm)	0.8	1.6	1.2	4.0
PTV-B (mm)	0.8	1.8	−2.4	5.6
ANS-Menton (mm)	0.9	1.9	−1.6	6.5
Dental-angular (°)				
SN-maxillary incisor	0.6	5.3	−8.3	6.5
SN-maxillary first premolar	−2.8*	4.0	−10.5	6.3
SN-maxillary first molar	−3.1*	2.8	−10.0	2.4
SN-maxillary second molar	−4.9*	4.7	−13.4	3.2
SN-maxillary third molar	−3.8*	4.1	−10.7	4.3
Dental-linear (mm)				
PTV-maxillary first premolar centroid	1.3*	1.5	−0.5	4.2
PTV-maxillary first molar centroid	−3.2*	1.4	−6.5	0.6
PTV-maxillary second molar centroid	−2.7*	1.8	−8.9	1.2
PTV-maxillary third molar centroid	1.5*	1.5	−6.6	0.3
PTV-mandibular first molar centroid	1.7*	2.1	−1.1	3.7
PP-maxillary incisor tip	0.6	0.9	−1.2	2.1
PP-maxillary first premolar centroid	1.1	1.6	−0.5	5.8
PP-maxillary first molar centroid	0.5	1.5	−1.4	4.6
PP-maxillary second molar centroid	1.1*	2.0	−0.4	6.7
PP-maxillary third molar centroid	0.8*	1.4	−2.2	3.6
MnPl-mandibular first molar centroid	1.7*	1.6	−0.9	4.6
Overjet	0.4	1.1	−2.5	2.4
Overbite	−0.3	0.8	−2.1	0.8

TABLE 3. Changes in Transverse Dental Measurements from Pre- to Postdistalization (N = 17)

Measure	Mean	SD	Min	Max
Between maxillary first premolars	0.5	2.2	−2.8	3.2
Between maxillary second premolars	1.0	1.7	−0.5	3.7
Between maxillary first molars				
Mesiobuccal cusp	2.9	2.9	−1.4	5.8
Distobuccal cusp	2.7	3.1	0.4	7.4
Between maxillary second molars				
Mesiobuccal cusp	1.1	1.6	0.0	2.3
Distobuccal cusp	0.8	3.2	−1.6	3.1

of a comparable sample of subjects (1.3 mm/side vs 2.0 mm/side). During distalization with the distal jet, the first premolars did not tend to tip mesially as found in many investigations of other intraoral distalizing devices.[22–24,27,28,30,34,36] In this study, the premolars exhibited 2.8° of distal tipping (Table 2). In comparison, Chiu[23] was the only investigator who has described distal tipping of the first premolar (−1.7°) with the pendulum appliance (Table 4). Thus, there is no consensus on the direction that premolars tip during the process of molar distalization with these popular devices.

Reports examining distal jets constructed with support on the second premolars and combined with full brackets described more anchorage loss (2.0–2.8 mm/side)[35,36] than the present sample featuring support to the first premolars and no brackets on the remaining teeth (Table 4). When second premolars were used for support, they were shown to tip from 4.3° distally to 6.3° mesially.[23,40] Chiu[23] attributed these variations in premolar angulation as simply because of ''tracing error.'' If, however, tracing error is used to explain the nearly 11° range in reported premolar tipping (mesially and distally), then this would cast doubt into the reliability of many of the other angular and perhaps linear measurements in studies evaluating other so-called distalizing devices.

Distal tipping of premolars with the distal jet may be due to the geometry of the appliance.[35,40] Specifically, the line of action of the distal force is directed by a couple from the tube/piston and coil spring assembly that is constructed superiorly to the crown of the first molar. The intent of this arrangement is to direct the forces parallel to the level of

TABLE 4. Results from Studies Examining the Effects of the Distal Jet. Note: Linear Measurements Are Per Side

Report	N	Starting Age	Treatment Time (Mos.)	Molar Crown Distalization	Molar Tipping (°)	Anchorage Loss	Premolar Tipping (°)
Patel, 1999[a]	35	11.7	10.5[b]	1.9	−2.2	2.8	−3
Huerter, 1999	28	13.1	6.8	3.1	−5.6	2.1	1.3
Gutierrez, 2001	30	12.5	7.8	2.6	−4.7	—	—
Gutierrez, 2001[c]	20	13.2	5.6	3.7	−7.3	—	—
Ngantung et al., 2001	33	12.8	6.7	2.1	−3.3	2.6	−4.3
Lee, 2001	25	12.6	7.0	3.2	−2.8	2.0	−2.3
Davis, 2001	30	12.5	7.9	3.0	−6.0	—	—
Chiu, 2001	33	12.3	10[b]	3.0	−5.0	2.5	0.3
Chiu, 2001[c]	20	11.3	10.5[b]	3.4	−3.8	2.0	2.4
Present sample[c]	20	13.0	5.0	3.2	−3.3	1.3	−2.8

[a] Results represent effects of the distal jet alone (N = 11) and with full fixed brackets (N = 24).
[b] Treatment intervals determined from pretreatment to postdistalization records dates, not actual starting date with the appliance.
[c] Results represent effects of the distal jet alone.

the center of resistance of the first molars to reduce molar tipping (Figure 1). Because the molars are distalized, these forces tend to cause some inferior rotation of the Nance palatal button, thereby tipping the first premolars distally.

In comparison with the distal jet, the pendulum appliance has demonstrated between 1.3 and 2.6 mm/side of first premolar anchorage loss[22,23] and from 1.7° of distal to 4.8° of mesial tipping.[23,24] The Jones jig exhibited similar amounts of second premolar anchorage loss (between 2.2 and 2.4 mm/side), but it also produced the most mesial tipping of the premolars (5.9–9.5°) of any of the appliances presently under discussion.[28,30] In conclusion, for the current methods of molar distalization involving reciprocal anchorage, some degree of anterior arch loss is the cost of achieving a Class I molar relationship.

Anchorage from first or second premolars

The pendulum typically has been constructed with support arms to the Nance button from the first premolars and the Jones jig from the second premolars. There are two more teeth to serve as anchorage when the distal jet is constructed with support derived from the second premolars.[43] When the present results for distal jets constructed using the first premolars are compared with those in which the second premolars were used, there is no significant difference in anchorage loss (Tables 4 and 5).[23,34–37,40,41]

Rate of distalization

After accounting for the contributions of reciprocal movements during distalization, it has been inferred that the average distalizing velocity of the distal jet for each first molar was 0.6 mm per month, somewhat less than that of both the Jones jig and pendulum.[23] The degree of tipping of the molars and premolars nonetheless plays a conspicuous role in the net amount of space created during distalization. If more distal tipping of molars and simultaneous mesial tipping of premolars is produced by an appliance (eg, pendulum, Jones jig), then more net space is created when producing a Class I molar relationship when compared with an appliance that produces less molar tipping and some distal tipping of the premolar (eg, distal jet). Because all subjects in the reports of the effects of the various distalizing devices were corrected to a Class I molar relationship in 5–7 months, the question arises, how much distalization do you need? "Enough to correct the Class II." Perhaps the relative rate of space opening vs tipping of the teeth adjacent to that space is of more importance clinically.

In the studies of noncompliance molar distalizing appliances, the dates of the pretreatment cephalograms were compared with the dates of the postdistalization radiographs to determine treatment intervals and hence the rate of distalization (amount of distalization/time). A methodological concern with some studies[23,35] is that the diagnostic records, including the cephalogram, are often taken several weeks or months before the delivery of some of these appliances. This treatment lag may be due to delays in scheduling the initiation of treatment or even delays required to outsource the fabrication of an appliance. For those clinicians interested in finding the fastest method of moving molars distally, these time differences and failing to account for the amount of molar and premolar tipping may confound estimates of the rates of distalization from different investigations.

Effects of second molar eruption

In the present sample, greater tipping of the maxillary first molars (4.3°) was found in the nine subjects whose second molars were unerupted (positioned at the apical third of the maxillary first molars) (Table 6). When the second molars were partly or totally erupted (N = 11) there was significantly less tipping of the first molar (2°). Normally, the center of resistance of the maxillary first molar is close to the trifurcation of the roots, but when the germ of the second molar is an obstacle to distal movement, the

TABLE 5. Effects of Molar Distalization Devices

Report	Appliance	N	Treatment Time (Mos.)	% Molar Distaliztion	% Anchorage Loss
Ghosh and Nanda, 1996	Pendulum	41	6.2	57	43
Byloff and Darendeliler, 1997	Pendulum	13	3.9	71	29
Bussick and McNamara, 2000	Pendulum	101	7.0	76	24
Burkhardt, 2000	Pendulum	30	6.5	84	16
Chaqués-Asensi and Kalra, 2001	Pendulum	26	6.5	71	29
Joseph and Butchart, 2000	Pendulum	7	3.4	58	42
Runge et al., 1998	Jones jig	13	6.2	50	50
Haydar and Uner, 2000	Jones jig	20	2.5	45	55
Gulati et al., 1998	Jones jig	10	3.0	74	26
Brickman et al., 2000	Jones jig	72	6.0	55	45
Patel, 1999[a]	Distal jet	35	10.5	38	62
Ngantung et al., 2000[a]	Distal jet	33	6.7	45	55
Huerter, 1999[a]	Distal jet	28	6.8	60	40
Lee, 2001[a]	Distal jet	25	7.0	62	38
Chiu, 2001[a]	Distal jet	33	10.0	67	33
Chiu, 2001	Distal jet	20	10.5	85	15
Present sample	Distal jet	20	5.0	71	29

[a] Results represent effects of the distal jet and full fixed preadjusted brackets.

TABLE 6. Effects of the Eruption Status of Maxillary Second Molars: Changes in Cephalometric Measurements from Pretreatment to Post-distalization (N = 20). Where a Difference is Concluded, the Null Hypothesis was Rejected at 5% Confidence by Student's *t*-test

	Maxillary Second Molars				
	Unerupted		Erupted		
Measure	Mean	SD	Mean	SD	*t*-test
Soft Tissue					
UL-*E* plane (mm)	−0.8	2.2	0.0	2.6	
LL-*E* plane (mm)	−0.2	3.1	−0.5	3.2	
Skeletal					
SN-palatal plane (°)	0.1	1.8	0.2	2.0	
SN-occlusal plane (°)	0.8	1.7	0.8	1.5	
FH-mandibular plane (°)	−1.0	2.9	0.3	1.2	
PTV-A (mm)	1.3	1.6	0.3	1.5	
PTV-B (mm)	1.8	2.0	0.6	1.0	
ANS-Menton (mm)	1.8	2.2	0.2	1.3	
Angular-dental (°)					
SN-maxillary incisor	0.2	4.7	1.3	5.7	
SN-maxillary first premolar	−1.5	4.1	−3.8	3.6	
SN-maxillary first molar	−4.3	2.7	−2.3	2.6	*
SN-maxillary second molar	−5.1	5.4	−4.6	4.3	
SN-maxillary third molar	−2.5	5.5	−4.8	3.6	*
Linear-dental (mm)					
PTV-maxillary first premolar centroid	1.7	1.7	0.9	1.3	*
PTV-maxillary first molar centroid	−3.2	1.8	−3.2	0.9	
PTV-maxillary second molar centroid	−2.8	2.7	−2.6	0.8	
PTV-maxillary third molar centroid	−1.0	1.0	−1.8	1.6	
PTV-mandibular first molar centroid	1.2	1.6	1.9	2.5	
PP-maxillary incisor tip	0.8	1.1	0.5	0.9	
PP-maxillary first premolar centroid	1.7	1.9	0.5	0.9	*
PP-maxillary first molar centroid	0.6	2.0	0.5	0.9	
PP-maxillary second molar centroid	2.1	2.5	0.2	0.5	*
PP-maxillary third molar centroid	1.2	1.8	0.6	1.2	*
MnPl-mandibular first molar centroid	1.7	1.7	1.7	1.1	
Overjet	0.6	0.7	0.1	1.3	
Overbite	−0.4	0.8	−0.3	0.8	

center of resistance tends to move superiorly and may lead to greater tipping. These findings confirm Graber's[9] observations of tipping of the first molar when distalizing with a cervical headgear before the eruption of the second molar.

There was also significantly less anchorage loss (1.7 mm vs 0.9 mm) and extrusion (1.7 mm vs 0.5 mm) measured at the first premolars for those subjects whose second molars were erupted as compared with those with unerupted second molars. As noted by other workers,[22,23,25,28,34,35] there was also no statistically significant difference in the amount of space created when second molars were unerupted or erupted (Table 6). In addition, there were no significant differences in the distalization and anchorage loss between males (N = 9) and females (N = 11). Despite the small sample size, these findings do not support the recommendations of Bussick and McNamara[27] and Gianelly[15] that distalization is always preferable before eruption of the second molars.

There was also an appliance design difference for those patients with erupted second molars and those without. A pair of precalibrated 240-g coil springs was used in constructing the distal jet for the 11 subjects whose second molars were erupted, whereas 180-g springs were used for the remainder. It was assumed that more force was necessary to distalize the first molars when the second molars were completely erupted. Perhaps, these greater forces played a significant role in reducing the tip of the molars and anchorage loss. Further investigation into the effects of using lower forces during distalization when second molars are erupted is being pursued.

Vertical effects

The maxillary first molars did not undergo any significant vertical changes during the molar distalization phase of treatment and, consequently, the mandibular plane remained virtually unchanged (−0.3°; Table 2). Similar results have been reported in other investigations of the distal jet.[34–37,41] In contrast, other noncompliance intraoral devices for molar distalization seem to produce a small increase in the mandibular plane angle.[12,22,25–28,30,31] There was also no significant increase in lower anterior face height (0.9 mm) in the present sample compared with that reported for the distal jet when combined with full fixed appliances (1.0–2.4 mm)[34,36] There were no significant changes in lower anterior face height among subjects with high, neutral, or low pretreatment mandibular planes, thereby confirming the findings reported previously by Huerter.[34]

Clockwise mandibular rotation may be produced when molars are distalized into the wedge. According to this simplified view of the relationship between the maxilla and mandible, the backwards movement of the molars would prop open the anterior dentition. Consequently, molar distalization often is not recommended as a treatment strategy for hyperdivergent patients (ie, those with open bites or

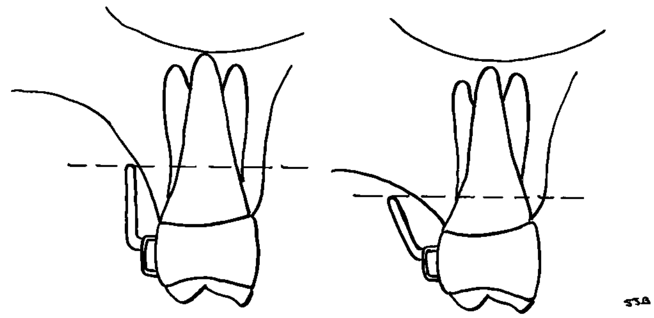

FIGURE 6. Effects of depth of the palatal vault on construction of the distal jet. (A) 4–5 mm of bayonet wire is recommended between the lingual sheath and the tube/piston to produce a line of action (by way of a couple) that is at the level of the center of resistance of the first molar. (B) Shallow palatal vaults may prevent the necessary length of wire and compromise the design of the Nance palatal button. Consequently, differences in construction may account for variations in performance of the distal jet.

high mandibular plane angles).[39] In reality, other elements such as the cant of the occlusal plane, the condyle to molar distance,[43–46] and occlusal forces,[47,48] may be more important risk factors for molar distalization if opening the vertical dimension is a concern.

Appliance construction

Regarding appliance construction, the orientation of the distalizing force, the anatomy of the palate, and the position of the germs of the maxillary second molars are all variables that influence molar tipping during distalization. The effects of these factors could help to explain the variation in results described in previous reports on the distal jet (Table 6).[23,33–37,40,41]

For example, the position of the tube/piston telescopic unit is critical for proper functioning of the distal jet. In the present study, the intent was to orient these tubes parallel but 4–5 mm superior to the occlusal plane (Figure 1).[21,32] The intent of this construction is to direct the line of action (by way of a couple) to the level of the center of resistance of the maxillary first molars. The depth of the palate also plays an important role in determining the position of this line of action and also the dimensions of the Nance palatal button. A shallow palate may prevent construction of a piston wire with sufficient vertical length from the first molar to the bayonet bend, thereby producing a line of action that is occlusal to the molar's center of resistance. This could, in turn, create more tipping of the molar during distalization (Figure 6).

In the present study, the orientation of the telescopic unit and presumably the line of action of the distal jet were evaluated on the lateral cephalogram. This orientation was measured to be an average of 4–5 mm apical to the maxillary first molar centroid; however, the telescopic units were not fabricated absolutely parallel to the occlusal plane but rather with the posterior portion of the device inclined

TABLE 7. Space Created (Per Side) During Distalization With Four Similar Methods

Report	Appliance	Molar Crown Distalization	Anchorage Loss	Total Space	Distance 6 to 4	"Effective" Space
Brickman et al., 2000	Jones jigs	2.5	2.4	4.9	11	1.6
Bussick and McNamara, 2000	Pendulum	5.7	1.8	7.5	14	4.3
Chiu, 2001[a]	Distal jet	3.0	2.5	5.5	12	4.1
Present sample	Distal jet	3.2	1.3	4.5	11	4.4

[a] Results represent effects of the distal jet and full fixed preadjusted brackets.

3.1° superiorly, towards the cranial base. This small difference in inclination may have reduced molar extrusion, and prevented increases in the vertical dimension but perhaps contributed to more molar tipping.

Large angulation errors in construction of the distal jet could result in more dramatic clinical concerns such as increased lower anterior face height resulting from extruded molars or the development of posterior open bites from intruded molars. Attention to detail, therefore, during the construction of this appliance is critical to its clinical performance. Previous studies of the distal jet have not described the construction details or commented on their significance to the final results. Consequently, the variation in performance seen in previous reports with this device may be partly because of differences in construction.

Molar width and rotational changes

Some maxillary expansion is often a prerequisite for Class II correction.[18,49] Subjects in the present sample demonstrated some transverse changes during molar distalization. Specifically, the intermolar width was increased an average of 2.9 mm (Table 3). This increase in width is necessary to maintain a proper transverse relationship of the maxillary to mandibular molars during distalization.

Lemons and Holmes[50] have reported that the majority of patients with Class II malocclusion exhibit maxillary first molars that are rotated mesially around the palatal root. Thus, a variety of methods to correct this molar rotation have been advocated.[10,18,49] In the present investigation, the first molars developed a mild but adverse distal rotation of the lingual cusps during distalization. Favorable molar expansion (3.7–4.4 mm) but undesirable rotations were also found in other studies of the distal jet.[34,35,41] In comparison, the pendulum, Jones jig, Greenfield appliance, and sagittal appliance produce a favorable distal rotation around the palatal roots; however, these appliances also delivered some undesirable constriction of the first molars.[19,22,27,28,35–37]

Altering the construction design can modulate the amount of maxillary first molar expansion from the distal jet. Typically, the distal jet is fabricated with the telescopic unit positioned parallel to a line passing through the contact points of the posterior teeth. With this geometry, distalization should produce divergence of the right and left molars along the natural shape of the dental arch form. Although this mild expansion is probably advantageous in Class II treatments,[18,49] patients who present a mild posterior crossbite might benefit from distal jet construction with a few degrees more divergence of the tube/piston or perhaps the addition of a jackscrew incorporated into the Nance palatal button.[43]

Because the distal force of the distal jet appliance is delivered lingually, it is not unreasonable to expect some distal rotation of the lingual cusps of the maxillary first molars. A simple modification to the design of the distal jet (a compensating bend placed in the double-back portion of the bayonet wire just before seating the distal jet)[43] may help to prevent adverse rotation of the molar or be used to create a distal rotation of the molar around the palatal root, a change that would be favorable to the correction of many Class II molar relationships.

A comparison with other distalization devices

If the total distance from the molars to the first premolars (the sum of the space created plus the width of the second premolars) for four popular distalization methods (ie, Jones jig, distal jet, distal jet with brackets, pendulum)[23,27,28] are compared, the total distance averaged 11 mm/side for the distal jet and Jones jigs, 12 mm/side for the distal jet with brackets, and 14 mm/side for the pendulum (Table 7). In the present sample, however, the distal jet produced significantly less tipping than that typically seen with other distalizing mechanics, such as the Wilson modular technique,[12] repelling magnets,[14,19,20] Jones jig,[28–31] and the pendulum.[22–27]

Each of these methods resolves the Class II molar relationship, but in the process there are some differences in the amount of space generated to achieve this correction. The total space created during distalization is defined as the sum of the molar distal movement and the anchorage loss. Each appliance produces some degree of tipping of both the molars and the premolars (Table 8). If the adverse tipping produced by each appliance is corrected to pretreatment angulations by molar or premolar uprighting (as though the appliance had generated pure bodily movement), then some decrease in the space that was created during distalization would be expected. The recovery of this tipping, therefore, would result in some degree of subsequent anchorage loss because the molars and premolars are tipped toward that space to parallel their roots.

A simple geometric calculation was performed for each of the appliances to account for the space loss that would

TABLE 8. Comparison of the Effects of Four Similar Molar Distalizing Appliances

Report	Appliance	Molar Crown Distalization	Molar Tipping (°)	Premolar Support	Anchorage Loss	Premolar Tipping (°)
Brickman et al., 2000	Jones jigs	2.5	7.0	second	2.4	5.9
Bussick and McNamara, 2000	Pendulum	5.7	10.6	first	1.8	1.5
Chiu, 2001[a]	Distal jet	3.0	5.0	second	2.5	0.3
Present sample	Distal jet	3.2	3.1	first	1.3	−2.8

[a] Results represent effects of the distal jet and full fixed preadjusted brackets.

result from uprighting the molars and premolars (Note: radius or r = estimated distance from centroid to apex):

$$\text{effective space} = \text{total} - ((\text{molar } \Delta/360°)(2)(\pi)(r) + (\text{premolar } \Delta/360°)(2)(\pi)(r))$$

The space remaining after the recovery of the tipping might be the effective space that each appliance created. The effective space was determined for each appliance by subtracting the anticipated space loss (from uprighting molars and premolars) from the total space that had been originally generated during the distalization process. From this examination, the Jones jig was the least effective because only 1.6 mm/side of space would be expected after uprighting the molars and especially the significantly tipped premolars. The pendulum, distal jet alone, and distal jet with fixed brackets all generated about four mm/side of effective space (Table 7).

Although the pendulum produced the greatest amount of total space between molars and premolars, it also required more recovery of the tipped molars and premolars (Table 7) than the distal jet used alone. The mechanics required to upright molars and premolars after distalization with the pendulum may increase the risk of further anchorage loss and introduce greater inefficiency into this system of Class II resolution.

Molar distalization vs Herbst mechanics

When the effects of maxillary molar distalization (subjects treated with the pendulum) were compared with the effects of mandibular protraction (subjects treated with the Herbst appliance), there were no significant differences in total treatment time (combining Phase I and II) or in the final skeletal, occlusal, and facial results.[51] Specifically, the amount of mandibular growth demonstrated in both samples was nearly identical, despite the fact that different jaws were being addressed by treatment in each sample. The present examination showed that the distal jet performed favorably when compared with the pendulum. Presumably, the distal jet would also be expected to compare favorably with Herbst-type mechanics for the treatment of Class II.

CONCLUSIONS

The distal jet is a fixed, lingual appliance designed to produce distalization of maxillary first molars. This device constitutes an effective and predictable method for the correction of a Class II malocclusion given that no patient cooperation is required. This consideration is particularly significant given that general patient compliance is said to be decreasing, is certainly individually unpredictable, and yet is the most important factor in determining treatment success.

The present study produced the following findings regarding the use of the distal jet appliance for the distal movement of maxillary first molars during the correction of Class II.

1. Class II molar relationships were corrected to Class I in about five months.
2. The typical age that treatment began was 12–13 years old, an age that corresponds to the optimum amount of mandibular growth, which may also be useful in resolving the Class II relationship.
3. The distalizing force on the maxillary molar resulted in 71% molar distalization and 29% reciprocal anchorage loss measured at the maxillary first premolar. This division is comparable to that reported for other types of intraoral methods of molar distalization.
4. The maxillary first molars were moved distally an average of 3.2 mm/side, with 3.1° of distal crown tipping. Net distalization was less than that seen with the pendulum; however, the amount of molar tipping was significantly less than has been found with comparable intraoral distalizing appliances, including the pendulum.
5. Anchorage loss, measured at the first premolars was 1.3 mm/side, with 2.8° of distal crown tipping. These results are comparable clinically to other intraoral distalizing appliances.
6. Less molar tipping (2.3° vs 4.3°) and anchorage loss (0.9 mm/side vs 1.7 mm/side) were noted for subjects whose maxillary second molars were partly or completely erupted when compared with those with second molars that were not erupted during distalization.
7. No significant vertical changes were observed during distalization.
8. If the recovery from tipping of both molars and premolars (ie, uprighting to pretreatment angulations) is subtracted from the total space generated by distalization, the effective space for the pendulum, distal jet with brackets, and distal jet alone was estimated to be about the same (four mm/side). It seems reasonable to assume

appliances that produce more tipping (eg, Jones jig, pendulum) may introduce more inefficiency into the system.

The distal jet appliance compares favorably with other intraoral distalization devices (eg, Jones jig and pendulum) and also with mechanics featuring mandibular protraction (eg, Herbst) for the resolution of patients with Class II, despite the fact that these appliances address different jaws.

ACKNOWLEDGMENTS

We thank Dr Lysle E. Johnston Jr, and Dr Robert W. Browne Professor of Dentistry and Chair, Department of Orthodontics and Pediatric Dentistry, the University of Michigan, for their editorial assistance in the preparation of this manuscript and Mr Brian Steele of Portage, Mich, for his assistance in the mathematic analysis.

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