Original Article

Biomechanics of a Distal Jet Appliance

Theoretical Considerations and In Vitro Analysis of Force Systems

Gero S. M. Kinzinger[a]; Peter R. Diedrich[b]

ABSTRACT

Objective: To analyze the forces and moments acting in the first molar region, induced by the Distal Jet appliance for maxillary molar distalization.

Materials and Methods: Over a working section of 3 mm with reactivation of the loaded spring systems, the force systems of three laboratory-fabricated appliances of identical design were analyzed with a 3D metering device.

Results: The force systems registered in vitro exhibited complex biomechanics. Regular reactivation of the loaded coils resulted in consistent distalizing forces and uprighting moments, in forces and moments toward buccal as well as slightly intrusive forces, and mesial-inwardly rotating moments. In the sagittal dimension, the Distal Jet appliance allows almost translatory molar distalization. Accordingly, applying uprighting activation is not necessary for treatment. Because of the application of the force palatal to the center of resistance of the molars, the teeth experience undesired mesial-palatal and distal-facial rotation.

Conclusions: The Distal Jet appliance allows almost translatory distal molar movement, and uprighting activation is not necessary for treatment. The force applied palatal to the center of resistance of the molars produces an undesired mesial-palatal and distal-facial rotation. Regular intraoral coil spring reactivation is needed.

KEY WORDS: Distal Jet; Molar distalization; Force-moment measurements

INTRODUCTION

Compliance-dependent appliances (headgear, removable plate appliances) were traditionally used for upper molar distalization. For over a decade, various innovative appliances have been described that are worn only intraorally, are placed to remain fixed temporarily, and make treatment success independent of patient compliance.

One of these appliances is the Distal Jet (American Orthodontics, Sheboygan, Wis).[1–3] The Distal Jet consists of a bilateral piston and tube arrangement, with the tube embedded in an acrylic Nance button in the palate, supported by attachments on the first or second premolars. A bayonet wire is inserted into the lingual sheath of each first molar band and the free end is inserted into the tubes, much like a piston. A nickel-titanium open-coil spring and an activation collar are placed around each tube. Compressing the coil spring generates a distally directed force. The activation collar is retracted and the mesial setscrew in each collar is locked onto the tube to maintain the force. The active components have to be placed palatally. Ideally, they result in lines of force running close to the center of resistance of the molars. As opposed to the cervical headgear with which molar distalization can be achieved only as a combination of dental crown tipping with subsequent root uprighting, the biomechanics of the appliance should, in theory, allow translatory molar distalization.

The aim of this study was to investigate the suitability of the Distal Jet for translatory distalization of the upper molars. To do so, in vitro analysis of the forces and moments exercised on the first molars was performed. Based on the results of the series of measurements, the efficiency of regular intraoral reactivation of the loaded compression springs is discussed along with the potential necessity to preactivate the appliance (uprighting activation, toe-in bend).

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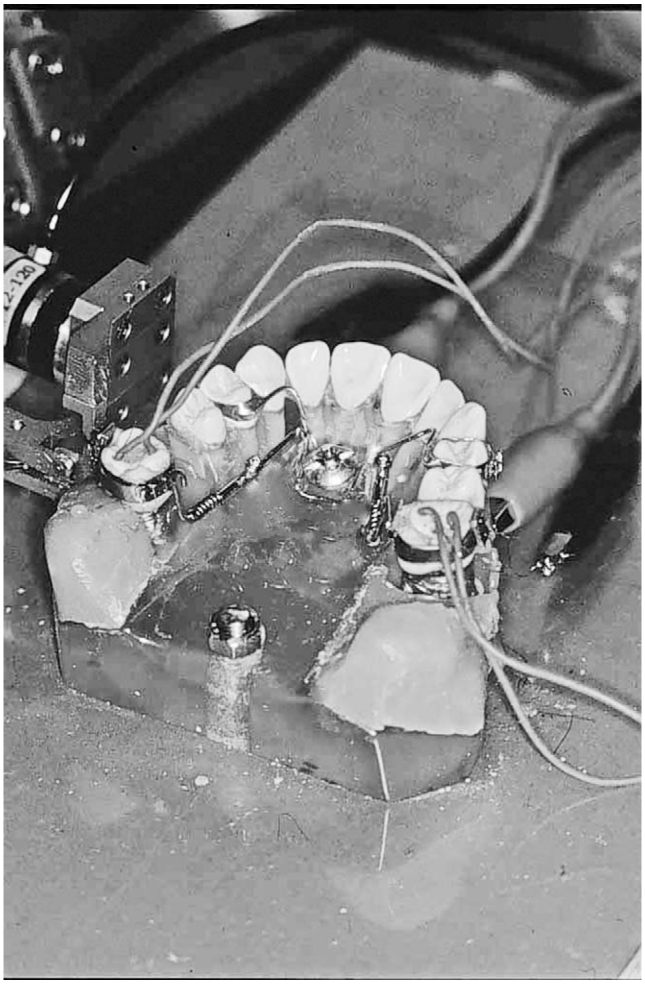


Figure 1. In vitro measurement: artificial jaw as anchorage unit and electrothermodynamic molars, rigidly fixed Distal Jet appliance, coupled force-moment sensor. Distal Jet design: bilateral piston and tube arrangement, tube embedded in an acrylic Nance button, supported by attachments on the first premolars; a bayonet wire inserted into the lingual sheath of each first molar band, the free end inserted into the tubes; a clamp-spring assembly around the tube, exerting a distal force on the first molar.

MATERIALS AND METHODS

In Vitro Measurement

The test setup comprised the following components: artificial maxilla of pressurized polymer with 10 rigidly fixed teeth as the anchorage unit, two electrothermodynamic molars,[4] electronic measuring unit for thermal control and regulation,[4] sensor unit with a force-moment sensor, analog/digital converter, and data readout unit (Figure 1).[5–7] To perform the measurements, prefabricated orthodontic metal bands were fitted to the molars, and a special bracket (Dentaurum, Ispringen, Germany) was laser-attached to each of the bands. Applying a defined voltage to the electrothermodynamic molars warmed them and liquefied the Kerr wax in their immediate vicinity.

At the start of the measurement series, the 3D sensor was connected to the sheath element of the special bracket using a clamping device and was then maintained in this position relative to the molar with a retainer. The measurement sensor at the heart of the metering device simultaneously sensed six components (3 forces and 3 moments) within a range of up to 10 N and 100 N mm with a resolution of 0.05 N and 0.1 N mm. The signals obtained from the meter were digitized by the data retrieval unit and then forces and moments were computed based on the calibration matrix. The values were subsequently processed on a portable metering computer. Three Distal Jet appliances each were constructed in the dental laboratory.

The loaded coil systems of the Distal Jet appliances were rigidly fixed to the artificial maxilla by two premolar bands and a screw at a median location, which simulated an orthodontic implant. The forces that the preactivated loaded spring systems exercised on the first molars were measured. Measurements were performed in all three spatial dimensions along a 3 mm distalization section by taking measurements every 0.5 mm. By reactivating the load of the compression springs, the distalization force of 200 cN was kept consistent over the entire length of distalization. Additional treatment-related preactivations (uprighting activation, toe-in bend) were not performed. Each Distal Jet appliance was registered four times on each side, ie, the appliance type was measured 24 times overall.

The components tooth, band, and palatal sheath were regarded as rigid. Because the midpoint of the system of coordinates of the sensor and the point where the force of the loaded coil systems is applied to the palatal sheath of the molar band are not identical, values were recalculated to match the midpoint of the palatal sheath using a conversion chart. It has to be noted that the dental arch of the artificial maxilla ended at the six-year molars. Therefore, since the design did not include second and third molars, the movement occurred free of any interference from distally neighboring teeth. The reactive forces and moments on the anchorage setup were not registered.

The data from the measuring series were registered and stored by the data readout unit. To facilitate interpretation of the results and for biomechanical analysis, the system of coordinates and the conventions governing signs were selected in accordance with the recommendations of Burstone and Koenig.[8] All mesially or buccally directed and extruding forces and all moments inducing mesial-inwardly rotating and buccally rotating movements of the tooth crown and uprighting of the root are preceded by a positive sign. All contrary, distally, or lingually directed and intrusive forces and moments inducing mesial-outwardly rotating or palatally rotating crown movements are given a neg-

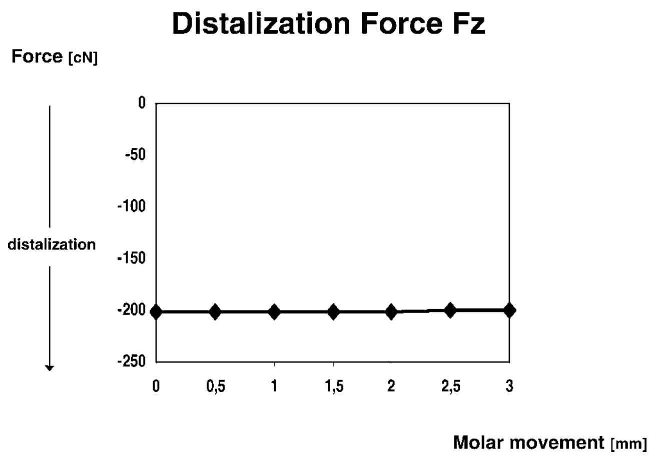


Figure 2. Distalization force Fz (means).

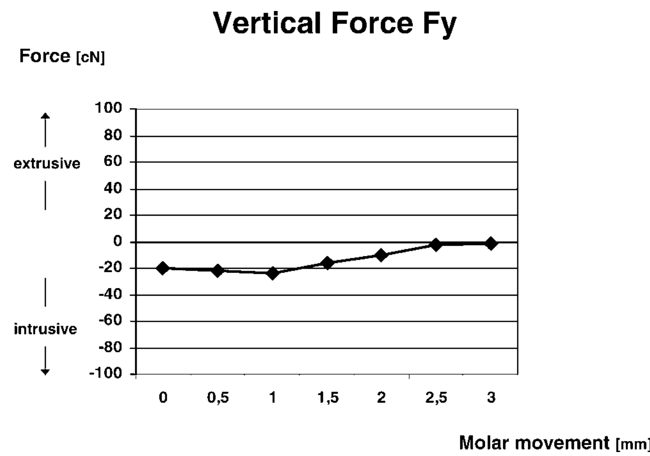


Figure 4. Vertical force Fy (means).

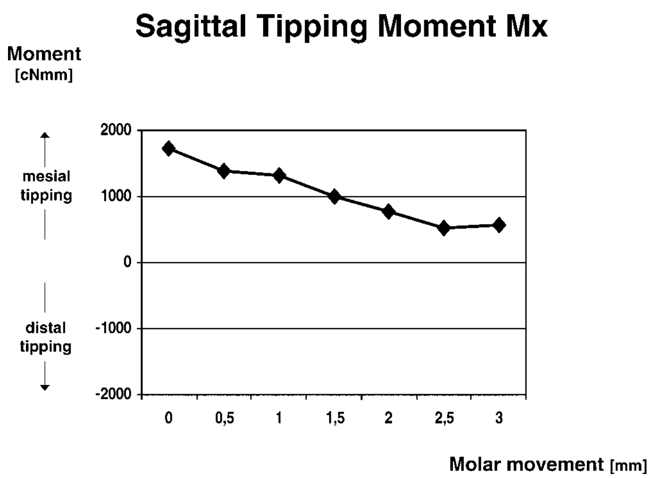


Figure 3. Sagittal tipping moment Mx (means).

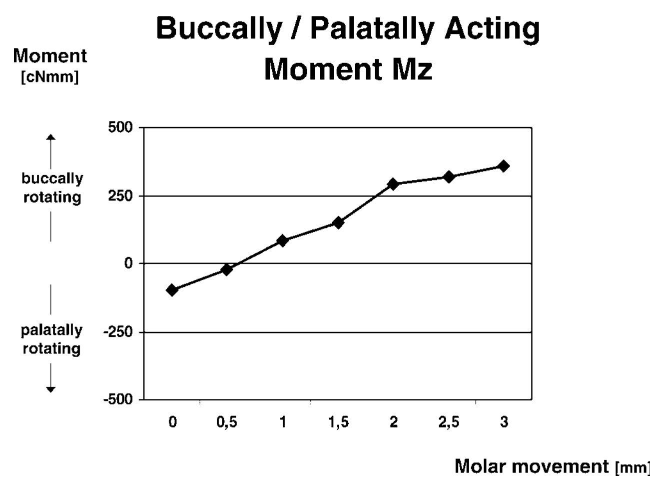


Figure 5. Buccally/palatally acting moment Mz (means).

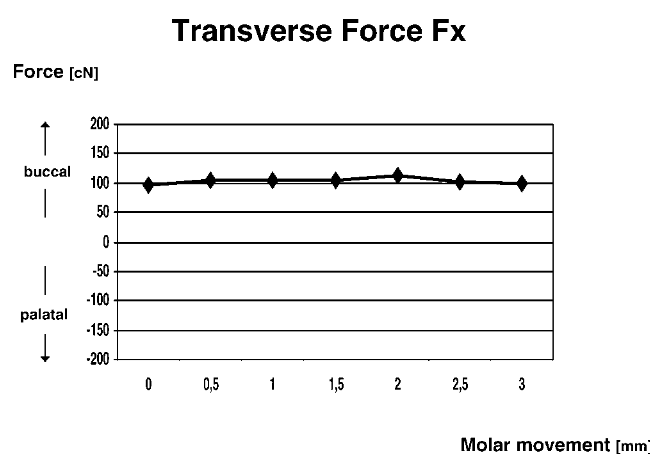


Figure 6. Transverse force Fx (means).

ative sign. The x-axis shows tooth movements in the transverse, the y-axis in the vertical, and the z-axis in the sagittal plane.

Statistical Analysis

The arithmetic means and the standard deviations were determined for each variable of the forces and moments. Measuring series designed for calibration of the sensor system have shown that the total error of electrical measurement was $<$2%.[5]

RESULTS

Details on in vitro measurement are shown in Figures 2 through 7 and Table 1. In the course of the series of measurements, the distalization force Fz was consistently kept at 200 cN by regular reactivation of the loaded compression coils. The moment Mx acting in the sagittal plane causes the molar to upright with initially high values of a mean 1718 cN mm which drop to 572 cN mm over the distalization length of 3 mm.

The vertical force Fy amounts to -21 cN at start and, accordingly, has an intrusive effect. It remains relatively stable until a distalization length of 1 mm is completed, and then drops consistently to approximate zero. The moment Mz causes a steadily increasing

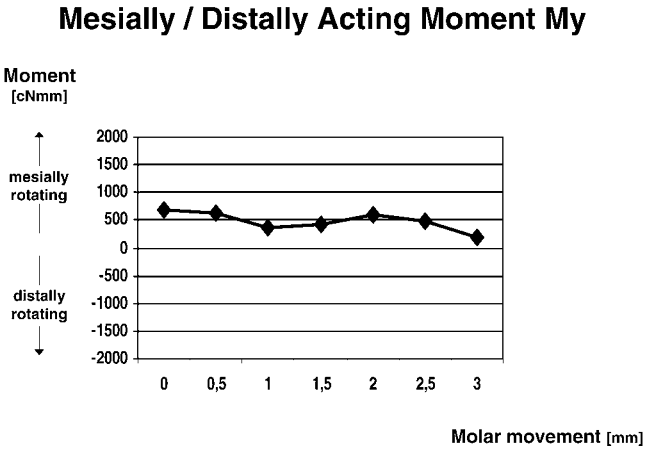


Figure 7. Mesially/distally acting moment My (means).

buccal coronal torque. The force Fx applied in the transverse dimension initially amounts to 97 cN and acts toward buccal. When the loaded springs are reactivated, the force values remain almost constant. The molars experience a mesially rotating moment My decreasing in the course of distalization (initially 700 cN mm; after 3 mm, 200 cN mm).

DISCUSSION

Distal molar movement should ideally be translatory, since histologic and clinical studies, just as finite element analyses, have shown that bodily tooth movements compromise the hard tissue less than tipping movements because of the more balanced distribution of force application across the surface.[9–16] It has yet to be seen if the biomechanics of the Distal Jet allows bodily, translatory movement of the molars toward distal and if supporting treatment measures (uprighting activation, toe-in bend) have to be taken.

One of the decisive factors of optimum effectiveness of the Distal Jet is its accurate construction in the dental laboratory: in every quadrant, the loaded coil systems have to be adjusted individually and three-dimensionally according to the position of the dental arch in the spongy alveoli. In the sagittal plane, the line of force which is a result of the application of the force −FD should ideally run through the center of resistance of the first molar (Figure 8A). An anatomic advantage in this respect is patients with a deep palate. No uprighting activation is necessary, which means that the corresponding vertical forces and moments exercised on the anchorage setup are nonexistent.

The distalization force $-F_D$ is counter-acted by a force F_A in the opposite direction that should be absorbed by the anchorage design as far as possible, in order to avoid undesired side effects (mesial movement of the anchorage teeth).

The distalization force $-F_D$ is applied in the horizontal dimension at the palatal sheath of the molar band. This results in a mesiopalatal and distobuccal torque M_R being exercised on the molars, which is the product of the force $-F_D$ multiplied by the vertical distance from the center of resistance of the molar (Figure 8B). Under the influence of the moment M_R, the molar experiences a therapeutically undesired mesial-inwardly and distal-outwardly rotation in the course of distalization.

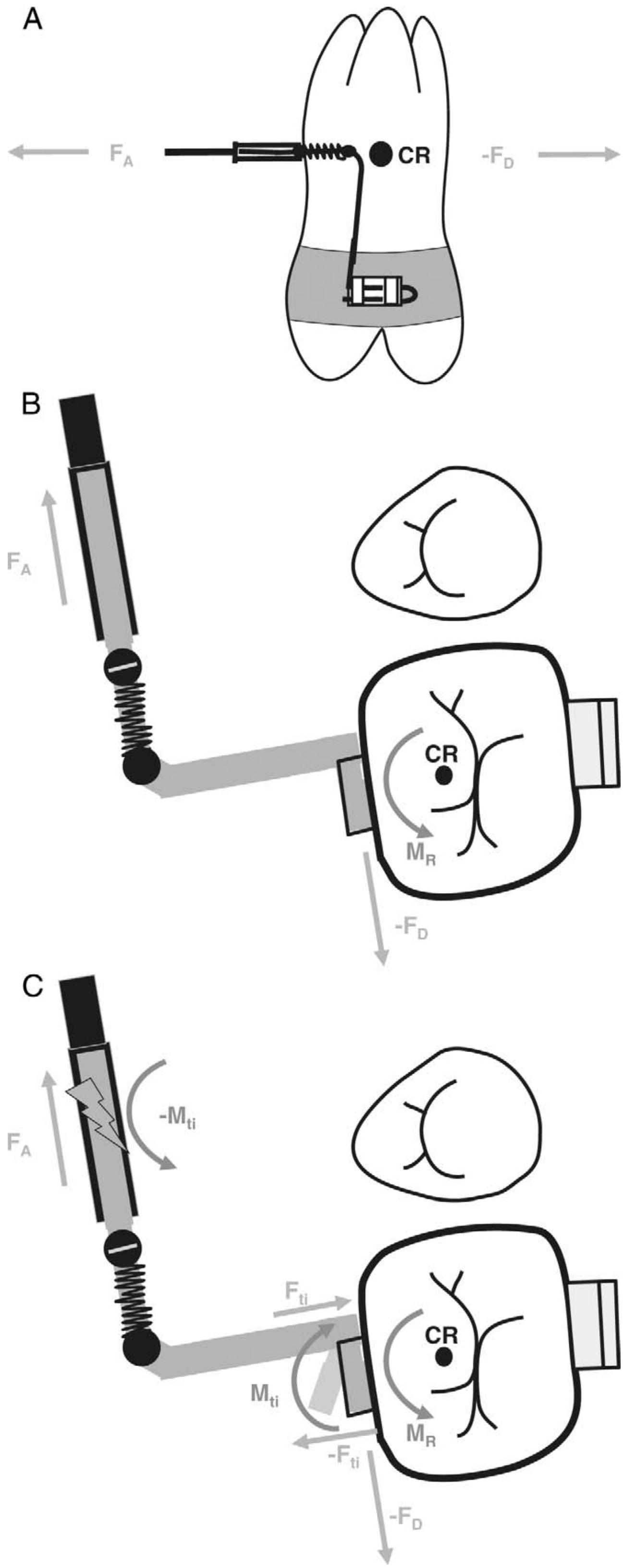
In theory, this effect can be compensated by making the application of a counter-moment part of the treatment. A toe-in bend incorporated directly into the wing of the arc section generates a moment $-M_{ti}$ acting mesiobuccally and distopalatally on the first molar and counter-acting the mesiopalatal and distobuccal moment M_R. At the same time, however, the moment $-M_{ti}$ acts onto the bayonet wire itself and causes friction in the guide tube of the appliance (Figure 8C). This effect was verified on the cast and by the in vitro measurements. The result is adhesion from tilting that substantially reduces distalization force and would hamper the distal movement of the tooth in clinical application.

Although it is therapeutically desirable, the incorporation of a toe-in bend should be avoided. Based on the appliance-specific biomechanics, it can be assumed that the first molar experiences a slight mesial-

Table 1. Forces and Moments Measured in Vitro at the Distal Jet Appliance[a]

Forces (F), cN / Moments M, cN mm	N	0 mm M	0 mm SD	0.5 mm M	0.5 mm SD	1 mm M	1 mm SD	1.5 mm M	1.5 mm SD	2 mm M	2 mm SD	2.5 mm M	2.5 mm SD	3 mm M	3 mm SD
Fx (transversal force)	24	97	51	104	60	106	71	104	70	113	66	103	59	101	64
My (mesially/distally acting moment)	24	700	1305	614	1049	367	976	425	910	611	1212	490	1014	200	898
Fy (vertical force)	24	−21	17	−22	14	−24	19	−16	19	−10	22	−3	22	−1	18
Mz (buccally/palatally acting moment)	24	−95	226	−22	232	83	314	151	321	294	397	317	350	358	430
Fz (distalization force)	24	−201	2	−201	2	−202	1	−201	1	−201	1	−200	2	−200	1
Mx (sagittal tipping moment)	24	1718	366	1395	440	1309	570	997	516	769	619	524	643	572	504

[a] N indicates number of measurements; M, mean; SD, standard deviation.



inwardly and distal-outwardly rotation in the course of distalization.

Results obtained from the in vitro measurements confirm the theoretical assumptions on the biomechanics. Over a distalization length of 3 mm, the distalization force Fz remained consistent thanks to regular reactivation of the loaded coil systems. In the sagittal plane, the combination of the consistently applied distal force of 200 cN plus a mesial inclining moment Mx allows an almost bodily movement of the tooth with uprighting effects for the dental root.

In the vertical dimension, a slightly intrusive force is acting at first, but consistently reduces in the course of the distalization. In parallel, the molar experiences buccal rotation. In the transverse plane, a consistent force toward buccal and a mesial rotating moment cause a combination of a buccal movement and a therapeutically undesired mesial-inwardly rotation of the six-year molar.

Clinical studies on the Distal Jet that are available today[17–20] have confirmed the mesial-inwardly rotation of the molars, but have also shown, as opposed to the results of the in vitro analysis, that in the sagittal plane the six-year molars experience slight distal tipping of the tooth crown rather than root uprighting.

Regarding appliance construction, the location of the center of resistance, 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 may explain the variation in results described in previous clinical studies on the Distal Jet.

However, the extent of distal tipping as reported in the clinical studies is very small. Therefore, uprighting activation is not needed during treatment. A potential analogy to the toe-in bend was verified in vitro and was found to occur insofar as the bayonet wire creates friction in the guiding tube. This hampers the distalization just as the toe-in. Rather, clinical practice should aim to perform an overcorrection distalizing the molars to a super Class I relationship, in order for them to be mesially uprighted to neutroclusion during the final stage of treatment. Subsequent to the Distal Jet treatment, molar derotation should be performed with an appropriate appliance, such as a transpalatal arch or a bihelix.

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Figure 8. Biomechanic approximations of the force systems acting in the horizontal and the sagittal dimensions. (A) Distalization of the first molar under the influence of the loaded coil system in the sagittal plane. (B) Distalization of the first molar under the influence of the loaded coil system in the horizontal plane. (C) Effects of a toe-in bend in the horizontal plane.

CONCLUSIONS

- In the sagittal dimension, the Distal Jet appliance allows almost translatory molar distalization. Accordingly, applying uprighting activation is not necessary for treatment.
- Because of the palatal force application to the center of resistance of the molars, the teeth experience therapeutically undesired mesial-inwardly and distal-outwardly rotation.
- Regular intraoral coil spring reactivation is needed.

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REFERENCES

1. Carano A, Testa M. The Distal Jet for upper molar distalization. *J Clin Orthod.* 1996;30:374–380.
2. Bowman SJ. Modifications of the distal jet. *J Clin Orthod.* 1998;32:549–556.
3. Carano A, Testa M, Bowman SJ. The distal jet simplified and updated. *J Clin Orthod.* 2002;36:586–590.
4. Rhee J-N, Chun Y-S, Row J. A comparison between friction and frictionless mechanics with a new typodont simulation system. *Am J Orthod Dentofacial Orthop.* 2001;119:292–299.
5. Rosarius N, Friedrich D, Fuhrmann R, Rau G, Diedrich P. Concept and development of a measuring system for in vivo recording of orthodontically applied forces and torques in the multiband technique. Part I. *J Orofac Orthop.* 1996;57:298–305.
6. Friedrich D, Rosarius N, Schwindke P, Rau G, Diedrich P. In vitro testing of a measuring system for in vivo recording of orthodontically applied forces and moments in the multiband technique. Part II. *J Orofac Orthop.* 1998;59:82–89.
7. Friedrich D, Rosarius N, Rau G, Diedrich P. Measuring system for in vivo recording of force systems in orthodontic treatment—concept and analysis of accuracy. *J Biomech.* 1999;32:81–85.
8. Burstone CJ, Koenig HA. Force systems from an ideal arch. *Am J Orthod Dentofacial Orthop.* 1974;65:270–289.
9. Hocevar RA. Understanding, planning, and managing tooth moment: orthodontic force system theory. *Am J Orthod.* 1981;80:457–477.
10. McGuinness NJP, Wilson AN, Jones ML, Middleton J. A stress analysis of the periodontal ligament under various orthodontic loadings. *Eur J Orthod.* 1991;13:231–342.
11. Plets JH, Isaacson RJ, Speidel TM, Worms FW. Maxillary central incisor root length in orthodontically treated and untreated patients. *Angle Orthod.* 1974;44:43–47.
12. Reitan K. Some factors determining the evaluation of forces in orthodontics. *Am J Orthod.* 1957;43:32–45.
13. Reitan K. Effects of force magnitude and direction of tooth movement on different alveolar bone types. *Angle Orthod.* 1964;34:244–255.
14. Reitan K. Initial tissue behavior during apical root resorption. *Angle Orthod.* 1974;44:68–82.
15. Reitan K. Biomechanical principles and reactions. In: Graber TM, Swain BF, eds. *Orthodontics. Current Principles and Techniques.* St. Louis, Mo: CV Mosby; 1985:101–192.
16. Wehrbein H, Diedrich P. Peridontal conditions after orthodontic tooth movement—a retrospective histological investigation in man (1st report). *Fortschr Kieferorthop.* 1992;53:167–178.
17. Ngantung V, Nanda RS, Bowman SJ. Posttreatment evaluation of the distal jet appliance. *Am J Orthod Dentofacial Orthop.* 2001;120:178–185.
18. Nishii Y, Katada H, Yamaguchi H. Three-dimensional evaluation of the distal jet appliance. *World J Orthod.* 2002;3:321–327.
19. Bolla E, Muratore F, Carano A, Bowman SJ. Evaluation of maxillary molar distalization with the distal jet: a comparison with other contemporary methods. *Angle Orthod.* 2002;72:481–494.
20. Chiu PP, McNamara JA Jr, Franchi L. A comparison of two intraoral molar distalization appliances: distal jet versus pendulum. *Am J Orthod Dentofacial Orthop.* 2005;128:353–365.