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Forces and moments on posterior teeth generated by incisor intrusion biomechanics

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Structured Abstract

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Objectives – To comparatively evaluate the extrusive forces and torquing moments on the posterior dentition generated during anterior intrusion with different intrusion techniques in the maxillary and mandibular dental arch.

Material and Methods – Seven wire specimens were used for each of the following intrusive arches: Utility arch 0.016 × 0.016′ Blue Elgiloy®, Utility arch 0.017 × 0.025′ TMA® and Burstone Intrusion arch 0.017 × 0.025′ TMA®. The wires were inserted on bracketed dental arches constructed on maxillary Frasaco models, segmented mesially to the maxillary canines. Simulated intrusion from 0.0–3.0 mm was performed on the Orthodontic Measurement and Simulation System (OMSS). The forces and moments were recorded in all three planes of space at 0.1 mm increments and the values at 3.0 mm for all wires were used for all statistical evaluations. The data were analyzed, separately for the forces and moments, by means of two-way analysis of variance (ANOVA) with forces and moments serving as the dependent variables and intrusion technique and jaw (maxilla or mandible) as the independent variable. *Post hoc* multiple comparisons were performed using the Tukey test at .05 error rate.

Results – The 0.016 × 0.016′ Blue Elgiloy® utility arch exerted the highest posterior extrusive forces, 15% higher than the 0.017 × 0.025′ TMA® utility and 40% higher in comparison with the 0.017 × 0.025′ TMA® Burstone intrusion arch.The lowest posterior moment in the saggital plane was generated by the 0.017 × 0.025′ TMA® Burstone intrusion arch. The 0.016 × 0.016′ Blue Elgiloy® utility arch exerted 15% higher posterior moments and the 0.017 × 0.025′ TMA® utility 25% higher. Forces and moments were consistently larger for the mandible compared to the maxilla for the same intrusion technique.

Conclusions – The upper Burstone 0.017 × 0.025′ TMA® intrusion arch exerted the lowest forces/moments on posterior teeth. The highest forces were generated by the 0.016 × 0.016-inch Blue Elgiloy® utility arch and the highest moments by the lower 0.017 × 0.025-inch TMA® utility arch.

Key words: biomechanics; bioprogressive technique; extrusion, segmented technique; intrusion; orthodontics

Introduction

The control of the reactive units is of major importance during orthodontic tooth movement. Regarding the intrusion of the anterior dentition, both developed techniques, the segmented arch (1–3) and the bioprogressive (4, 5), use intrusion arches with anchorage on posterior teeth but with fundamental biomechanical differences in their construction/use and consequently in their mode of action (6). Burstone noted that the best control over the posterior teeth is the minimization of force magnitude used for the intrusion. Additionally, as many posterior teeth as possible should be rigidly stabilized with stiff sectional arches and a transpalatal or lingual arch. Occipital headgear could help to control the posterior segment, however various issues arising from the necessity of compliance for adolescent but also for adult patients effectively limit its use in selected cases (3). Similar mechanics were proposed by Ricketts during intrusion with utility arches in addition with a molar tip-forward (down) bend in the posterior sectional arches (5).

Currently, the few clinical trials that have evaluated the side effects of the bioprogressive or the segmented arch techniques have focused on the anterior segment (7–12) and only two of them evaluate the side effects on the posterior segment (13, 14). A few clinical studies compared the segmented (15) or the Ricketts technique (16) with a continuous archwire technique, whereas one study focused on incisor intrusion in patients with marginal bone loss using both techniques (17).

Regarding anterior intrusion with the bioprogressive technique, Otto et al. (7) stated that overbite reduction was due to more than intrusion alone. Lower face height increased during treatment and this may have reflected bite opening due to treatment mechanics. The comparison of this technique with a modified Tweed approach using reverse curve of Spee continuous archwires, revealed that both techniques produced similar amounts of mandibular molar extrusion and minimal increases in mandibular plane angle and anterior facial height during treatment (16).

During anterior intrusion with the segmented arch technique, it was stated that posterior extrusion is sufficiently controlled (9), whereas, in comparison with a continuous archwire leveling technique, Burstone mechanics resulted in overbite reduction by incisor intrusion without any substantial extrusion of posterior teeth. As a consequence, no significant posterior rotation of the mandible took place in this group (15). More recent publications found that a high-pull headgear is not necessary for the prevention of possible side effects on the posterior dentition. Using 20 g of intrusive force per side, a buccal segmented arch wire extending from canine to first molar, with both premolars included, is sufficient to counteract side effects (13, 14).

The aim of this study was to compare the segmented arch and the bioprogressive technique with respect to the extrusive forces and torquing moments on the posterior dentition in the maxilla and the mandible generated during anterior intrusion.

Materials and methods

Experimental apparatus and configuration

The Orthodontic Measurement and Simulation System (OMSS) was used for the *in-vitro* evaluation of the different intrusion mechanics (18). The OMSS is based on the principle of the two-tooth model and allows the measurement of all forces and moments three-dimensionally acting on two regions simultaneously. For this purpose, the OMSS has two stepping motor-driven positioning tables equipped with force/moment transducers, monitored by a personal computer that controls the measurements. Absolute measurements were recorded of the forces/moments generated by an orthodontic appliance, when the positioning tables are moved along a specified path (19).

An acrylic Frasaco model was constructed for each jaw, with an ideal, leveled and aligned, dental arch. With the use of a straight $0.018 \times 0.025'$ stainless steel archwire, formed on the initial acrylic model, double $0.018'$ slot tubes with $0°$ angulation/torque/distal offset were placed on first and second molars and $0.018'$ slot brackets were placed on the rest of the teeth (Forestadent, Pforzheim, Germany). Each model was split into two segments after bracket placement: the anterior segment that included the four incisors and the posterior segment which included the teeth from the canine to the second molar. An appropriate adaptor was fixed on each of these model segments in order to become mountable to the positioning tables of the OMSS (Fig. 1). The straight $0.018 \times 0.025'$ stainless steel archwire was subsequently ligated to

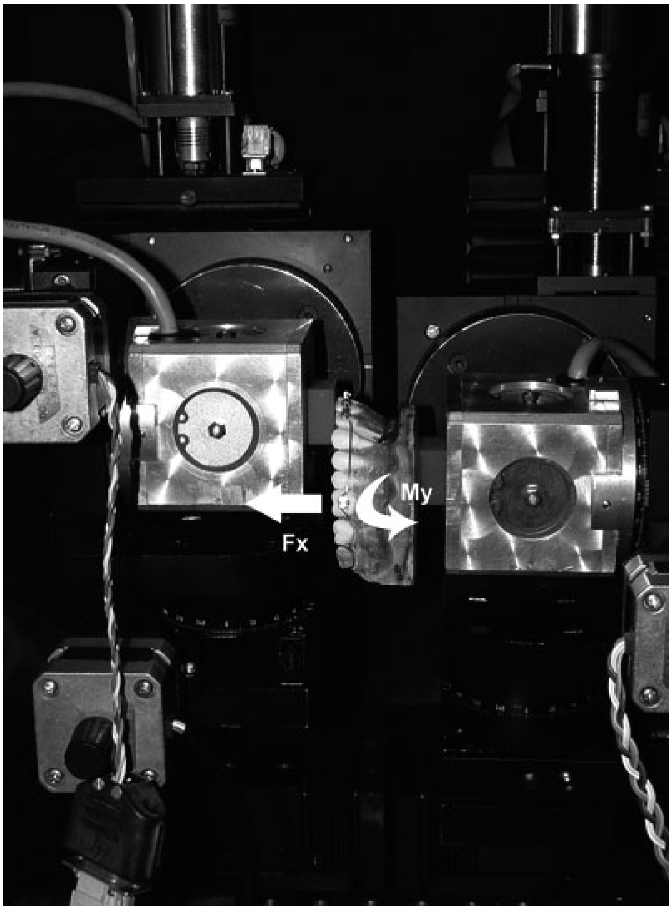

Fig. 1. The acrylic Frasaco model mounted to the positioning tables of the OMSS.

the two segments and they were both mounted on the positioning tables of the OMSS. An adjustment of the system was conducted with the straight wire in place and all forces/moments generated were nullified in this configuration.

In the absolute measurement mode, the dental arch was initially leveled. During the measurement procedure for the utility and the Burstone intrusion arches, the anterior segment was gradually extruded up to 3 mm and afterwards intruded to its initial position. The forces/moments generated in the sagittal plane in the posterior segment were measured in 0.1-mm steps and maximum values, recorded at 3 mm for all wires, were used for all statistical evaluations.

Materials

The following intrusion arches were evaluated with the absolute measurement system, as regard to the forces/moments generated in the posterior segment:

1. Utility arch $0.016 \times 0.016'$ Blue Elgiloy® (Rocky Mountain Orthodontics, Denver, CO, USA).
2. Utility arch constructed of $0.017 \times 0.025'$ TMA® wire (Ormco, Glendora, CA, USA).
3. Burstone Intrusion arch constructed of $0.017 \times 0.025'$ TMA® wire, ligated distal to the lateral incisors and gingivally of the anterior sectional wire.

Seven utility and seven Burstone intrusion arches were fabricated by the first author for each of the above-mentioned combinations and for each jaw. These arches were measured once.

The segmented intrusion arches were constructed according to the specifications given by Burstone (3). The 3-mm helix of the intrusion arch was wound and placed mesial to the molar tube. The diameter of the helix was measured with a measuring gauge, and a 45° molar tip-back was incorporated in the wire. The intrusion arch was ligated gingivally to the anterior segmented arch. The posterior segment consisted of both molars and premolars on each side, which were stabilized with a sectional passive $0.018 \times 0.025'$ stainless steel wire. An anterior, passive sectional arch from the same wire was fabricated for the stabilization of the incisors. A palatal/lingual arch was not deemed necessary since the posterior segments of the model were united. The utility arches were fabricated with 45° molar tip-back, as described by Ricketts (4, 5). Neither molar rotation, nor molar buccal root torque were incorporated in the wire. During the experimental intrusion, the helix of the Burstone archwires was ligated to the tube and the utility archwires were cinched back.

For the objectives of this study, which targeted at the pure extrusive and buccolingual torque components of the intrusion configurations, only the extrusive forces (Fx) and the moments My (posterior torque in the sagittal plane) were used for the final evaluations of simulated intrusion. The remaining force and moment components in the horizontal and coronal planes are greatly affected by factors such as proper adjustment of the anterior segment relatively to the posterior segment, degree of symmetry between the two sides, proper archwire insertion, ligation and activation. Since all the aforementioned factors introduce unnecessary variability and confound the results that are of real interest during anterior maxillary intrusion these components were adjusted to zero.

Statistical analysis

The data were statistically analyzed by means of two-way analysis of variance (ANOVA). Forces and moments were the dependent variables whereas intrusion technique and jaw (maxilla or mandible) were the independent variable. *Post hoc* multiple comparisons were performed using the Tukey test at 0.05 error rate. Statistical analysis was performed with the Statistical Package for Social Sciences (SPSS Inc., version 15.0, Chicago, IL, USA).

Results

At 3 mm vertical displacement of the incisors, the Utility intrusion archwires recorded mean extrusive forces in the range of 1.59–2.10 Newton. The Utility 0.016 × 0.016-inch Blue Elgiloy® exerted higher force than the Utility 0.017 × 0.025-inch TMA®. The recorded magnitudes for the Burstone 0.017 × 0.025′ TMA® intrusive arches were 1.30–1.56 Newton (Table 1). The analysis of variance indicated significant differences for both wire type and jaw variables (Table 2). The Tukey *post hoc* comparison determined that the extrusion forces were significantly different for all wires (Table 1). Marginally significant difference ($p = 0.045$) between the maxilla and the mandible was observed, and for the same wire type, the forces were always higher in the mandible.

Regarding the moments generated in the posterior part of the dentition, the highest mean value was recorded for the upper utility 0.017 × 0.025′ TMA (23.09 Nmm), and the lowest for the lower Burstone TMA intrusion system (17.03 Nmm). A significant difference between the maxilla and the mandible was observed, and for the same wire type, the moments were always higher in the mandible (Tables 3 and 4). The range of extrusion forces (Fx) and posterior moments (My) per wire type and vertical displacement from 0.0–3.0 mm (0.5 mm increments) for the Utility and Burstone archwires are depicted in Figs 2 and 3.

Table 1. **Mean and standard deviation of posterior extrusion forces (N) at 3 mm**

	Mandible		Maxilla	
Wiretype:	Mean	SD	Mean	SD
BurstoneTMA 017 × 025 A	1.56	0.07	1.30	0.07
Utility Elgiloy 016 × 016 B	2.10	0.11	1.82	0.13
Utility TMA 017 × 025 C	1.81	0.06	1.59	0.02

Table 2. **General linear model of posterior extrusion forces vs. wiretype and jaw**

Source	Type III sum of squares	d.f.	Mean square	F	Sig.
Corrected model	2.44	3	0.82	106.17	0.000
Intercept	114.98	1	114.98	14983.36	0.000
Wiretype	1.88	2	0.94	122.65	0.000
Jaw	0.64	1	0.64	83.12	0.000
Error	0.29	38	0.01		
Total	123.61	42			
Corrected Total	2.74	41			

Dependent variable: intrusion force at 3 mm displacement.

Table 3. **Mean values, standard deviation of posterior moments (Nmm) at 3 mm**

	Mandible		Maxilla	
Wiretype:	Mean	SD	Mean	SD
Burstone TMA 017 × 025 A	18.25	2.77	17.03	1.73
Utility Elgiloy 016 × 016 B	21.27	3.11	19.53	2.36
Utility TMA 017 × 025 B	23.09	2.85	21.20	2.06

Table 4. **General linear model of posterior moments (Nmm) vs. wiretype and jaw**

Source	Type III sum of squares	d.f.	Mean square	F	Sig.
Corrected model	156.730	3	52.243	9.102	0.000
Intercept	16098.897	1	16098.897	2804.727	0.000
Wiretype	128.951	2	64.476	11.233	0.000
Jaw	27.081	1	27.081	4.718	0.036
Error	218.117	38	5.740		
Total	17234.539	42			
Corrected Total	374.847	41			

Dependent variable: torque at 3 mm displacement.

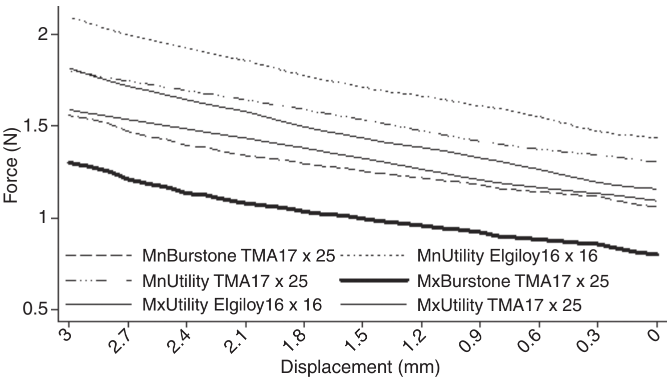

Fig. 2. Graph depicting the variation of extrusion forces (Fx) with vertical displacement from 0.0–3.0 mm for the biomechanical systems included in the study.

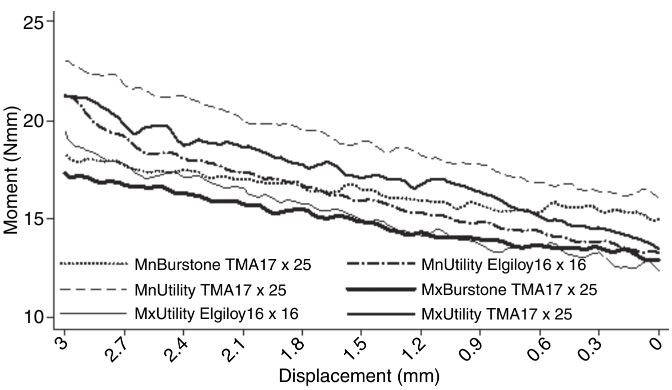

Fig. 3. Graph depicting the variation of posterior moments in the sagittal plane (My) with vertical displacement from 0.0–3.0 mm (0.5 mm increments) for the biomechanical systems included in the study.

Discussion

During anterior intrusion with the segmented or the bioprogressive technique, the posterior teeth are subjected to a vertical force, which tends to extrude them and a moment or torque, which in the upper arch will steepen the occlusal plane and in the lower arch flatten it (3, 5). According to principles of static equilibrium, the magnitudes of the posterior extrusive and anterior intrusive forces are equal. If intrusive forces are kept low, occlusal forces tend to negate the eruptive tendency of the posterior teeth (3). The effective extrusive forces should be of about the same magnitude as those for tipping, higher than these required for intrusion (20) and for one molar should be 60–100 g (21). In our experimental simulation of incisor intrusion, the non heat-treated 0.016×0.016-inch Blue Elgiloy® utility arch exerted the highest forces, 15% higher than the 0.017×0.025-inch TMA® utility and 40% higher in comparison with the 0.017×0.025-inch TMA® Burstone intrusive arch (mean values at 3.0 mm of simulated intrusion). The latter presented the lowest forces from the configurations tested (1.30 N in the maxilla, 1.56 N in the mandible) due to the presence of a 3-mm helix, which increased wire length and because it was not tightly anchored to the anterior segment. Thus, a buccal segment extending from canine to second molar may be sufficient to counteract the posterior extrusive forces generated from the 0.017×0.025-inch TMA® Burstone intrusive arch tested, which is in accordance with clinical research (13).

The difference in force magnitude between the utility arches evaluated was due to the different wire composition. Despite the smaller cross section of the Elgiloy archwires, these showed 15% higher extrusive forces relative to the 0.017×0.025-inch TMA® utility arch. This was expected, since the moduli of elasticity and the force delivery of Elgiloy® and stainless steel wires are similar (22). Beta-titanium wires offer a desirable combination of strength and springback and their moduli of elasticity are around 40% of that of stainless steel (23). They deliver about half the amount of force compared with that of stainless steel (24) or Co-Cr wires (23) of comparable cross section and equal amounts of activation. A 0.017×0.025-inch cantilever is about 86% stiffer than the 0.016×0.016-inch one from the same material (25) but in case of a rectangular supported beam, its properties are primary determined by the dimension in the direction of bending. Additionally, if the ends are tightly anchored, i.e. not free to slide, the beam is stronger and less flexible (20).

The loss of anchorage during anterior intrusion is primarily produced by the moment rather than by the force. This posterior moment generated in the sagittal plane is large because of the length of the moment arm, i.e. the distance from the incisor to the center of resistance of the molar/posterior segment (3). The lowest posterior moment recorded in this experiment was generated from the 0.017×0.025-inch TMA Burstone intrusion arch. The 0.016×0.016-inch Blue Elgiloy utility arch exerted 15% higher posterior moments and the 0.017×0.025-inch TMA utility 25% higher (mean values). Although there was no torque incorporated in the anterior part of the utility arches, the gradual extrusion of the incisor segment during the simulation, increased not only the extrusion force but the couple on the molar too (6, 20).

In this simulation, the extrusive forces, as well as the generated moments, were always higher in the mandible, since the length of the buccal bridge of the mandibular utility arches, calculated as the distance between the anterior and posterior vertical steps, was 25 mm, which is 3 mm shorter than in the maxillary arches. For the same reason, the points of contact in the maxillary Burstone intrusive arches were more anteriorly located, in comparison to the mandibular arches. The extrusive force on the buccal segments could be counteracted by the forces of occlusion if it is small enough (14) but the posterior moment generated in the sagittal plane remains large because of the length of the moment arm. Several methods have been suggested to decrease this side effect: increasing the number of teeth of the buccal segment, wearing high-pull headgear, decreasing the amount of intrusive force or decreasing the length of the moment arm doing initially as much retraction as possible (21). Clinically, it should considered that with a given activation of an intrusion arch, the smaller the length of the dental arch, the larger the magnitude of the intrusion and extrusion forces.

The results of this experiment contribute to the clarification of some clinical aspects of the incisor intrusion techniques, regarding the magnitudes not only of the exerted forces but of the moments too. The force magnitude of a 0.018 × 0.025-inch stainless steel intrusive arch for a given activation could be measured from the force-deflection graphs, provided for different arch lengths (3) or with a force gauge but in a two-couple utility arch system the load required to bring the incisor segment of the wire to the incisor brackets does not accurately reflect the intrusive/extrusive load acting at the teeth (6). In this system, the torque bends or cinch back which are probably required additionally to the activation bends, change the biomechanical geometry and under these circumstances, it is difficult to be certain which of the moments will prevail or whether the intrusion force is appropriate (20).

As in most *in vitro* investigations, there are some limitations and difficulties in extrapolating clinical relevance. The OMSS is based on the principle of the two-tooth model and although it comes very close to the clinical situation, it fails to take account of some factors which have additional influence in practice, such as intraoral aging and influence of saliva. Furthermore, it has not yet been possible to predict the centre of resistance of the four incisors or the posterior segment of the dentition and in every case the intrusion of the anterior teeth should be carefully monitored in order to avoid side-effects. Further investigation in this area should be conducted regarding the influence of the length of the moment arm and the location of the anterior points of contact in the segmented intrusion technique on the biomechanical system.

Conclusions

The comparison of the two major intrusion techniques for the anterior teeth- segmented and bioprogressive- as described by their inventors, revealed that the non heat-treated 0.016 × 0.016-inch Blue Elgiloy utility arch exerted the highest posterior extrusive forces, 15% higher than the 0.017 × 0.025-inch TMA utility and 40% higher than the 0.017 × 0.025-inch TMA Burstone intrusion arch.

The lowest posterior moment in the sagittal plane in this experiment was generated from the 0.017 × 0.025-inch TMA Burstone intrusion arch. The 0.016 × 0.016-inch Blue Elgiloy utility arch and the 0.017 × 0.025-inch TMA applied 15% and 25% higher posterior moments, respectively.

Clinical Relevance

This *in vitro* simulation of incisor intrusion, evaluated the forces and moments generated on the posterior teeth in the sagittal plane by the segmented arch and the bioprogressive techniques. With the same amount of activation, the extrusive forces/moments generated by the Burstone 0.017 × 0.015-inch TMA® intrusion arch are of low magnitude within the configurations tested and theoretically not capable of extruding a long posterior segment extending from canine to first or second molar. The data suggest that the activation of the utility arches should be less than the Burstone intrusive arches to avoid the generation of excessive forces.

References

1. Burstone CJ. Rationale of the segmented arch. *Am J Orthod* 1962;48:805–22.

2. Burstone CJ. The mechanics of the segmented arch techniques. *Angle Orthod* 1966;36:99–120.
3. Burstone CJ. Deep overbite correction by intrusion. *Am J Orthod* 1977;72:1–22.
4. Ricketts RM. Bioprogressive therapy as an answer to orthodontic needs. Part II.. *Am J Orthod* 1976;70:359–97.
5. Ricketts RM, Bench RW, Gugino CF, Hilgers JJ, Schulhof RJ. *Bioprogressive Therapy*, 1st edn. Denver: Rocky Mountain/Orthodontics; 1979.
6. Davidovitch M, Rebellato J. Two-couple orthodontic appliance systems utility arches: a two-couple intrusion arch. *Semin Orthod* 1995;1:25–30.
7. Otto RL, Anholm JM, Engel A. A comparative analysis of intrusion of incisor teeth achieved in adults and children according to facial type. *Am J Orthod* 1980;77:437–46.
8. McFadden WM, Engstrom C, Engstrom H, Anholm JM. A study of the relationship between incisor intrusion and root shortening. *Am J Orthod Dentofac Orthop* 1989;96:390–6.
9. Goerigk B, Diedrich P, Wehrbein H. Intrusion of the anterior teeth with the segmented-arch technic of Burstone: a clinical study. *Fortschr Kieferorthop* 1992;53:16–25.
10. Costopoulos G, Nanda R. An evaluation of root resorption incident to orthodontic intrusion. *Am J Orthod Dentofac Orthop* 1996;109:543–8.
11. van Steenbergen E, Burstone CJ, Prahl-Andersen B, Aartman IH. The influence of force magnitude on intrusion of the maxillary segment. *Angle Orthod* 2005;75:723–9.
12. van Steenbergen E, Burstone CJ, Prahl-Andersen B, Aartman IH. The relation between the point of force application and flaring of the anterior segment. *Angle Orthod* 2005;75:730–5.
13. van Steenbergen E, Burstone CJ, Prahl-Andersen B, Aartman IH. The role of a high pull headgear in counteracting side effects from intrusion of the maxillary anterior segment. *Angle Orthod* 2004;74:480–6.
14. van Steenbergen E, Burstone CJ, Prahl-Andersen B, Aartman IH. Influence of buccal segment size on prevention of side effects from incisor intrusion. *Am J Orthod Dentofac Orthop* 2006;129:658–65.
15. Weiland FJ, Bantleon HP, Droschl H. Evaluation of continuous arch and segmented arch leveling techniques in adult patients – a clinical study. *Am J Orthod Dentofac Orthop* 1996;110:647–52.
16. Dake ML, Sinclair PM. A comparison of the Ricketts and Tweed-type arch leveling techniques. *Am J Orthod Dentofac Orthop* 1989;95:72–8.
17. Melsen B, Agerbaek N, Markenstam G. Intrusion of incisors in adult patients with marginal bone loss. *Am J Orthod Dentofac Orthop* 1989;96:232–41.
18. Bourauel C, Drescher D, Thier M. An experimental apparatus for the simulation of three-dimensional movements in orthodontics. *J Biomed Eng* 1992;14:371–8.
19. Drescher D, Bourauel C, Thier M. Application of the orthodontic measurement and simulation system (OMSS) in orthodontics. *Eur J Orthod* 1991;13:169–78.
20. Proffit WR, Fields HW. *Contemporary Orthodontics*, 3rd edn. St. Louis: Mosby; 2000.
21. Burstone CJ, van Steenbergen E, Hanley KJ. *Modern Edgewise Mechanics & the Segmented Arch Technique*, 1st edn. Glendora, California: ORMCO; 1995.
22. Kusy RP, Greenberg AR. Effects of composition and cross section on the elastic properties of orthodontic wires. *Angle Orthod* 1981;51:325–41.
23. Kapila S, Sachdeva R. Mechanical properties and clinical applications of orthodontic wires. *Am J Orthod Dentofac Orthop* 1989;96:100–9.
24. Burstone CJ, Goldberg AJ. Beta titanium: a new orthodontic alloy. *Am J Orthod* 1980;77:121–32.
25. Thurow RC. *Edgewise Orthodontics*, 4th edn. St.Louis: Mosby; 1982.