Iosif Sifakakis, Theodore Eliades and Christoph Bourauel*

Residual stress analysis of fixed retainer wires after *in vitro* loading: can mastication-induced stresses produce an unfavorable effect?

DOI 10.1515/bmt-2015-0013
Received January 23, 2015; accepted May 7, 2015; online first June 9, 2015

Abstract: The aim of the present study was to compare four different types of fixed canine-to-canine retainer regarding the maximum and residual force system generated on a canine during the intrusive *in vitro* loading of the rest of the anterior teeth. Retainers constructed from Ortho-FlexTech gold chain 0.038×0.016-inch (rectangular, 0.96×0.40 mm²), Tru-Chrome® 7-strand twisted 0.027-inch (round, 0.68 mm diameter) steel wire, and Wildcat 0.0175-inch (round, 0.44 mm) and 0.0215-inch (round, 0.55 mm) 3-strand Twistflex steel wire bonded on the anterior teeth of an acrylic resin model, installed in the Orthodontic Measurement and Simulation System. The force system on the canine was recorded during the loading of the anterior teeth as well as the residual force system at the same tooth after the unloading. During maximum loading, the gold chain exerted the lowest and the 0.0215-inch archwire the highest force and moment magnitude. Residual forces and moments were exerted on the canine after the unloading in all retainer types, i.e., the evaluated fixed retainers were not passive after *in vitro* vertical loading. The lowest magnitude was measured in gold chain retainers and the highest in cases of the high formable/low yield strength 0.027-inch archwire. This fact may explain the unexpected movements of teeth bonded on fixed retainers detected long-term *in vivo*.

Keywords: fixed retainer; plastic deformation; orthodontics; unexpected tooth movement.

***Corresponding author: Christoph Bourauel,** C+M Department of Oral Technology, School of Dentistry, University of Bonn, Bonn 53111, Germany, Phone: +49 228 28722332, Fax: +49 228 28722385, E-mail: bourauel@uni-bonn.de
Iosif Sifakakis: Department of Orthodontics, School of Dentistry, University of Athens, Athens 11527, Greece
Theodore Eliades: Department of Orthodontics and Paediatric Dentistry, Center of Dental Medicine, University of Zurich, Zurich 8032, Switzerland

Introduction

After cessation of the active orthodontic treatment, retention of the treatment result is necessary to prevent relapse of the malocclusion. Fixed retention, i.e., the bonding of an archwire piece on two or more teeth prone to relapse, is a rather unavoidable procedure in that phase, at least for specific malocclusions or specific population groups. According to a conservative approach, if maximum stability is required, fixed canine-to-canine retainers combined with removable retention appliances in both arches should be used until the patients reach their late twenties [15] because successful treatment maintenance only with bonded retainers cannot be achieved in the long term [2, 4, 16, 19, 24]. The increase of irregularity is strongly related to the bonding failures of the retainer [23], but in 3–5% of patients, unexpected posttreatment changes in the mandibular anterior teeth have been reported, on which a flexible spiral wire retainer (0.0195-inch 3-strand heat-treated) was still bonded. These changes show a specific clinical pattern, and they could not be explained by the pretreatment malocclusion. More specific, torque differences between two adjacent incisors or increased buccal or lingual inclination and movement of a mandibular canine were observed. The exact reason for these changes is unknown. It was initially proposed that an active component of the wire due to either an elastic deflection caused by the clinician or a mechanical deformation from masticatory forces could probably cause these movements [13, 23]. Because the retainer is constructed and bonded passively across the surfaces of the teeth, and these unexpected changes are not usually observed short term after debonding, it is more reasonable to consider the wire deformation during its long-term function in mouth or its inability to prevent the unexpected movements and the posttreatment tooth movement tendency as possible causes [22]. The major consequence of these movements could be the thinning of the periodontium, which leads to bone thinning and dehiscences or even to fenestrated periodontal defects on the canine root (Figure 1). In addition, esthetic problems arise due to differences in the height of

Figure 1: Unexpected buccal movement of the root of the lower right canine caused gingival recession, 3 years after debonding. A 0.027-inch fixed retainer, constructed from the same archwire evaluated in the present study, was still intact.

the clinical crowns and in the anteroposterior alignment of the incisal edges, as well as functional problems from improper occlusion with the antagonists.

The most commonly fixed retainers used are the thick (0.030- or 0.032-inch) mandibular canine-and-canine retainer and the thin (0.0215-inch or thinner), flexible, spiral wire canine-to-canine retainer. As regards their mechanical properties, multistranded wires have high stored energy (modulus of resilience) when compared with solid stainless steel wires. This implies that they produce lower forces that dissipate over longer periods of time. In addition, they have high springback and low stiffness. However, high stiffness is advantageous in resisting deformation [11, 12]. Moreover, solid stainless steel wires could better resist torsion. In contrast to conventional stainless steel wires, in which spring back decreases with increasing thickness, multistranded wires have springback properties that are not influenced to the same extent as solid wires by the cross-sectional size [11]. As regards their clinical behavior, the thick canine-and-canine retainer could lead to a small increase in mandibular incisor irregularity during the retention period but displays lower detachment rate than the thinner canine-to-canine retainer type [1, 21, 24].

The purpose of the present study was to compare four common flexible archwires used for fixed canine-to-canine retention regarding the maximum and residual intrusive forces and labiolingual moments generated on a canine during the intrusive loading of the rest of the anterior teeth.

Materials and methods

All measurements were conducted on the Orthodontic Measurement and Simulation System (OMSS). This is a measuring system used widely in the field of orthodontic biomechanics, and its setup and applications have been described in detail [3, 5]. OMSS is capable of three-dimensionally evaluating the initial force system exerted by an orthodontic appliance as well as the alterations of this force system during the simulation of the desired tooth movement. The simulation of tooth movement with the OMSS is conducted using two measuring tables composed of a six-axis positioning table and a six-component force-torque sensor, monitored by a personal computer.

An acrylic resin model (Palavit G, Heraeus Kulzer, Hanau, Germany) of the mandibular anterior segment, with an ideal, leveled, and aligned dental arch, was used for the construction of the retainers. Fifteen retainers were constructed from each of the following wires by one of the authors: (1) Ortho-FlexTech gold chain 0.038×0.016 inch wire (Reliance, Itasca IL, Lot 310151), (2) Tru-Chrome® 7-strand twisted 5″ 0.027-inch steel wire (Batch WO-433524; RMO, Denver, CO, USA), (3) Wildcat 0.0175-inch 3-strand twist-flex steel wire (lot 13-25; GAC, Bohemia, NY, USA), and (4) Wildcat 0.0215-inch 3-strand twist-flex steel wire (lot 13-16, GAC). A small hole was drilled with a bur for retention and standardization purposes, in the middle of the lingual surface of every tooth (diameter, 2 mm; depth, 2 mm; distance between the holes, 4 mm), and all the retainers were constructed on that level.

After the construction of the retainers, the resin model was split into two segments to consolidate the canine. An appropriate adaptor was fixed on each model segment, and both segments were mounted to the OMSS (Figure 2). The bigger segment (consisting of the incisors and one canine) was mounted on a specialized specimen holder consisting of a spring damped telescope. The spring was adjusted and preloaded such that a displacement of the segment by 0.2 mm generated a counterforce of 15 N, thus simulating the force/displacement behaviour of a tooth segment in the alveolar bone. The lesser segment (consisting of the other canine) was directly connected to one of the force-torque sensors of the OMSS via an adaptor. The initial leveled position of these segments was maintained throughout the experiment.

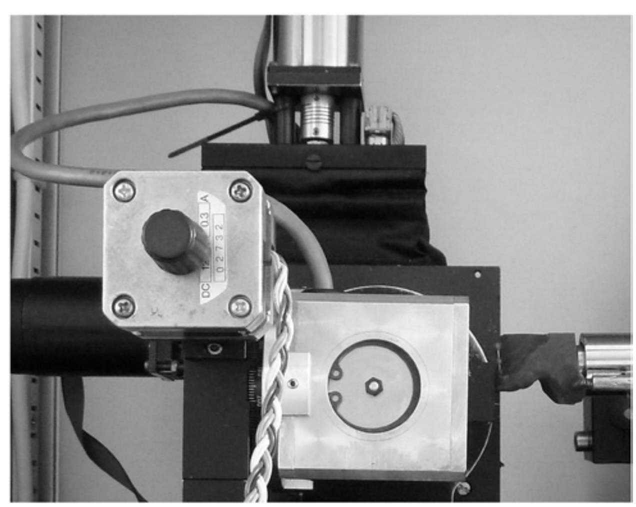

Figure 2: The resin model of the anterior segment mounted on the Orthodontic Measurement and Simulations System. On the left, one force-torque sensor is shown, used for load application on the bigger tooth segment. On the right, a part of the telescope, simulating the physiological tooth mobility of the canine, is visible.

Each retainer was bonded on the teeth (canine to canine) by using equal amounts of light-cured composite (Transbond™ XT Light Cure Adhesive, 3 M, Monrovia, CA, USA). The intercomposite distance was 4 mm. During the measurement procedure, an intruding force was gradually applied on the bigger segment (consisting of the incisors and one canine), which was intruded in 0.05-mm increments. When this force reached a maximum of 18 N, the OMSS released the load and returned in its initial position at the same incremental decrease. OMSS measured the maximum intrusive force and labiolingual moment on the lesser segment (consisting of the consolidated canine) during the load and unload of the bigger segment. In addition, the residual force system at the end of the unloading cycle at the lesser segment was also evaluated. For the objectives of this study, only the intrusive forces and the labiolingual moments were used for the evaluations of the lingual retainers. The remaining force and moment components were adjusted to zero. Every specimen was evaluated once, and all procedures were performed by one author.

Statistical analysis

All statistical tests were performed by STATA version 11.0 (STATA Corporation, College Station, TX, USA). Data are presented graphically through histograms and box plots. Differences between types of wire are assessed through permutation-based (1000 replications) versions of Kruskal-Wallis and Mann-Whitney tests. p values for the pairwise comparisons by type of group have been adjusted for multiple comparisons (Bonferroni correction).

Results

The intrusion force and labiolingual moment results (mean, SD) for all the wire types are shown in Table 1. Overall differences in maximum force, residual force, maximum moment, and residual moment, according to the wire type, were statistically significant (global test $p<0.001$ in all cases). All pairwise comparisons between two different types of wire, in terms of maximum or residual force, were also statistically significant (all p values <0.05). Average maximum moment and residual moment differed significantly between all couples of wire types that have been compared, except the comparison between the 0.027- and the 0.0215-inch wire type, where results were not statistically significant ($p=0.240$ and $p=0.282$ for maximum and residual moment, respectively).

The rank of the different wire types in increasing order of maximum force and torque magnitude is as follows: gold chain (2.0 N/7.6 N·mm), 0.027-inch wire (4.4 N/13.8 N·mm), 0.0195-inch wire (3.8 N/11.5 N·mm), and 0.0215-inch wire (4.8 N/15.2 N·mm). Regarding the residual force and moment magnitude, the rank in increasing order is as follows: gold chain (0.1 N/0.9 N·mm), 0.027-inch wire (0.8 N/2.2 N·mm), 0.0195-inch wire (0.5 N/1.3 N·mm), and 0.0215-inch wire (0.6 N/1.8 N·mm). Distribution (box plots) of maximum and residual forces and moments by wire type are depicted in Figures 3–6.

Table 1: Distribution of intrusion forces (N) and labiolingual moments (N·mm) measurements by type of wire; mean (SD).

	Type of wire			
	Gold chain	**0.027**	**0.0195**	**0.0215**
Maximum force	2.0 (0.4)[a]	4.4 (0.3)[b]	3.8 (0.3)[c]	4.8 (0.3)[d]
Residual force	0.1 (0.1)[a]	0.8 (0.1)[b]	0.5 (0.1)[c]	0.6 (0.1)[d]
Maximum moment	7.6 (1.5)[a]	13.8 (1.2)[b]	11.5 (1.1)[c]	15.2 (1.9)[b]
Residual moment	0.9 (0.2)[a]	2.2 (0.6)[b]	1.3 (0.4)[c]	1.8 (0.4)[b]

Mean values with the same letter are not significantly different at the 0.05 level. This applies only within each raw.

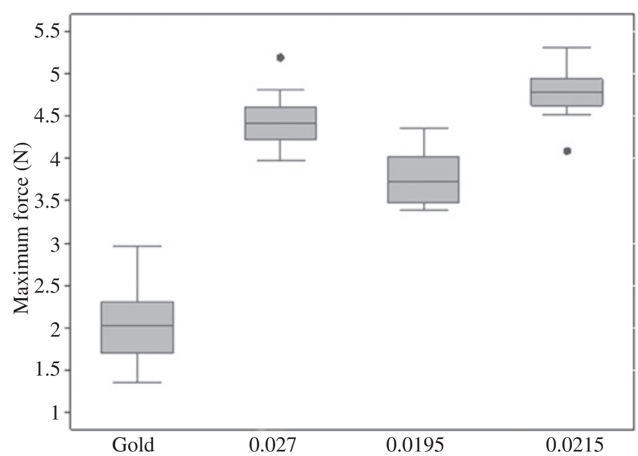

Figure 3: Distribution (box plots) of maximum force (N) by wire type.

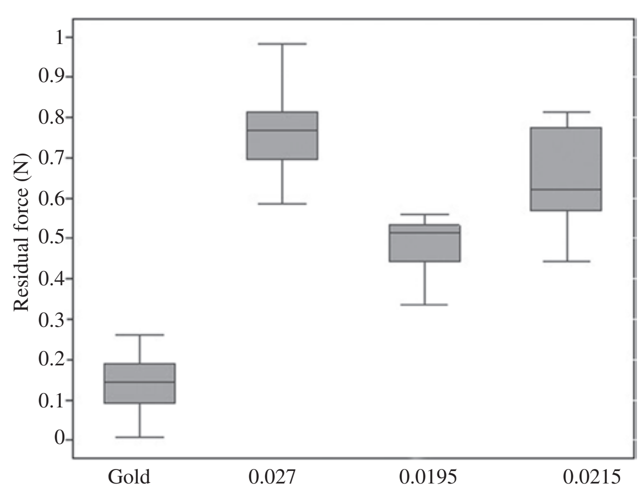

Figure 4: Distribution (box plots) of residual force (N) by wire type.

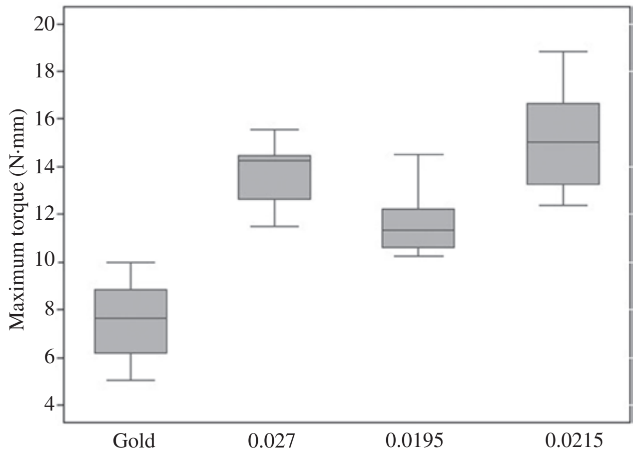

Figure 5: Distribution (box plots) of maximum moment (N·mm) by wire type.

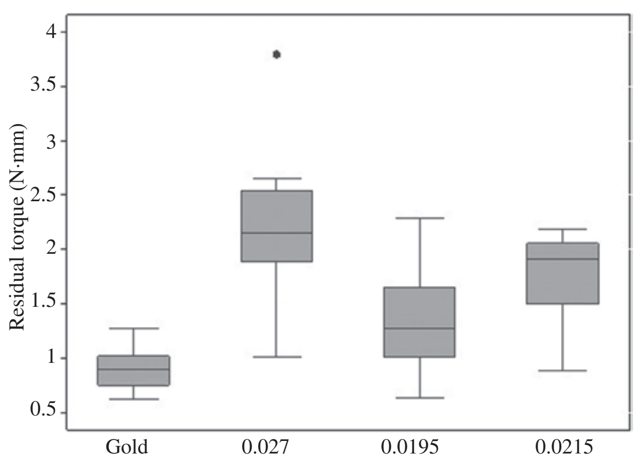

Figure 6: Distribution (box plots) of residual moment (N·mm) by wire type.

Discussion

In both types of unexpected posttreatment changes, the main movement is the labiolingual rotation of the tooth. In addition, bending of the last part of the retainer wire, supporting usually the canine, may occur. The present study evaluated the maximum and residual vertical forces and labiolingual moments on the terminal canine of a fixed canine-to-canine retainer during an intrusive load on the rest of the anterior teeth. This configuration simulated anterior biting because the intrusive force exerted on the anterior teeth by OMSS approximated the vertical incisor bite force during mastication [9, 17]. If this force level is maintained within the elastic limits of the retainer wire/adhesive and the periodontal ligament, the tooth remains relatively stable. If it exceeds the elastic limit of the wire/adhesive, bond failure or deformation of the retainer wire may occur. The load of 18 N used in the present study was decreased by the adaptors fixed on the model segments and transferred on the canine through the retainer wire to a different extent, according to the elastic properties of the wire. This wire between the canine and lateral incisor resembles a beam restrained at both ends, and the loads could be axial, bending, and torsional. The canine experienced the lowest force/moment during this loading in the case of the gold chain and the highest in the case of the 0.0215-inch 3-strand twist-flex steel wire. The 7-strand twisted 0.027-inch steel wire exerted lower forces/moments on the canine in comparison with the thinner 0.0215-inch wire.

In the instruction sheets provided by the manufacturer of the gold chain, it is stated that this material may stretch, slightly allowing space to reopen. Accordingly, the use of a secondary retainer wire is advised in cases of diastemas. The low forces exerted on the canine in the case of the gold chain retainer in the present experiment justify the above-mentioned statement. The wire processing of the 0.027-inch twisted steel wire is not clear. The manufacturer claims that these retainer wires are constructed from a softer temper than archwire temper, which enables the operator to more easily form the wire into retainer appliances, and that the forming of the wire work hardens it, providing a working resiliency for retainer appliances. However, wires with a high degree of annealing are described in the literature as "dead soft". As the degree of annealing increases, formability is progressively enhanced at the cost of yield strength [20]. After the unloading of the retainer, a residual force/moment was maintained on the canine in all evaluated configurations, a fact that implies plastic deformation of the retainer wires. The residual force systems from the twisted archwires were always higher in comparison with those exerted from the gold chain, and the highest values were recorded in the case of the high formable/low yield strength 7-strand twisted 0.027-inch steel wire.

The labiolingual moment experienced by the canine from the intrusion of the rest of the anterior teeth was expected because the intrusive force was applied labially to the canine. The magnitude of this moment on the canine may be influenced by the twist direction of the wire strands (left-handed or S-twist and right-handed or Z-twist), which could potentially favor a specific rotation. Moreover, an extrinsic moment could more easily deform the wire in the direction of straightening/untwisting. The opposite is also true: the wire could better withstand the deformation if the moment tends to twist its strands.

The optimal magnitude of a force for tipping movement of one tooth is 50–75 cN [20], but for intrusion, this magnitude is even lower [25]. The residual forces measured in the present experiment are capable of inducing tooth movement; however, the fixed retainer allows only a minor tipping movement of the canine. There is no consensus in the orthodontic literature regarding ideal torquing moment. Most of the authors agree that 5.0 N·mm is the minimum torque required for an upper central incisor [6, 8, 10, 18]. Under this aspect, the residual moments measured in the present experiment are not capable of inducing tooth movement. However, torque differences between two adjacent teeth are reported, which are possible only through a moment induced/allowed by the archwire. The vertical loads reported in the literature during biting vary intra- and interindividually and could reach 250 N in the incisor area [14]. The lateral components of bite forces in that area in adults remain in lower levels, 20 N [7]. As a result, the maximum and residual force systems of a retainer wire in clinical use may be considerably higher than those reported in this study. Moreover, a minor tipping force/labiolingual moment on the canine could have detrimental impact on the root position because the centre of rotation remains near the bonding area of the retainer wire. In addition, in the case of the last tooth bonded on the retainer, every proximal force that is not exerted axially on the retainer wire may have lingual or buccal components and could induce a labiolingual moment as well as mesiodistal moment.

The findings of the present study suggest that the evaluated twisted archwires used as a lower canine-to-canine fixed retainer may not be passive after short- or long-term clinical use, especially the archwires with a high degree of annealing. Archwires with higher bending and torsional stiffness may be more suitable for this clinical application. Nevertheless, the unexpected movements of the anterior teeth bonded on a retainer are not found in cases of thick stainless steel canine-and-canine retainers, even at 5 years posttreatment [22].

Limitations exist within the experimental setup used in the present study, which is a model that approximates the clinical situation where forces and moments are exerted onto the teeth. The OMSS is based on the principle of the two-tooth model and simulates only the initial tooth movement. Intraoral ageing and saliva are factors that are not taken into consideration. The mechanical properties of the periodontal ligament affect the transmission of the force system, and as a result, the actual force system acting on a canine bonded on a fixed retainer will probably vary. However, the residual force system described in this study correspond to the actual residual force system on a canine bonded on a fixed retainer in the clinical setting, independent of the periodontal ligament, if this canine experiences a differential (i.e., between this canine and the rest of the anterior teeth) intrusive force of the magnitude described in Table 1 (Maximum force row).

Further laboratory investigation of heavier stranded or solid archwires used for fixed retention would expand the conclusions of this study. Another suggested area for future clinical research would be the evaluation of the effect of the twist direction of the wire strands on the unexpected movements of the teeth bonded on twisted fixed retainers.

Conclusions

The twisted archwires used as a lower canine-to-canine fixed retainer may not be passive after short- or long-term clinical use, especially the high formable/low yield strength archwires with a high degree of annealing.

Archwires with higher bending and torsional stiffness may be more suitable for this clinical application.

Acknowledgments: This work was supported by the German Academic Exchange Service (DAAD) (research grant no. A/14/01558).

The authors have no conflict of interest. IS received a scholarship from DAAD (German Academic Exchange Service).

References

[1] Al-Nimri K, Al Habashneh R, Obeidat M. Gingival health and relapse tendency: a prospective study of two types of lower fixed retainers. Aust Orthod J 2009; 25: 142–146.
[2] Årtun J, Spadafora AT, Shapiro PA. A 3-year follow-up of various types of orthodontic canine-to-canine retainers. Eur J Orthod 1997; 19: 501–509.
[3] Bourauel C, Drescher D, Their M. An experimental apparatus for the simulation of three-dimensional movements in orthodontics. J Biomed Eng 1992; 14: 371–378.
[4] Dahl EH, Zachrisson BU. Long-term experience with direct bonded lingual retainers. J Clin Orthod 1991; 25: 619–632.
[5] Drescher D, Bourauel C, Their M. Application of the orthodontic measurement and simulation system (OMSS) in orthodontics. Eur J Orthod 1991; 13: 169–178.
[6] Gmyrek H, Bourauel C, Richter G, Harzer W. Torque capacity of metal and plastic brackets with reference to materials, application, technology and biomechanics. J Orofac Orthop 2002; 63: 113–128.
[7] Graf H. Occlusal forces during function. In: Rowe NH, editor. Occlusion. Research on form and function. Ann Arbor center for growth and development, The University of Michigan 1975: 90–111.

[8] Harzer W, Bourauel C, Gmyrek H. Torque capacity of metal and polycarbonate brackets with and without a metal slot. Eur J Orthod 2004; 26: 435–441.
[9] Helkimo E, Carlsson GE, Helkimo M. Bite force and state of dentition. Acta Odontol Scand 1977; 35: 297–303.
[10] Huang Y, Keilig L, Rahimi A, et al. Numeric modeling of torque capabilities of self-ligating and conventional brackets. Am J Orthod Dentofacial Orthop 2009; 136: 638–643.
[11] Ingram SB Jr, Gipe DP, Smith RJ. Comparative range of orthodontic wires. Am J Orthod Dentofacial Orthop 1986; 90: 296–307.
[12] Kapila S, Sachdeva R. Mechanical properties and clinical applications of orthodontic wires. Am J Orthod Dentofacial Orthop 1989; 96: 100–109.
[13] Katsaros C, Livas C, Renkema AM. Unexpected complications of mandibular lingual retainers. Am J Orthod Dentofacial Orthop 2007; 132: 838–841.
[14] Kiliaridis S, Kjellberg H, Wenneberg B, Engström C. The relationship between maximal bite force, bite force endurance, and facial morphology during growth. A cross-sectional study. Acta Odontol Scand 1993; 51: 323–331.
[15] Lang G, Alfter G, Göz G, Lang GH. Retention and stability – taking various treatment parameters into account. J Orofac Orthop 2002; 63: 26–41.
[16] Lie Sam Foek DJ, Ozcan M, Verkerke GJ, Sandham A, Dijkstra PU. Survival of flexible, braided, bonded stainless steel lingual retainers: a historic cohort study. Eur J Orthod 2008; 30: 199–204.
[17] Linderholm H, Wennström A. Isometric bite force and its relation to general muscle forge and body build. Acta Odontol Scand 1970; 28: 679–689.
[18] Major TW, Carey JP, Nobes DS, Heo G, Major PW. Mechanical effects of third-order movement in self-ligated brackets by the measurement of torque expression. Am J Orthod Dentofacial Orthop 2011; 139: e31–e44.
[19] Pandis N, Fleming PS, Kloukos D, Polychronopoulou A, Katsaros C, Eliades T. Survival of bonded lingual retainers with chemical or photo polymerization over a 2-year period: a single-center, randomized controlled clinical trial. Am J Orthod Dentofacial Orthop 2013; 144: 169–175.
[20] Proffit WR, Fields HW. Contemporary orthodontics. 4th ed. St Louis: Mosby 2007.
[21] Renkema AM, Al-Assad S, Bronkhorst E, Weindel S, Katsaros C, Lisson JA. Effectiveness of lingual retainers bonded to the canines in preventing mandibular incisor relapse. Am J Orthod Dentofacial Orthop 2008; 134: 179.e1–179.e8.
[22] Renkema AM, Al Assad S, Katsaros C. Effectiveness of bonded lingual retainers in controlling relapse of the lower incisors. Eur J Orthod 2003; 25: 439.
[23] Renkema AM, Renkema A, Bronkhorst E, Katsaros C. Long-term effectiveness of canine-to-canine bonded flexible spiral wire lingual retainers. Am J Orthod Dentofacial Orthop 2011; 139: 614–621.
[24] Störmann I, Ehmer U. A prospective randomized study of different retainer types. J Orofac Orthop 2002; 63: 42–50.
[25] 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: 723–729.