Original Article

Forces of Various Nickel Titanium Closed Coil Springs

Anthony Louis Maganzini[a]; Alan M. Wong[b]; Mairaj K. Ahmed[c]

ABSTRACT

Objective: To compare the forces generated by 14 different 9 mm springs supplied by five different companies.

Materials and Methods: Five replicates of 14 different 9 mm springs were evaluated, resulting in 70 total specimens. Each was extended once from its resting length to 12 mm and then was deactivated. All tests were performed in a 37°C water bath. Forces were recorded at the 12 mm extension and deactivation distances of 9 mm, 6 mm, 3 mm, and 1 mm using an MTS force gauge. Data were collected with Testworks software, version 4.0, and were analyzed by analysis of variance (ANOVA) with one factor alternated.

Results: Mean peak load forces at 12 mm were significantly different between springs, and these forces varied from 147 to 474 grams. Mean unload forces measured at 9 mm, 6 mm, and 3 mm of deactivation values were highly variable, and only 6 of the 14 springs exhibited a "physiologic" mean unload force of 50 grams or less over the total deactivation range.

Conclusions: Few springs tested exhibited physiologic peak load forces and constant deactivation forces. This study suggests that labeling of nickel titanium closed coil springs is confusing and misleading. (*Angle Orthod.* 2010;80:182–187.)

KEY WORDS: Nickel titanium; Closed coil springs; Force comparisons

INTRODUCTION

The use of nickel titanium closing coils serves as one of many techniques for space closure, individual tooth retraction or protraction, distal movement of teeth, and traction on impacted teeth (Figure 1). Nickel titanium coil springs do not exhibit rapid force decay such as that seen with elastic chain or elastic modules, nor do they display the extremes in space closing forces of stainless steel coils or closing loops.[1–5] Their use does not require reliance on patient cooperation, as does interarch elastic wear.[3] It has been suggested that excessive force in space closure can produce adverse effects such as loss of incisor torque control and loss of tip and rotational control of upper molars with relative extrusion of their palatal cusps.[6] The low constant force of nickel titanium springs may be more biologically compatible than the intermittent high forces delivered by elastic chain,[6] which has been found to degrade by up to 50% after 4 weeks of activation.[7] The rate of space closure has been found to be quicker and more consistent with nickel titanium coils than with elastic modules, with no observable differences in final tooth position.[1]

Nickel titanium closed coil springs typically are used in 9 mm and 12 mm lengths. It should be noted that only a portion of a 9 mm or 12 mm nickel titanium coil spring can be activated or stretched. As is illustrated in Figure 2, a 9 mm nickel titanium coil spring has an active coil portion of approximately 5 mm. The remaining 4 mm of coil spring comprises 2 mm eyelets at each end of the coil spring (Figure 2).

Numerous orthodontic suppliers of nickel titanium closed coil springs may be used. Based on a clinician's "constant" force requirement, many suppliers offer more than one type of 9 mm or 12 mm coil. However, an examination of numerous orthodontic supply catalogs can be confusing, because suppliers label their nickel titanium closed coil springs with descriptive terms, including "Ultra Light, Light, Medium, Heavy, and Extra Heavy" (*Ormco Product Catalog.* 2003;12:8; Ormco Corporation, Orange, Calif). Others list the

[a] Professor and Department Chair, Dentistry/Orthodontics, Montefiore Medical Center, Albert Einstein College of Medicine, Bronx, NY.

[b] Private Practice, Clermont, Fla.

[c] Resident, Dentistry/Orthodontics, Montefiore Medical Center, Albert Einstein College of Medicine, Bronx, NY.

Corresponding author: Dr Anthony Louis Maganzini, Dentistry/Orthodontics, Montefiore Medical Center, Albert Einstein College of Medicine, 111 East 210th Street, Bronx, NY 10467-2490 (e-mail: amaganzi@montefiore.org)

Accepted: March 2009. Submitted: January 2009.

 DOI: 10.2319/011509-592.1

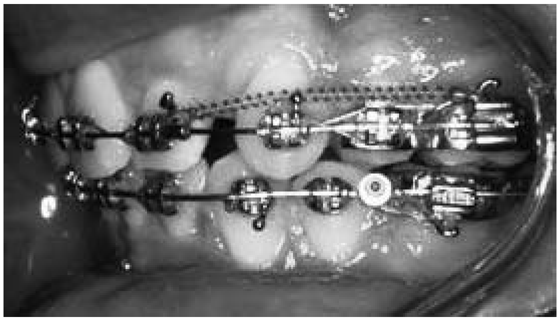

Figure 1. Intra-arch nickel titanium closed coil spring used for space closure and anterior retraction.

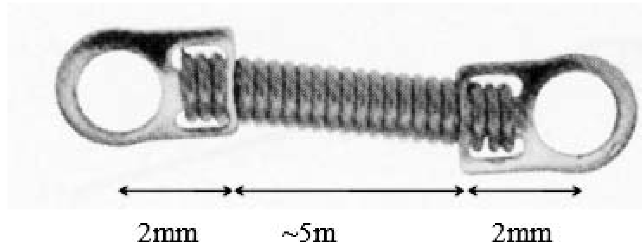

Figure 2. Representative nickel titanium closed coil spring.

"constant force values" that their coils provide, such as "100 grams, 150 grams, and 200 grams" (*G&H Wire Company Catalog.* 2006:9; G&H Wire Company, Greenwood, Ind). Some suppliers identify coils by coil lumen diameter, such as 0.010″, 0.011″, and 0.12″ (*Rocky Mountain Orthodontics Catalog.* 2002:165; Rocky Mountain Orthodontics, Denver, Colo).

The unique mechanical properties exhibited by nickel titanium include superelasticity and shape memory. Both of these properties are related to the phase transitions that nickel titanium allows between its martensitic (flexible/low temperature) and austenitic (stiff/high temperature) forms. These properties of nickel titanium have made a significant impact in terms of orthodontic treatment mechanics.[7–9]

Superelasticity refers to the ability of an alloy to exhibit fairly constant stress values over a large range. In orthodontics, this property would allow a nickel titanium spring to exhibit approximately the same amount of force whether it was stretched a small or a large distance. Also unique to superelastic materials is the force difference in loading/unloading curves. A hysteresis graph indicates that the force delivered by a nickel titanium spring (unload force) is not the same as the force applied to activate the spring (load force). The difference between loading and unloading curves allows the clinician to change force delivery by simply unloading and reloading a nickel titanium coil spring, or releasing and retying a nickel titanium wire.[9]

Shape memory is the ability of a material to return to its original form (austenitic phase) after it was deformed in the martensitic phase. These phase transitions can occur through changes in temperature, known as thermoelasticity.[7,8] More typically, these phase transitions can be stress induced by engaging an archwire in a deflected tooth, or stretching a spring over a hook. Shape memory is evident when a deflected nickel titanium archwire that is engaging significantly rotated teeth attempts to return to its original arch form (martensitic phase). These properties have made nickel titanium the preferred material for orthodontic applications in which a long range of activation is required with a relatively constant force.

Length, gauge, lumen size, winding configuration of coil, manufacturing, and exact composition of nickel titanium springs are all parameters that affect the force generated by nickel titanium coil springs.[10] However, it is difficult to obtain this information from some suppliers. Clinicians should not assume that all nickel titanium wires or springs perform in the same way. Bourauel et al[11] showed remarkable differences in forces delivered by nickel titanium alloys from different manufacturers. They also reported that coils from the same manufacturer, but from different batches, could produce significant differences in the forces generated.

Studies using nickel titanium closing coils have varied with regard to how unloading force values have been measured. An ideal constant unload force would exhibit no change in force over a determined deactivation range of a coil. However, it is unlikely that any coil would exhibit such a consistent force over any distance of deactivation. Manhartsberger et al[12] measured unload forces of four types for GAC Sentalloy 3 mm nickel titanium closed coils from peak extension of 12 mm deactivated to 0 mm of extension. Their parameters were based on the manufacturer's recommendations for constant force delivery of the coils. Investigators concluded that deactivation ranges were variable, depending on the type of coil. However, the longest range of deactivation that still provided a constant force was determined to be 8 mm for Sentalloy 100 gram coils. Less than a 34 gram change in force was noted over this range of deactivation. Tripolt et al[13] used 5 mm coils and tested coil unload forces from 15 mm of peak extension back to resting length. They concluded that "constant" unload forces of the nickel titanium coil springs were best exhibited in a 5 mm range, from 7.5 mm to 2.5 mm of deactivation. At this range of deactivation, investigators determined the constant force range for their coils to be no greater than approximately 48 grams (converted from Newtons). Although numerous suppliers of nickel titanium closed coil springs have been used in both in vitro and in vivo studies, GAC Sentalloy nickel titanium closed coils springs have been the most widely tested.[1,3,5,12,13]

Figure 3. Force application device with load cell and computer calibration.

The main objective of this study was to compare forces generated by 14 types of 9 mm nickel titanium closed coil springs supplied by five orthodontic companies. The null hypothesis was that these coils did not differ in terms of measured peak load force or the range of forces delivered during deactivation. If such differences did exist, they could bring into question the present terminology of ''light, medium, and heavy'' and ''constant force delivery.'' The hope was that the manner in which suppliers label these products could be based on the characteristics of the coils themselves, and not on some arbitrary nomenclature.

MATERIALS AND METHODS

Coils were tested from the following five suppliers: American Orthodontics (American Orthodontics, Sheboygan, Wis), GAC (GAC International Inc, Bohemia, NY), G&H Wire (G&H Wire Company, Greenwood, Ind), Ormco (Ormco Corporation, Orange, Calif), and Rocky Mountain Orthodontics (Rocky Mountain Orthodontics, Denver, Colo). Fourteen types of 9 mm nickel titanium coils with eyelet attachments were used:

American Orthodontics—Closed Coil Adjustable Force Springs with Eyelet (AO)
GAC—Sentalloy 100 gram Closed Coil Springs (GAC 100)
GAC—Sentalloy 150 gram Closed Coil Springs (GAC 150)
GAC—Sentalloy 200 gram Closed Coil Springs (GAC 200)
G&H Wire—Original Light Niti Closed Coil Springs (GH ORI L)

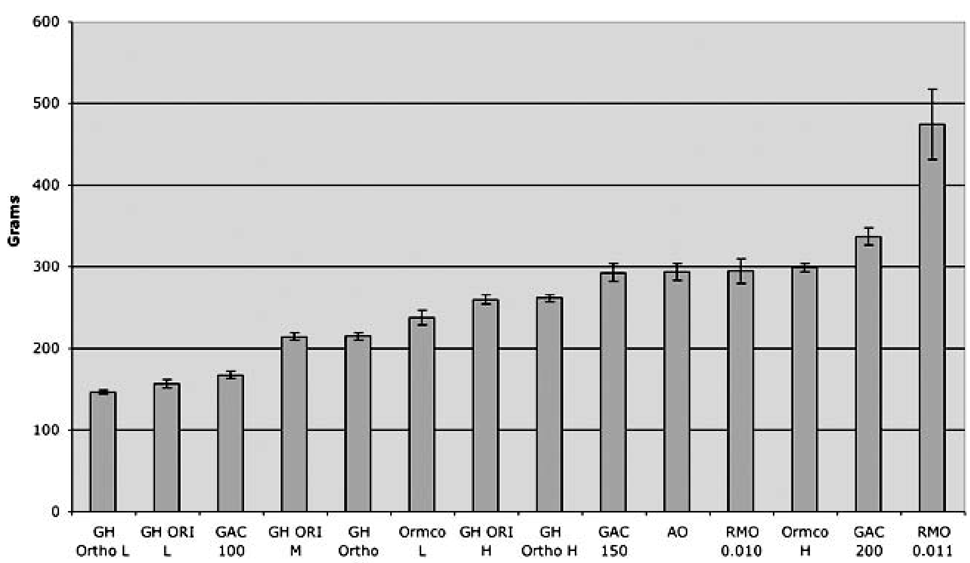

Figure 4. Mean peak load measured at 12 mm of extension.

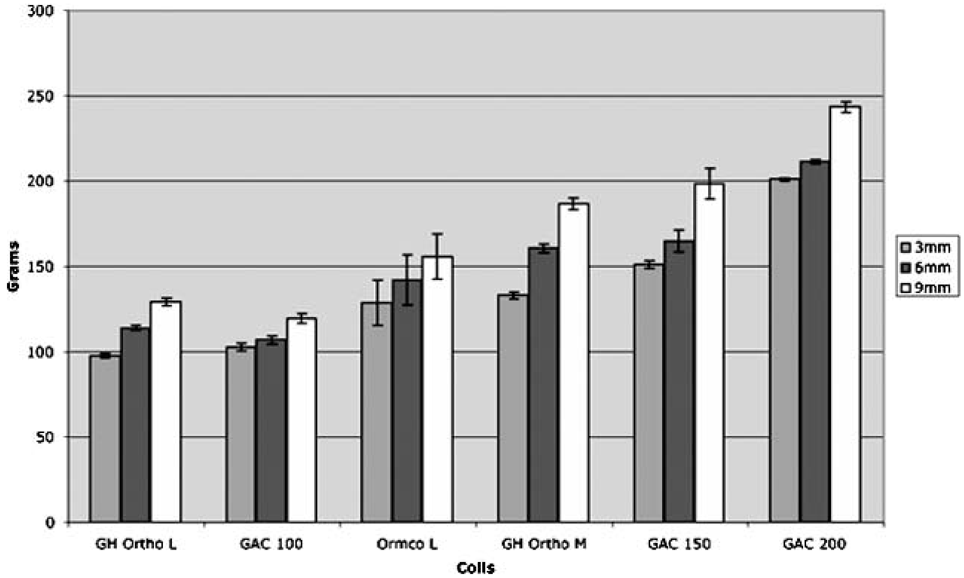

Figure 5. Coils with a mean unload force indicative of "constant force."

G&H Wire—Original Medium Niti Closed Coil Springs (GH ORI M)
G&H Wire—Original Heavy Niti Closed Coil Springs (GH ORI H)
G&H Wire—Orthoforce Light Niti Closed Coil Springs (GH Ortho L)
G&H Wire—Orthoforce Medium Niti Closed Coil Springs (GH Ortho M)
G&H Wire—Orthoforce Heavy Niti Closed Coil Springs (GH Ortho H)
Ormco—Light 0.010″ × 0.030″ Ni-Ti Springs—Extension (Ormco L)
Ormco—Heavy 0.010″ × 0.030″ Ni-Ti Springs—Extension (Ormco H)
Rocky Mountain Orthodontics—0.010″ × 0.030″ Extension Springs (RMO 0.010)
Rocky Mountain Orthodontics—0.011″ × 0.030″ Extension Springs (RMO 0.011)

Five replicate coils from each coil type were evaluated, resulting in 70 total specimens. The evaluation of nickel titanium coils was performed with the use of a specialized force gauge (Model Insight 1, MTS, Eden Prairie, Minn). Tests were performed in a 37°C temperature-controlled water bath. The MTS Insight 1 was fitted with 0.030″ hooks on its base and the load arm to engage the coil eyelets. A 50 Newton load cell was used for load activation of each coil. The rate of extension and recovery was performed at 10 mm per minute (Figure 3). To avoid slight manufacturer differences in resting active coil length (5.1 mm to 5.6 mm) and to limit human error, each coil was preloaded to a baseline preload of 3 grams.

Following this preload, each coil measurement was started at 0 mm of extension and was stretched to a peak extension of 12 mm. As suggested by the manufacturer and similarly used in prior studies,[13] the peak extension length was established at less than three times the passive coil length of 5 mm to avoid detachment of the eyelet. Each coil was activated once to a peak extension of 12 mm, at which point peak load forces were established and recorded. The springs then were deactivated and unload forces were recorded at 9 mm, 6 mm, 3 mm, and 1 mm of coil extension. Changes in mean unload forces of 50 grams or less over the deactivation range from 9 mm to 3 mm of extension were the criteria established for "constant force." Data were recorded with Testworks software, version 4.0 (Advanced User Systems Pty Ltd, New South Wales, Australia). Following data acquisition, statistical analysis was performed with SAS statistical software (SAS Institute Inc, Cary, NC), employing analysis of variance with one factor alternated.

RESULTS

The actual mean peak load force measured at 12 mm of extension exhibited statistically significant differences between most coil types. As illustrated in Figure 4, peak load forces ranged from a high of 474 grams for Rocky Mountain 0.011″ × 0.030″ Extension Springs to a low value of 147 grams for G&H Orthoforce Light Niti Closed Coil Springs.

The mean change in the unload force as measured from 9 mm to 3 mm of deactivation demonstrated significant variability, as demonstrated in Figures 5 and 6. The following six (out of fourteen) coil types exhibited changes in mean unload force of 50 grams or less over the deactivation range of 9 mm to 3 mm:

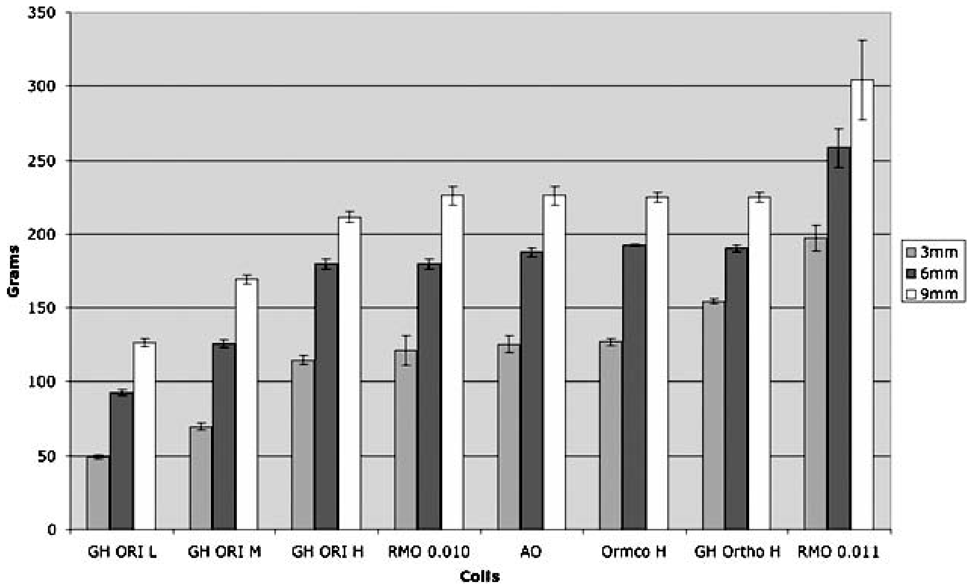

Figure 6. Coils with a variable mean unload force.

GAC—Sentalloy 100 gram Closed Coil Springs (GAC 100)
GAC—Sentalloy 150 gram Closed Coil Springs (GAC 150)
GAC—Sentalloy 200 gram Closed Coil Springs (GAC 200)
G&H Wire—Orthoforce Light Niti Closed Coil Springs (GH Ortho L)
G&H Wire—Orthoforce Medium Niti Closed Coil Springs (GH Ortho M)
Ormco—Light 0.010″ × 0.030″ Ni-Ti Extension Springs (Ormco L)

The change in mean unload force of the coils from 9 mm to 3 mm of activation and the mean peak load force measurements are summarized in Table 1. The GAC Sentalloy 100 gram Closed Coil Spring exhibited the least change in force over the designated range of deactivation with a 17 gram force change. The Rocky Mountain Orthodontics 0.011″ × 0.030″ Extension Spring exhibited the greatest variability, with a change of 107 grams. It should be noted that the 53 gram force change for the G&H 9 mm Orthoforce Medium Niti Closed Coil Spring was not statistically different from the designated 50 gram change in force established in this protocol.

DISCUSSION

This study found large variations in the peak load and unload forces produced by the 14 nickel titanium closed coils that were tested. The concepts of ‘‘physiological load’’ and ‘‘constant force’’ therefore were brought into question.

Only six of the fourteen coil types had less than a 50 gram change in force from 9 mm to 3 mm of de-

Table 1. Summary of Results in Grams

Coil Type	Deactivation Force	Variation	Peak Load
GAC—Sentalloy 100 Gram Closed Coil Springs	120-103	17	167
G&H Wire—Orthoforce Light NiTi Closed Coil Springs	129-97	32	147
Ormco—Light NiTi Springs—Extension Springs	155-128	27	235
G&H Wire—Orthoforce Medium NiTi Closed Coil Springs	186-133	53	210
GAC—Sentalloy 150 Gram Closed Coil Springs	198-151	47	288
GAC—Sentalloy 200 Gram Closed Coil Springs	243-201	42	335
G&H Wire—Orthoforce Heavy NiTi Closed Coil Springs	224-154	70	255
G&H Wire—Original Light NiTi Closed Coil Springs	126-49	77	155
G&H Wire—Original Medium NiTi Closed Coil Springs	169-70	99	208
G&H Wire—Original Heavy NiTi Closed Coil Springs	211-115	96	250
American Orthodontics—Closed Coil Adjustable Force Springs	226-125	101	290
Rocky Mountain—.010 × .030 Extension Springs	226-121	105	292
Ormco—Heavy NiTi Springs—Extension Springs	232-127	105	300
Rocky Mountain—.011 × .030 Extension Springs	304-197	107	474

activation. Within this 9 mm to 3 mm deactivation range, some coils exhibited changes in force greater than 100 grams. This evidence is contrary to what one would expect the ''constant'' force of a nickel titanium coil to provide. Ormco's Heavy Extension Springs, Rocky Mountain Orthodontics 0.010″ × 0.030″ Extension Spring, and American Orthodontics Nickel Titanium Closed Coils Springs all exhibited comparable force values over the 9 mm to 3 mm deactivation range. However, the mean observed change in force over this range was over 100 grams for each coil.

GAC's Sentalloy coils were the most successful of all suppliers in that all three of their coils tested supplied relatively ''constant'' unload forces within the designated deactivation range. G&H Wire's Orthoforce Light and Orthoforce Medium coils and Ormco's Light coils also displayed relatively constant forces over deactivation. Our results are consistent with the findings of Tripolt et al,[13] who noted that significant peak loads relative to the unload forces generated by the nickel titanium closed coil springs reinforce the need to overactivate the coils before engaging them for clinical use.

Unfortunately, the labeling of coils could still confuse clinicians as they choose the correct nickel titanium coils for their needs. As an example, GAC's lightest coil tested, GAC 100, produced forces between 120 and 103 grams, and Rocky Mountain Orthodontics' lightest force coil, 0.010″ × 0.030″ Extension Spring, produced forces ranging from 226 to 121 grams. This study suggests that the present labeling of nickel titanium closed coil springs is confusing and may be misleading.

CONCLUSIONS

- Nickel titanium closed coil springs vary greatly in the peak load forces generated during activation. Most nickel titanium closed coils tested had inconsistent unload forces generated throughout deactivation.
- Although nickel titanium closed coil springs with physiologic peak load forces and constant deactivation forces might be desirable, most coils tested failed to exhibit these characteristics.
- This study suggests that the present labeling of nickel titanium closed coil springs is confusing and may be misleading.

REFERENCES

1. Samuels RH, Rudge SJ, Mair LH. A comparison of the rate of space closure using a nickel-titanium spring and an elastic module: a clinical study. *Am J Orthod Dentofacial Orthop.* 1993;103:464–467.
2. Samuels RH, Rudge SJ, Mair LH. A clinical study of space closure with nickel-titanium closed coil springs and an elastic module. *Am J Orthod Dentofacial Orthop.* 1998;114:73–79.
3. Dixon V, Read MJF, O'Brien KD, Worthington HV, Mandall NA. A randomized clinical trial to compare three methods of orthodontic space closure. *J Orthod.* 2002;29:31–36.
4. Rock WP, Wilson HJ, Fisher SE. Force reduction of orthodontic elastomeric chains after one month in the mouth. *Br J Orthod.* 1986;13:147–150.
5. von Fraunhofer FA, Bonds PW, Johnson BE. Force generation by orthodontic coil springs. *Angle Orthod.* 1993;63:145–148.
6. Bennett JC, McLaughlin RP. Controlled space closure with a preadjusted appliance system. *J Clin Orthod.* 1990;24:251–260.
7. Santoro M, Nicolay O, Cangialosi T. Pseudoelasticity and thermoelasticity of nickel-titanium alloy: a clinically oriented review. Part II: deactivation forces. *Am J Orthod Dentofacial Orthop.* 2001;119:594–603.
8. Santoro M, Nicolay O, Cangialosi T. Pseudoelasticity and thermoelasticity of nickel-titanium alloy: a clinically oriented review. Part I: temperature transitional ranges. *Am J Orthod Dentofacial Orthop.* 2001;119:587–593.
9. Schneevoigt R, Haase A, Eckardt VL, Harzer W, Bourauel C. Laboratory analysis of superelastic NiTi compression springs. *Med Eng Phys.* 1999;21:119–125.
10. Angolkar PV, Arnold JV, Nanda RS, Duncanson MG. Force degradation of closed coils springs: an in vitro evaluation. *Am J Orthod Dentofacial Orthop.* 1992;102:127–133.
11. Bourauel C, Drescher D, Ebling J, Broome D, Kanarachos A. Superelastic nickel titanium alloy retraction springs—an experimental investigation of force systems. *Eur J Orthod.* 1997;19:491–500.
12. Manhartsberger C, Seidenbusch W. Force delivery of Ni-Ti coil springs. *Am J Orthod Dentofacial Orthop.* 1996;109:8–21.
13. Tripolt H, Burstone CJ, Bantleon P, Manschiebel W. Force characteristics of nickel-titanium tension coils springs. *Am J Orthod Dentofacial Orthop.* 1999;115:498–507.