FORCE-DEFLECTION CHARACTERISTICS OF THE FATIGUE-RESISTANT DEVICE SPRING: AN IN VITRO STUDY

Moaaz Mohamed El-Sheikh, BDS, MSc[1]

Keith Godfrey, BDS, MDS, DD, FACE[2]

Montein Manosudprasit, DDS, Cert, MDS[2]

Nita Viwattanatipa, DDS, MSD[3]

Aim: *The Forsus fatigue-resistant device spring is a 3-piece telescoping compression spring used for Class II correction. The aims of this study were:* (1) *to measure the mean force delivered at different amounts of deflection;* (2) *to determine and compare the mean stiffness between loading and unloading; and* (3) *to determine the resilience of the fatigue-resistant device springs.* ***Material and methods:*** *Twelve fatigue-resistant device springs were tested with a universal testing machine and Winrcon software, with the load cell of 100 N, crosshead speed at 0.5 mm/second. Force-deflection data during loading and unloading were recorded at 2-mm intervals up to 12 mm compression.* ***Results:*** (1) *The mean force-deflection loading and unloading curves generally were linear, with a small area of hysteresis;* (2) *the loading mean stiffness (19.4 g/mm) was significantly greater than the unloading mean stiffness (18 g/mm), although this is clinically insignificant;* (3) *fatigue-resistant device springs exhibited good resiliency. A calibrated table of force-deflection of fatigue-resistant device springs is presented for clinicians to select the appropriate length of the device for the particular orthodontic force needed.* World J Orthod 2007;8:30–36.

Functional appliance systems have been advocated for correction of skeletal Class II discrepancies due to small mandible size or mandibular retrusion. There is a wide variety of intraoral-functional appliances that can be either removable or fixed. Fixed functional appliances first appeared in 1900 when Emil Herbst presented his system at the Berlin International Dental Congress. Since then, and up to the 1970s, little was published on this appliance. Later, Pancherz[1] revived discussion about the use of the Herbst appliance with publication of several articles on the subject.

In terms of the force vector applied, fixed-functional appliances can be categorized into 2 groups: *(1)* appliances producing pulling forces, such as the Saif spring (Pacific Coast Manufacturing, Woodinville, WA, USA),[2] developed in 1957, which delivered a pulling force vector, and *(2)* appliances producing pushing forces, which deliver a pushing force vector, forcing the attachment points of the appliance away from one another. Pushing-force appliances include the Herbst appliance, Jasper jumper, fatigue-resistant device springs (FRD), etc. This type of pushing appliance produces vectors that are sagittal and vertically intrusive.[3,4] In addition, the forces tend to produce transverse expansion and are oriented more in the downward and forward direction of facial growth.[5]

Fixed functional appliances can be classified as: *(1)* flexible fixed functional appliance (FFFA), eg, Jasper jumper and Klapper super spring; *(2)* rigid fixed functional appliances (RFFA), eg, Herbst and Universal bite jumper; or *(3)* hybrid, eg, the Forsus FRD spring and Eureka spring. The hybrid represents a combination of a rigid fixed appliance (eg, Herbst, Universal bite jumper) with a flexible fixed functional appliance (eg, Jasper jumper, adjustable bite corrector) because they include coil-spring type systems.

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[1] Faculty of Dentistry, Garyounis University, Abdul Monem Riad, Benghazi, Libya.

[2] Associate Professor, Orthodontic Department, Faculty of Dentistry, Khon-Kaen University, Khon-Kaen, Thailand.

[3] Assistant Professor, Orthodontic Department, Faculty of Dentistry, Khon-Kaen University, Khon-Kaen, Thailand.

CORRESPONDENCE
Dr Nita Viwattanatipa
Orthodontic Department
Faculty of Dentistry
Khon-Kaen University
Khon-Kaen, Thailand
E-mail: Nitaviw@hotmail.com

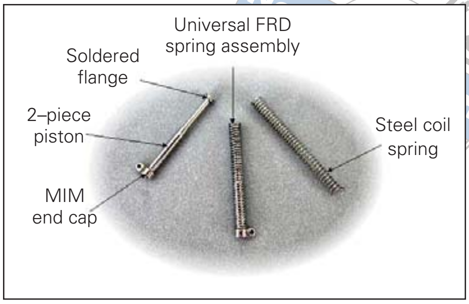

Fig 1 The Forsus FRD spring (3M Unitek, Monrovia, CA, USA): Force module assembled and unassembled (coil spring and 2-piece piston).

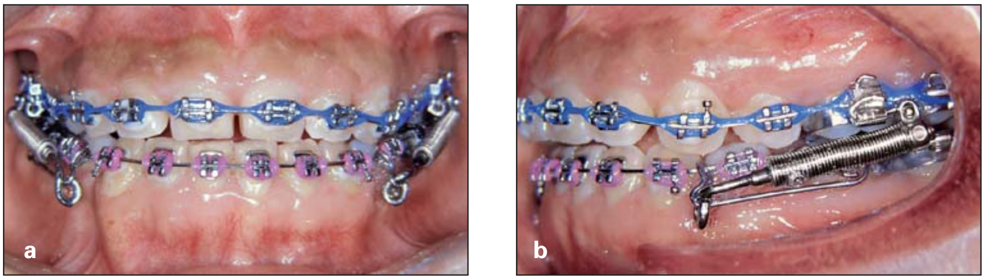

Fig 2 *(below)* The Forsus FRD spring, recommended for Class II malocclusion. **(a)** The FRD spring attached on both sides. **(b)** Close-up of 1 side of the FRD spring.

STUDY OBJECTIVES

The control of the level of force delivered by an appliance is of paramount importance, not only with regard to treatment efficiency and treatment time, but also to minimize any iatrogenic effect of treatment from the use of too-high force. Few of the different varieties of fixed functional appliances have known force levels. It would benefit orthodontists to have information regarding the measurable force-deflection characteristics of the FRD coil springs. The specific aims of this study were: *(1)* study the force-deflection characteristics of the as-received FRD spring during loading and unloading; *(2)* calculate and compare FRD spring stiffness between loading and unloading; *(3)* calculate the resilience of the FRD spring (energy storage capacity and energy loss); and *(4)* develop a calibrated table, which displays the force delivered at various spring deflections.

MATERIAL AND METHODS

Fatigue-resistant device

The Forsus™ FRD spring (3M Unitek, Monrovia, CA, USA) is an intraoral 3-piece telescoping compression spring device. The module generating force is called the universal spring assembly, which consists of a 2-piece piston assembly and a steel coil spring (Fig 1). The intraoral placement of the device is as follows: On the distal side of the universal spring assembly, an L pin (insertion) will engage the universal spring to the maxillary first molar headgear tube. A properly sized push rod is selected and inserted into the spring piston on the proximal part, which will then be looped onto the bypass device or the main archwire (Fig 2). The device has been claimed to deliver continuous orthopedic forces and is intended to overcome breakage problems that can occur with other intraoral fixed functional Class II appliances. Its use has been reported in a clinical trial for Class II correction.[6]

Twelve as-received Forsus FRD springs consisting of a 0.015 × 0.10-inch (wire diameter × lumen coil spring) stainless steel compression coil spring and a 2-piece piston assembly were randomly investigated.

Mechanical testing

The mechanical testing involved the use of a holding jig for the FRD springs, designed by Keith Godfrey and developed in the Department of Orthodontics, Khon

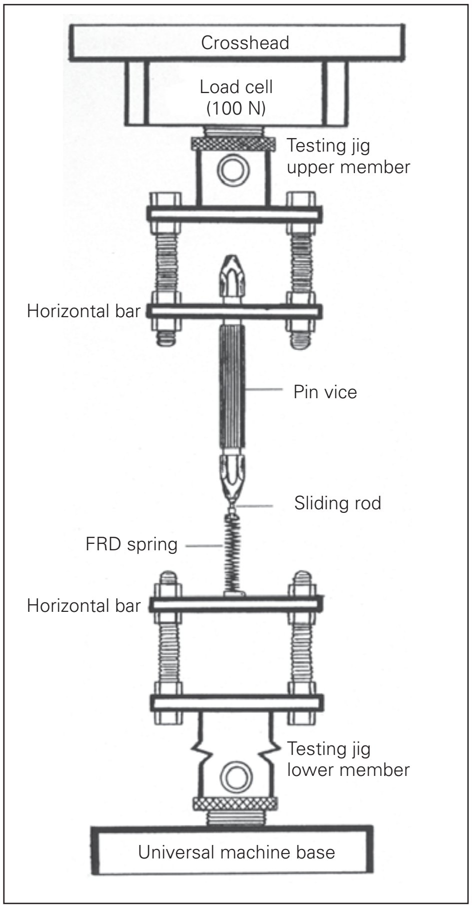

Fig 3 Testing jig with a 100 N load cell, pin vice holding a 0.045-inch rod, which slid into the FRD force module during loading and unloading.

Kaen University (Fig 3), to be used with the universal testing machine (LR30K; Lloyd Instruments, Hampshire, UK). The holding jig consisted of an upper jig member with a horizontal steel bar secured to double-ended pin vise (Zona 37-145; Zona Tool, Bethel, CT, USA), which holds a sliding rod made of a stainless steel round wire 0.045 inch in diameter. The upper jig member was attached to a 100 N load cell, on the crosshead of the universal testing machine. The spring rests on a horizontal steel bar of the lower jig member, which is integrated in the universal testing machine base. Before starting the test, the upper and lower jig members were leveled to reduce the misalignment between the spring and the sliding rod, which might affect the data accuracy.

Before testing, the springs were stored in collected saliva for a few minutes. Saliva was used as a lubricant to minimize friction between the spring telescope and the guiding rod. The test was carried out at ambient room temperature of 27°C.

When activated, the universal testing machine crosshead moved the upper jig member downward at a speed of 0.5 mm/second to compress the spring from 0 mm to 12 mm, about 40% of its free length. The machine crosshead motion was then reversed, maintaining the same speed as the spring unloaded. The loading and unloading force curves were registered and plotted against deflection on an X-Y recorder in Newtons and millimeters using the Winrcon 7.61 software program (LR30K; Lloyd Instruments).

Statistical analysis

The force-deflection data were reported in grams and millimeters. Descriptive statistics of sample means and standard

Fig 4 Force-deflection diagram for 12 FRD springs in as-received condition, comparing the mean loading and unloading force levels at 2-mm intervals of deflection.

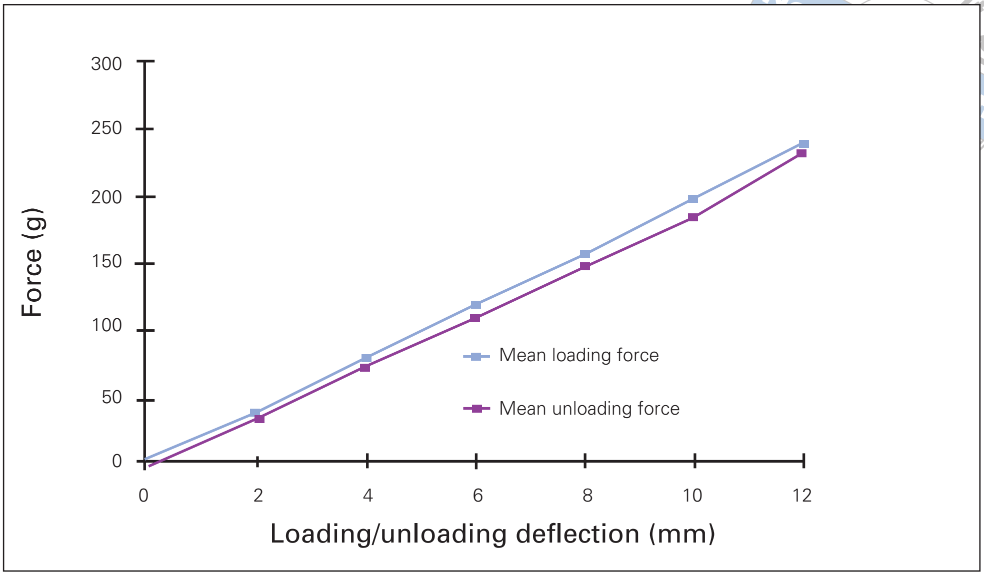

Table 1 **Mean force-deflection for FRD springs (as-received condition) at 2-mm intervals of deflection**

Deflection (mm)	Loading force Mean (g)	Loading force SD	Unloading force Mean (g)	Unloading force SD
2	38.5	2.4	34.5	4
4	77.7	2.9	71.2	3.4
6	116.9	2.8	107.5	4.5
8	155	5.2	144.5	5.6
10	194.7	6.1	180.5	7.3
12	233.3	6.7	226.5	7.4

n = 12; SD, standard deviation.

deviations were obtained. Student *t* test was used to compare the mean stiffness between loading and unloading.

RESULTS

Figure 4 demonstrates the force-deflection graph of the FRD spring in as-received condition, which shows the mean loading and unloading force level at 2-mm intervals of spring deflection. Descriptive mean and standard deviation of loading and unloading force for 2 mm to 12 mm deflection is given in Table 1.

The FRD spring stiffness assumes a linear force-deflection line. The stiffness of a spring was determined by calculating the slope on the graph using mean force-deflection coordinates between the 2-mm and 10-mm deflection. Statistically significant between-group differences were found as shown in Table 2.

Figure 5 compares the mean strain energy stored during loading and unloading for 12 FRD springs in as-received condition. Assuming linear characteristics, the mean strain energy was calculated from the area beneath the force-deflection lines of Fig 4.

DISCUSSION

While there have been several designs of fixed functional Class II correction appliances for reducing the need for patient compliance,[7] information regarding the amount of force delivered by some of these appliances is lacking.[8–13] It may be difficult, if not impossible, to measure force delivered by some appliances,[14–17] such as the Eureka spring, Jasper jumper, adjustable bite corrector, or NiTi flat spring. The force level obtained by activating these appliances can be considered uncontrolled and

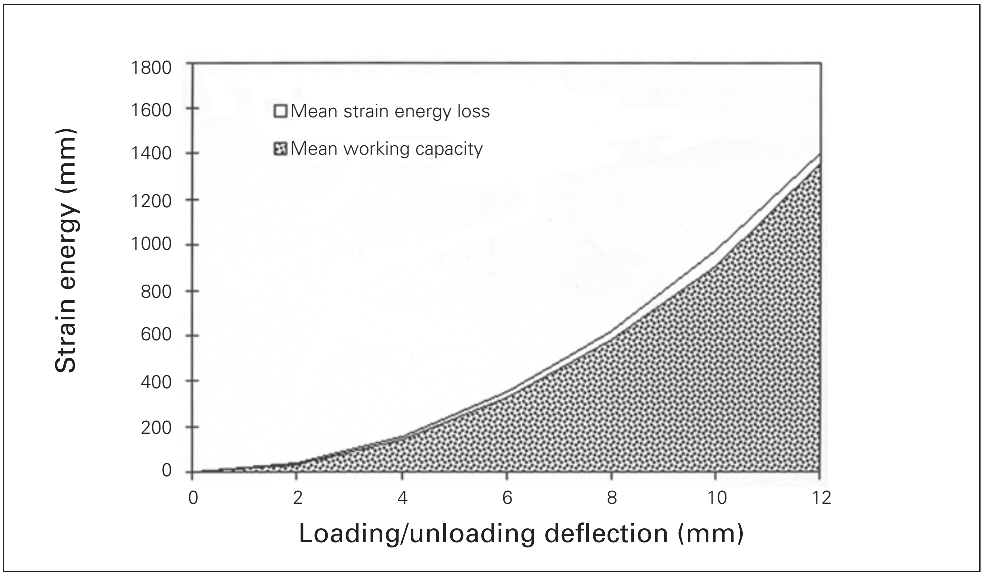

Fig 5 Strain energy diagram for 12 FRD springs in as-received condition, comparing the mean total strain energy and hysteresis during loading and unloading.

Table 2 Statistical comparison between mean loading and unloading stiffness for FRD springs (as-received condition) at 2-mm intervals of deflection

	Loading	Unloading	*P*
Mean stiffness (g/mm)	19.4	18.0	0.00
Standard deviation	0.65	0.7	

P value significant at < .05; n = 12.

subjective. This study aimed to find objective information regarding the amount of force delivered by the Forsus FRD spring.

The force-deflection characteristics of the as-received FRD spring during loading and unloading can be considered linear behavior, following Hookes' Law. The force and deflection of the spring are proportional. The FRD spring assembly, however, demonstrates small hysteresis between loading and unloading (see Fig 4). This may be due to other variables, such as friction interplay between the FRD spring, piston and sliding rod, and perhaps spring buckling.

Theoretically, the stiffness of a spring can be calculated. The following equation relates the material and geometry of the spring to its stiffness[18,19]:

$$k = P/\delta = Gd^4/8D^3N$$

where *k* is the stiffness of the spring, *d* is the diameter of the wire used to make the spring, *G* is the shear modulus of the material (usually steel), *D* is the diameter of the spring itself, *N* is the number of coils in the spring, *P* is the load, and δ is the deflection.

Given this formula, it is possible to calculate the stiffness of the 1-piece FRD steel coil spring. However, the stiffness of the entire 3-piece universal spring assembly, due to its complexity, would be difficult to calculate. Evaluation of the FRD spring required the design of a unique experimental testing device, as proposed in this study (see Fig 3), as similar to the actual clinical situation as possible. From this study, the loading mean stiffness (19.4 g/mm) was significantly greater than the unloading mean stiffness (18 g/mm); however, this difference is clinically insignificant.

The spring is considered an energy source. Theoretically, when the spring is compressed, the energy is stored. The working capacity of the spring is that process during which the spring is unloaded and, to some extent, equals the stored strain energy (energy added during the compression process). Usually the energy storage capacity is equal to $\frac{1}{2} P \times \delta$, where *P is* the load and δ is the deflection.[20] Figure 5 shows that most of the added strain energy of spring compression was recovered on the release of the applied force. Taking into account the friction interplay between the device assemblies, only 41 g.mm of mean strain energy loss was detected for the 12-mm

Table 3 **Mean unloading forces and percentages of force delivered by FRD springs (as-received condition) at 2-mm intervals of deflection**

Deflection (mm)	Unloading mean force (g)	SD	Force %
2	34.5	4	15
4	71.2	3.4	30
6	107.5	4.5	46
8	144.5	5.6	62
10	180.5	7.3	77
12	226.5	7.4	97

n = 12; SD, standard deviation.

Table 4 **Calibrated activation of the FRD spring: Amount of spring deflection and force delivered at various available interarch distances and push-rod sizes**

	Spring deflection/force value			
Interarch distance*	25-mm rod	29-mm rod	32-mm rod	35-mm rod
25 mm	12/226			
29 mm	4/139	12/226		
32 mm	5/80	9/155	12/226	
35 mm	2/30	6/107	9/155	12/226

*Available distance from distal of the maxillary first molar to mesial of the mandibular canine bracket.

deflection range, this amount can be considered minimal. The FRD spring, therefore, exhibits good resiliency.

Clinical application

For several fixed functional appliances, only the initial force value was given by the manufacturers. Due to the fact that the nature of force delivered by spring is proportional to deflection range, this information may be insufficient. It is the authors' objective to develop a calibrated table that displays the force delivered at various deflections. Table 3 shows the mean unloading forces and percentages of force relative to maximal compressive force delivered by Forsus FRD springs, at 2-mm intervals of deflection. This table should help the clinician understand the force-delivery system of the FRD springs.

According to the guideline for installation of the FRD, the proper size push rod must first be selected. The 3M Unitek Kit provides 4 sizes of push rods to match with full compression of the spring (25, 29, 32, and 35 mm). To determine the proper size of the push rod, the measuring gauge provided should be used to measure the distance from the distal end of the maxillary first molar tube to the distal side of the mandibular canine bracket, while the patient is in centric occlusion without advancing the mandible.

The force system delivered by the FRD springs is dynamic. It can be inferred from Table 3 that if the distance measured is 25 mm, using the 25 mm push rod length will compress the spring to the full extent of 12 mm, thereby delivering an initial force value of 226 grams. It can be hypothesized that this active force may elicit a reflex involving postural change of the mandible in the forward and downward direction. This can result in less deflection of the spring, perhaps a few millimeters less deformed than initially calculated. Therefore, the mean force can drop to the range of 144 to 180 g. As the molar teeth begin to move distally, the force value will increasingly degrade. Table 4 demonstrates mean force values at different distances from the distal end of the maxillary first molar tube to the mesial side of the mandibular canine bracket, using various push rod lengths. Therefore, depending on the clinical application, the force level can be modified by varying the push-rod size to the desired force level. For example, clinicians who prefer a stepwise increase of force, rather than force delivered at the full capacity all at once, could start treatment with 6-mm compression, continue that for 2 to 4 months (preconditioning), and then apply full compression (12 mm) to maximize the orthopedic effect.

CONCLUSIONS

It would benefit the orthodontist to know the force characteristics of a fixed functional Class II appliance, which is possible with the Forsus FRD spring. The clinician should consider the unloading stiffness diagrams of the FRD spring and choose a deflection range to match the required force.

Since clinicians can modify the selection to match their preference, the calibrated force value at the different deflections presented in this study can be more useful than just knowing the initial maximal force value.

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