Original Article

Effects of stress relaxation in beta-titanium orthodontic loops: *Part II*

Roberto S.S. Júnior[a]; Sergei G.F.R. Caldas[b]; Lídia P. Martins[c]; Renato P. Martins[d]

ABSTRACT

Objective: To determine which regions of beta-titanium T-loop springs (TLSs) are more affected by the stress relaxation over a 12-week period.

Materials and Methods: Fifty TLS were previously activated by concentrated bends and divided into five groups of 10 each according to their evaluation periods: immediate assessment (G0), 24 hours (G1), 48 hours (G2), 1 week (G3), and 12 weeks (G4). Groups 1 to 4 were mounted into a structure simulating a clinical situation. After the experimental periods, the springs were scanned for measurement of their angles and numbered from 1 to 9. A two-way analysis of variance was used to detect differences among the angles measured and differences caused by time and also to detect interactions between those two factors. Tukey's test was used to find differences among the groups.

Results: Time influenced the angulations of the TLSs ($P < .001$). Tukey post hoc test showed that G0 (84.1°) presented a different profile, whereas G1 (90.2°), G2 (90.7°), and G3 (91.1°) had similar profiles among each other, with G4 (92.6°) showing a mean value different from all other groups. A significant interaction was detected between activation time and angular deformation in the TLSs ($P < .01$).

Conclusion: Stress relaxation was observed in the TLSs. It was greatest within 24 hours and gradually increased up to 12 weeks. Two regions were identified as responsible for the relaxation of the TLSs: one at the bend between the vertical extensions of the springs and the base arch and the other at the preactivation bends made in the base arch. (*Angle Orthod.* 2016;86:386–390.)

KEY WORDS: Orthodontics; Biomechanics; Titanium

INTRODUCTION

Orthodontic space closure can be achieved by the use of loops or sliding mechanics. The former has certain advantages compared with the latter, such as absence of friction and the possibility of controlling the moment to force ratio (M/F), which could provide more control during space closure.[1] Among the springs that are normally used, the T-loop spring (TLS) made of beta-titanium alloy (β-Ti) is considered one of the best because it produces the highest M/F ratio as well as a lower load-deflection ratio when compared with other conventional vertical loops.[2]

Similar to other springs, the TLS is submitted to a constant stress when it is secured to the orthodontic appliance. This constant stress, when applied over time, can lead to changes in the original shape of the spring and affect the force system that had been initially planned.[3] This phenomenon is called stress relaxation, which is the attempt of the crystalline structure of the alloy to reorganize itself following stress concentration.[4] This type of relaxation has well-defined characteristics, and its more significant effect happens within the first 24 hours of stress application,[3,5] something that has already being observed in orthodontic archwires made of different alloys[5–10] and in TLSs.[3,11]

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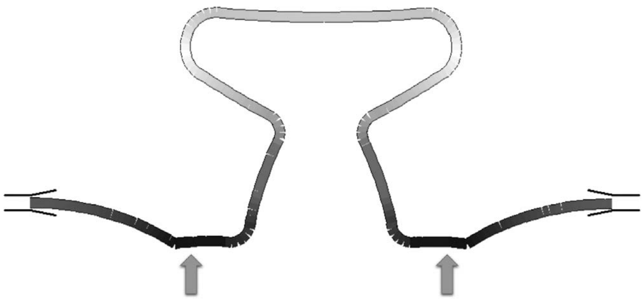

Figure 1. Activation of the T-loop springs preactivated by bends, as simulated by the Loop Software. Different contrast areas reflect stress distribution over the wire, going from dark areas being high-stress areas (arrows) to light being low-stress areas. Modified from Caldas et al., Effects of stress relaxation in beta-titanium orthodontic loops. *Am J Orthod Dentofacial Orthop.* 2011;140:e85–e92. Courtesy of Elsevier Inc.

Nonetheless, the specific sites where stress relaxation occurs in TLSs have not yet been identified, but it is suspected that it occurs in places of high stress concentration. Using the Loop Software (dHAL Orthodontic Software, Athens, Greece), which allows orthodontic loops to be designed and assessed in addition to predicting the forces, moment, and MF ratio produced, a simulation of a TLS can be done and the stress distribution along its different regions can be observed (Figure 1). There are different amounts of stress that occur along the loop structure, but the regions of the bends between the base wire and vertical stems and where the preactivations bends are placed on the base wire (Figure 1) seem to be the areas with the greatest concentration of stress. Therefore, there is a possibility that these sites are the most responsible for the stress relaxation of the TLS.

Thus, the aim of the present study was to determine which regions of the beta-titanium TLS are more affected by stress relaxation through measurement of structural modifications in the loops over a 12-week period.

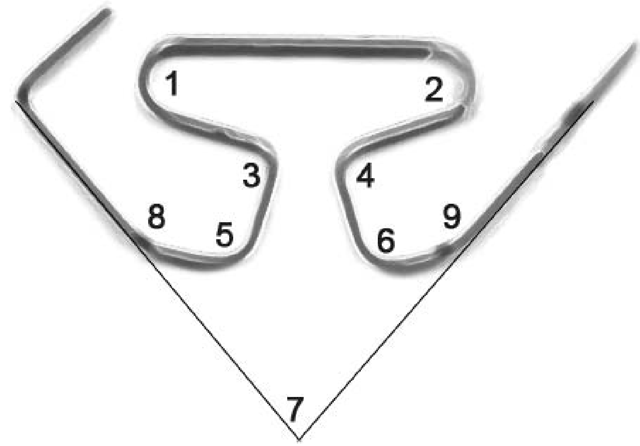

Figure 3. T-loop springs preactivated by bends with their measured angles, numbered from 1 to 9.

MATERIALS AND METHODS

The sample consisted of 50 TLSs measuring 6 $\times$ 10 mm hand bent by one person out of straight 0.017 $\times$ 0.025-inch beta-titanium wires (TMA, Ormco Co, Glendora, Calif) using a Marcotte plier (No. 678-316, Hu-Friedy Dental Instruments, Chicago, Ill). For standardization of the production of the TLS and its preactivation, templates were developed with the Loop Software (dHAL Orthodontic Software; Figure 2) and printed in real scale.

The springs were preactivated and trial activated for stress relief until their shape fitted the template accordingly, then they were randomly divided into five groups (n = 10) according to the time they were going to remain activated. In one group (G0), the springs were immediately scanned with an HP scanner (Scanjet 3670, Hewlett-Packard, Palo Alto, Calif) at high resolution (600 dpi) so that each one of the nine angles could be measured (Figure 3). The springs from the other groups were secured onto a structure

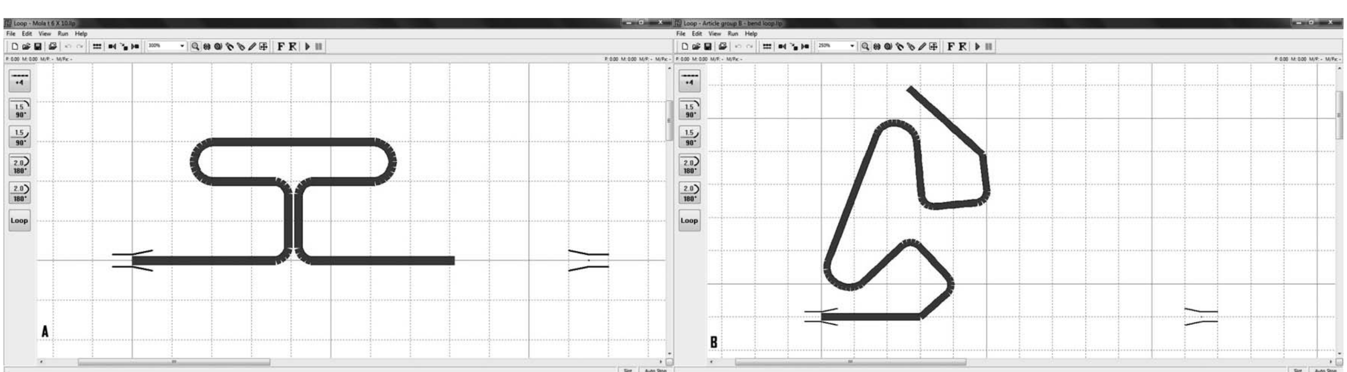

Figure 2. Template developed in the Loop software (dHAL Orthodontic Software, Athens, Greece) used for the design of the T-loop springs (TLS). (A) Confection of springs. (B) Preactivation of the springs. The software allows the template to be printed in a 1:1 ratio. Each square measures 1 mm². From Caldas et al., Effects of stress relaxation in beta-titanium orthodontic loops. *Am J Orthod Dentofacial Orthop.* 2011;140:e85–e92. Courtesy of Elsevier Inc.

Figure 4. Structure simulating a clinical situation used for adaptation of springs in different times. From Caldas et al., Effects of stress relaxation in beta-titanium orthodontic loops. *Am J Orthod Dentofacial Orthop*. 2011;140:e85–e92. Courtesy of Elsevier Inc.

simulating a clinical situation (Figure 4), where the TLSs were centralized on a 23-mm interbracket distance and maintained activated 5 mm for 24 hours (G1), 48 hours (G2), 1 week (G3), and 12 weeks (G4). After each respective period, the springs from each group were scanned for data collection. The position of the springs and their 5-mm activation were standardized by marking both sides of the base arch of the TLSs 9 mm from the center of the spring before preactivation. Those markings were then used as guides to the TLSs' horizontal activation by matching then to the entry of the structure's tubes (Figure 5). The TTLSs were prepared, stored, and tested at room temperature.

The Screen Protractor software 4.0 (Iconico, Inc, New York, NY) was used to measure the nine angles of the TLSs of all groups. The measurements were taken by one operator twice at a 7-day interval for error assessment. Dahlberg's test showed variation in casual errors ranging from 0.001° to 2.23°, whereas a paired *t*-test showed no systematic differences between both measurements ($P = .152$), which allowed the average of both measurements to be used for statistical analysis.

Statistical analysis was carried out by using the IBM SPSS Statistics for Windows v.22.0 (IBM Co, Armonk, NY). Since the data were normally distributed, a two-way analysis of variance was used at 5% significance level to detect differences between angles and between groups (time), as well as to detect any interaction between those two factors. Post hoc Tukey's test was performed at 5% significance level to identify the differences detected.

RESULTS

Time influenced significantly the angulations of the springs ($f = 40.2$; $P < .001$). G0 showed a different angle profile (84.1°) when compared with the other groups, whereas G1, G2, and G3 showed similar profiles to each other, with values of 90.2°, 90.7°, and 91.1°, respectively. G4 showed a higher angle profile than all the other groups (92.6°; Table 1).

Differences were observed between the angles measured ($F = 4082.4$; $P < .001$). Angles 1 and 2 were the same (19.8° and 21.0°) but were different from angles 3, 4, and 7 (93.3°, 93.1°, and 92.9°, respectively), which were similar among themselves but different from angles 5 and 6 (100.2° and 100.2°), which also were similar. Finally, all the angles cited above were found to be different from angles 8 and 9 (143.4° and 144.0°), which were similar between each other (Table 1).

A significant interaction was detected between time and the angles of the springs ($f = 7.2$; $P < .001$; Figure 6).

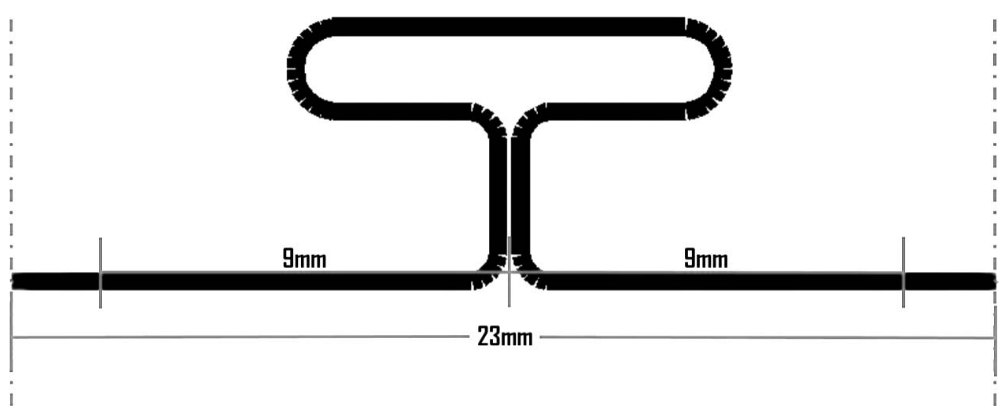

Figure 5. T-loop springs shape simulated by the Loop Software when positioned symmetrically in an interbracket distance of 23 mm and markings on the horizontal edges to preactivation.

Table 1. Means and Standard Deviations for Angulation (°) of Each Group and Each Angle Measured[a]

Time	Angulation	SD
G0	84.1^{A}	40.9
G1	90.2^{B}	42.4
G2	90.7^{BC}	42.9
G3	91.1^{BC}	42.9
G4	92.6^{C}	42.8
	$P < .001$	
Angle	Angulation	(SD)
1	19.8^{A}	2.9
2	21.0^{A}	2.1
3	93.3^{B}	3.0
4	93.1^{B}	2.8
5	100.2^{C}	5.8
6	100.0^{C}	5.2
7	92.9^{B}	15.2
8	143.4^{D}	6.7
9	144.0^{D}	4.8
	$P < .001$	

[a] Different superscript letters indicate different homogenous subsets defined by Tukey's post hoc test.

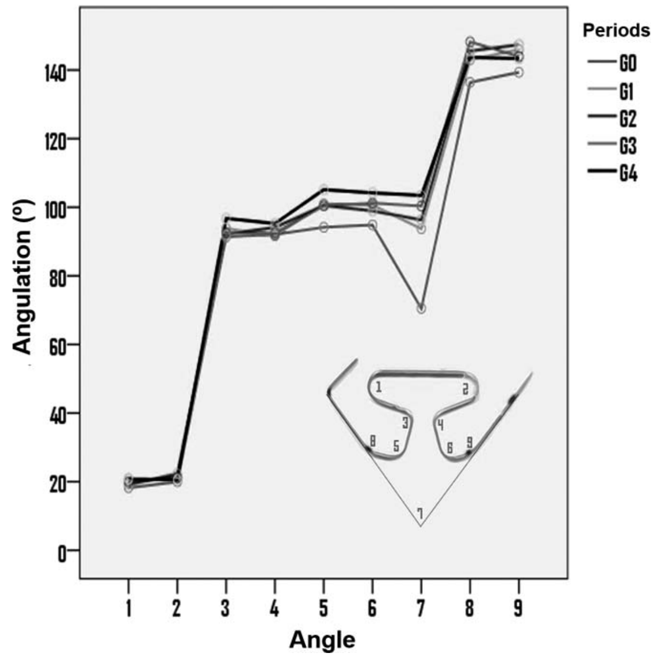

Figure 6. Variation of each of the angles in five evaluated periods.

DISCUSSION

There was a significant increase in the angulations of the TLSs after 24 hours, which caused the bends to unravel. This occurred due to the stress relaxation effect on the TLSs, which were kept under constant strain. An alloy submitted to constant strain within its elastic limit for a certain period of time can have its crystalline structure changed, which then tries to reorganize itself through stress relaxation by modifying its shape.[4] Such an effect had already been demonstrated in stainless steel,[6–9] Elgiloy,[9,10] nickel-titanium,[5,7–9,12] and beta-titanium wires,[8,11] in clips of self-ligating brackets,[13] and more recently in beta-titanium springs.[3,11] As is characteristic of this phenomenon,[9,10,12] the effect of stress relaxation was gradual, occurring majorly during the first 24 hours and gradually increasing during the 12 remaining weeks. The literature suggests that a 24-hour period would be enough to access stress relaxation in orthodontic wires,[5] but it has been shown that significant changes can occur after the first 24 hours. Clinically, the deformation suffered during the first 24 hours will result in a decrease of the force level and of the moments produced.

Different deformation occurred in the TLSs' angles measured, which was an expected finding, since different stresses were applied throughout the angles of the TLSs. Angles 5 and 6 as well as 8 and 9 (mentioned as pairs because they are contralateral angles of same location) were the most affected by stress relaxation, since they are sites of acute and localized bends where strains are more likely to be absorbed.[14] Although there are studies in the literature reporting deformations[11] and modifications in the force system of beta-titanium TLSs over time, none of them indicated exactly where in the TLS the stress relaxation occurred, thus not allowing a further discussion on the results found.

There was a significant interaction between time and the angles measured; thus, the angles of the TLSs had different behaviors over time due to the stress applied to them over time. The "ears" of the TLSs (angles 1 and 2) were the most stable region of the TLS, since no change was detected over time ($P = .194$ and .132, respectively), which was expected because this region is submitted to very little stress (Figure 1). Deformation of the springs was concentrated in angles 5, 6, 7, 8, and 9, which are located on the base arch part of the TLS. These regions suffered greater deformation because they are located where stress is more concentrated during the activation of these springs. In addition, it can be noted that there was significantly more change on those angles within the first 24 hours than in the remaining periods (Figure 6).

The angulation measurements were carried out by using the Screen Protractor software 4.0 (Iconico, Inc) and are not affected by the possible dimensional variations resulting from the process of digitalization, since they are angles. This software has already been used for angular measurements in several papers on biological areas,[15–18] and it has been shown to be valid. Dahlberg's test of our data detected relatively few random errors, and the paired *t*-test showed no statistically significant systematic error.

CONCLUSIONS

- There was stress relaxation in the beta-titanium TLSs.
- Stress relaxation occurred more intensively within the 24-hour period and gradually over the 12-week period.
- Two regions were identified as responsible for the relaxation of the TLSs: one at the bend between the vertical extensions of the springs and the base arch (angles 5 and 6) and the other at the preactivation bends made in the base arch (angles 8 and 9).
- Since the loops tested changed over time, clinicians might need to adjust those loops on angles 5, 6, 8, and 9 if they want to maintain the system of forces they originally planned or find another solution for the relaxation phenomena.

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