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# TENDENCY OF TOOTH MOVEMENT PRODUCED BY DIFFERENT CROSS-SECTIONS OF A *T-LOOP* ORTHODONTIC SPRING: AN ANALYSIS BY THE FINITE ELEMENT METHOD

**Fábio Rodrigo Mandello Rodrigues**
Federal University of Technology – Paraná, Department of Mechanical Engineering, Pato Branco, Brazil
fabiormr@utfpr.edu.br

**Paulo César Borges**
**Marco Antônio Luersen**
Federal University of Technology – Paraná, Graduate Program in Mechanical Engineering, Curitiba, Brazil
pborges@utfpr.edu.br, luersen@utfpr.edu.br

**Marcelo do Amaral Ferreira**
Private practice, DDS, PhD, Curitiba, Brazil
regunteriat@gmail.com

***Abstract.*** *The use of orthodontic retraction springs for the correction of dental positions has been very efficient over the years, especially T-loop orthodontic springs. These springs are made with metallic wires of various sections and alloys. The present study aims to analyze the influence of different cross sections of wires in the dental movement, with the use of T-loop geometry of titanium-molybdenum (TiMo) beta III metal alloy. The device was modeled three-dimensional and simulations were carried out by the finite element method for large displacements. It has been observed that there is an increase in the values of forces and reactive moments in the tooth, as well as in the stiffness of the spring, with the increase of the cross-section of the metallic wire. Regarding tooth movement, no significant difference was observed for the sections considered since the moment/force ratio (M/F) remained practically unchanged. The study also pointed out that there are restrictions in the use of some cross sections in certain activation values, since the reactive forces found are outside the zone of ideal orthodontic forces.*

***Keywords:*** *T-loop orthodontic spring, finite element method, biomechanical analysis, tooth movement.*

## 1. INTRODUCTION

The prediction of a tooth movement produced by an orthodontic appliance is essential for orthodontic planning. The tooth movement, which is produced after the elastic deformation of the periodontal ligament, has often been used to predict orthodontic movement, when a moment (M) and a force (F) are applied to the tooth at its center of gravity (G) if teeth are considered indivudually or at its center of resistance ($C_{res}$) if considering their circunferential environment, the periodontium. The type of movement is controlled by the M/F ratio (Kojima and Fukui, 2012). The types of  movements (Raboud, *et al.,* 1997) in the sagittal plane for canines can be as follow: can be translational when the M/F ratio is 8.5 mm, controlled root inclination (clockwise) for M/F less than 8.5 mm, uncontrolled root tipping (clockwise) with zero M/F, controlled tipping of the dental crown (counterclockwise) when the M/F ratio is greater than 8.5 mm and finally uncontrolled root tipping for M/F ratio tendency to infinity.

A device used to obtain tooth movement is the orthodontic spring (closing loop), which has the capacity to produce reactive forces and moments in their extremities, after activation, as indicated some researches found in the literature (Chen, Markham and Katona, 2000), (Geramy, *et al.,* 2016), (Rodrigues, *et al.,* 2013). There are numerous geometries of orthodontic springs to induce controlled tooth movement, one of the most used is the spring with *T-loop* (TLS) geometry. Figure 1 shows an example of a TLS spring (Rodrigues, *et al*., 2016) and Figure 2 the extremitiy efforts obtained during its activation.
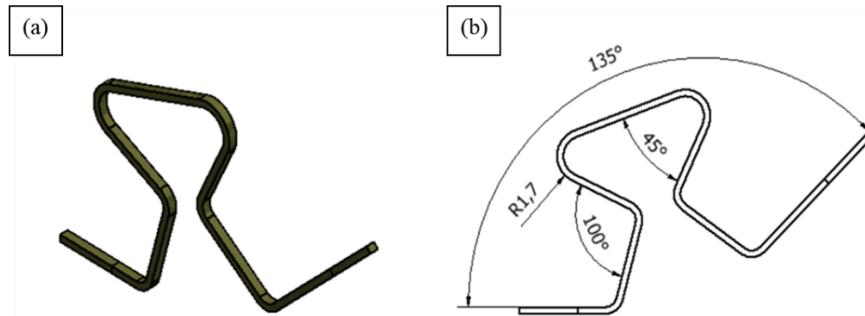
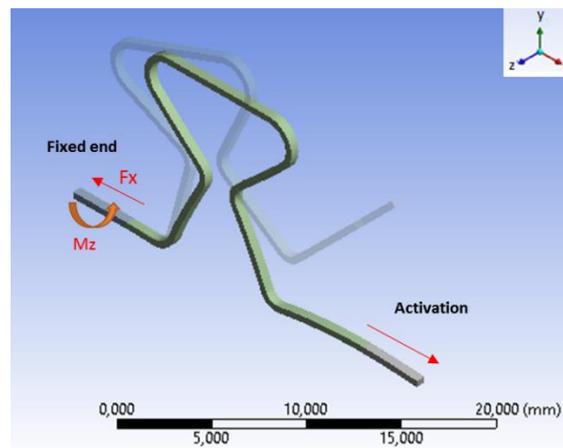Figure 1. Three-dimensional TLS model (a); principal dimensions (b)



Figure 2. Reactive force $F_x$ and reactive moment $M_z$

Figure 2 depicts in green the T-loop spring adapted into the brackets. The shaded T-loop represents the spring pre-activated and not inserted in the distal attachment.

The combination of three-dimensional design and the finite element method (FEM), sometimes combined with experimental data, for the determination of the mechanical efforts in the tooth, is a very strong tool, as found in some studies (Rodrigues, *et al*., 2013), (Rodrigues, *et al*., 2015), (Techalertpaisarn, 2013), (Mazza and Mazza, 2000), (Almeida, *et al*., 2016), (Rodrigues, *et al*., 2014a), (Rodrigues, *et al*., 2014b).

In this study, through the finite element modeling, the influence of the cross-section of a TLS spring after activation is analyzed.

## 2. COMPUTATIONAL PROCEDURE

Based in an anterior TLS spring found in the literature (Rodrigues, *et al*., 2016) we modeled a three-dimensional model using the Autodesk Inventor® software and its behavior was simulated using the FEM in the Ansys Workbench® program for the determination of stresses, forces ($F_x$, $F_y$ and $F_z$), and the force-moments ($M_x$, $M_y$ and $M_z$). Also, the M/F ratios are obtained, being possible to simulate the tooth movement in a clinical situation.

In the TLS orthodontic spring considered in this work, four rectangular cross-sections were used (Table 1). The interbracket distance (IBD) adopted was 20.3 mm (Rodrigues, *et al*., 2016). This corresponds to the distance between the brackets and tubes where spring´s extremities are attached. In the neutral position ($\Delta = 0$) the spring is not still activated, but only pre-activated (gable bends in their extremities and the vertical extremities separated by 3-4 mm).

The inclusion of other cross-sections used in an orthodontic treatment (B, C and D), despite the section A are also found in the literature and provides new resultant forces and moments as well as analysis of the M/F ratio.

Table 1. Cross-sections for TLS spring

| Cross-section A (Rodrigues, *et al.*, 2016) | Cross-section B | Cross-section C | Cross-section D |
|---|---|---|---|
| 0.4064 x 0.5588 mm (0.016" x 0.022") | 0.4318 x 0.5588 mm (0.017" x 0.022") | 0.4572 x 0.635 mm (0.018" x 0.025") | 0.4826 x 0.635 mm (0.019" x 0.025") |

In addition to the forces, moments and M/F ratios, it is possible to determine the stiffness for each spring studied, considering that its behavior is non-linear (Rodrigues, *et al.*, 2016), we have the following relation of Equation 1:

$$k = \frac{dF_x}{d\Delta} \tag{1}$$

Where,

k – Stiffness (N/mm);
$F_x$ - Reactive force in the *x* direction (N);
$\Delta$ - Spring activation in the *x* direction (mm);

The knowledge of the elastic constant of the orthodontic springs is important because a low stiffness allows the application of smaller forces, a more constant force over time when the spring undergoes deactivation and higher accuracy in the application of forces (Kapila and Sachdeva, 1989), (Ferreira, 1999).

The material considered in this work is the titanium-molybdenum alloy (TiMo) beta III, widely used by orthodontists. Its properties are presented in Table 2 (Rodrigues, *et al.*, 2016).

Table 2. Mechanical properties of titanium-molybdenum alloy

| Modulus of elasticity (E) | 69 GPa |
|---|---|
| Yield stress ($\sigma_e$) | 1240 MPa |
| Poisson's ratio | 0.3 |
| Shear modulus | 26.54 GPa |

The simulations for the determination of the mechanical efforts were made using numerical analyzes through the FEM considering large deformations and non-linear analysis. The maximum element size in the mesh was 0.4 mm, with a total of 3019 tetrahedral elements and 6339 nodes. Figure 3 shows the finite element used in the mesh.
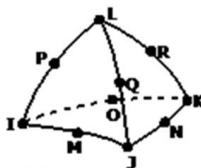


Figure 3. Ten-node tetrahedral finite element

## 3. RESULTS AND DISCUSSION

### 3.1 Reactive forces and moments

After simulations it was possible to determine the force system Figures 4 and 5 shows the behavior of the forces and moments found in this study.
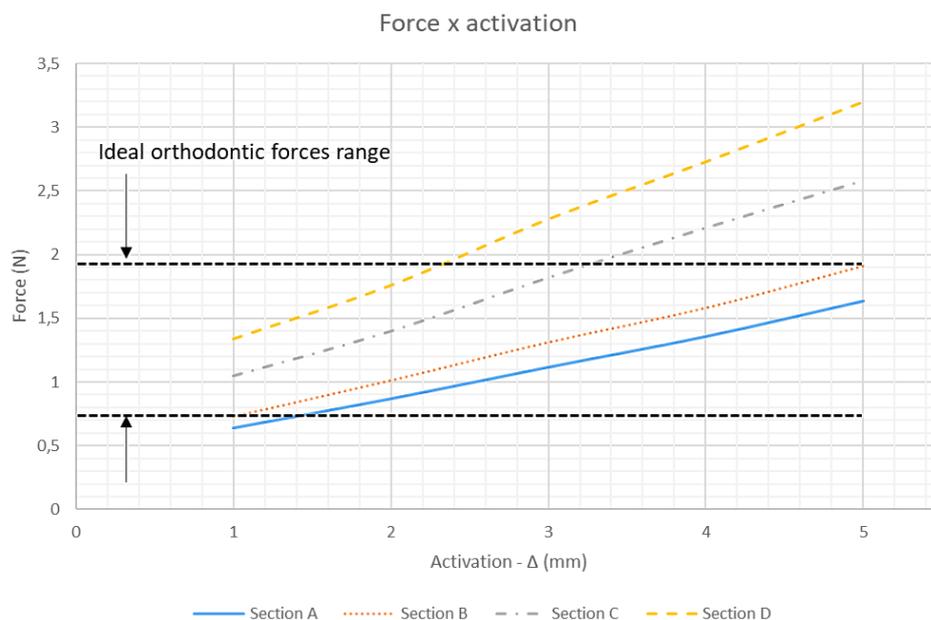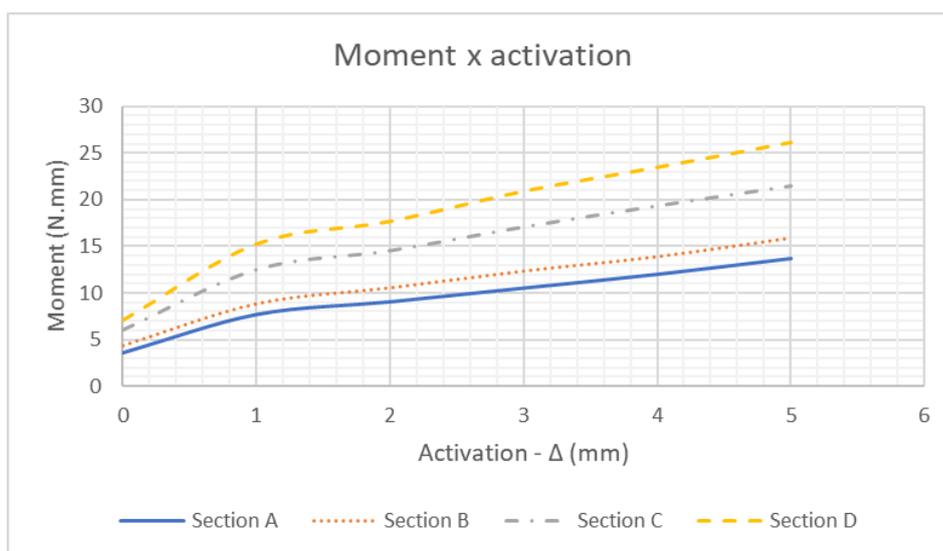
Figure 4. Resulting forces



Figure 5. Resulting moments

Although there is no consensus on ideal force values in orthodontic treatments, some authors (Rodrigues, *et al.*, 2015), (Nicolai, 1975), (Gjessing, 1985) estimate this interval to be somewhere close to 0.76 to 1.96 N considering a minimum value force to occur tooth movement, as well as a maximum value that prevents damage to the tissue. The graphs in Figures 4 and 5 shows that while obtaining a very broad range of forces for different orthodontic wire profiles at different activation values, it is important to note the appropriate range for their use.

**3.2 T-loop orthodontic stiffness**

It is possible to determine the stiffness for the different cross-sections adopted in the present study. According to the literature (Kapila and Sachdeva, 1989) low load deflection rates allows more constant and lower force magnitudes during deactivation. Table 3 show the equations from force and stiffness for each cross-section studied (equation 1).

Table 3. Spring stiffness

| Cross-Section | Force Magnitude (N) | Stiffness - $\frac{dFx}{d\Delta}$ (N/mm) |
|---|---|---|
| A | $0.582\Delta^{0.62}$ | $0.36\Delta^{-0.38}$ |
| B | $0.7\Delta^{0.59}$ | $0.413\Delta^{-0.41}$ |
| C | $1.01\Delta^{0.55}$ | $0.56\Delta^{-0.45}$ |
| D | $1.29\Delta^{0.54}$ | $0.7 \Delta^{-0.46}$ |

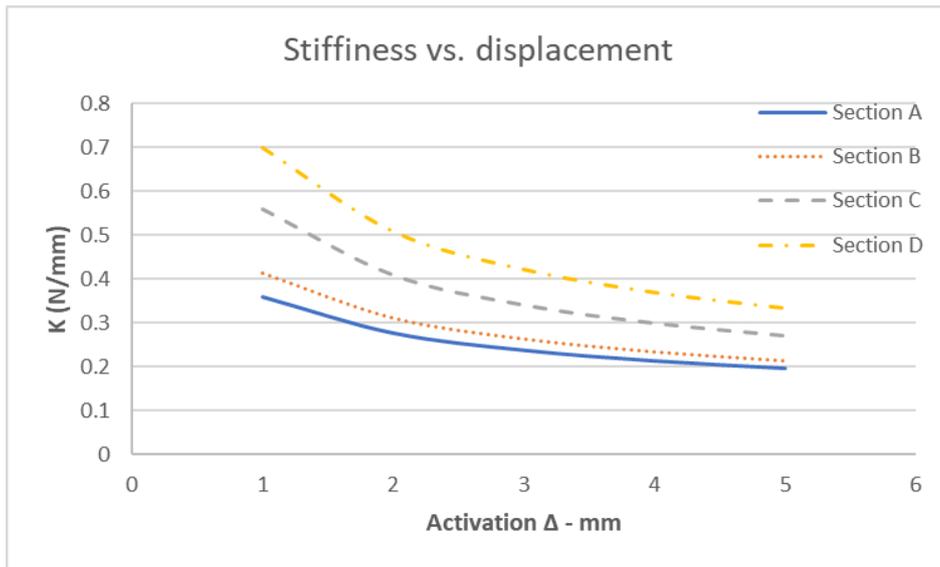Figure 6 show the stiffness behavior for each cross-section.



Figure 6. Stiffness vs. Displacement

According to Figure 6 the stiffness increase as cross-section increase but the inverse occurs as the spring is activated.

### 3.3 Moment-to-force ratio (M/F) and tooth tendency movement

With the values of forces and moments it is possible to determine the M/F ratio. Figure 7 shows the M/F ratio for the different cross-sections.
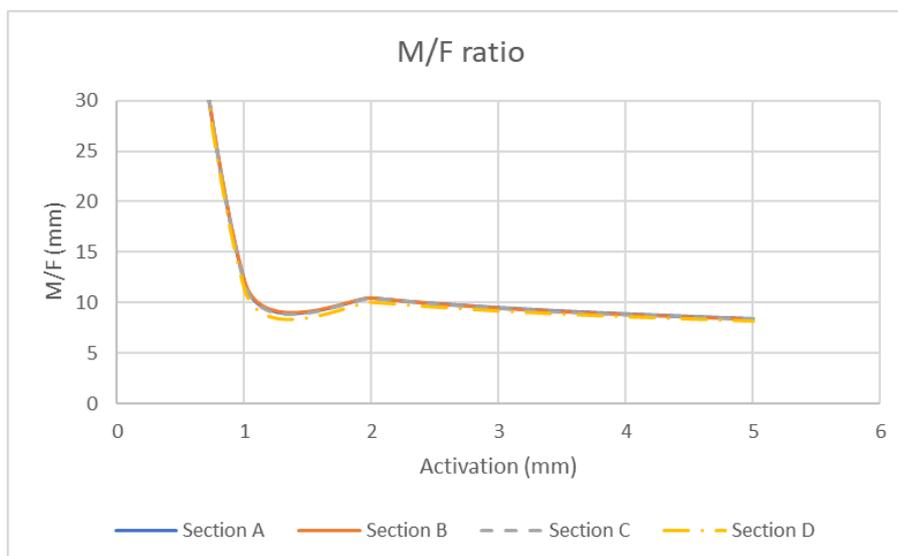


Figure 7. M/F ratio

There is no significative difference among the different cross-sections and the resulting tooth movement tendency. According to the results the TLS considered here is capable to produce translation from 5.0 to 4.0 mm of deactivation, controlled tipping (clockwise) from 3.0 to 1.0 mm and finally root correction (counterclockwise) when the activation stops. To better understanding we consider in this paper the molars the local where the spring attachs its posterior extremity or the activation side, or beta side and the canines the local where the spring attachs its anterior extremity or alfa side, according to Figure 1 the fixed end).

## 4. CONCLUSIONS

According to the numerical results obtained in this study, varying the cross-section for orthodontic spring TLS, with 135° angle between extremities, it can be concluded that:

- Increasing the cross-section increases the reactive forces in the tooth, for any activation value;
- Considering the range of ideal forces to produce safely tooth movement and low stiffness the TLS made of 0.4318 x 0.5588 mm (0.017 x 0.022-in) is more appropriate to be used extrapolating clinically, for all range of deactivation (from 5.0 to 1.0mm);
- The ideal orthodontic force range is obtained for deactivation from 5.0 to 2.0 mm for cross-section A; 5.0 to 1.0 mm for cross-section B; 3.0 to 1.0 mm for cross-section C and 2.0 to 1.0 mm for cross-section D;
- The reactive moments increase when the cross-section increases;
- Although the reactive forces $F_x$ and the reactive moments $M_z$ increase with the increase in the wire cross-section, no significant differences were observed for the $M_z/F_x$ ratio responsible for influencing tooth movement in any of the values of the activations studied;
- The possible dental movements for this spring, regardless of the cross-section used, can be: translation for deactivation from 5.0 and 4.0 mm, controlled tipping (clockwise) for deactivation from 3.0 to 1.0 mm and root correction (counterclockwise for neutral position.

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## 6. RESPONSIBILITY NOTICE

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