ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

THREE-DIMENSIONAL (3-D) MECHANICAL ANALYSIS FOR DELTA ORTHODONTIC RETRACTION SPRING WITHOUT LOOP: AN APPROACH THROUGH THE FINITE ELEMENT METHOD

Fábio Rodrigo Mandello Rodrigues
Paulo César Borges
Marco Antônio Luersen
Universidade Tecnológica Federal do Paraná, Curitiba – Pr, CPGEI.
e-mails: fabiormr@utfpr.edu.br, pborges@utfpr.edu.br, luersen@utfpr.edu.br

Marcelo Ferreira do Amaral
Cirurgião dentista – Curitiba - Pr
email: regunteriato@yahoo.com.br

Abstract.
The objective of this study is to analyze through the finite element method the system forces three-dimensional (x, y, z) for a delta orthodontic retraction spring and reactive moments after activation, identifying the ratio moment/force (M/F) activation during the displacements and Von Mises stresses acting on the device. The orthodontic retraction spring are widely used in orthodontic clinical area of orthodontics constituting a device necessary to correct dental distortions. The model proposed in this paper is a novel geometry within the model delta recently explored. For a full analysis of deformations, forces and moments and verification of reactive relationship M/F was designed three-dimensional model in CAD system and performed several analyzes by finite element method in 3D. The procedure contemplated orthodontic retraction springs alloys β-titanium obtaining the end curves, illustrations and fundamental mathematical equations that describe the general displacement and off the retraction spring, connecting with its forces and resultant moments. It was found by the relationship M/F obtained, that the performance of this type of retraction spring can assist in most dental deformations in the literature.
Keywords: *Biomedical engineering, orthodontic retraction spring, finite element method.*

1. INTRODUCTION

One of the major factors for the success of a clinical orthodontics treatment is the correct orthodontic tooth movement, either translation, inclination uncontrolled or controlled inclination according to patient need. To obtain tooth movement, an option that orthodontists are using devices known orthodontic retraction springs whose geometries have a variety and applications. Such devices produce reactive forces and moments in the teeth by moving the orthodontic coil applied. This displacement is known as activation.

Studies showing the relationship between geometric parameters of orthodontic retraction springs and their activation with the forces and moments as demonstrated by Fraunhofer et. al (1993), Rinaldi and Johnson (1995), Ferreira (1999), Mazza and Mazza (2000), Kuhlberg and Priebe (2003), Ferreira et al. (2005), Pulter (2005), Ferreira et al. (2008), Ferreira (2010), Ferreira et al. (2011), among others. A orthodontic retraction spring example is shown in Figure 1. Figure 2 shows an example of reactive forces and moments that arise after an orthodontic activation.

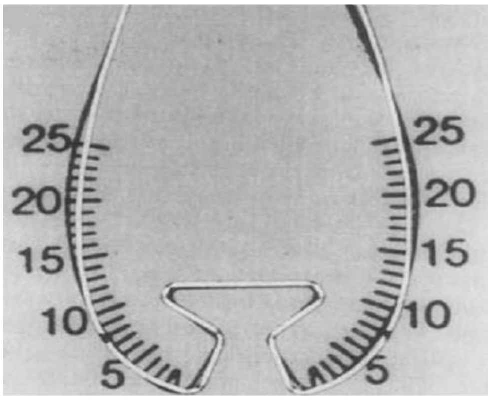

Figure 1. T-loo orthodontic retraction spring (Martins, *et al.*, 2008)

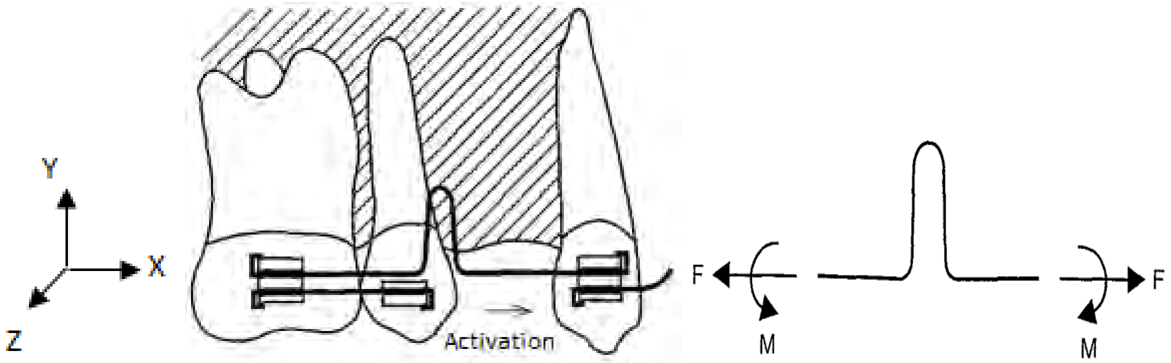

Figure 2. Forces and moments in an orthodontic retraction spring (Raboud et al., 1997)

According to the research Raboud et al. (1997) the ratio moment-force in the sagittal plane xy, with force acting in the x direction and momentum around the z axis (M/F) establishes the type of tooth movement as:

M/F = 8.5 mm (translation);
M/F = 0.0 mm (tilt movement uncontrolled, clockwise);
0<M/F<8.5 mm (movement controlled tipping, clockwise);
M/F> 8.5 mm (tilting motion controlled, counter-clockwise);
M/F $\rightarrow \infty$ mm (tilt uncontrolled, counterclockwise)

Ferreira et al. (2011) studied and developed the delta orthodontic retraction spring with loop through experimental analysis and finite element line. Figure 3 shows an illustration of this type of device by the author.

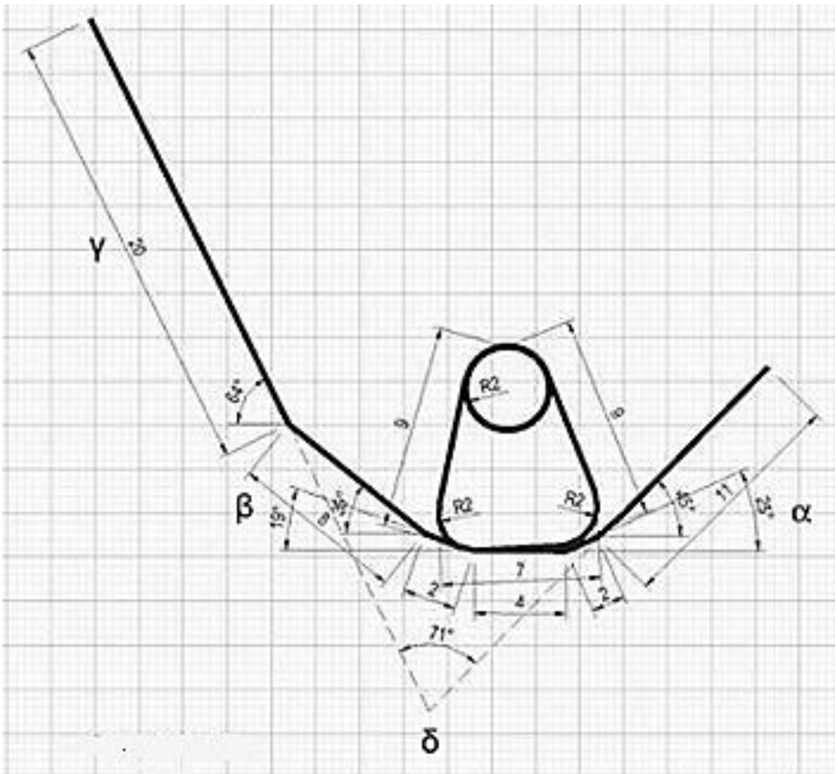

Figure 3. Delta retraction spring (Ferreira, 2011)

To contribute to the development of this orthodontic retraction spring, this work has as main objective to develop a delta retraction spring according to Figure 4 and Figure 5. This new prototype was modeled three-dimensionally by the aid of the SolidWorks program and analyzed numerically by the finite element method (FEM) with three-dimensional elements through the program Ansys Workbench.

ISSN 2176-5480

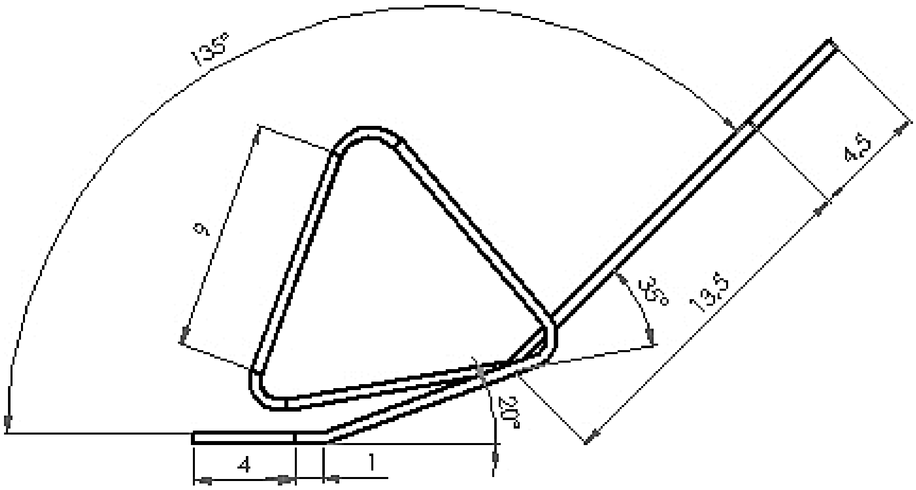

Figure 4. Delta orthodontic retraction spring (sagital view)

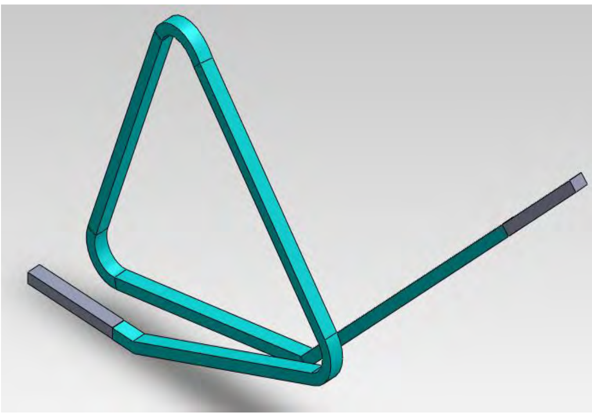

Figure 5. Delta orthodontic spring (isometric view)

2. FINITE ELEMENT ANALYSIS OF DELTA ORTHODONTIC RETRACTION SPRING WITHOUT LOOP

The appliance proposed in this paper has dimensions of section 0.4318 x 0.635 mm (0.017 x 0.025 inches) and made of beta titanium alloy material with yield strength of 1240 MPa and tensile modulus of 69 GPa This material is widely used in the field of orthodontics for manufacturing orthodontic springs.

For finite element analysis were considered large displacements (nonlinear analysis) mesh generated with 1872 quadratic elements solids (types of tetrahedral and hexahedral 10 knots 20 knots), totaling 4406 nodes. The Figure 6 shows the handle in a position ready for pre-deformed displacements similar to that shown by activation T-loop straps (Figure 2).

ISSN 2176-5480

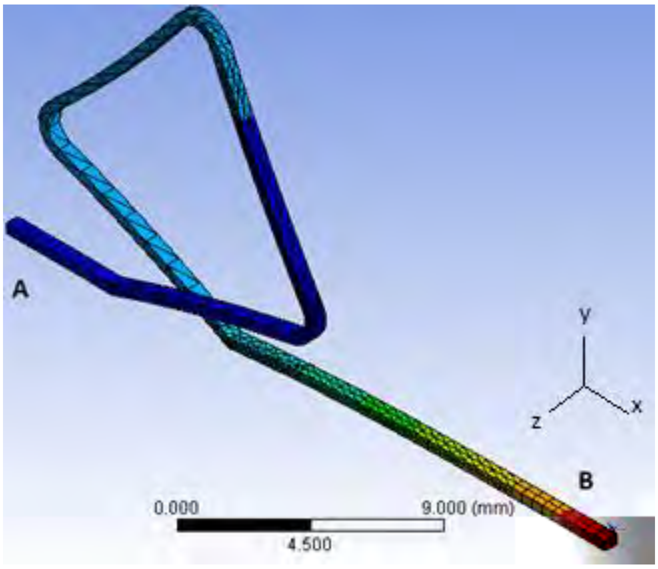

Figure 6. Delta orthodontic spring without loop pre-activated

The activation values applied on the stem B, the x direction, ranging from 0.0 mm to 8.0 mm since after this value there was the beginning of plastic deformation on the orthodontic spring, in accordance with section 2.2 of this work. For each value of activation, there were reactive forces and moments on the steam A.

2.1 Analysis of reactive forces

With numerical simulations it was determined the values and plot graphs of reactive forces of orthodontic delta spring with the help of programs like Microsoft Excel , as shown in Figure 7. It is observed that the force values on the y-axis for any activation are zero. Reactive forces in the x direction are zero initially and increases nonlinearly with activation. It was found that reactive forces acting in the z direction are negligible.

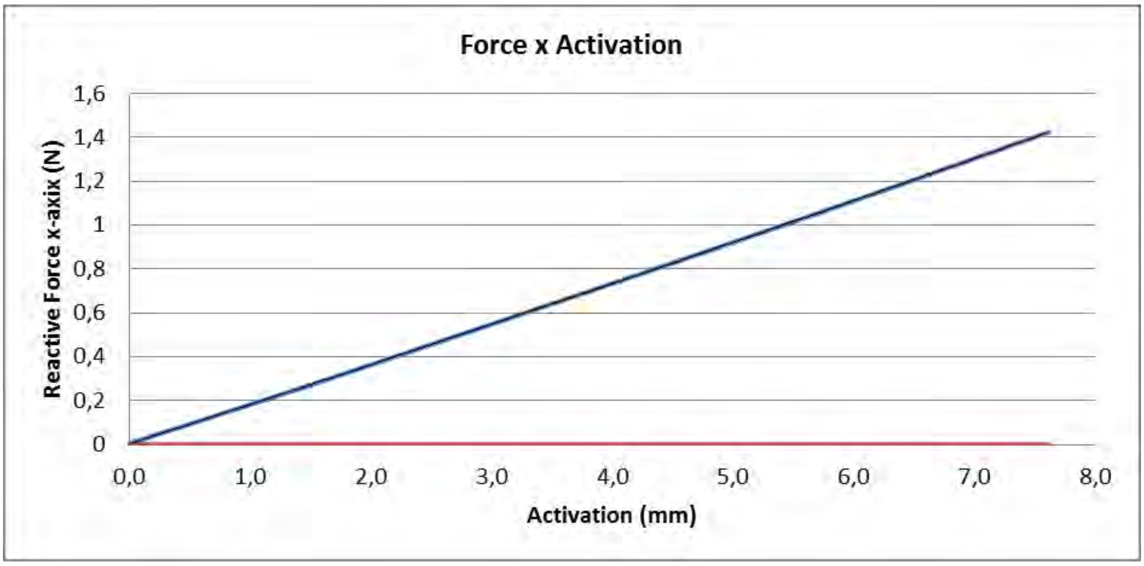

Figure 7. Reactive force

With the curve of force is possible to determine the Equation (1) activation values that relate to reactive forces as:

$$Fx = 0{,}0057a^2 + 0{,}2555a + 0{,}0075 \quad (1)$$

Where,

F_x[N] – Reactive force *x* axis.
a [mm], $0 \leq a < 8{,}0$. - Activation.

ISSN 2176-5480

2.2 Von Mises's stresses analysis

The stress analysis of von Mises provides parameters to determine the maximum value of the activation. When applying an activation in the delta orthodontic spring tensions arise at various points, whose values do not exceed the yield stress of the material in this case, is 1240 MPa. Numerical analysis is particularly important since it can predict the behavior of the material before manufacturing the device. Figure 8 shows the values of stresses observed in activation of 9.0 mm, a value that emerged in the first tensions above the yield strength.

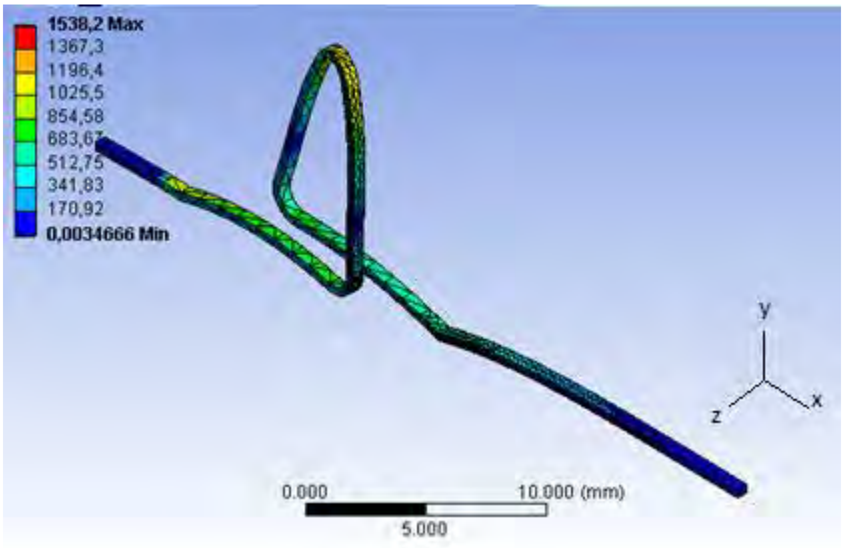

Figure 8. Distribution of von Mises stress for activation (legend in MPa)

According to Figure 8, there initiation of plastic deformation in the upper part of the delta orthodontic spring and the shaft next to the collet as shown in legend with red orange coloring. To prevent plastic deformation, was chosen a maximum activation of 8.0 mm for this type of device.

2.3 Analysis of moments

In addition to the reactive force, important for determining the ratio moment/force and resulting movement of the tooth, have the values of the reactive moment tab in the delta orthodontic spring. The Figure 9 shows the reactive moment variation function of the activation.

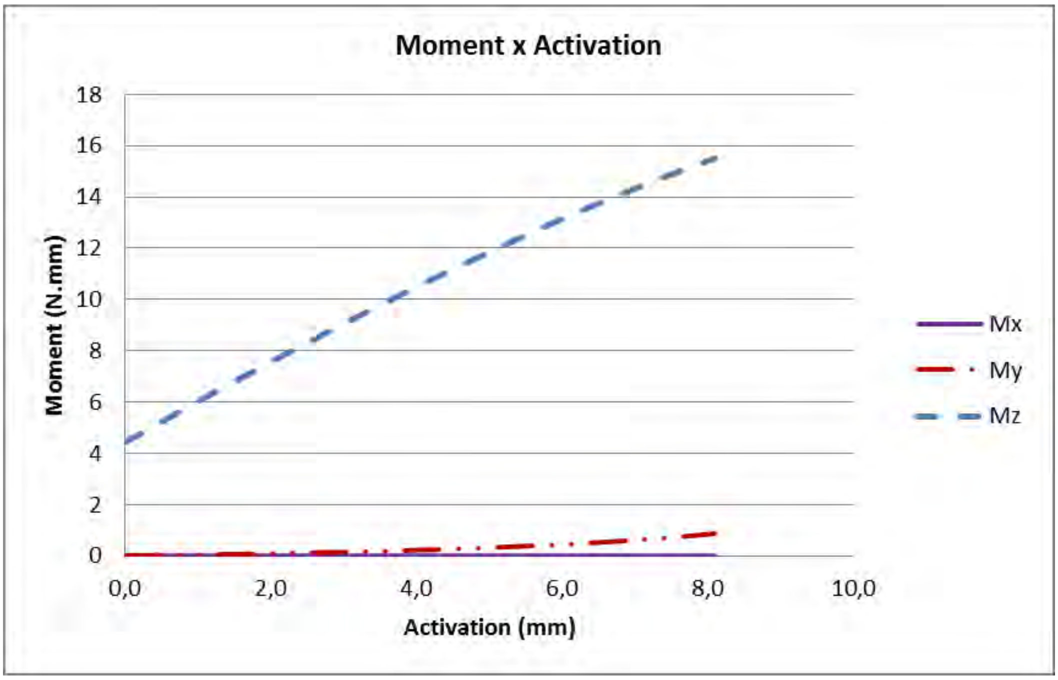

Figure 9. Reactive moment

The reactive moments considered in this research are the moments about the z axis (MZ), most significant, providing ratio M/F for tooth movement in the sagittal plane (xy). It is observed that as reactive forces on the x axis of the moment Mz increases non-linear manner with the increase of the activation in the delta orthodontic spring.

2.4 Moment/force ratio and dental movement

With the values of forces and moments identified is possible to determine the ratio M/F in the sagittal plane and relate it to the type of tooth movement, assisting the clinician in the most suitable for activation of delta orthodontic spring without loop with the geometry shown. Figure 10 shows the ratio M/F found.

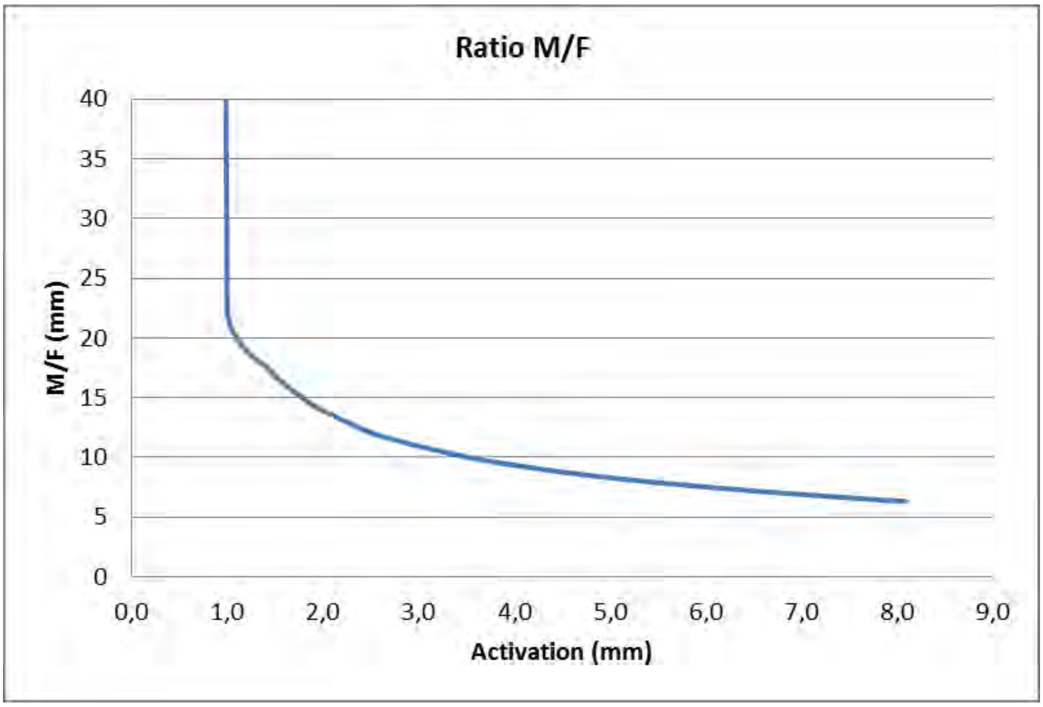

Figure 10. Ratio moment-force (M/F)

The Equation (2) show the ratio M/F for this device,

$$\left(\frac{Mz}{Fx}\right) = 6{,}0786 - 0{,}2282a + \frac{16{,}606}{a} \quad (2)$$

Where,

M_z[mm] – Moment arround z-axis.
F_x[N] – Reactive force x-axis.
a [mm], $1{,}0 \leq a \leq 8{,}1$. - Activation.

3. CONCLUSIONS

In accordance with the ratio M/F shown in the Figure 10, with values found in literature described above, it is concluded that this orthodontic spring is capable of producing the dental movement in the sagittal plane:

- The forces produced with activation less than 1.0 mm can induce an uncontrolled counterclockwise dental tilt;
- For activation between 1.0 and 4.5 mm, the movement produced is a tilt dental controlled, counter-clockwise;
- In activations between 4.5 and 5.0 mm: Translation tooth movement;
- Activation between 5.0 and 8.0 mm: Induce a tilt dental controlled, clockwise.

According to the activation intervals described, the professional can use this device with different results in the clinical use.

ISSN 2176-5480

4. REFERENCES

Ferreira, M.A., 1999. “The wire material and cross-section effect on double delta closing loops regarding load and spring rate magnitude: An in vitro study”. *American Journal of Orthodontics and Dentofacial Orthopedics*, Vol. 115, n.3, p.275-282.

Ferreira, M.A., 2010. *Efeito da Distância Interbraquetes Sobre o Sistema de Forças em Alças de Retração Ortodôntica com Geometria Delta: Estudo Numérico Experimental*. Ph.D. thesis, Universidade Tecnológica Federal do Paraná, Curitiba.

Ferreira, M.A., Assumpção, A., Luersen, M.A., Borges, P.C., 2011. “Mechanical behaviour of a prototype orthodontic retraction spring: a numerical-experimental study”. *The European Journal of Orthodontics Advance Access Published,* p. 1-7.

Ferreira, M.A., Borges, P.C., Luersen, M.A., 2008. “Alguns aspectos da mecânica das alças de retração ortodôntica”. *R. Dental Press Ortop Facil*, Vol. 13, n. 3, p.112-123.

Ferreira, M.A., Oliveira, F.T., Ignácio, S.A., Borges, P.C., 2005. “Experimental Force Definition System for a New Orthodontic Retraction Spring”. *Angle Orthodontist*, Vol. 75, n. 3, p. 334-343.

Fraunhofer, J.A., Bonds, P.W., Johnson, B.E., 1993. “Force generation by orthodontic coil springs”. *The Angle Orthodontist*, Vol. 63, n. 2, p. 145-148.

Kuhlberg, A. J., Priebe, D., 2003. “Testing force systems and biomechanics—Measured tooth movements from differential moment closing loops”. *Angle Orthodontist*, Vol. 73, n. 3, p. 270-280.

Martins, R.P., Buschang, P.H., Viecilli, R., Santos-Pinto, A., 2008. “Curvature versus v-bends in a group b titanium t-loop spring”. *Angle Orthodontist*, Vol. 78, n. 3, p. 517-523.

Mazza, D., Mazza, M., 2008. “Specialized spring design in segmented edgewise orthodontics: Further verification of dedicated software”. *Angle Orthodontist*, Vol. 70, n. 1, p. 52-62.

Pulter, M. J., 2006. *Caracterização mecânica e microestrutural de alças ortodônticas pré-fabricadas e destinadas ao fechamento de espaços*. MSc. dissertation, Universidade Tecnológica Federal do Paraná, Curitiba.

Raboud, D.W., Faulkner, M.G., Lipsett, A.W., Haberstock, D.L., 1997. “Three-dimensional effects in retraction appliance design”. *American Journal of Orthodontics and Dentofacil Orthopedics*, Vol. 112, n. 4, p. 378-392.

Rinaldi, T.C., Johnson, B.E., 1995. “An analytical evaluation of a new spring design for segmented space closure”. *The Angle Orthodontist*, Vol. 65, n. 2, p. 187-198.

5. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.