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Tooth movement tendency induced by orthodontic delta springs with and without helix: a finite element study

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Abstract. *The purpose of this research is to analyze the influence of orthodontic delta springs with and without upper helix on the tooth movement. Two different types of delta geometries (with and without helix) are analyzed. The springs are made of TiMo alloy wire with a cross section of 0.016 x 0.022 inches. Numerical simulations are performed by three-dimensional finite element models considering large displacements. Within the linear elastic material range, it was found that delta springs with helix can be activated up to 12.0 mm and springs without helix up to 8.0 mm. For the same activation, forces and reactive moments without helix are larger than those produced by delta springs with helicoid. The tooth movement tendencies observed for both orthodontic springs in the sagittal plane, considering the* M_z/F_x *ratio and the interbracket distance of 24.0 mm, are: not controlled tipping root, controlled tipping crown, translation and controlled tipping root. Also, considering the* M_y/F_x *ratio values found for both springs, there is no tendency of tooth movement in the occlusal plane.*

Keywords: *Biomechanics, numerical simulations, finite element method, orthodontic delta spring, moment/force ratio*

1. INTRODUCTION

Orthodontic springs are often used to provoke tooth movement. The type of movement is usually defined by the relation between the moment and the force (M/F) produced in the ends of the device. The aim of orthodontic springs is the correction of poor dental formations according to specific clinical needs. In many studies, these devices are used to close spaces between teeth and it can be highlighted the use of T-loop spring types and recently delta geometry as those developed and/or studied by Ferreira *et al*., (2005), Ferreira *et al.*, (2013), Rodrigues *et al*., (2013), Rodrigues *et al.*, (2014a), Rodrigues *et al*., (2014b) and Rodrigues (2014). In the study by Faulkner *et al*. (1989), T-loop springs are analyzed to evaluate strengths and intrusion dental extruder according to differences in their geometry. There are several studies in the literature evaluating the use of orthodontic springs with *T* geometry as the researches presented by Kuhlberg and Priebe (2003), Martins *et al*., (2009), Chen *et al*., (2000), among others.

Currently, besides geometries of orthodontic springs in the literature, such as *T* loop spring, delta geometry has been explored as an alternative for clinical treatments. Fig. 1 shows some geometrical characteristics of a delta orthodontic springs.

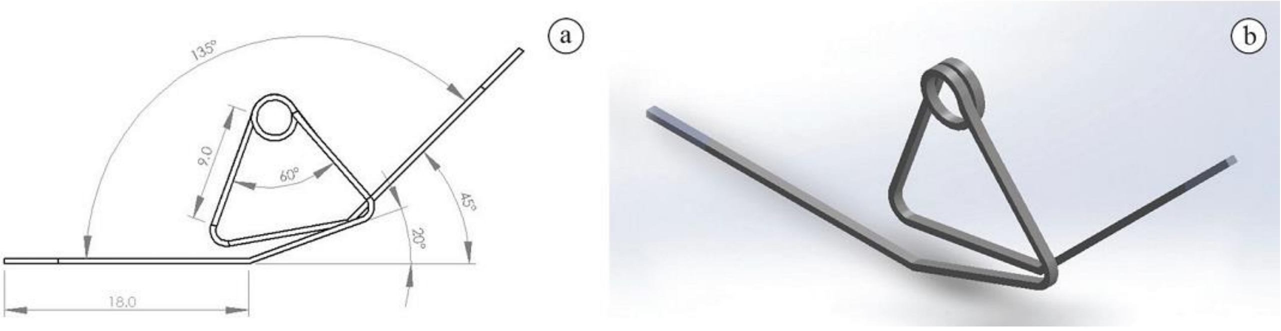

Figure 1. Orthodontic delta spring with helix: (a) frontal view, (b) isometric view (Rodrigues *et al.*, 2014a)

In addition to delta orthodontic spring (DOS) with helix (Fig. 1), there is a variation of this orthodontic spring that has no top helix, as illustrated in Figures 2 and 3, having the same dimensions of the delta spring shown in Fig. 1.

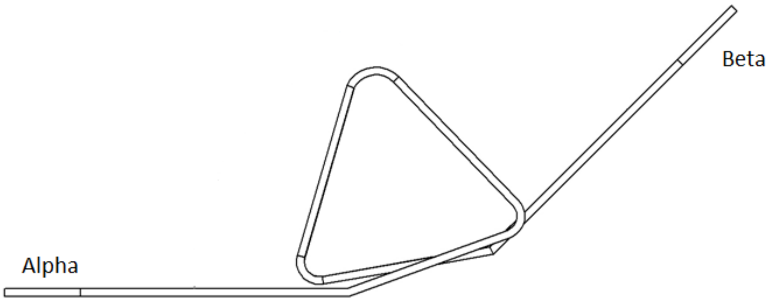

Figure 2. Orthodontic delta spring without helix

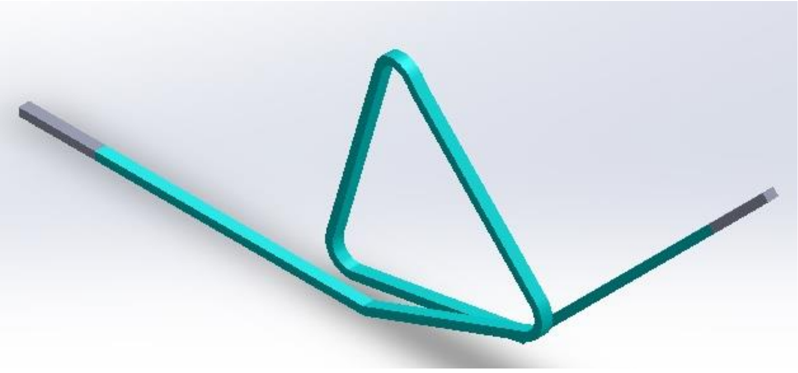

Figure 3. Orthodontic delta spring without helix – Isometric view (Rodrigues *et al*., 2014b)

Techalertpaisarn and Versluis (2013), who analyzed *T* and *L* spring geometries, show the influence of the helix.

For the clinical use of this type of device, in the elastic range, the Beta extremity for acting in the same direction of Alpha extremity (Fig. 4). Activation promoted in Beta extremity causes reactive forces on Alpha side in the *x* (F_x); *y* (F_y) and reactive moments around the y-axis (M_y) and *z* (M_z). In accordance to the literature, the range values of the moment/force ratio indicates the type of tooth movement trend.

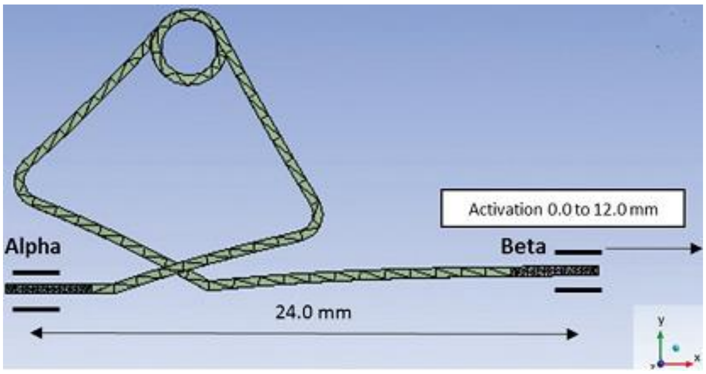

Figure 4. Orthodontic delta spring pre-activated for moving in the *x* axis (Rodrigues *et al*., 2014a)

According to Raboud *et al*., (1997), considering the M_z/F_x ratio values, the following tooth movement tendency are observed:

<u>Sagittal plan</u>

- $Mz / F_x = 0.0$ mm (uncontrolled tipping tendency root clockwise);
- $Mz / F_x < 8.5$ mm (controlled tipping root tendency clockwise);
- $Mz / F_x = 8.5$ mm (tooth translation tendency);
- $Mz / F_x > 8.5$ mm (controlled tipping tendency crown counter-clockwise);
- $Mz / F_x \rightarrow \infty$ (tilt uncontrolled tendency root counter-clockwise).

<u>Occlusal plan</u>

- $M_y/F_x = 0.0$ mm (Tipping clockwise tendency);
- $M_y/F_x = 3.5$ mm (Translation tendency);
- $M_y/F_x > 3.5$ mm (Counter-clockwise tipping tendency).

To check the delta orthodontic spring behavior with and without upper helix, these devices were three-dimensionally modeled in SolidWorks software and then analyzed by the finite element method (FEM) for large deflections using Ansys Workbench program.

2. FINITE ELEMENT ANALYSIS

2.1 Materials and methods

The method adopted in this study was three-dimensional modeling and simulation by finite elements, aiming to obtain the forces, moments and M/F ratios on all planes and directions reproducing the clinical use the orthodontic springs. Large deflections is considered in the FEM analyses. The wire material properties used in this work are the same as those adopted by Rodrigues *et al.*, (2014a), titanium alloy molybdenum beta III (TiMo), with yield strength stress $\sigma_e = 1240$ MPa, elastic modulus E = 69 GPa and Poisson's ratio 0.3. The wire has rectangular cross section 0.4064 x 0.5588 mm (0.016 x 0.022 inches). The finite element mesh was generated with 1766 quadratic solid elements (tetrahedrals with 10 nodes and hexahedrals with 20 nodes), totaling 4406 nodes for delta spring with helix. In the delta spring without helix the mesh has 1489 nodes and 414 elements divided in quadratic tetrahedral, hexahedral. The mesh refinement is similar to that used by Rodrigues *et al*., (2014a), where a converge study is presented.

As shown in Figure 4, successive displacements in the extremity Beta generate reactive forces and moments on the extremity Alpha. For orthodontic with helix springs delta activation values can be up to 12.0 mm and orthodontic springs without helix activation values are up to 8.0 mm as indicated in the analysis of von Mises stress.

2.2 Von Mises stress results

The von Mises stress analysis provides information about the maximum activation the springs can be subjected without plastic deformation. It was observed that for the same activation the stress value is different in each orthodontic spring. For the spring with helix, a maximum activation of 12.0 mm is possible without reaching the elastic limit. For the spring without helix, this value is reduced to 8.0 mm. Figs. 5 and 6 shows the maximum stresses caused at zero activation and maximum activation.

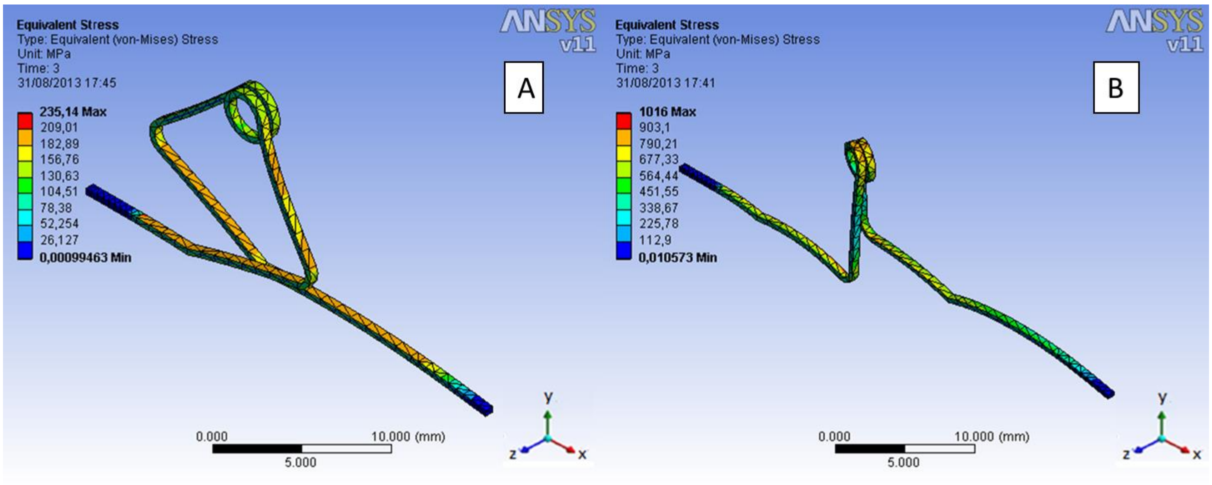

Figure 5. Von Mises stress in delta spring with helix: - (A) nule activation, (B) maximum activation (12.0 mm)

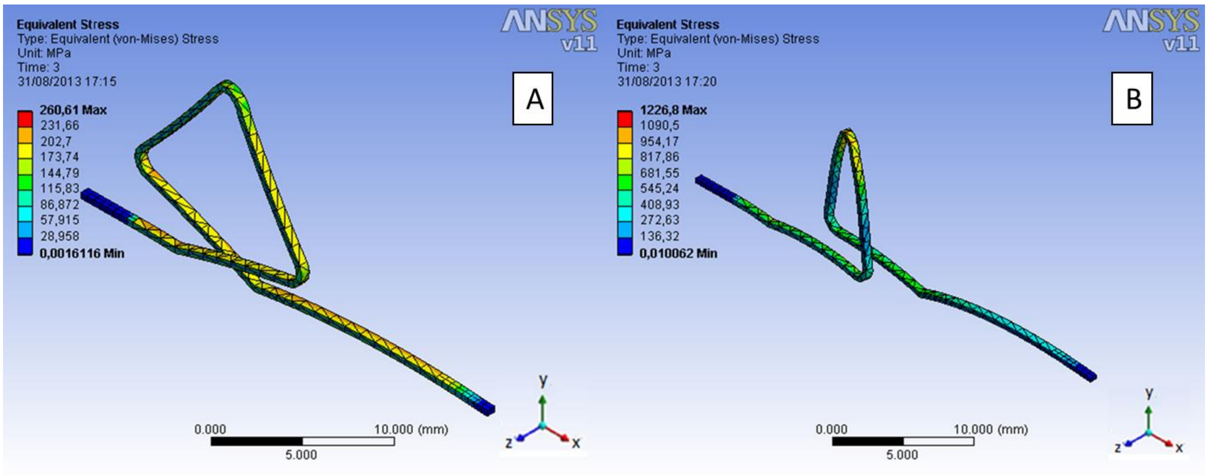

Figure 6. Von Mises stress in delta spring without helix: (A) nule activation, (B) maximum activation (8.0 mm)

According to the obtained results, orthodontic delta springs without helix can be activated with lower values than those with helix once they reach the elastic limit faster.

2.3 Reactive forces

According to the literature (Gjessing 1994; Nikolai 1975), the ideal orthodontic force is the one that provides the best desirable biological response, resulting in rapid tooth movement with little or no discomfort to the patient. Exact values of ideal orthodontic forces have not yet been established but very high levels of force can result in tissue damage and unwanted changes in the relationship M/F. Approximate values for translation forces are between 75 to 260 gf (0.73 to 2.55 N).

Here, reactive forces in the fixed end (extremity Alpha) were negligible in the direction *z* and very low in the *y* direction, then F_y and F_x were not considered in this study. Reactive forces on the *x* axis (F_x) nonzero contribute directly in relations M_z/F_x and M_y/F_x that induce the type of tooth movement in the occlusal and sagittal planes which behavior is illustrated in the graph in Fig. 7.

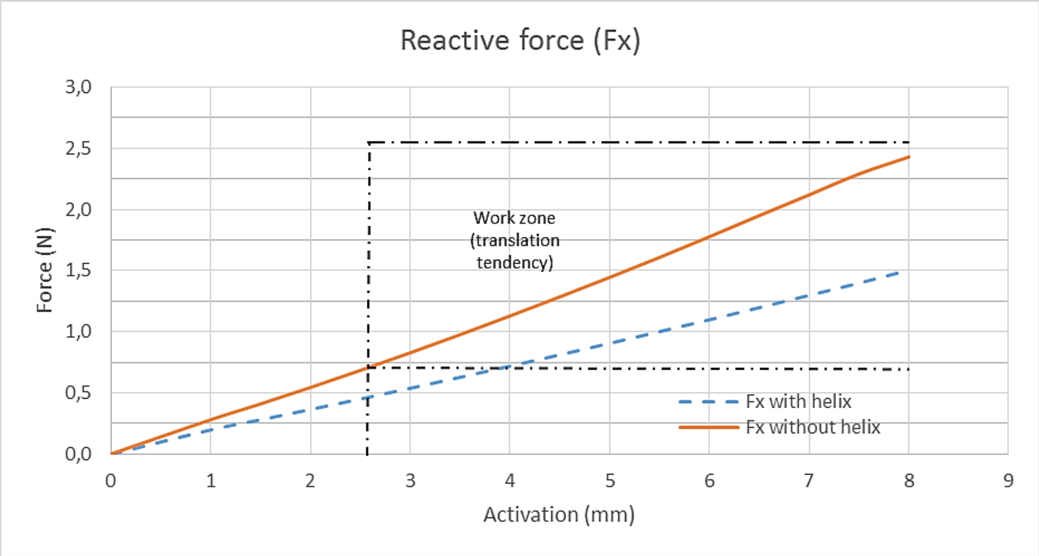

Figure 7. Reactive forces in *x* axis versus activation

In the graph shown in Figure 7, it is observed that springs with helix provide lower forces than those found in springs without helix. Equations 1 and 2, found by regression strategies (Rodrigues *et al*., 2014a, Rodrigues *et al*., 2014b) provide the nonlinear behavior of reactive forces acting on the delta spring with helix and without helix respectively.

$$\boldsymbol{Fx = 0.0015a^2 + 0.174a + 0.0082} \qquad (1)$$

$$\boldsymbol{Fx = 0.0059a^2 + 0.2592a + 0.0032} \qquad (2)$$

Where,

F_x [N] – Reactive force (x-axis);

a [mm] – Activation (x-axis).

The reduction of elastic spring constant is desirable as it allows greater displacement of the teeth within the desired range of forces. For the case study an example of the possible displacement between 0.73 and 2.55N is 1.5 mm (Gjessing 1994) for springs with and without helix.

2.4 Reactive moments and M/F ratio

Reactive movements around the x-axis are very small and are not considered in this study. Reactive moments around the *z* and *y* axes and the reactive forces acting on the *x* axis provide the M_z/F_x and M_y/F_x ratios that are responsible by tooth movement in the occlusal and sagittal planes respectively. The graph of Fig. 8 shows the behavior of reactive moments versus the activation. In Figs. 9 and 10 are depicted the M_y/F_x and M_z/F_x ratios for DOS with and without helix.

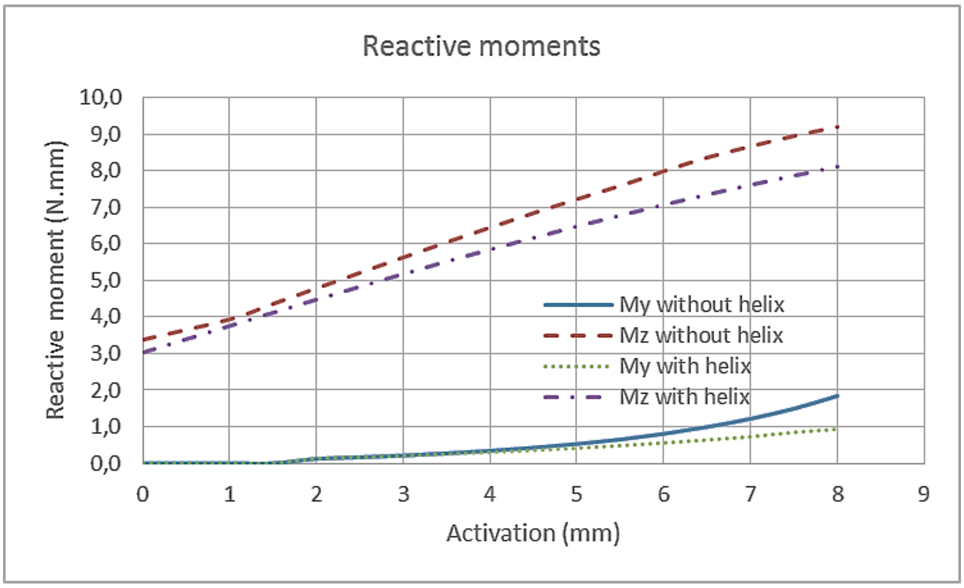

Figure 8. Reactive moments versus activation

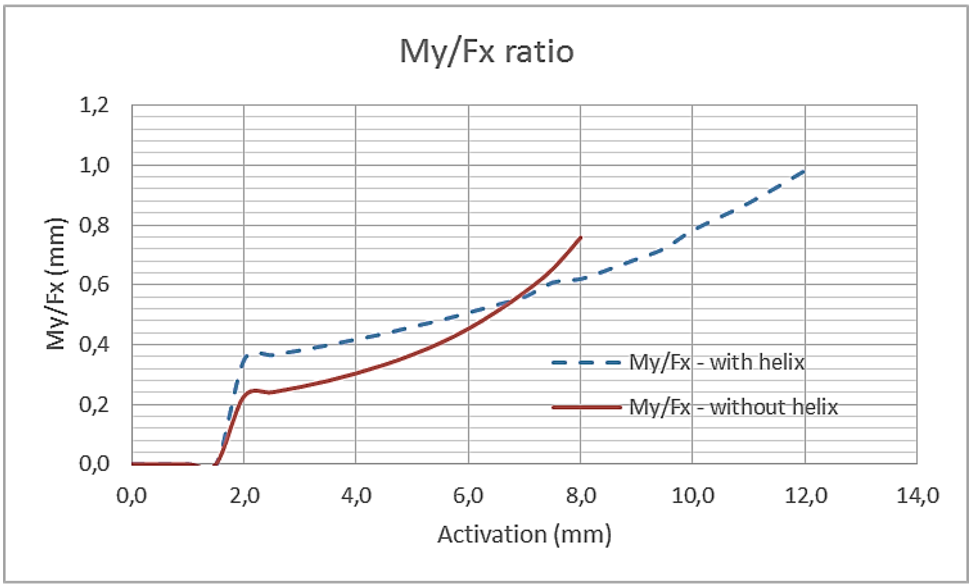

Figure 9. M_y/F_x ratio versus activation

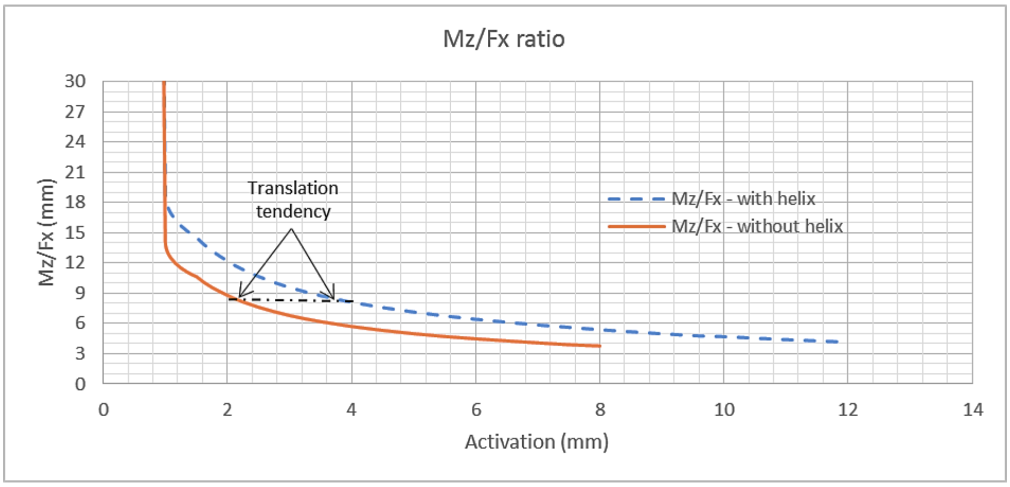

Figure 10. M_z/F_x ratio versus activation

The values of M_y/F_x ratio found show that cannot be determined influence of delta springs (with and without helix) on tooth movement in the occlusal plane, according to reference values found in the literature (Raboud *et al*., 1997). For the ratio M_z/F_x can be determined by the following equations as a function of activation according to Equations 3 and 4 (Rodrigues *et al*., 2014a), (Rodrigues *et al*., 2014b):

$$\frac{Mz}{Fx} = \left(\frac{1000+2052.96a-69.944a^2}{1+162.799+74.741a^2-0.81a^3}\right) \tag{3}$$

$$\frac{Mz}{Fx} = \left(6.0786 - 0.2282a + \frac{16.606}{a}\right) \tag{4}$$

Where,

Equation 3 – M_z/F_x ratio for delta orthodontic spring with helix.

Equation 4 - M_z/F_x ratio for delta orthodontic spring without helix.

M_z/F_x [mm] – Moment-force ratio sagittal plan.

a [mm], $0.0 \leq a \leq 8.0$. – Activation (delta spring without helix);

a [mm], $0.0 \leq a \leq 12.0$ – Activation (delta spring with helix);

3. CONCLUSIONS

According to the numerical results, based on M/F ratio values, the presence or absence of the helix in delta orthodontic springs describes the following behaviors:

- Orthodontic delta springs without helix provide higher reaction forces than those of orthodontic delta springs with helix.
- Considering the yield stress of the material and the distance between brackets adopted, delta springs without helix can be activated up to 8.0 mm while delta springs with helix up to 12.0 mm;
- There was no significant influence in the tooth movement, according to the literature, in the occlusal plane from delta orthodontic springs;
- Orthodontic delta springs with helix tend to influence tooth movement in the following way: tilting uncontrolled root for activation values lower than 1.0 mm, controlled tipping crown for activation between 1.0 and 3.5 mm, translation for activation from 3.5 to 4.0 mm and controlled tilt root from 4.5 to 12.0 mm activation;
- Delta springs without helix tend to influence tooth movement in the following way: uncontrolled tipping root movement for activation between 0.0 and 1.0 mm, controlled tipping crown between 1.0 and 2.0 mm, translation at 2.0 up to 3.0 mm and controlled tipping root from 3.0 to 8.0 mm activation.

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