Original Article

Qualitative evaluation in photoelastic experimental models of the force system generated by T-springs placed in the center of the interbracket space with pre-activations advocated by Burstone

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Abstract

Objective: To evaluate the force system generated by T-springs placed in the center of the interbracket space using the pre-activations advocated by Burstone. **Methods:** Photoelastic models were used to assess T-springs fabricated with 0.017x0.025-in rectangular titanium-molybdenum alloy wire (TMA), centrally positioned, with 6.0 mm activation, 3 mm activation, and in neutral position. To ensure reliable results, tests were repeated on three photoelastic models equally duplicated and fabricated by the same operator. An interbracket distance of 27.0 mm was used. For a better understanding of the results, the fringes were viewed in a polariscope, then photographed and qualitatively analyzed. **Results:** Through qualitative analysis of the fringe order in the photoelastic model it was noted that both the retraction and anchorage ends displayed force system symmetry across the full extent of the root.

Keywords: Orthodontic space closure. Biomechanics.

INTRODUCTION

When orthodontic treatment is administered with the aid of a detailed diagnosis premolar extraction is sometimes performed, which requires that orthodontists have an accurate knowledge not only of biomechanics for the closure of remaining spaces but of histological, anatomical and physiological principles.[24] Space closure may occur by distalization of anterior teeth, mesial movement of the posterior segment or a combination of both.[4,21] At this stage it is important that health professionals choose the device to be used in accordance with the type of anchorage needed, noting the force system being released, so as to ensure adequate movement control without damaging the structures adjacent to the teeth.[1-7,12,13,15,16,21,27,28,30]

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Considering this force system and the principles of the segmented arch technique,[3] Burstone,[6] in 1982, envisioned the T-spring, fabricated with titanium-molybdenum wire, cross-section size 0.018x0.025-in or 0.017x0.025-in, which would allow clinicians to work with enhanced predictability. Arguably, the force system thus released would be closely related to the amount of activation and incorporation of pre-activation bends,[6] thereby making it possible to control the center of rotation of the teeth with a greater degree of accuracy.

In a unique manner, T-springs provide low force magnitude in high activation quantities.[6,7,21,25-28,30] This is due to the type of alloy used and the substantial quantity of wire incorporated into its design. Clinically, this is very positive since the amount of activation is considerable while the loss of force is relatively low when compared to other space closure devices. Therefore, this device continues to provide satisfactory levels of moment/force (M/F) and load/deflection (L/D) ratios.

Scientific literature on studies of mechanical testing and clinical research shows that the T-spring advocated by Burstone[6] delivers an efficient force system for controlled tooth movement, but little has been studied on this device using the photoelastic method.[18] This method is the qualitative observation and / or quantitative areas of tension in resin models that are optically visualized by order of the fringes, when subjected to tension.[2,8,9,10,11,14,16,19,23,29]

Thus, the purpose of this study is to evaluate, in experimental photoelastic model, the system of force generated by Burstone´s T-spring, centered in interbracket space, seeking, through qualitative analysis, support to complement the existing research.

MATERIAL AND METHODS

The photoelastic experimental analysis technique was used as it transforms internal mechanical forces into visible light patterns that indicate the location and magnitude of stress. It is based on the principle that when a beam of polarized light passes through a birefringent material differences in the speed of the beams can be observed with a polarizing filter. The equipment used for viewing the photoelastic effect was a circular polariscope (Fig 1) consisting of: A lighting system (Fig 1A), a pair of polarizers (Fig 1B), a support to sustain the photoelastic model (Fig 1C) to be observed, and a camera to acquire images and analyze results[19,23] (Fig 1D).

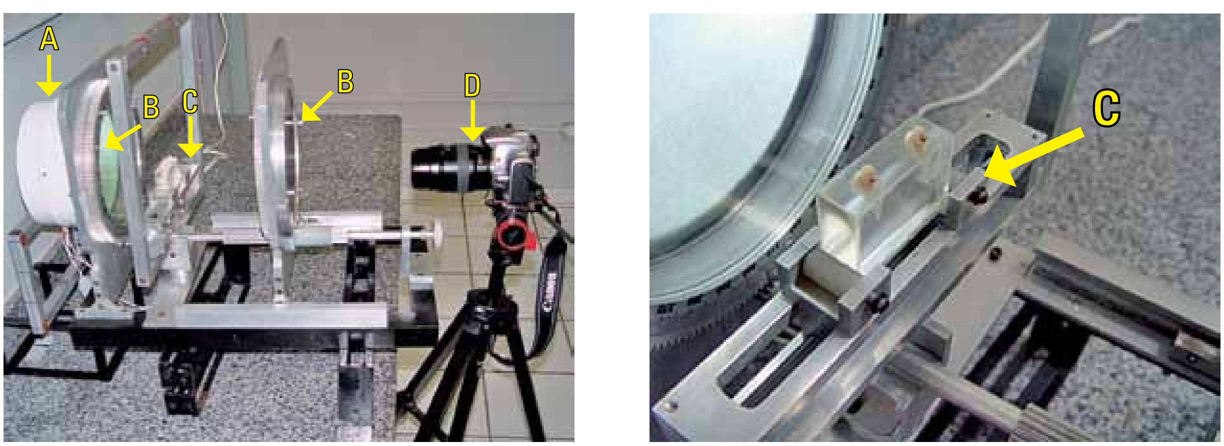

FIGURE 1 - Circular polariscope, designed and manufactured by Faculty of School of Mechanical Engineering, Federal University of Uberlândia, Minas Gerais State.

Initially, tests were performed on 5 experimental pilot models in order to determine proper methodology research, materials to be used, number of repetitions needed, model fabrication technique, reading technique and researcher calibration to ensure result accuracy.[23]

The pilot study and literature review enabled the definition of criteria for obtaining the ideal materials and models in order to conduct the photoelastic tests, namely:

1. Fringe overlap was avoided. This phenomenon occurs when multi-rooted teeth are used, or else when the distance between the teeth is too small, causing fringes to overlap when forces are applied.
2. Materials were used that quickly return to their initial condition when force delivery ceases, and which do not exhibit residual stresses before and after such forces are suspended.[23]
3. Ideally, the material used in fabricating the model should provide a high optical constant, low elasticity modulus, high optical and mechanical resistance, high strain and flexibility ratio. Moreover, it should be readily available, easy to machine, transparent, free from stains and residual stresses, and affordable.[23]

After fabrication of the pilot models three photoelastic models were made with Formica based on a master model, measuring 60.0 mm in length, 40.0 mm in height and 20.0 mm thickness. To simulate and reproduce the position of canines in the photoelastic model two canine crowns were positioned and bonded with Loctite® universal instant adhesive (Super Bonder) at a distance that would allow the brackets to be positioned at 27.0 mm in future (Fig 2).

A utility wax box was made with the following dimensions: 120.0 mm wide, 140.0 mm long and 90.0 mm in height so that the master model could be positioned, and subsequently ASB-10 blue silicone rubber manufactured by Polipox *Indústria e Comércio Ltda., São Paulo, Brazil,* was poured and properly handled with a rubber catalyst

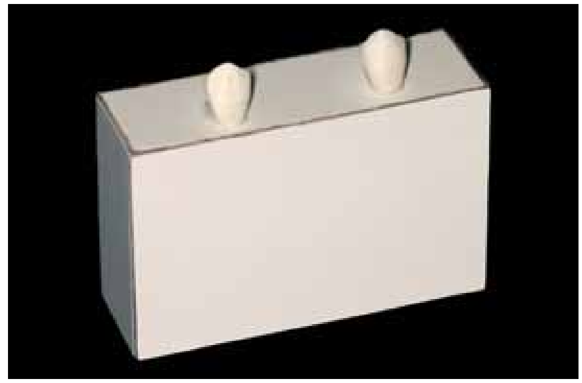

FIGURE 2 - Master model fabricated with Formica to serve as duplicator. Note position of canine crowns that will serve as parameters for photoelastic model.

manufactured by the same company (Fig 3) according to manufacturer's specifications, thus obtaining a negative mold. At this stage, other teeth were positioned in their respective sites while carefully preventing contamination by moisture and/or grease on the root surfaces of the canines and on the silicone. At this point, photoelastic epoxy resin was manipulated and used as inlay (Fig 4) to obtain the definitive photoelastic model.

In manipulating photoelastic resin, component A was gradually blended (20.0 ml) with component B (10.0 ml) (Figs 5A and 5B) in a glass container scaled in milliliters. The two components were placed in a Becker and carefully manipulated for 10 minutes to prevent the incorporation of air bubbles. The mixture was then placed in an oven at a constant temperature of 25° C for 24 hours to complete the setting reaction. After this time period the model was removed from the mold. At this stage one needs to check the optical conditions of the photoelastic model in a polariscope. If the model does not display satisfactory optical properties,[23] which may interfere with the analysis, one should discard it and repeat the same steps over again until an ideal model is produced.

Once the photoelastic models had been defined and the insertion of a T-spring was in order, the authors chose to use crossed tubes. To this

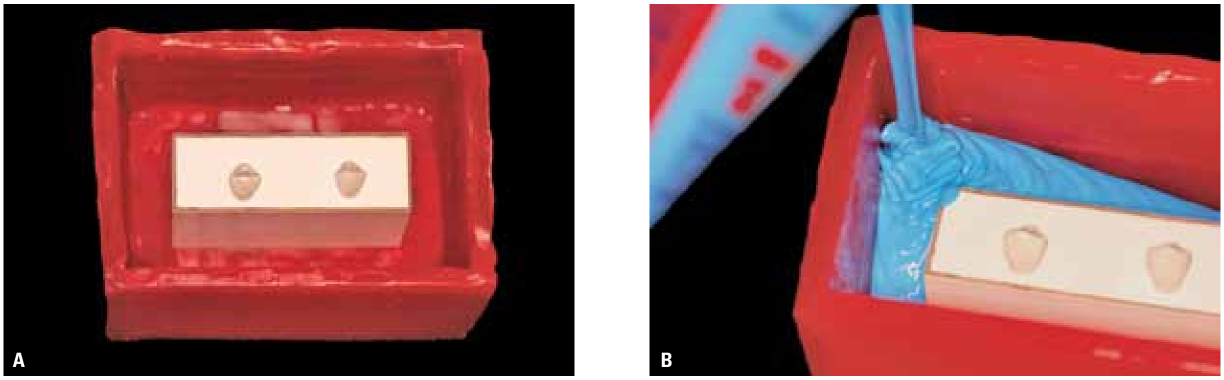

FIGURE 3 - ASB-10 Blue silicone rubber, poured after proper manipulation to obtain negative mold.

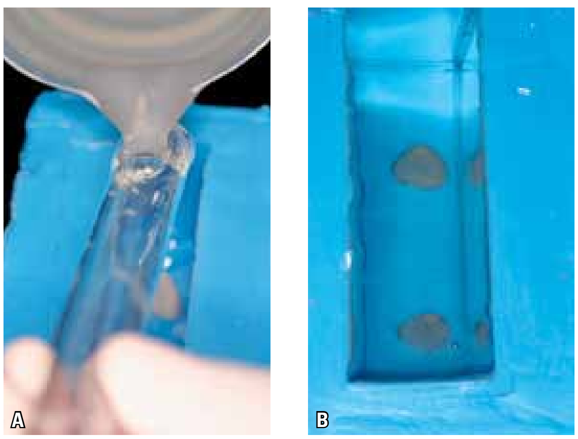

FIGURE 4 - After placement of teeth in their respective places, resin with photoelastic properties was manipulated and inserted it in negative mold to obtain photoelastic model.

FIGURE 5 - Photoelastic resin: **A**) Component "A" Epoxy resin, flexible CMR-201 and **B**) Component "B" Flexible CME-252 Hardener.

end, a vertical slot was drilled on the crowns of the teeth where the tubes were fitted and bonded with acrylic resin (Fig 6).

For each model, a T-spring was used, made with titanium-molybdenum wire (TMA), with a cross-section of 0.017x0.025-in. In order to maintain the T-spring standard defined by Burstone[6] when he first fabricated it, a template was made with the following measurements: 10.0 mm in length and 7.0 mm in height. At this point, pre-activation bends were incorporated into the spring, following the standard set by Burstone[6] (Fig 7).

After checking the T-springs in neutral position, they were inserted into the horizontal slots of the crossed tubes, centered at an interbracket distance of 27.0 mm and evaluated under three different activations: 6.0 mm, 3.0 mm and in neutral position (0.0 mm).

The tests were performed in the laboratory of Mechanical Engineering, Federal University of Uberlândia-MG (Department of Physics). Evaluation was conducted with a refraction polariscope and photographed with a digital camera.

After application of stress resulting from the installation and activation of the T-spring, reading of the fringe order was performed through the violet and blue interface as far as the distal, mesial and apical surface of each tooth. This distance

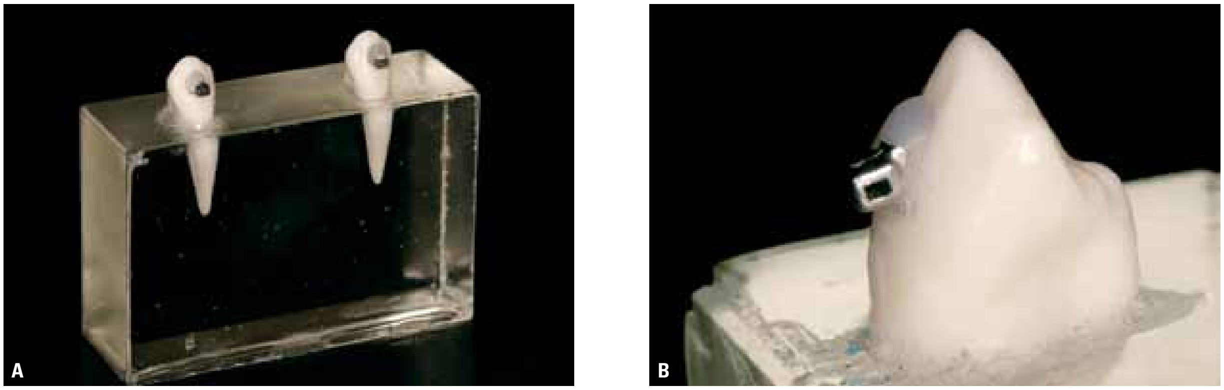

FIGURE 6 - **A**) Photoelastic model with crossed tubes in position. **B**) Close up of crossed tubes inserted to the crowns of acrylic teeth.

FIGURE 7 - Template for standardizing spring fabrication.

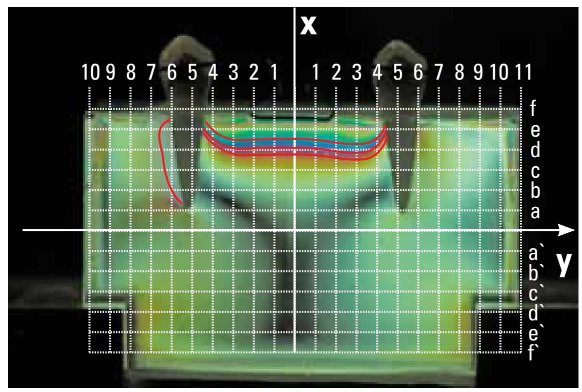

FIGURE 8 - Layout of Cartesian axis to facilitate reading of fringe order points on photoelastic model. **X Axis,** reading of fringe order with 0.5 mm variation. **Y Axis,** reading in millimeters with numerical and alphabetical nomenclature.

would be used as reference to produce the analysis charts. Between the lowest stress level and the highest stress level the following colors are formed: black, yellow, red, blue, yellow, red, green, yellow, red, green (Fig 8).

RESULTS AND DISCUSSION

Orthodontic literature has shown that several techniques are currently used for assessing the force system generated by the T-spring.[6,7,12,15,17,21,25,27,28,30] On the one hand, mechanical tests[4,6,7,15,21,25,27,28,30] and the finite element[17] have proven that the T-spring can provide predictable results, thereby assuring its safe clinical use. On the other hand, clinical research[12] has demonstrated such efficiency through adequate results with no damage to adjacent tissues.

In this study, evaluation of the force system generated by the T-spring was performed according to the pre-activations suggested by Burstone,[6] with the T-spring centered in the interbracket space and using the photoelastic experimental method for qualitative analysis of pressure and stress areas.[1,2,8,9,10,11,14,16,19,23,29] This method is widely used in dentistry in the research of biomaterials, especially in the areas of prosthodontics, dental implants and occlusion, and consists of a method for direct visualization, in photoelastic models, of the effects occurring in these materials when subjected to forces and/or stresses.[2,8,9,10,19,23] Just as importantly, this method is also used in dentistry in the fields of surgery[11] and periodontics.[14] It has been used in orthodontics since 1935[30] to assess the types of tooth movement that take place when forces are delivered from different points to the teeth. Since then, much research has been conducted in all dental specialties using photoelasticity. As a result, this evaluation method has been increasingly refined. However, studies often fail to clarify their methodologies. This tends to complicate the work of researchers, who are often unaware of such experiments and are therefore led to withdraw from them.

In this study, the results were obtained through qualitative reading of the fringes formed in the photoelastic models with the use of T-springs, centrally positioned and under the pre-activations recommended by Burstone[6]. Each spring was analyzed under three different activations, i.e., the first in neutral position, the second with a 3.0 mm activation, and the last with a 6 mm activation.[6]

Interpretations were evaluated descriptively and depicted in charts. Charts were made for the mesial, apical and distal root surfaces and analyzed separately, one at a time (Fig 9). The order of the fringes formed in the photoelastic model resulting from the stress caused by the activations was represented in a Cartesian axis showing a yellow line (neutral position), a blue line (3.0 mm activation) and a red line (6.0 mm activation).

Figure 10 shows that in the absence of a T-spring no photoelastic fringes are formed. The point located at the vertex of Figure 11 depicts a stress-free photoelastic model where the fringe order is 0.0 across the entire root surface of both teeth.

Upon insertion of Burstone's T-spring in neutral position (Fig 12), a fringe order with less than 0.5 was formed across the root surface. This means that in this qualitative analysis, although stress was equally distributed from the cervical region

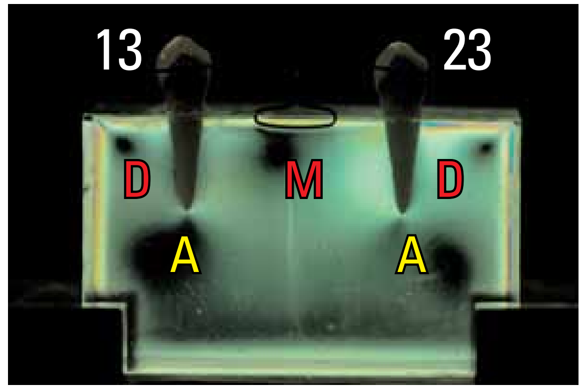

FIGURE 9 - Nomenclature suggested for reading and interpreting fringe orders on photoelastic model. **13** - Left tooth – observer's view. **23** - Right tooth – observer's view. **D** - Distal surface of teeth. **M** - Mesial surface of teeth. **A** - Apical surface of teeth.

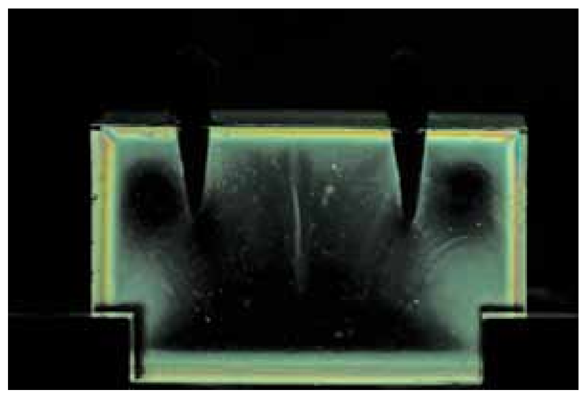

FIGURE 10 - In the absence of T-spring, fringe order of 0.0 observed through the polariscope, indicating absence of forces and moments.

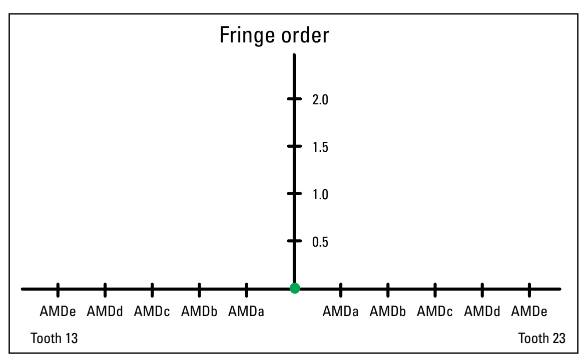

FIGURE 11 - The green dot at the vertex of the graph represents the fringe order zero.

down to the root apex, apparently only a small amount of energy or a very low force magnitude was applied to these teeth (Figs 15, 16 and 17).

When the T-spring was given a 3.0 mm activation, stress was formed symmetrically with a fringe order of 1.5 in the cervical-most region of the mesial surface (Figs 13 and 15). In this same activation, the fringe order on the apical surface (Fig 16) and on the distal surface of the roots (Fig 17) was smaller than 0.5, showing that the stress generated in these regions is lower than the stress formed on the cervical region of the mesial surface, demonstrating that the onset of movement had characteristics indicative of controlled inclination.

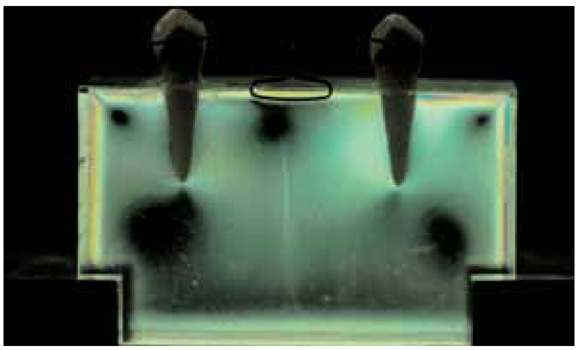

FIGURE 12 - Insertion of T-spring in neutral position generated fringe order very close to zero over entire root surface.

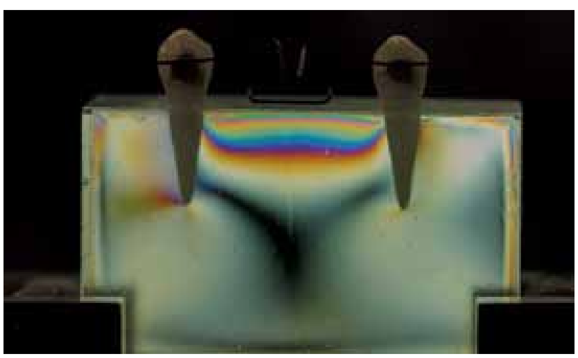

FIGURE 13 - View of photoelastic model with 3.0 mm activation.

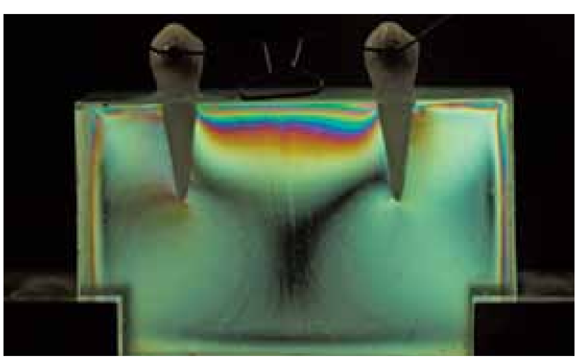

FIGURE 14 - 6.0 mm T-spring activation.

The 6.0 mm activation (Fig 14) showed fringes across the entire mesial surface that were also symmetrical for both teeth. There was a fringe order of nearly 0.5 on the apical surface of tooth 13 and lower for tooth 23, suggesting a slight asymmetry in Burstone's T-spring or an asymmetry in its activation, or even an asymmetry during the fabrication process. This difference, however, was barely perceptible, indicating that this activation is likely to perform its expected functions, such as space closure through controlled inclination. The fringe order in the mesial region of the root located closest to the cervical third was 2.5, suggesting that stress concentration is higher in this region. On the distal surface of the roots the fringe order was 0.0, indicating that no significant stress occurs on this surface.

Scientific literature shows that when a T-spring is given maximum activation it promotes a controlled inclination movement and the greater its deactivation, the greater the M/F ratio in the tooth, bodily movement and root correction. Burstone and Pryputniewicz[5] asserted that in anterior teeth the center of resistance is found at 1/3 of the space between the alveolar crest and tooth apex. They also stated that if a controlled inclination movement is to be achieved the device should release an M/F ratio of 7.1/11, and in order to generate translational movements and root correction this ratio should be, respectively, 9.9/1 and 11.4/1.

In 1984, Smith & Burstone[26] advanced that to attain a controlled inclination movement the M/F ratio should be 8/1, and for translation and root movements the ratio should be 10/1 and 12/1, respectively. In this study, T-spring deactivation resulted in a loss of energy in the cervical mesial region and an increase in energy in the distal apical region. A change was observed from controlled inclination movement to bodily movement, and finally root correction. At no time during this study was the formation of a fringe greater than 0.5 ever noted in the distal apical region of the tooth roots, which in this case would have demonstrated a tendency towards uncontrolled inclination movement.

Asymmetries were negligible, with a fringe order below 0.5. Hypothetically, the emergence of these asymmetries may have been due to some interference in the central position of the T-spring, or else some asymmetry during fabrication in the final design of the T-spring.

Another important finding in the tests using photoelastic models was the symmetrical formation of photoelastic fringes under all activations. In comparing the results depicted in the charts, similar values could be found for both teeth (13 and 23) in the distal, mesial and apical regions, suggesting that, regardless of the T-spring activation, when the T-spring is centered in the interbracket space, the M/F and L/D ratios will be identical for both the active unit (retraction) and the reactive unit (anchorage). This force system released between the segments of the active and reactive units was also observed in studies using mechanical tests[4,7,24,27,28] i.e., moments of equal magnitude and in opposite directions are generated by a symmetrical V-shaped pre-activation bend. Moreover, when this end is inserted in the bracket slots an activation moment will be released. In 2006, Thiesen et al[30] reported that the greater the pre-activation bend, the greater the M/F ratio.

The use of a T-spring to close spaces is efficient in the opinion of many researchers. Hence the orthodontic community's interest in researching this type of orthodontic device from different angles, such as which wire cross-section to use, the type of alloy, moment/force and load/deflection rations, the incorporation or not of helices into these springs, and height and length increases in its design.[6,7,12,15,20,21,22,25,27,28,30]

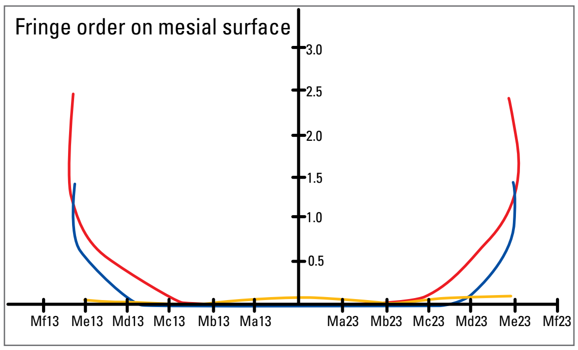

FIGURE 15 - Representation of the mesial surface.

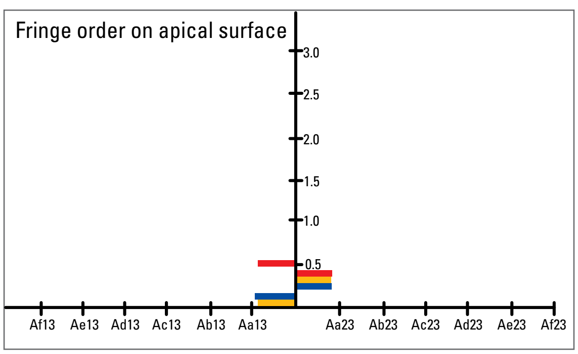

FIGURE 16 - Representation of the apical surface.

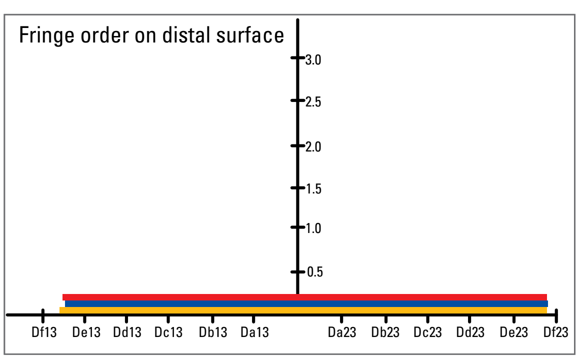

FIGURE 17 - Representation of the distal surface.

CONCLUSIONS

After implementing the experimental photoelastic method for qualitative analysis of the force system delivered by centered T-springs fabricated with 0.017x0.025-in TMA wire, the following conclusions could be drawn:

1. In neutral position, the T-spring displayed a very low fringe order across the entire root surface.
2. With a 3.0 mm activation, the fringe order exhibited a tendency towards controlled inclination movement.
3. At 6.0 mm activation, the concentration of energy or force was clearly higher.
4. The fringe order did not show any characteristics indicative of uncontrolled inclination movement under any of the activations.

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