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PHOTOELASTIC STRESS ANALYSIS OF DIFFERENT MOLAR UPRIGHTING SPRINGS

ANÁLISE FOTOELÁSTICA DAS TENSÕES DE DIFERENTES MOLAS PARA VERTICALIZAÇÃO DE MOLARES

ANÁLISIS FOTOELÁSTICO DE LAS TENSIONES DE DIFERENTES RESORTES PARA LA VERTICALIZACIÓN DE MOLARES

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ABSTRACT

The aim of this study was to analyze and compare the stress distributions in three molar uprighting techniques: cantilever, uprighting spring and Sander's Spring, using quantitative and qualitative photoelastic analysis. Seven photoelastic models were made, the second molar was tipped forward 30º and the mandibular right canine and the first and second premolars were the anchor teeth. In each of the photoelastic models, we tested uprighting mechanics randomly. A software Fringes® was used to quantify the model's shear stress. In the quantitative analysis the nonparametric Kruskal-wallis test demonstrated that only one point of the 18 analyzed, presented statistically significant difference, on point 14 (P=.033). The Post hoc Dunn's test showed difference between cantilever group and the group Sander's Spring bended 135°. In the qualitative analysis, the highest concentration order of isochromatic fringes was on point 6 of the molar. There was no statistically significant difference in all molar points. On anchor teeth the Sander's Spring bended 135º presented higher values on the order of fringes. With the results obtained in this research, the clinical decision of which mechanism of verticalization to use will be a personal preference of the orthodontist.

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Keywords: Orthodontic. Biomechanics. Forces. Tipping. Materials. Photoelasticity.

RESUMO

O objetivo deste estudo foi analisar e comparar a distribuição de tensões em três técnicas de verticalização de molares — cantilever, mola de verticalização e mola de Sander — por meio de análise fotoelástica quantitativa e qualitativa. Foram confeccionados sete modelos fotoelásticos, nos quais o segundo molar foi inclinado para mesial em 30°, sendo o canino mandibular direito e o primeiro e o segundo pré-molares utilizados como dentes de ancoragem. Em cada modelo fotoelástico, as mecânicas de verticalização foram testadas de forma aleatória. O software Fringes® foi utilizado para quantificar as tensões de cisalhamento do modelo. Na análise quantitativa, o teste não paramétrico de Kruskal–Wallis demonstrou que apenas um dos 18 pontos analisados apresentou diferença estatisticamente significativa, no ponto 14 (P = 0,033). O teste pós-hoc de Dunn evidenciou diferença entre o grupo cantilever e o grupo mola de Sander dobrada a 135°. Na análise qualitativa, a maior ordem de concentração das franjas isocromáticas foi observada no ponto 6 do molar. Não houve diferença estatisticamente significativa em todos os pontos do molar. Nos dentes de ancoragem, a mola de Sander dobrada a 135° apresentou valores mais elevados na ordem das franjas. Com base nos resultados obtidos, a decisão clínica sobre qual mecanismo de verticalização utilizar dependerá da preferência pessoal do ortodontista.

Palavras-chave: Ortodontia. Biomecânica. Forças. Inclinação. Materiais. Fotoelasticidade.

RESUMEN

El objetivo de este estudio fue analizar y comparar la distribución de tensiones en tres técnicas de verticalización de molares —cantilever, resorte de verticalización y resorte de Sander— mediante análisis fotoelástico cuantitativo y cualitativo. Se elaboraron siete modelos fotoelásticos, en los que el segundo molar fue inclinado hacia mesial 30°, utilizando como dientes de anclaje el canino mandibular derecho y el primer y segundo premolares. En cada modelo fotoelástico, las mecánicas de verticalización se evaluaron de forma aleatoria. El software Fringes® se utilizó para cuantificar las tensiones de cizallamiento del modelo. En el análisis cuantitativo, la prueba no paramétrica de Kruskal–Wallis demostró que solo uno de los 18 puntos analizados presentó diferencia estadísticamente significativa, en el punto 14 (P = 0,033). La prueba post hoc de Dunn mostró diferencia entre el grupo cantilever y el grupo resorte de Sander doblado a 135°. En el análisis cualitativo, la mayor concentración de franjas isocromáticas se observó en el punto 6 del molar. No se encontraron diferencias estadísticamente significativas en los puntos del molar. En los dientes de anclaje, el resorte de Sander doblado a 135° presentó valores más elevados en el orden de las franjas. A partir de los resultados obtenidos, la decisión clínica sobre qué mecanismo de verticalización utilizar dependerá de la preferencia personal del ortodoncista.

Palabras clave: Ortodoncia. Biomecánica. Fuerzas. Inclinación. Materiales. Fotoelasticidad.

1 INTRODUCTION

Loss of first permanent molars in adult patients is very commonly encountered. Frequent consequences are mandibular second molars tipped mesially, whereas the premolars, canines, and incisors moved distally toward the extraction space and there is a progressive vertical bone resorption of this area.[1]

There are several mechanical techniques to upright the lower molars: simple tip-back mechanics,[2] cantilever,[3] two cantilevers system,[4] T-loop spring,[5] uprighting spring,[6] NiTi -SE -Steel uprighting spring, commonly known Memory Titanol® Spring (MTS).[7]

For orthodontics it is important to have control of tensions generated by the application of external forces on the teeth. To demonstrate these tensions, it was developed a methodology, the photoelastic analysis for dental studies. It is a method of measuring changes in optical properties, from the application of internal forces to transparent materials. This change is generated by stress and interpreted through fundamentals of the theory of elasticity and force of materials. The authors used photography to demonstrate this technique. The polariscope is the basic instrument of photoelastic study.[8]

However, there are scarce studies about stress distribution when uprighting molars. The aim of this study is to analyze and compare the stress distributions in three molar uprighting techniques: cantilever, uprighting spring and Memory Titanol® Spring, using a quantitative and qualitative photoelastic analysis.

2 MATERIAL AND METHODS

At first, we made a simulation of the maloclussion to produce the master model made of wax, artificial teeth and an MDF wood board with an opening (Figure 1). It was based on study to position the teeth. The second molar was tipped 30º forward in the sagittal plane, using the mandibular right canine and the first and second premolars as anchor teeth.[6]

Figure 1

Master model for malocclusion simulation

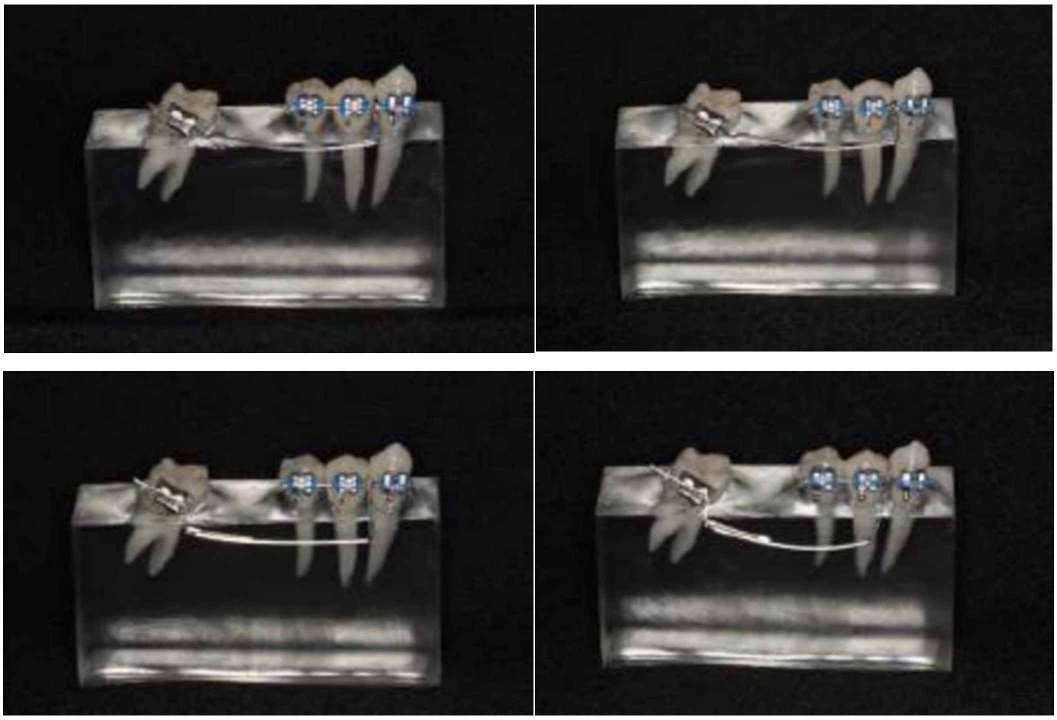
The master model was constructed with wax and artificial teeth on an MDF board, featuring a mandibular second molar tipped 30º forward in the sagittal plane to simulate the clinical condition.

For the fabrication of the photoelastic model, we used a copy of the master model made of silicone (Xiameter™, Germany). A flexible epoxy resin (Aradilte® GY 279 BR and catalyst Aradur HY 2963; Araltec Chemicals Ltd) was manipulated with a proportion of 2 parts of resin to 1 part of catalyst, for 1 minute, resulting in a homogeneous mixture. To prevent bubbles, the mixture was placed in a pressure chamber of 5.9 Mpa for 20 minutes. The photoelastic resin was slowly poured over the impression. After the resin polymerization time (72 hours) the photoelastic model was obtained.[9]

In this study we used seven photoelastic models. Only models that showed adequate translucency and good surface finish were used. A buccal tube (Roth Kirium .018, 3M; Abzil-Brazil) was bonded in the mandibular second molar, brackets (Roth Kirium .018, 3M; Abzil-Brazil) were bonded to the canine and the first and second premolars, and a 0.017”x 0.025” stainless steel archwire (3M; Abzil-Brazil) was used as an anchorage system.Three types of verticalization mechanisms were evaluated, divided into four groups: Cantilever,[4] uprigthing spring in Geometry VI, [6,10] t the prefabricated Memory Titanol® Spring (MTS) bended in 90° and bended in 135 °.[11] (Figures 2A-D).

Figure 2

Photoelastic models of the evaluated uprighting mechanisms

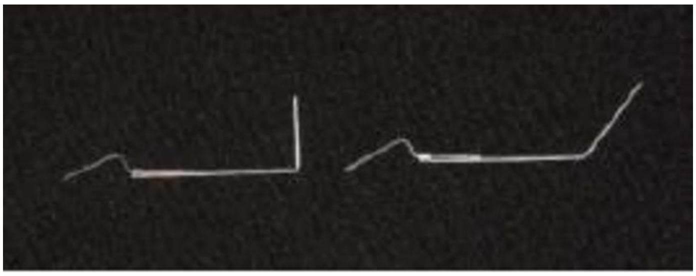


The models represent the four experimental groups tested: (A) Cantilever; (B) Uprighting spring; (C) Memory Titanol® Spring (MTS) bended in 90°; and (D) Memory Titanol® Spring (MTS) bended in 135°.

The Memory Titanol® Spring (MTS) is a prefabricated uprighting spring. The posterior superelastic segment is inserted in the molar tube, and the stainless-steel sectional area is marked between the canine and first premolar. For simultaneous uprighting and intrusion, the bend is 135°. For uprighting with extrusion, at 90° bend is made. (Figure 3) This study followed the guidelines of the manufacturer Forestadent®.

Figure 3

Activation types of the Memory Titanol® Spring (MTS)



Representation of the two types of activation according to the manufacturer: a 90° bend for uprighting with extrusion and a 135° bend for simultaneous uprighting and intrusion.

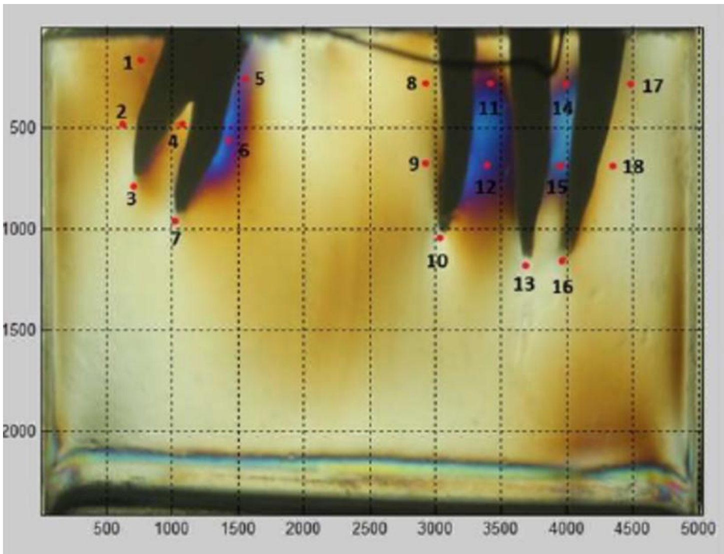
Three types of molars uprighting springs were standardized to have a length of 30mm. We used the force of 50 g all mechanics. This way, the standardization of the generated moment in the molar was 1500 g/mm. In each of the seven photoelastic models, we tested uprighting mechanics randomly.

Photoelastic analysis was performed 72 hours after the fabrication of the photoelastic model with a circular polariscope of horizontal transmission (Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas, Sao Paulo, Brazil). The polariscope consists of: white light resource, two $^{1}/_{4}$ retardant wave filters, 2 polarizing filters, the polarizer, and the analyzer. To record the results, we used a digital camera (EOS Rebel T5- Canon®).

The isometric fringes were observed after obtaining the images. A software (Fringes®; Mechanical Design Laboratory, FMEC, Federal University of Uberlandia, Brazil) was used to quantify the model's stress. Eighteen points of interest were determined along all the roots of the teeth to obtain the stress rates (Figure 4) For each point, the maximum shear stress (Ʈ) was calculated by using the formula (Ʈ=KNf /2b), where K=11.271 N/mm is the optical constant of the photoelastic resin, N is the fringe order, and b= 18 mm is the thickness of the model. The results of the qualitative analysis demonstrated a clear pattern (Figure 4).

Figure 4

Strategic points of interest for shear stress analysis



Location of the 18 points (marked in red) determined along the roots of the molar and anchor teeth (canine and premolars) used to calculate the fringe order and shear stress rates.

Qualitative analysis observed the zones where the fringes were formed such as their intensities. The software Fringes® was used also to qualify the fringe order. The fringes are recognized when the transition from one band to another occurred, according to the change of fringe coloration.

2.1 STATISTICAL ANALYSIS

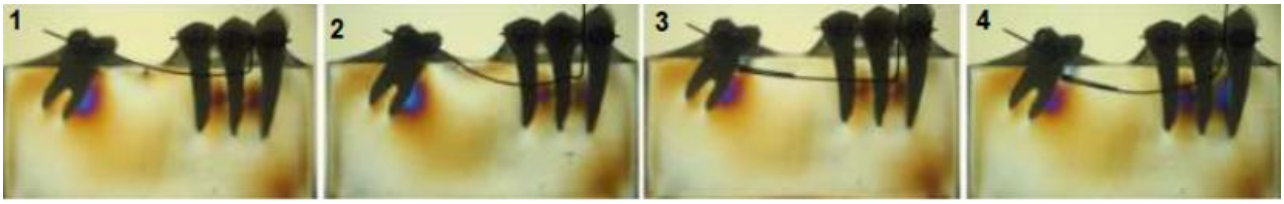
All quantitative data included in this study were tested concerning normality by Shapiro-wilk test. When normality was not found in the data, thus opting for the nonparametric Kruskal-wallis test. When the test showed statistically significant difference, multiple nonparametric paired comparisons (*post hoc* test by Dunn) were performed to verify the types of mechanical differences. The test was performed with a significance level of 5%. All analyses were conducted by software (IBM SPSS® Statistics 20.0; IBM Corp., United States). For the qualitative data we used descriptive statistical analysis.

3 RESULTS

In the variable shear stress, the nonparametric Kruskal-wallis test demonstrated that only one point of the 18 presented statistically significant difference, the point 14 (P=.033). *The post hoc* Dunn's test showed difference between cantilever group and the group Memory Titanol® Spring (MTS) bended in 135°. The results of the qualitative analysis demonstrated a clear pattern. Still in the qualitative analysis, the following results are summarized in (Figure 8).

Figure 5

Qualitative comparison of isochromatic fringe distribution



Visualization of the fringe patterns formed by each mechanism: (1) Cantilever, (2) Uprighting spring, (3) MTS bended in 90º, and (4) MTS bended in 135º, showing higher stress concentration at point 6.

We observed in the tipped molar; the highest concentration order of isochromatic fringes was in the cervical zone of the mesial root (Points 5 and 6). This result appeared in all techniques for upright. In the anchor teeth, the greatest concentration and number of fringes were more expressive in the region the canine and the first premolar (Points 14 and

15). The order of fringes on anchor teeth was higher in the prefabricated Memory Titanol® Spring (MTS) bended in 135º (Table 1).

Table 1

Photoelastic analysis data (mean fringe order) by point and device

Point of Interest	Mean (Cantilever)	Mean (Uprighting Spring)	Mean (Sander's Spring 90°)	Mean (Sander's Spring 135°)
1	0.7	0.9	0.7	0.8
2	0.7	1.0	0.7	0.8
3	0.5	0.8	0.6	0.7
4	0.5	0.8	0.6	0.7
5	0.9	0.9	0.8	0.9
6	0.9	0.9	0.8	0.9
7	0.6	0.7	0.6	0.7
8	0.6	0.7	0.6	0.7
9	0.8	0.9	0.7	0.8
10	0.8	0.9	0.7	0.8
11	0.6	0.8	0.5	0.6
12	0.6	0.8	0.5	0.6
13	0.8	0.9	0.7	0.8
14	0.8	0.9	0.7	0.8
15	0.7	0.8	0.6	0.7
16	0.7	0.8	0.6	0.7
17	0.4	0.6	0.4	0.4
18	0.4	0.6	0.4	0.4

Data presented as mean fringe order for each of the 18 points of interest across the four experimental groups[2]. Point 14 showed a statistically significant difference ($P=.033$) between the Cantilever and MTS 135° groups[33]. MTS: Memory Titanol® Spring[4].

4 DISCUSSION

Several studies in orthodontics have used photoelastic analysis to study stress in orthodontic components: Mandibular molar distal movement,[12] tensions generated by T-loop springs,[5] comparation between conventional and self-ligating brackets.[13]

The greatest advantage of using a methodology with photoelastic analysis is to be able to use real materials (brackets, tubes, orthodontic wires), thus being able to simulate a clinical scenario, unlike other methodologies such as finite elements analysis.[9]

The use of a computer program to analyze images produced by the photoelastic analyses, provides more reliable data when compared to traditional methods of image analysis, which normally depends on the researcher's Kappa calibration and visual acuity. The Fringes® program allows both qualitative and quantitative analysis of shear stress. This computational program has already been validated and used in several studies.[14,17]

This study was a pioneer in evaluating tensions by photoelastic analyses in both the molar and the anchoring teeth. The only study found in the literature to analyze the mechanics of verticalization with this type of methodology evaluated only the molar where the cantilever was also studied.[18] In our study, test in Cantilever formed a greater number and concentration of fringes in the cervical zone of the mesial root of the molar, the most relevant area. The second area with the largest order of fringes was the region of the cervical and mesial zone distal root. Lower order of fringes was found in the apical zones of the molar. These results are similar to the previous cited study.

The results obtained in this research verified that no significant differences were found in shear stress of the molar between the three verticalization mechanisms tested. This result contradicts what was proposed by Wichelhaus & Sander (1995) in the creation of Memory Titanol® Spring (MTS). They proposed a prefabricated dispositive composed of two wires, one made by Niti, and the other wire made of steel. The use of Niti alloy in the rod that connects to the molar was proposed because of the physical properties of this material which presents less rigidity and high resilience, providing the molar with light and continuous forces. In the present study, it was verified that the Niti wire did not provide any lower molar tensions when compared to the other types of mechanics with TMA wire. In the literature found there are few articles on Memory Titanol® Spring (MTS) although it is marketed and used broadly in the United States and Europe. The articles are summarized in clinical experiments and case reports.[11,19]

The result obtained in anchor teeth was found to be statistically significant in point 14 (the cervical point between canine and first premolar). The difference was in the Cantilever and Memory Titanol® Spring bended in 135º. We believe it occurred because it was the point near the place of insertion of the Memory Titanol® Spring (MTS), in the cross tube. This site generates the moment of tension. This difference was possibly expected, because the cantilever has a statistically determined system, which means it is not inserted into the cross tube. Another possible factor is the difference in materials, the cantilever was made of TMA wire (beta-titanium) material of greater flexibility and lower magnitude of force compared to steel wires.[20]

There are many methods for molar uprighting, but there are very few studies reporting the tensions generated by this type of orthodontic mechanics. Adult patients usually have some type of periodontal disease, therefore knowledge about the tensions generated is important for safe clinical decision. Systematic reviews have shown that ideal orthodontic strength should provide maximum tooth movement with minimal damage to the periodontal tissues and maximum patient comfort. The ideal force for tooth movement may differ for each tooth and for each individual.[21]

We observed a greater number and concentration of fringes in the cervical zone of the mesial root of the molar, this result is important once it is very common to find in adults patients with periodontal disease in this area. The orthodontic mechanical loading modulates the inflammatory response of periodontal tissues to periodontal diseases, by increasing the expression of several pro-inflammatory mediators and receptors, which leads to increased bone resorption.[22]

This study corroborates to a good clinical practice as it investigates the tensions generated by verticalization mechanisms and study of Memory Titanol® Spring (MTS), a mechanism that had never been evaluated by this type of methodology. The limitation of this methodology is not to be able to analyze the real system of forces. It is a simulation to identify the shear stress areas and their localization for which upright mechanism.

5 CONCLUSIONS

According to the simulations of this *in vitro* study, we can conclude:

- All vertical force mechanisms produced shear stress in the 18 points evaluated. The most stressed region for all groups was point 6 (cervical zone of the molar's mesial root).
- There was no statistically significant difference between the uprighting mechanisms in all regions analyzed of the molar.
- There is statistically significant difference in point 14 (the cervical point between canine and first premolar) on the anchorage unit, being that the Memory Titanol® Spring (MTS) bent at 135º presented the highest values of the orders of fringes.
- With the shear stress results obtained in this research, the clinical decision of which molar uprighting mechanism to use will be a personal preference of the orthodontist.

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