UNESP - Universidade Estadual Paulista
"Júlio de Mesquita Filho"
Faculdade de Odontologia de Araraquara

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Simulação da verticalização de molares por arco lingual de TMA: uma análise biomecânica tridimensional de diferentes ativações

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Dissertação apresentada à Universidade Estadual Paulista (Unesp), Faculdade de Odontologia, Araraquara para obtenção do título de Mestre em Ciências Odontológicas, na Área de Ortodontia.

Orientador: Prof. Dr. Helder Baldi Jacob

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Carolina Servidoni Spreafico

Simulação da verticalização de molares por arco lingual de TMA: uma análise biomecânica tridimensional de diferentes ativações

Comissão julgadora

Dissertação para obtenção do grau de Mestre em Ortodontia

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DADOS CURRICULARES

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"A mente que se abre a uma nova ideia jamais voltará ao seu tamanho original"

Albert Einstein

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RESUMO

Esse estudo avaliou por meio de uma máquina de ensaio mecânico, *Orthodontic Force Tester* (OFT), o sistema de força tridimensional gerado pelo arco lingual (AL). Diferentes ativações para a verticalização do segundo molar inferior foram efetuadas e a força vertical (FZ), o torque de coroa (MX) e o momento de verticalização (MY) foram mensurados. A pesquisa foi dividida em dois capítulos: Capítulo 1, com as aferições efetuadas após a confecção e ativações (simétricas de 10°, 20° e 30° por meio de dobras e curvaturas) dos ALs e no Capítulo 2, com as aferições mensuradas após um período de 28 dias devido ao relaxamento estrututal do estresse (alívio de tensão estrutural) dos ALs. Material e Método: O primeiro estudo comparou dois tipos de ativações no AL, em dobra (G1) e em curvatura (G2), com subgrupos de ativações simétricas de 10°, 20° e 30°. Foram utilizados no total 60 arcos linguais de Burstone 0.032” x 0.032” TMA (ORMCO), 30 para G1 e 30 para G2, sendo 10 unidades para cada subgrupo. O segundo estudo avaliou e comparou a perda da desativação do arco lingual após 28 dias. Resultados: No capítulo 1, tanto o G1 quanto o G2 apresentaram baixas forças extrusivas (FZ): -28,3 cN (G1_10°), -52,2 cN (G1_20°), -65,8 cN (G1_30°), -12,7 cN (G2_10°), -28,3 cN (G2_20°), e -46,8 cN (G2_30°). O momento de verticalização (MY) foi no sentido mésio-distal para ambas as ativações, e os valores obtidos variaram entre -1087,5 cN.mm (G2_10°) e -4298,9 cN.mm (G1_30°). Não houve diferença entre o torque da coroa, ambas ativações tiveram torque vestibular. Conclusão: No capítulo 1, pode-se concluir que ativação do arco lingual em dobra produziu maiores valores de sistema de força, e no capítulo 2, observou-se perda gradual em ambos os grupos, sendo o efeito relaxamento do estresse é mais evidente no grupo ativado por dobra.

Palavras chave: Fenômenos Biomecânicos. Técnicas de movimentação dentária. Arco dental.

Spreafico CS. Simulation of molar uprighting by TMA lingual arch: a 3-dimentional biomechanical analysis of different activations [dissertação de mestrado]. Araraquara: Faculdade de Odontologia da UNESP; 2023.

ABSTRACT

This study evaluated, using a mechanical test machine, Orthodontic Force Tester (OFT), the three-dimensional force system generated by the lingual arch (AL). Different activations for uprighting the mandibular second molar were performed and the vertical force (FZ), crown torque (MX) and uprighting moment (MY) were measured. The research was divided into two chapters: Chapter 1, with the measurements taken after making and activations (symmetrical 10°, 20° and 30° through folds and curvatures) of the LAs and in Chapter 2, with the measurements measured after a period of 28 days due to structural stress relaxation (structural strain relief) of the LAs. Material and Method: The first study compared two types of activations in the LA, bending (G1) and curvature (G2), with subgroups of symmetrical activations of 10°, 20° and 30°. A total of 60 Burstone 0.032” x 0.032” TMA (ORMCO) lingual archwires were used, 30 for G1 and 30 for G2, 10 units for each subgroup. The second study evaluated and compared the loss of lingual arch deactivation after 28 days. Results: In chapter 1, both G1 and G2 showed low extrusive forces (FZ): -28.3 cN (G1_10°), -52.2 cN (G1_20°), -65.8 cN (G1_30°), -12.7 cN (G2_10°), -28.3 cN (G2_20°), and -46.8 cN (G2_30°). The verticalization moment (MY) was in the mesio-distal direction for both activations, and the values obtained varied between -1087.5 cN.mm (G2_10°) and -4298.9 cN.mm (G1_30°). There was no difference between crown torque, both activations had buccal torque. Conclusion: In chapter 1, it can be concluded that activation of the lingual arch in bending produced higher force system values, and in chapter 2, gradual loss was observed in both groups, with the relaxation effect of stress being more evident in the fold-activated group.

Keywords: Biomechanical phenomena. Tooth movement techniques. Dental arch.

SUMÁRIO

1 INTRODUÇÃO

A perda de elemento dentário prejudica a capacidade de mastigar e digerir alimentos, além de gerar problemas psicológicos por impactar negativamente a autoestima da pessoa. Os dentes mais acometidos pela perda dentária são os primeiros molares permanentes devido a lesão cariogênica e doenças periodontais[1]. Essa perda dentária acarreta uma alteração na oclusão bem como na capacidade mastigatória, sendo que os dentes adjacentes e antagonistas apresentam uma modificação em sua posição[2].

Normalmente com a perda de um elemento dentário, o dente posterior ao espaço edêntulo apresenta uma mesialização[3] e o dente anterior sofre uma distalização, implicando na formação de uma bolsa periodontal[4] e colapso na oclusão[5], além de extrusão do dente antagonista [2,6]. O movimento dentário dos dentes adjacentes normalmente está associado a uma inclinação da coroa na direção do movimento. Independentemente de optar-se por adequar o espaço edêntulo ou fechá-lo[7], a verticalização de molares se faz importante em ambos os aspectos.

Vários métodos para a verticalização de molares têm sido propostos utilizando sistemas de forças estaticamente determinado (sistema de força não altera durante a movimentação das unidades ou devido a desativação do sistema de forças – um binário) ou indeterminado (sistema de força altera durante a movimentação das unidades ou devido a desativação do sistema de forças – dois binários). O uso do arco lingual (AL) é uma abordagem muito utilizada na técnica do arco segmentado, onde o arco dentário é dividido em unidade ativa e passiva, permitindo uma melhor análise do sistema de força a ser empregado, ou seja, onde os valores de força e momento são conhecidos e/ou mensuráveis. Com um sistema de força previamente determinado, pode-se prever o comportamento de um dente ou unidade dentária. Quando o número de variáveis é muito elevado, como com uma técnica de arco contínuo, a previsão ortodôntica torna-se praticamente impossível de maneira simples e clinicamente viável[8,9]. É importante enfatizar que o conhecimento das magnitudes relativas das forças e momentos e, especialmente suas direções, são mais relevantes do que a descrição dos valores reais. Sem esse conhecimento os ortodontistas são incapazes de prever os movimentos dos dentes alcançáveis por seus aparelhos[10].

Dentro da técnica do arco segmentado, podemos usar três formas de sistema de força para verticalizar o segundo molar: um e dois cantiléver, e mola de correção radicular. Tanto o cantilever quanto a alça de correção são, normalmente, construídos com fio ortodôntico 0,017" X 0,025" de titânio molibidênio (*Titanium Molybdenum Alloy* – TMA), pois essa liga apresenta maior flexibilidade que o aço, fornecendo uma distribuição de força contínua[5], sendo mais favorável para a saúde periodontal, especialmente em pacientes adultos[8].

O arco transpalatino e/ou arco lingual têm se mostrado como boas opções com o intuito de verticalização de molares. O uso do arco lingual (AL) é uma abordagem muito utilizada na técnica do arco segmentado, onde o arco dentário é dividido em unidade ativa e passiva, permitindo uma melhor análise do sistema de força a ser empregado, ou seja, os valores de força e momento são conhecidos e/ou mensuráveis. Esses arcos, com ativação simétrica (Geometria VI), fornecem um sistema de forca mensurável e relativamente previsível (momento e força), gerando verticalização do molar e evitando sua extrusão. Ativações anteriores e posteriores simétricas são indicadas para inclinação correta sem geração de forças verticais[4].

Outra possibilidade terapêutica para verticalização de dentes é o uso de mini parafuso ou mini implante ortodôntico (MI) como forma de ancoragem, direta ou indireta. Os MIs são muito efetivos, possui facilidade de instalação, remoção, conforto, baixo custo e com necessidade mínima de colaboração dos pacientes. Também são indicados para casos complexos onde a mecânica tradicional não pode ser utilizada, principalmente em pacientes adultos[11]. Em casos de moderada a grave mesialização do molar, o momento gerado por uma única força é limitado devido à distância reduzida da linha de ação da força ao centro de resistência, e a força extrusiva é um efeito inevitável[9].

Alguns dispositivos associam diferentes ligas metálicas para movimentação de dentes. A mola de Sander, um dispositivo pré-fabricado que associa fios de níquel-titânio e de aço conectados por um tubo transversal, apresenta vários protocolos de ativações para controlar momentos e forças verticais dependendo da sua indicação[12]. Embora diferentes ativações e comprimentos de fios são propostos para melhor controlar o sistema de força, testes mecânicos mostraram forças verticais extrusivas no movimento de verticalização dentário[13].

A maioria dos aparelhos de verticalização dentária produz, além do momento, forças extrusivas. Em muitos casos a extrusão é indesejável e resulta em contato prematuro e mordida aberta. Em pacientes com forte padrão muscular, a força oclusal ajuda a neutralizar a força extrusiva[5]. Portanto, existem várias formas de abordagem para verticalização de molar, sendo o efeito de extrusão vantajoso para alguns pacientes, mas na maioria das situações a verticalização sem extrusão é o melhor objetivo[5,14]. Para esse efeito indesejado de extrusão, é necessário um maior controle da força vertical. Para tanto arco lingual e/ou barra transpalatina podem ser utilizados aplicando a geometria VI, preconizada por Burstone em 1970[15]. O princípio da geometria VI compreende exatamente a situação de verticalização de molar; o sistema de força que atua sobre o fio é composto de momentos iguais e opostos e as forças se anulam[16].

Para verticalização de molar, a força aplicada deve ser avaliada com um medidor de força, e os momentos devem de aproximadamente 2000 cN.mm, mas não superior a 3000 cN.mm[10]. Um sistema de força que gera com extrusão significativa do molar, produzirá uma força de intrusão excessiva no segmento de ancoragem (unidade passiva). Em casos onde forças verticais não são possíveis de serem evitadas, uma força menor deve ser produzida, ou mais importante, um braço de alavanca mais longo deve ser utilizado, já que o momento é resultante da força e da distância. Outra forma de evitar as forças e manter apenas momentos, é a utilização de ativação simétrica (geometria VI) do dispositivo de verticalização dentária, como anteriormente mencionado.

Entre as várias ligas metálicas utilizadas para confecçõs de dispositivos de verticalização de dentes, a liga de titânio molibidênio (β-titanium) é umas das mais comuns, devido suas propriedades mecânicas como formabilidade e carga-deflexão. A liga de titânio molibdênio apresenta uma capacidade do fio retornar a sua forma e estrutura original, dispersando a energia acumulada, conhecido como efeito Baushinger[11]. Após a pré-ativação do dispositivo ortodôntico, se faz necessário a liberação da tensão incorporada no fio antes de sua instalação, fazendo com que os sistemas de forças gerados sejam adequados para tal movimentação indicada. Essa simulação da ativação consiste em posicionar o AL em posição neutra, ou seja, simulando o encaixe do dispositivo de movimentação dentária ao acessório. A posição neutra pode ser definida como a separação horizontal e vertical da mola antes da introdução de uma força no plano horizontal ou mesiodistal[12].

Embora de simples confecção e universalmente utilizado, o AL não apresenta estudos reportados pela literatura avaliando o sistema de força utilizado para verticalização de molares. O objetivo desse estudo é avaliar tridimensionalmente e comparar o sistema de carga produzido por um arco lingual na verticalização de molar, aplicando Geometria VI de Burstone, por meio do Orthodontic Force Tester (OFT), com dois tipos de ativação: em dobra e em curvatura no arco, e após 28 dias avaliar os sistemas de força na desativação do arco.

2 PROPOSIÇÃO

Comparar o sistema de força produzido por um arco lingual na verticalização de molar, utilizando a Geometria VI de Burstone, por meio da *Orthodontic Force Tester* (OFT).

2.1 Objetivos Específicos

Publicação 1:

- Avaliar tridimensional, por meio do OFT, o sistema de força gerado na verticalização de segundos molares com ativação em dobra no arco lingual.

- Avaliar tridimensional, por meio do OFT, o sistema de força gerado na verticalização de segundos molares em curvatura no arco lingual.

Publicação 2:

- Avaliar por meio da OFT, o sistema de força gerado pela desativação do arco lingual na verticalização do molar com diferentes ativações após 28 dias devido ao alívio de tensão estrutural.

3 PUBLICAÇÕES

Desta pesquisa foram produzidos dois trabalhos que apresento abaixo e que serão publicados posteriormente:

- Simulação da verticalização de molar com arco lingual de TMA: uma análise biomecânica de diferentes ativações.
- Avaliação do sistema de forca na verticalização do molar com uso de arco lingual devido ao efeito do relaxamento de tensão: comparação de dois métodos diferentes de pré-ativação.

3.1 Publicação 1*

Simulação da verticalização de molar com arco lingual de TMA: uma análise biomecânica de diferentes ativações

RESUMO

Introdução: A perda dentária pode acarretar uma alteração na oclusão bem como na capacidade mastigatória. Este estudo teve como objetivo avaliar biomecanicamente a verticalização do molar com uso de um arco lingual (AL) de TMA. Dois grupos foram comparados de acordo com o tipo de ativação. **Material e Método:** Um modelo de gesso inferior foi escaneado, seguido de manipulação para apresentar um alinhamento e nivelamento dos dentes. O primeiro molar direito foi removido antes da impressão do modelo de trabalho. O modelo inferior de resina foi fixado em uma mesa de teste de força ortodôntica (OFT). Os segundos molares inferiores foram conectados a duas células de carga para avaliar a força vertical (FZ), os momentos transversais (MX) e anteroposterior (MY). Um total de 60 LAs pré contornados de 0,032" x 0,032" de TMA (ORMCO) foram usados. A amostra foi dividida em dois grupos: G1 (ativação em dobra) e G2 (ativação em curvatura). As pré-ativações foram baseadas em 10°, 20° e 30° graus da forma passiva. **Resultados:** Foram observadas diferenças entre os grupos para FZ e MY. As forças extrusivas foram muito baixas, variando de -12,7 cN (G2_10°) a -65,8 cN (G1_30°). Os momentos de verticalização variaram de -1087,5 cN.mm (G2_10°) a -4298,9 cN.mm (G1_30°). **Conclusões:** As ativações em *V-bend* apresentam consistentemente maiores forças extrusivas e momentos verticais do que a ativação em curva. Com base neste estudo, a ativação da curvatura em 20° é a recomendada para atingir o momento ideal de verticalização molar.

Palavras–chave: Verticalização de molar, Arco Lingual, Biomecânica.

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ABSTRACT

Simulation of molar uprighting by TMA lingual arch: a 3-dimentional biomechanical analysis of different activations

This study aimed to evaluate biomechanically the molar uprighting using a TMA precision lingual arch (LA). Two groups were compared according to activation type. **Materials and Method**: A mandibular stone cast was scanned followed by manipulation to present near to perfect alignment and leveling of the teeth. Right first molar was removed before the working model to be printed. The mandibular resin model was secured onto a desktop table of the orthodontics force tester (OFT). The mandibular second molars were connected to two load cells to evaluate the vertical force (FZ), the transverse (MX) and anteroposterior moments (MY). A total of 60 preformed 0.032-in x 0.032-in TMA (ORMCO) LAs were used. The sample was divided into two groups: G1 (bend activation) and G2 (curvature activation). Pre-activations were based on 10°, 20°, and 30° of the passive shape. **Results:** Some differences were observed between groups for FZ and MY. Extrusive forces were very low, ranging from -12.7 cN (G2_10°) to -65.8 cN (G1_30°). Uprighting moments ranged from -1087.5 cN.mm (G2_10°) to -4298.9 cN.mm (G1_30°). **Conclusions:** V-bend activations present consistently higher extrusive forces and upright moments than curve activations. Based on this study, the curvature activation at 20° is the recommended to reach the ideal uprighting molar moment.

Keywords: Molar uprighting, Lingual Arch, Biomechanics.

INTRODUCTION

The loss of the dental element reduces the ability to chew and digest food, and, additionally, it can generate psychological problems by negatively impacting the person's self-esteem. The teeth most affected by tooth loss are the first permanent molars due to cariogenic injury and periodontal diseases.[1] This tooth loss causes change in occlusion as well as in masticatory capacity, and adjacent and antagonist teeth change their position.[2]

Usually, with the loss of a dental element, the posterior tooth and anterior tooth to the edentulous space undergo a mesialization and distalization,[3] respectively, resulting in formation of a periodontal pocket,[4] collapsing the bite,[5] and extrusion of the antagonist tooth.[2,6] Tooth movement of the edentulous adjacent teeth is usually associated with inclination of the crown in the direction of missing tooth. Regardless of opting to adjust the edentulous space or close it,[7] uprighting molar is important in both aspects.

There are several methods in the literature for correcting molar uprighting. It is relevant for the clinician to anticipate how the tooth or tooth unit will move. Producing a force system that can be calculated and predicted is very important. In a two-unit system, the systems can be classified as a statically determinate or statically indeterminate. Statically determinate system allows for exact measurement of the forces and moments (the whole force system is known), and it can be represented by a cantilever (one-couple). On the other hand, the statically indeterminate system presents wire ends inserted into brackets, making difficult to determine all the forces and moments during the deactivation or to predict from the initial force system. It is important to emphasize that the knowledge of the relative magnitudes of forces and moments, and especially their directions, is more relevant than the description of actual values. Without this knowledge, orthodontists are unable to predict tooth movements achievable by their appliances.[8]

The use of the lingual arch (LA) is an approach widely used in the segmented arch technique, where the dental arch is divided into active and passive units. The relationship between two bracket slots, which are not perfectly parallel and aligned, should be evaluated.[9] The interaction between these two brackets resulted in six so called geometry classes. LAs, with symmetrical activation of Geometry VI, can provide a theoretical known force system (moment and force), generating molar uprighting and preventing extrusion.[4,9] The principle of Geometry VI understands exactly the situation of molar uprighting; the force system acting on the arch is composed of equal and opposite moments where the forces cancel each other out.[10] The extrusion effect may be advantageous for some patients, but, in majority of the situations, verticalization without extrusion is the best strategy.[4,11]

It is also important to provide, not only the ideal force system, but the approximately correct amount of uprighting moment. The literature has shown that the uprighting moments should be about 2000 cN.mm but not more than 3000 cN.mm;[12] despite in physics force is expressed in Newton (or in centesimal part known as centinewton), in orthodontics force is frequently represented in gram or gram-force, and 1 cN is approximately 1 gram-force. It is also important to check the neutral position to evaluate the force system that is acting. The neutral position can be defined as the horizontal and vertical separation of the spring before the introduction of a force in the horizontal or vertical plane.[13]

Although it is simple to design and universally used, the literature is scarce with regards to LA and its force system used for molar uprighting. The objective of this study was to evaluate the force system produced by a lingual arch in molar uprighting, applying Burstone's Geometry VI, using the Orthodontic Force Tester (OFT). A 3-dimensional (sagittal, coronal and axial planes) evaluation was obtained. The clinical application of two types of activation (bend and curvature) and three amounts of activation were used.

MATERIAL AND METHOD

A mandibular stone cast of Class II template was used as a basic model to evaluate the tridimensional changes of the second molars uprighting. The model was scanned (Identico light, 3shape, Copenhagen, Denmark) followed by three-dimensional manipulation (Archform 1.9.5) to present near to perfect alignment and leveling of the mandibular teeth, symmetric arch shape, and removal of the left first molar (Figure 1). The second molars were kept parallel to each other along perpendicular axis to the mandibular occlusal plane. After the digital manipulation, the working model was printed (Photon Mono SE, Anycubic, Shenzhen, China). The second molars received a band presenting a welded 0.032-in slot hinge-cap lingual tube (Ormco, Glendora, CA, USA). An original Cold Weld two-part epoxy system (JB Weld, Sulfur Springs, TX) was used to cement the bands.

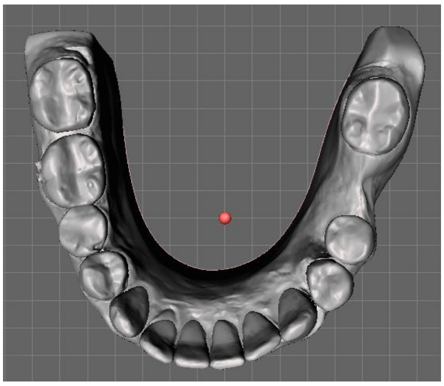

Figure 1. 3D mandibular model after manually aligned and leveled.

Figure 2. 3D printed resin model with second molars receiving bands.

After cast preparation and printing, the second molars were manually detached from the 3D printed model using a carborumdum disc attached to an electric machine hand piece. Prior to the second molar detachment, a transfer impression was made with condensation silicone (Coltene, Vigodent S/A, Rio de Janeiro, Brazil). Afterwards, the teeth were repositioned to the cast with wax (Lysanda, São Paulo, Brazil) using the silicone as a guide, keeping the original position (Figure 2).

Figure 3. Transfer impression with condensation silicone for second molar manipulation.

Figure 4. 3D resin model presenting second molars cut out, received wax and condensation silicone for molars original setup position.

The mandibular resin model was secured on a desktop table of the orthodontics force tester (OFT) machine (Department of Mechanical Engineering, Purdue University, Indianapolis, IN) using J-B Kwik glue (JB Weld, Sulfur Springs, TX). Two load cells (Multi-Axis Force/Nano 17 Torque, Industrial Automation, Apex, Ind) with a 0-20 N and 0-100 N.mm range were glued to the second mandibular molars (Figure 3). Subsequently, the second molars were separated from the cast attached to the OFT machine desktop table (Figure 4). A customized software (Mechanical Engineering Department Purdue University) was used to identify the forces and moments measured by the OFT load cells.

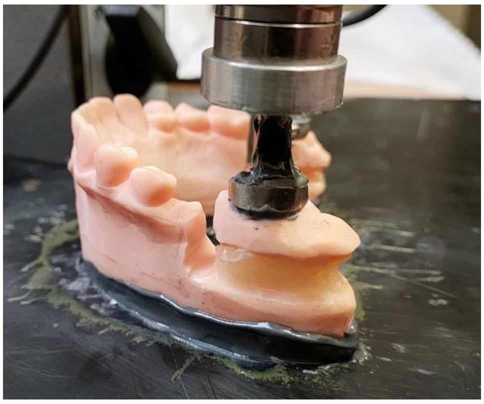

Figure 5. 3D resin model fixed onto the desk top table of the orthodontics force tester machine.

Figure 6. The two load cells positioned and glued to the second molars, which were previously separated from the 3D resin and repositioned back with.

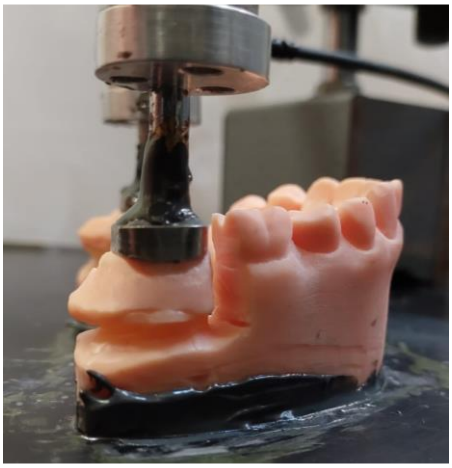

Figure 7. Second molars completely separated from the 3D resin model, which is glued onto the OFT desk top, but attached to the OFT machine load cell.

Once the load cells were vertically attached to the second molars, the software allowed for rotational calibration of the origin (zero) of the measurements in all 3 dimensions. Calibration of the OFT was concluded when the sensors measured forces and moments equal to zero at the center of the lingual tubes of the second mandibular molars; no forces and moments were applied. The force read in the cervico-occlusal direction was carried out along the Z-axis (FZ), with negative sign representing crown extrusion. The X-axis carried out the moment read in the buccolingual direction (MX), which was perpendicular to the lingual tube, with negative sign identifying the bucco-lingual crown torque. The Y-axis represented the uprighting of the crown in the mesio-distal direction (MY), with negative sign representing the moment of distalization of the crown.

Sixty Burstone precision TMA .032-in x .032-in lingual arches (ORMCO, California USA) were used to perform the experiment. A sample calculation was performed using the GPower 3.1 program (Franz Faul, Germany), and 5% significance. A minimum of nine arches per activation type would be necessary (n=54) for the study. The lingual arches (LA) were divided into two groups, G1 (bend activation) and G2 (curvature activation) and subdivided equally according to the amount of angle of activation (10°, 20° and 30°). A digital image printed at 1:1 scale of the model allowed the design of a passive standardized LAs to the molar tubes (Figure 5). Its passivity was also verified by means of software force and moment measurements.

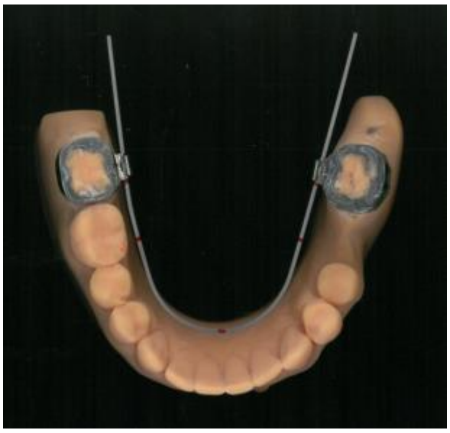

Figure 8. Printed 1:1 occlusal template.

A passive lingual arch was inserted into the tube. The passivity in all three planes (sagittal, axial, and coronal) was confirmed using the OFT. Pre-activations, which were the changes in the shape of the arch, were performed only at the time of the insertion into the lingual arch tube using the generated template as aforementioned. The bend activation was performed 1 mm mesial to the lingual tubes. The curvature activation was made starting 10 mm mesial from the mesial of the tube until 1 mm of the lingual tube. As above-mentioned, three amounts of symmetrical activation were performed for each group using the Loop Software (dHAL Software, Atenas, Greece): 10°, 20° and 30°, and double-checked using a protractor (Figure 6). Data was collected for force (FZ) and moments (MX and MY) and transferred to an Excel spreadsheet. SPSS statistical software (IBM SPSS version 20.0; Armonk, NY) was used for data analysis.

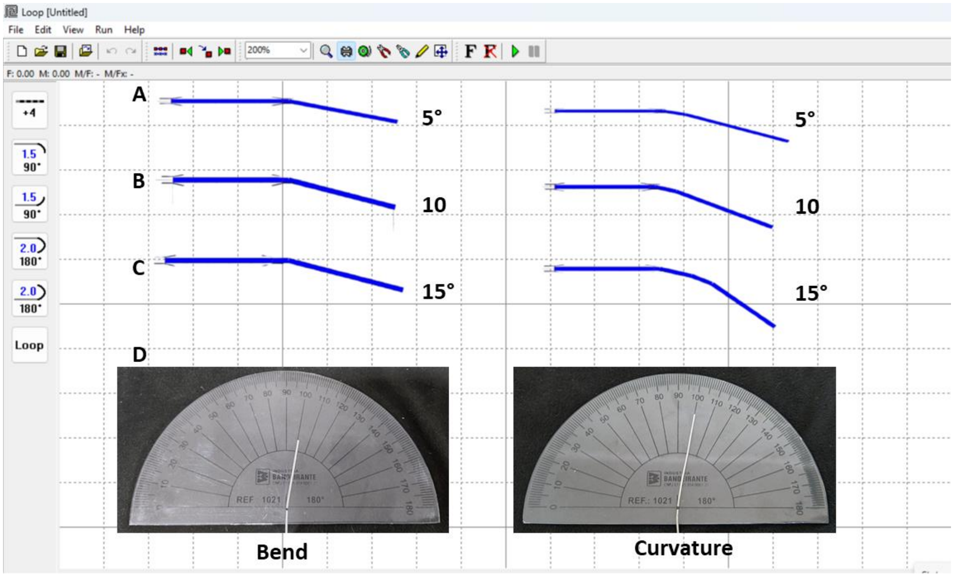

Figure 6. Sagittal template generated by the Loop Software for the symmetrical activation (this figure is illustrating the A: 10° or 5° per side, B: 20° or 10° per side, C: 30° or 15° per side, D: checked using a protractor)

A descriptive analysis of FZ, MX and MY was performed for each group. The assumption of normality was evaluated using the Shapiro-Wilk test. The assumption of homoscedasticity was evaluated using Levene's F test. Based on the skewness and kurtosis statistics, the variables were judged to be normally distributed. Although points were not completely on the line, standardized residuals (P-P plot) indicated that the data contained approximately normally distributed errors. Independent t-tests were used to compare the two groups. Analysis of Variance (ANOVA One-Way) followed by Tuckey's post-tests were used to compare subgroups (amount of activation) within the groups. A probability level of .05 was used to determine statistical significance.

RESULTS

The type of lingual arch activation produced significant vertical force differences between the groups (Table I). Lingual arches activated with bends showed consistently larger extrusive forces than the ones activated with curvatures when the same amount of activation was compared. At 10° activation, the main difference between groups was 15.5 cN (28.3± 6.8 cN and 12.7± 29.8 cN for group 1 and 2, respectively). With 20° activation, the main difference was reported the largest between groups: 0.239 N (52.2± 4.4 cN and 28.3± 2.6 cN for G1 and G2, respectively). With 30° activation, G1 showed the largest vertical force of extrusion (65.8± 69.5 N) while G2 presented vertical force of 46.8± 3.0 cN.

On the second molar lingual tube, the LA activation bend produced uprighting forces larger than the LA with curvature activation (Table II). With 10° activation, G1 presented (1953.1± 68 cN.mm) and while the G2 showed only 1087.5± 115.0 cN.mm; The 10° activation produced the smallest moment variation between groups (8.656 N.mm). On 20° activation, the second molar tube received a moment of 33.050±0.835 N.mm and 2258.8± 79.8 N.mm for groups 1 and 2, respectively. As expected, the 30° activation generated the largest moments due to bend and curvature activation at the LA (4298.9±147.9 cN.mm and 3307.0±162.9 cN.mm for G1 and G2, respectively).

A small buccolingual torque was measured at the second molar lingual tube (Table II). The only significant difference between the two types of activation was observed at 20° (172.7 cN.mm); the bend activation (G1) generated a lingual crown torque of 26.3±150.7 cN.mm and the curvature activation (G2) produced a buccal crown torque of 146.4±131.7 cN.mm.

Table I. Descriptive statistics and statistics comparison for force and moments in Group 1 and Group 2 for each of the activation quantity.

Obs.: (-) means extrusive force (FZ), lingual (MX), and distal (MZ); Prob.

	G1 - Bend		G2 - Curvature		Diff. (G1-G2)	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**Prob.**
Angulation			***FZ***			
10°	-28.3	6.8	-12.7	29.8	-15.5	<0.001
20°	-52.2	4.4	-28.3	2.6	-23.9	<0.001
30°	-65.8	66.7	-46.8	3.0	-19.0	<0.001
			MY			
10°	-1953.1	6.8	-1087.5	115.0	-865.6	<0.001
20°	-3305.0	83.5	-2258.8	79.8	-1046.1	<0.001
30°	-4298.9	147.9	-3307.0	162.9	-991.8	<0.001
			MX			
10°	0.7	56.9	34.8	48.4	-34.0	0.210
20°	26.3	150.7	-112.9	82.8	172.7	0.014
30°	4.2	69.5	-11.6	187.8	15.8	0.403

Obs.: (-) stands for extrusive force (FZ), mesial-distal moment (MY) and bucco-lingual moment (MX), and Diff.: difference; SD: standard deviation; Prob.: probability.

LAs with bend and curvature activation showed significant differences when the amount of activation was compared within groups (Table II). As expected, the larger activation produced the highest values. The groups 1 and 2 presented the largest difference between the 10° activation and 30° activation (37.46 cN and 34.05 cN, respectively). The same pattern of variation was observed for the uprighting moment, with the largest differences between 10° and 30° for both groups (2345.8 cN.mm and 2219.5 cN.mm, respectively). G1 did not show differences in buccolingual moment between the activations, but the G2 produced a significant difference of buccolingual torque of 181.3 cN.mm.

Table II. Statistics intragroup comparison.

		Angulation (I)	Angulation (J)	Mean Diff. (I-J)	SE	Prob.
G1	FZ	10	20	23.8	0.273	<0.001
			30	37.4	0.273	<0.001
		20	30	13.5	0.273	<0.001
	MY	10	20	1351.8	0.472	<0.001
			30	2345.7	0.472	<0.001
		20	30	993.9	0.472	<0.001
	MX	10	20	-25.5	0.453	0.840
			30	-34.8	0.453	0.997
		20	30	22.0	0.453	0.878
G2	FZ	10	20	15.5	0.013	<0.001
			30	34.0	0.013	<0.001
		20	30	-15.5	0.013	<0.001
	MY	10	20	1171.3	0.554	<0.001
			30	2219.5	0.554	<0.001
		20	30	-1171.3	0.554	<0.001
	MX	10	20	181.2	0.665	0.029
			30	46.4	0.665	0.767
		20	30	-134.8	0.665	0.125

Obs.: Extrusive force (FZ); mesial-distal moment (MY) and bucco-lingual moment (MX); Diff.: difference; SE: standard error; Prob.: probability.

DISCUSSION

Lingual arches activated using Geometry VI do not produce an uprighting moment without vertical force at the molar lingual tube. Regardless of the type of the LA activation (bending or curving), small vertical forces (less than 66 cN or approximately 66 grams) were associated with the mesial-distal moments. There is a direct relationship between the amount of uprighting moment and extrusive force. In other words, the smaller amount of activation, the smaller vertical forces. The literature has shown that as larger the angle of entry (relationship between the wire and slot) the higher the vertical forces.[14,15] It has been shown that forces are obtained even when using Burstone's geometry VI.[8,16,17] In order to control the vertical forces, the molar buccal tube can placed more occlusal decreasing up to 43% the vertical force on the uprighting tooth.[14] Clinically, tooth extrusion can lead to premature contact and discomfort to the patient.[18] Clinicians need to understand the importance of the design of the appliance and the control of the vertical forces.

LA with curvature activation presented smaller forces than the ones activated with bends. At minimum amounts of activation, the LA with curvature showed minor vertical forces (from 45% at 10° activation to 71% at 30° activation). Theoretically, the bends incorporated into LA to provide the upright molar movement creates vertical forces followed by the neutral position idea describe by Burstone.[19] As described by Braun and Garcia (2002),[13] after activating the orthodontic wire, the wire could be held in similar positions to those of the tubes and bring the plier tips simulating the tube slot; the bend type activation of the LA keeps the ends of the wire at different level (creating vertical forces), while adding curvature on LA should keep the wire ends at the same level during the simulation contributing to the elimination or decrease in the vertical forces. As observed in this study, the curvature activation decreases the vertical forces, but does not eliminate it as praise by the neutral position. Limited information is available in the literature regarding neutral position and its influence on TPAs and LAs activation.

The LAs produce uprighting moments to correct molar position. Bend activation presented a larger moment at the molar lingual tubes than curve activation at the same amount of activation. At smaller activation (10 degrees) the curvature activation presented only 56% of the amount of moment of the bend activation. As the activation increased, the curvature activation presented a higher moment proportion of the bend activation (68% and 77% of the 20 degrees and 30 degrees, respectively). Based on the scarce literature, the ideal moment to upright a molar tooth is approximately 2000 cN.mm,[14] and only the LA with 10° bending activation (1950 cN.mm) and the LA with 20° curvature activation (2250 cN.mm) were able to generate such amount. Clinically, moments smaller than 2000 cN.mm might not upright the molar, and the tooth may receive undesirable extrusive force. On the other hand, higher moments (greater than 3000 cN.mm) as presented in some of the studied activations (G1_20, G1_30, and G2_30) could cause not only excessive vertical forces, but a moment detrimental to the PDL. It is important for the clinician to control for the type and amount of activation to keep the moment within the ideal moment.

As expected, a higher amount of activation produces a larger uprighting moment, regardless of the type of activation. A moment of the smaller activation (10 degrees) represented only 45% and 33% of the larger activation (30 degrees) for the bending and curving types of LA activation, respectively. It seems that a V-bend can easily move from an ideal to excessive uprighting moment due to a significant increase from a minor to major activation. In addition, it is very difficult to precisely place V-bends leading to changes in the well-defined Burstone's geometry.

Although pretty much insignificant, a buccolingual moment is present during the molar uprighting movement. Except for the activation at 20 degrees, the torque differences between the two types of activation (bending and curving) did not show differences. In addition, most of the activations did not show differences within the group. During the experiment, the bucco-lingual torque control was the hardest to control during passive and pre-active phase. Any small activation could contribute creating a couple system at the LA insertion into molar tubes. Careful activation is needed to prevent the arch wire twist prior to tube insertion. After calibration, buccolingual moments were small, that could be due to vertical forces acting to the uprighting tooth movement; this small side effect could be expected because the force acts distant of the center of resistance of the tooth. Even though the lingual-buccal moment is small, careful observation over time is essential for a good control of the tooth movement.

Theoretically, symmetrical V-bend activation should only present moments in a symmetrical model.[10] Although mathematical models were used to demonstrate the theoretical values obtained from the angles between the arch wire and the slot, clinical simulations were not able to reproduce the predicted force system.[8,17,20] Our results are in accordance with the literature because the simulated symmetrical activation of the LAs (Geometry VI) produced not only the uprighting moment, but also the vertical force, which is not expected in a symmetrical activation. The unexpected vertical forces, which were clinically marginal, occurred despite the precaution to produce a symmetrical model and activation. The mathematical model proposed by Burstone and

Koenig is very sensitive to the position of the arch wire bend in a symmetrical model.[12] Small adjustments of the LA before the activations could have work-hardened the lingual arch and the limit of elasticity.[17,21] In addition, the gap between the lingual arch and the molar tube slot, which was minimum, and the wire deflection in both ends of the lingual arch could contribute to create minor vertical forces. Therefore, both careful activation and clinical monitoring are necessary to assure predicted tooth moment and minimal side effects such as extrusion.

The ability to predict and apply the desired force system relies on both shape and material of the lingual arch, and the symmetry of the activation. Although an optimal force system should present proper force and moment magnitude, the most important requirement is that forces and moments are in a proper direction and/or magnitude. Comparisons are problematic because most of the literature analyzed transpalatal arches force system.[8,16,17] To reach the ideal molar uprighting moment[21] our largest activation reached a 5 mm distance from the center of the LA end to the center of the molar tube. Previous studies reported much higher moments and forces than ours, but their study designs were different, and activations reach up to 10 mm.[8,16,17] However, the moments and forces were in similar direction. Again, the clinician should monitor the movement of the tooth, specifically the extrusive forces due to deleterious premature contact.

Overall, it is important for the orthodontist to acquire a more complete understanding of the mechanical behavior of lingual arches. More research is required, and a clinical study would be a great support establishing an effective and accurate orthodontic tooth movement prediction. Static tooth positions are common shortcomings in simulation studies such as this one, however, normally, the clinical situation is more complex because the teeth move in response to the orthodontic loads, under masticatory performance and tongue pressure. Nevertheless, this experimental set-up serves as good representation for treatment starting points and understanding the differences between types and quantification of activation.

The results of this study shall be carefully interpreted due to extensive requirements with regards to preparation and equipment. Despite all the precautions taken to achieve the same activation at both ends of the LA, it was not a simple task to fabricate it with only vertical activation (although small, buccolingual torques were measured by the OFT). This torque movement could have influenced the amount of vertical forces and uprighting moment obtained in the study, other than forces offcentered to the center of dental resistance' unit[21] and the accessory.[14] However, understanding about results like those of the present study may constitute an added benefit for clinicians using LAs in daily clinical practice and may contribute for successful upright molars. Since tooth movements under clinical conditions can be simulated, the results of this study can be compared directly with the clinical results. Therefore, confirmation of the tooth movements predicted by our results must be left for the future.

CONCLUSION

Based on our findings in this specific clinical setup tested, using a prefabricated horseshoe type lingual arch (0.032'x0.032" TMA) inserted into a precision hinge cap with symmetrical activation, it can be concluded:

- Bending activations produced higher values for extrusive force, torque, and verticalization moments than curvature activation, regardless of the applied angulations.
- Less amounts of activations produced minor forces and moments, regardless of the activation type.
- Both activations produced low vertical forces, ranging from 23-43 cN (approximately 23-43 grams) with symmetric angulations at LA from 10° to 30°;
- LA presenting curvature activation at 20° is the recommended type to deliver the ideal upright moment amount (2000-3000 cN.mm).

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3.2 Publicação 2*

Evaluation of the force system in molar uprighting using a lingual arch due to the effect of tension relaxation: comparison of two different pre-activation methods.

ABSTRACT

Evaluates the changes in the force system of the beta-titanium lingual arches (LAs) caused by stress relaxation. **Materials e Method:** A mandibular stone cast was scanned followed by manipulation to present near to perfect alignment and leveling of the teeth. Right first molar was deleted before the working model be printed. The mandibular resin model was secured onto a desktop table of the orthodontics force tester (OFT). Mandibular second molars were connected to two load cells to evaluate the vertical force (FZ) and anteroposterior moments (MY). A total of 60 preformed 0.032” x 0.032” TMA (ORMCO) LAs were used. The sample was divided into two groups: G1 (bend activation) and G2 (curvature activation). Pre-activations were based on 10, 20, and 30 degrees of the passive shape. After activation, the LA remained in a model prototype for 28 days. **Results:** Both groups showed a decrease in force and moments levels over time. But only FZ: G1_10° (<.001) and G2_20° (2.6 cN), MY: G1_30° (<.001) showed different statistics. **Conclusion:** The effect of stress relaxation is more evident in the bending group compared to the curvature group.

INTRODUCTION

Lingual arches and transpalatal arches are used as passive or active appliances in the dental clinic as part of preventive and interceptive orthodontics.[1-5] Regardless of how they are used, these accessories can be made either removable or fixed. Different alloys (for example, stainless steel or titanium-molybdenum), cross-section (0.032”, 0.032”x 0.032”, among other dimensions), and shapes (such as Goshgarian or Burstone) can be used, depending on the orthodontic planning.

Lingual arches in their active form can be used for first, second and third order tooth movement. In their active form, lingual and transpalatal arches are commonly used to correct molar rotations,[6-8] but these accessories have frequently been used for uprighting molars. With a previously determined force system (based on Burstone geometries), the behavior of a tooth or dental unit can be predicted, specifically using the activation of geometry VI.[6,9]

Lately, pre-contoured stainless steel or titanium-molybdenum lingual archwires have been used associated with precision fittings.[5,11] The precision fitting system

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* Artigo formatado segundo as normas do periódico *Angle* para o qual será submetido.

facilitates the production, insertion, fitting, and removal of lingual arches, allowing greater control and predictability of tooth movement even though it is a statically indeterminate system.[5,12]

The literature has shown that the form[6,13], the type of fitting,[8,14] the alloy, and the form of activation (symmetrical or asymmetrical)[6,13] they can influence tooth movement. The use of TMA instead of stainless steel in the construction of lingual archwires allows for a reduction in force and moments and results in better arch formability when compared to stainless steel.[5,8,12]

TMA wire has a balance of low stiffness, high springback, formability and weldability that indicates its use in a wide range of clinical applications.6 Bends tend to concentrate stress in specific areas of the wire, causing spacing and instability of the crystalline structure to dissipate over time, a gradual bend could distribute these stresses across the wire, which could reduce the stress relaxation effect.[16] It is necessary to understand and evaluate the properties of the wires when incorporated into bends, and how they behave over time. Although many studies have been done studying tooth movements using transpalatal archwires made with TMA, no reports have been made with lingual archwires and the force system generated by their deactivation due to structural stress relief, which is defined as deformation as a function of time.

The shape of the lingual arch, the fitting system and variations in activation can be considered an individual choice by the orthodontist, and often the simplest form of handling ends up being the most used clinically. The choice of system design, material and activation has a direct influence during clinical use.

It is also important to provide, not only the ideal force system, but the approximately correct amount of uprighting moment. The literature has shown that the uprighting moments should be about 2000 cN.mm but not more than 3000 cN.mm;[14] despite in physics force is expressed in Newton (or in centesimal part known as centinewton), in orthodontics force is frequently represented in gram or gram-force, and 1 cN is approximately 1 gram-force. It is also important to check the neutral position to evaluate the force system that is acting. The neutral position can be defined as the horizontal and vertical separation of the spring before the introduction of a force in the horizontal or vertical plane.[15]

Therefore, the present study aims to compare the decrease in force and moments produced by the lingual arch for molar uprighting with different forms and amounts of activations after 28 days, due to stress relaxation.

MATERIALS AND METHOD

A mandibular stone cast of Class II subject was used as a basic model to evaluate the tridimensional changes of the second molars uprighting. The model was scanned (Identico light, 3shape, Copenhagen, Denmark) followed by three-dimensional manipulation (Archform 1.9.5) to present near to perfect alignment and leveling of the mandibular teeth, symmetric arch shape, and removal of the right first molar (Figure 1). The second molars were kept parallel to each other with their long axis perpendicular to the mandibular occlusal plane. After the digital manipulation, the working model was printed (Photon Mono SE, Anycubic, Shenzhen, China). The second molars received a band presenting a welded 0.032”slot hinge-cap lingual tube (Ormco, Glendora, CA, USA). An original Cold Weld two-part epoxy system (JB Weld, Sulfur Springs, TX) was used to cement the bands (Figure 2).

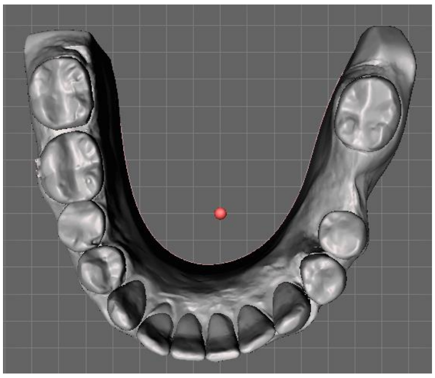


Figure 1. 3D mandibular model after manually aligned and leveled.

Figure 2. 3D printed resin model with second molars receiving bands.

After cast preparation and printing, the second molars were manually detached from the 3D printed model using a carborumdum disc attached to an electric hand piece. Prior to the second molar detachment, a transfer impression (Figure 3) was made with condensation silicone (Coltene, Vigodent S/A, Rio de Janeiro, Brazil). Afterwards, the teeth were repositioned to the cast with wax (Lysanda, São Paulo, Brazil) using the silicone as a guide, keeping the original position (Figure 4).

Figure 3. Transfer impression with condensation silicone for second **molar** manipulation.

Figure 4. 3D resin model presenting second molars cut out, received wax and condensation silicone for molars original setup position.

The mandibular resin model was secured onto a desktop table of the orthodontics force tester (OFT) machine (Department of Mechanical Engineering, Purdue University, Indianapolis, IN) using J-B Kwik glue (JB Weld, Sulfur Springs, TX). Two load cells (Multi-Axis Force/Nano 17 Torque, Industrial Automation, Apex, Ind) with a 0-2000 cN and 0- 10000 cN.mm range were glued to the second mandibular molars (Figure 5 and Figure 6). Subsequently, the second molars were separated from the cast attached to the OFT machine desktop table (Figure 7). A customized software (Mechanical Engineering Department Purdue University) was used to identify the forces and moments measured by the OFT load cells.

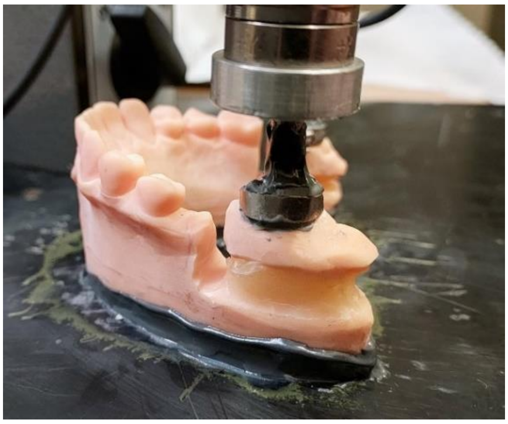


Figure 5. 3D resin model fixed onto the desk top table of the orthodontics force tester machine.

Figure 6. The two load cells positioned and glued to the second molars, which were previously separated from the 3D resin and repositioned back with.

Figure 7. Second molars completely separated from the 3D resin model, which is glued onto the OFT desk top, but attached to the OFT machine load cell.

Once the load cells were vertically attached to the second molars, the software allowed for rotational calibration of the origin (zero) of measurements in all 3 dimensions. Calibration of the OFT was concluded when the sensors measured forces and moments equal zero at the center of the lingual tubes the second molars mandibular when no force and moments were applied. The X-axis carried out the moment read in the buccolingual direction (MX), which was perpendicular to the lingual tube, with negative sign identifying the bucco-lingual crown torque. The Y-axis represented the uprighting of the crown in the mesio-distal direction (MY), with negative sign representing the moment of distalization of the crown.

Sixty Burstone TMA .032” x .032” lingual arches (ORMCO, California USA) were used to perform the experiment. A sample calculation was performed using the GPower 3.1 program (Franz Faul, Germany), and 5% significance. A minimum of nine arches per activation type would be necessary (n=54). The lingual arches (LA) were divided into two groups, G1 (bend activation) and G2 (curvature activation) and subdivided according to the amount of angle of activation (n=10): 10°, 20° and 30°. A digital image printed at 1:1 scale of the model allowed the design of a passive standardized LAs to the molar tubes (Figure 8). Its passivity was also verified by means of software force and moment measurements.

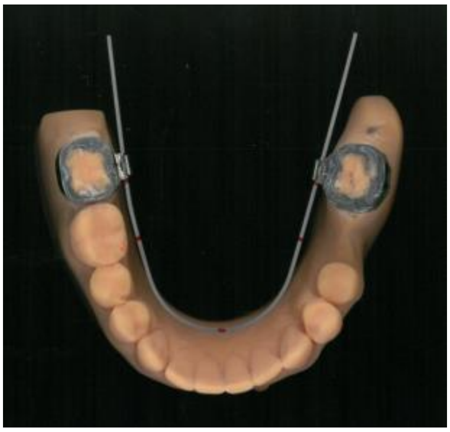


Figure 8. Printed 1:1 occlusal template.

A passive lingual arch was inserted into the tube. The passivity in all three planes (sagittal, transverse, and coronal) was confirmed using the OFT. Pre-activations, which were the changes in the shape of the arch, were performed only at the time of the insertion into the lingual arch tube using the generated template as aforementioned. The bend activation was performed 1 mm mesially to the lingual tubes. The curvature activation was made starting 10 mm mesially from the mesial of the tube until 1 mm of the lingual tube. As above-mentioned, three amounts of symmetrical activation were performed for each group using a Loop Software (dHAL Software, Atenas, Grécia): 10°, 20° and 30° (Figure 9). 60 prototypes of the same model were made without anterior teeth, with parallel molars, received a band and hinge caps. After activation, the LA was inserted into hinge cap lingual tube on a model prototype for 28 days (Figure 10). Data were collected for force (FZ) and moments (MY), and transferred to an Excel spreadsheet. SPSS statistical software (IBM SPSS version 20.0; Armonk, NY) was used for data analysis.

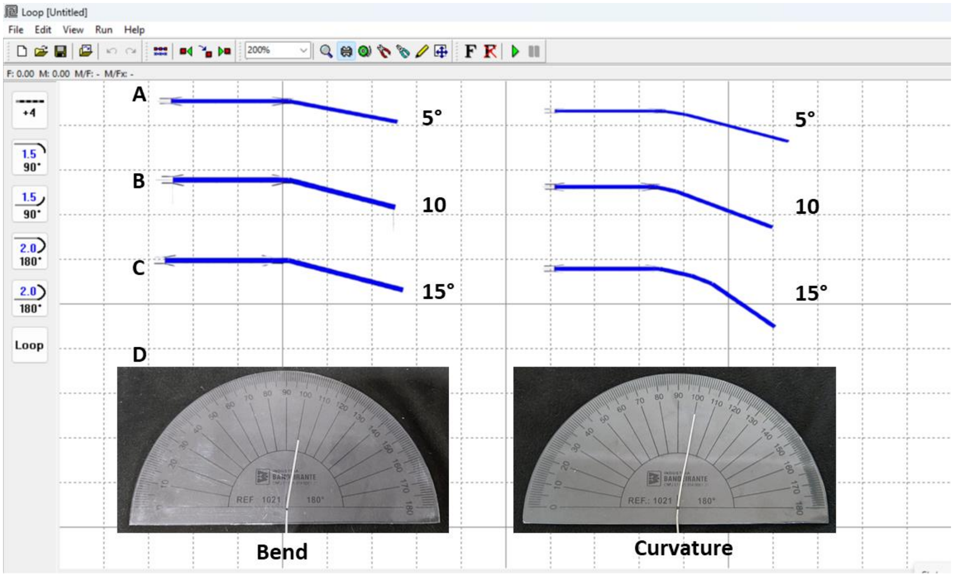


Figure 9. Sagittal template generated by the Loop Software for the symmetrical activation (this figure is illustrating the 30° activation, or 15° per side).

Figure 10 – The LA was inserted into hinge cap lingual tube on a model prototype for 28 days.

A descriptive analysis of FZ and MY was performed for each group. The assumption of normality was evaluated using the Shapiro-Wilk test. The assumption of homoscedasticity was evaluated using Levene's F test. Althought points were not completely on the line, standardized residuals (P-P plot) indicated that the data contained approximately normally distributed errors. Independent t-tests were used to compare the two groups. Analysis of Variance (ANOVA One-Way) followed by Tukey's post-tests were used to compared subgroups (amount of activations) within the groups. A probability level of .05 was used to determine statistical significance.

RESULTS

Although the vertical forces (FZ) and moments of verticalization (MY) showed a decrease after 28 days, there were few activations that showed a significant loss in values (Table I and Grafhs 1-4). Lingual arches with bend activations showed significant losses only with 10° activation (difference between means of 5.2 cN). The lingual arches activated by curvature showed a significant decrease only for activations of 20° (difference between means of 3.6 N). Within each group, the decreases were significant in 5 of the 6 comparisons, except for the difference between 10° and 20° for the activated V-bend group (Table II). As expected, the greatest differences between the amounts of activation due to structural stress relief were observed between 10° and 30° (98.9 N and 33.6 cN for bending and curvature groups, respectively). MY behavior in the groups seems to remain more stable, except for the 30° bend group.

Table I. Mean. Std. Deviation. T test comparing force and moments between each activation.

	FZ					
	G1 - T1		**G1 - T2**		**Diff**	
Angulation	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**Prob.**
10°	-28.3	6.8	-23.1	5.6	-5.2	***< .001***
20°	-52.2	4.4	-37.7	32.0	-14.5	0.056
30°	-65.8	69.5	-62.9	86.0	-2.9	0.073
	G2 - T1		**G2 - T2**			
10°	-12.7	29.8	-9.8	7.2	-2.9	0.058
20°	-28.3	2.6	-24.7	3.4	-3.6	***0.026***
30°	-46.8	3.0	-43.4	22.9	-3.4	0.493
			MY			
	G1 - T1		**G1 - T2**			
10°	-1953.1	6.8	-1619.2	112.6	-333.9	0.384
20°	-3305	83.5	-3017.6	115.8	-287.4	0.125
30°	-4298.9	147.9	-3634.8	344.5	-664.1	***<.001***
	G2 - T1		**G2 - T2**			
10°	-1087.5	115.0	-957.4	47.8	-130.1	0.076
20°	-2258.8	79.8	-1928.1	79.3	-330.7	0.113
30°	-3307	162.9	-3033.8	94.4	-273.2	0.342

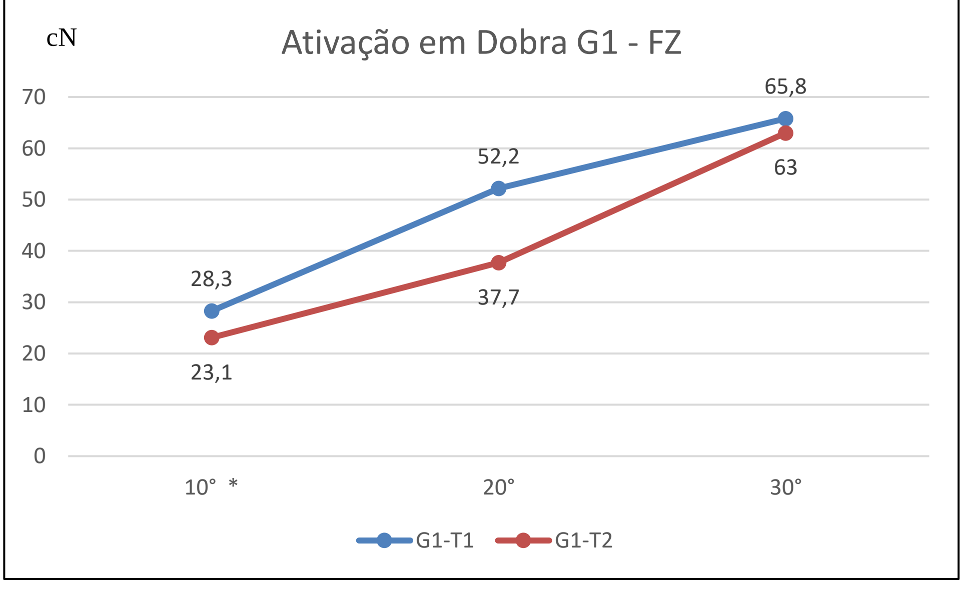
Obs.: (-) stands for extrusive force (FZ), mesial-distal moment (MY), and Diff.: difference T1-T2; SD: standard deviation; Prob.: probability. G1: bend activation and G2: curvature activation. T1: initial time and T2: final time.

Table II. Statistics intragroup comparison.

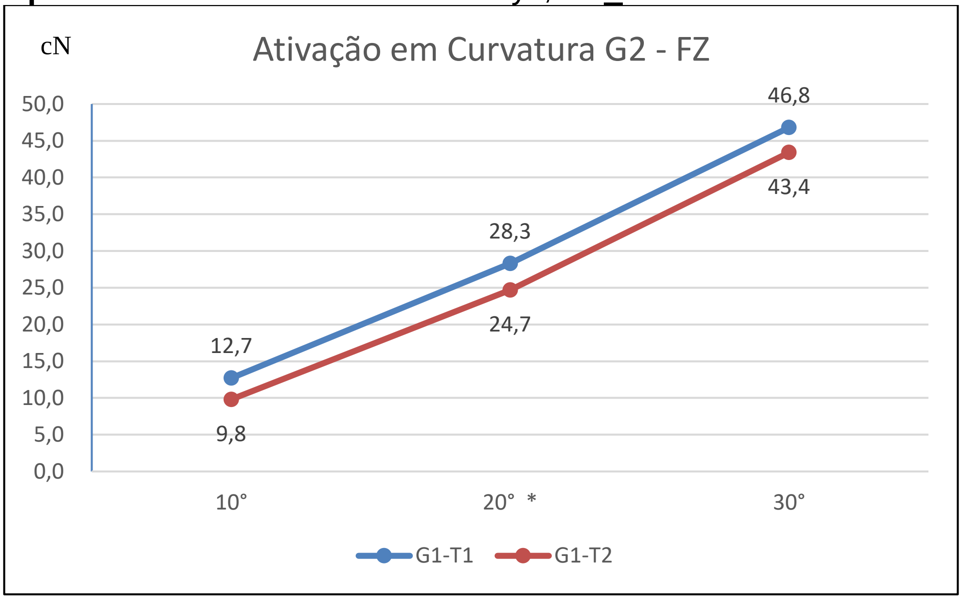
		Angulation(I)	Angulation (J)	Mean Difference (I-J)	Std. Error	Sig.
G1	FZ	10	20	14.5	8.7	0.234
			30	98.9	8.7	<0.001
		20	30	25.2	8.7	0.019
	MY	10	20	1398.3	98.2	<0.001
			30	2015.5	98.2	<0.001
		20	30	617.1	98.2	<0.001
G2	FZ	10	20	14.8	21.4	<0.001
			30	33.6	21.4	<0.001
		20	30	18.7	21.4	<0.001
	MY	10	20	970.7	34.1	<0.001
			30	2076.4	34.1	<0.001
		20	30	1105.7	34.1	<0.001

Obs.: Extrusive force (FZ); mesial-distal moment (MY) Diff.: difference; SE: standard error; Prob.: probability.

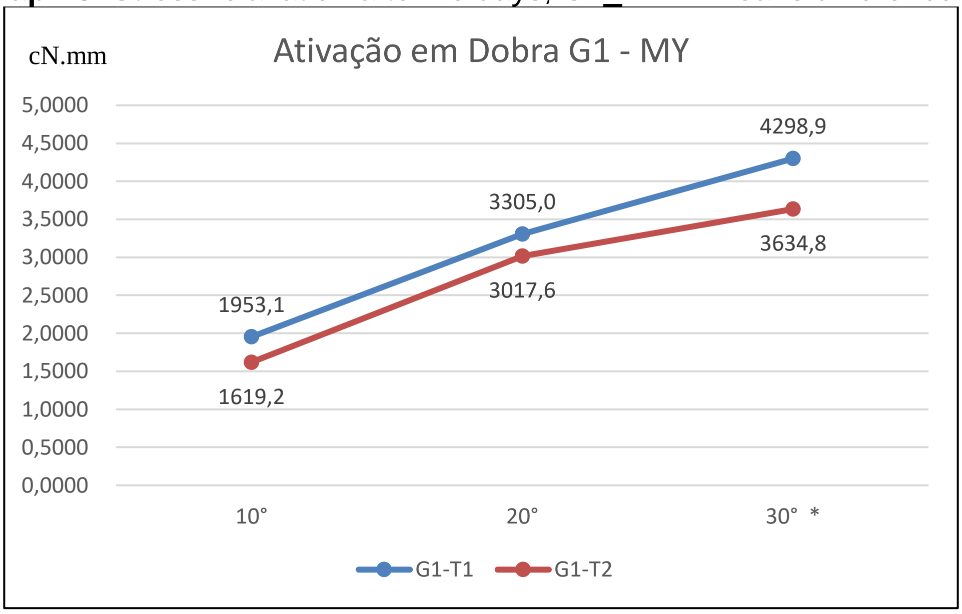
Graph 1. Stress relaxation after 28 days, G1_FZ.* Means difference.



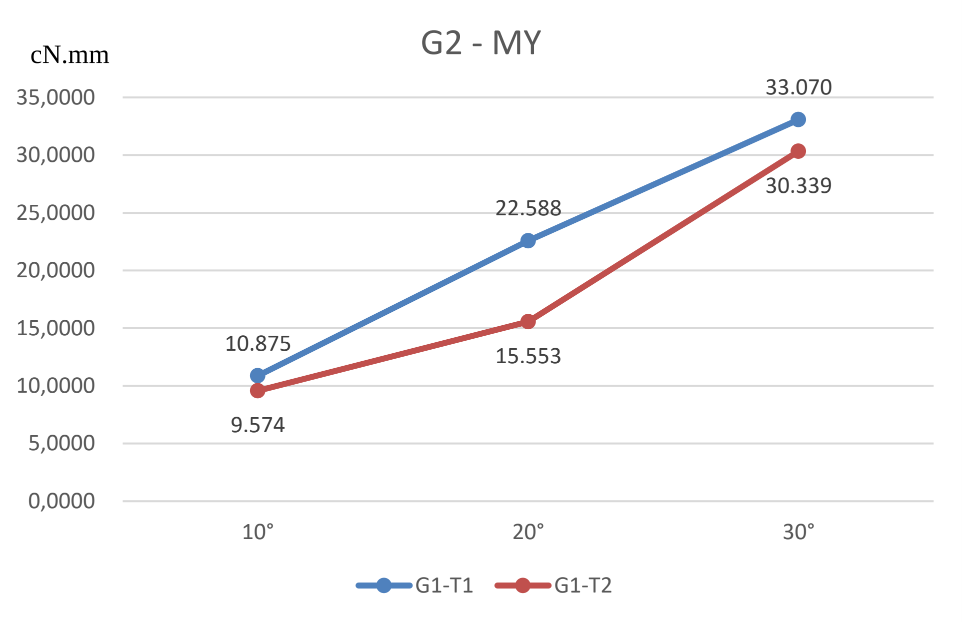
Graph 2. Stress relaxation after 28 days, G2_FZ. * Means difference.



Graph 3. Stress relaxation after 28 days, G1_MY. * Means difference.



Graph 4. Stress relaxation after 28 days, G2_MY.



DISCUSSION

Metallic orthodontic materials have both complex compositions and microstructures containing multiple phases. Orthodontists need to understand the basic principle of metallic orthodontic alloys. Orthodontic wires frequently receive bends to facilitate tooth movement. These bends accumulate stress that can change the crystalline structure.[17] Overtime, this constant stress can change the original shape or even the force system applied by the clinician.

Stress-relaxation is defined as deformation over time. This time-related deformation, which is also called creep, is the result of a decrease in stress or an increase in strain. This phenomenon is caused by microscopic progressive movement of dislocations in the material structure due to high stressed metals, leading to changes in the crystalline structure of the alloy. Understanding the material design and behavior, orthodontists can estimate reactivation time depending on the clinical situation, allowing the force level being constant to provide a more efficient tooth movement. Due to its characteristics, Beta-titanium alloys, when compared to stainless steel, can deliver gentler forces on teeth during deactivation showing higher springback. It also exhibits better formability over nickel-titanium alloys.[18]

Regardless of the type of activation, bending or curvature, TMA preformed lingual arches showed a drop in strength and momentum over 4 weeks after preactivation. Both groups showed a decrease in the levels of the force system, and the bending activation showed a higher level of wire tension relaxation. This was due to the relaxation of tension suffered by keeping the LAs under constant tension. Although the effect of stress-relaxation is gradual, most of the shape change occurs within 24 hours.[19] It has also been proposed that significant changes would be accessed in the 24-hour period.[20]

Vertical forces decrease over time as effect of stress-relaxation. Lingual arches activated by bends showed larger vertical force decay than the ones activated by curvature (17% and 14%, respectively). Concentrated bends converge stress to specific place in the wire, causing dislocations and unstable displacements in the crystalline structure of the alloy. This crystalline change tends to rearrange itself over time due to stress relaxation.[17,18] Differently when a gradual bend is used, this stress is distributed over the entire length of the bend, lessening the stress relaxation effect.[17,21] Although this study only evaluate a 4-week period after the initial preactivation, it is expected not much force decay after the initial influence of time as it showed in previous studies.[22]

As expected, due to force decay, the moment also decreased over time. The deactivation of the vertical moment was greater in the bend group (14%) than in the curvature group (12%). Other studies have also shown a decrease over time.[23] Therefore, the lingual arch providing constant verticalization moment is desired, and the pre-activated curvature group presented best results. When sharp or concentrated bends are placed in an arch wire, the arch is subject to permanent deformation, and it will converge the tension to specific points on the wire. On the other hand, gradual curvature distributes the tension over long part of the wire reducing the effect of stress relaxation. Clinically, it is suggested that the force system is more stable in the absence of concentrated bending, which is more susceptible to relaxation over time. Thus, it is recommended that the orthodontist activate these appliances by gradual curvatures, as this could produce a more controlled movement than when using pre-activation by concentrated curves.[23] However, in clinical practice, the creation of bends is easier to perform, whereas for curvature it is more appropriate to print an individualized template plastic leading to a relaxation over time. These changes have been proposed to occur at microstructural level or within grain.[24,25]

An alloy subjected to constant stress within its elastic limit for a given period of time can have its crystalline structure modified, which then tries to reorganize itself through stress relaxation, changing its shape. For all alloys, the initial deflection of a wire is due to elastic stretching of the bonds between atoms. By removing the force, the bonds are re-established, as the atoms have not been displaced from their positions in the lattice. This bond stretching mechanism is responsible for the initial linear segment of the stress-strain curve. If the force exceeds the strength of the bond, the atoms will be displaced from their equilibrium positions.[26]

Since both deactivation force ratings are approximately the same, pre-curvature activation maintains a lower force decays throughout the deactivation range. Clinically, it is suggested that the force system is more stable using gradual curvatures instead of concentrated bends. Curvature activation provides a more stable force system, and it is less susceptible to relaxation over time. Based on the type and amount of activation evaluated in this study, preformed TMA lingual arches will perform better under the gradual curvature activation using 20° of activation. This type of activation is within upper and lower ideal ranges and the force system decays approximately 15% over the period of four weeks. Normally, orthodontists schedule patients' appointments every four to eight weeks, and this study suggests that the LA presenting 20° of curvature as activation should be reactivated within four weeks. Uprighting moment smaller than 2000 cN.mm will not provide enough moment to generate ideal force system acting on molar. In the literature there are several works that evaluated the deformations and modifications in the spring force system over time.[21,27] However, none reported tension relaxation in the LA, which precludes a broader discussion of the results. it is important to consider the permanent deformation that beta-titanium wires suffer as a function of time when exposed to long periods of deflection.[21,23]

Although previous studies have used different devices, shapes or alloys, the results of this study corroborate the literature regarding the decay of the force system.[20,27-29] The results of this study need to be cautiously interpreted. As this is a laboratory study, some behavioral limitations must be considered. The intraoral arch may undergo greater deformation with mastication; therefore, evaluations need to be more constant, and new activations must be considered. In addition, to better understand the LAs' behavior, X-ray diffraction test should be used to analyze the changes on the surface characteristics of the crystallographic structure.

CONCLUSION

Based on studies using the lingual arch with bending and curvature activation, it can be concluded:

- Both groups showed a decrease in the levels of the force system, with activation in bending with greater relaxation compared to curvature.
- Bend activation is simpler to standardize, no need for a template. Already by curvature is more indicated.

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4 CONSIDERAÇÕES FINAIS

Publicação 1:

Os arcos linguais podem produzir nos molares inferiores momentos de verticalização ideais com pequenas ativações por dobras;

Arcos linguais podem ser usados para verticalizar molares com pequenas forças extrusivas verticais;

Arcos linguais com ativações de curvatura produzem forças verticais menores do que ativações em V;

Os momentos vestíbulo-linguais gerados pelos arcos linguais ativos são mínimos;

Arcos linguais com ativações de dobra produzem valores maiores do que os que usam ativações de curvatura.

Publicação 2:

Os valores da desativação do sistema de força em arco lingual ativado em dobra são mais evidentes do que em curvatura;

Sendo os momentos clinicamente aceitáveis, 20 N.mm para verticalização de molares, ativação em curvatura com 20° de ativação e talvez uma periodicidade de acompanhamento de 28/28 dias seria o recomendado.

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