Cristiane de Sousa Alves Magalhães

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*Influence of non-carious cervical lesion and bone loss associated with orthodontics movements: finite elements analysis*

Dissertação apresentada a Faculdade de Odontologia da Universidade Federal de Uberlândia, como requisito parcial para obtenção do título de Mestre em Odontologia na Área de Clínica Odontológica Integrada

**Uberlândia, 2019**

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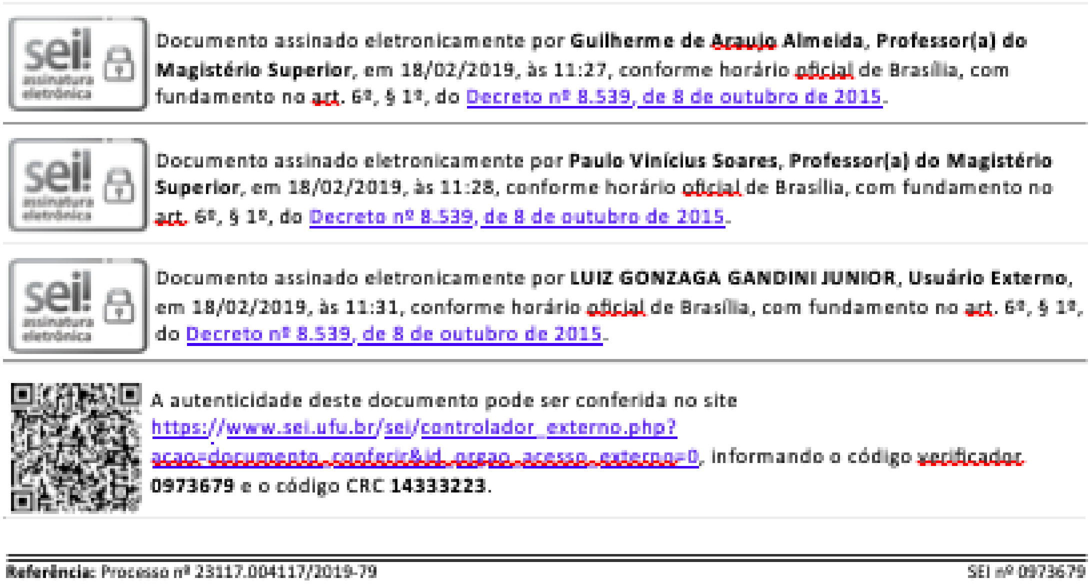
Orientador: Prof. Dr. Guilherme de Araújo Almeida

Banca Examinadora:
Prof. Dr. Luiz Gonzaga Gandini Junior
Prof. Dr. Paulo Vinícius Soares

**Uberlândia, 2019**



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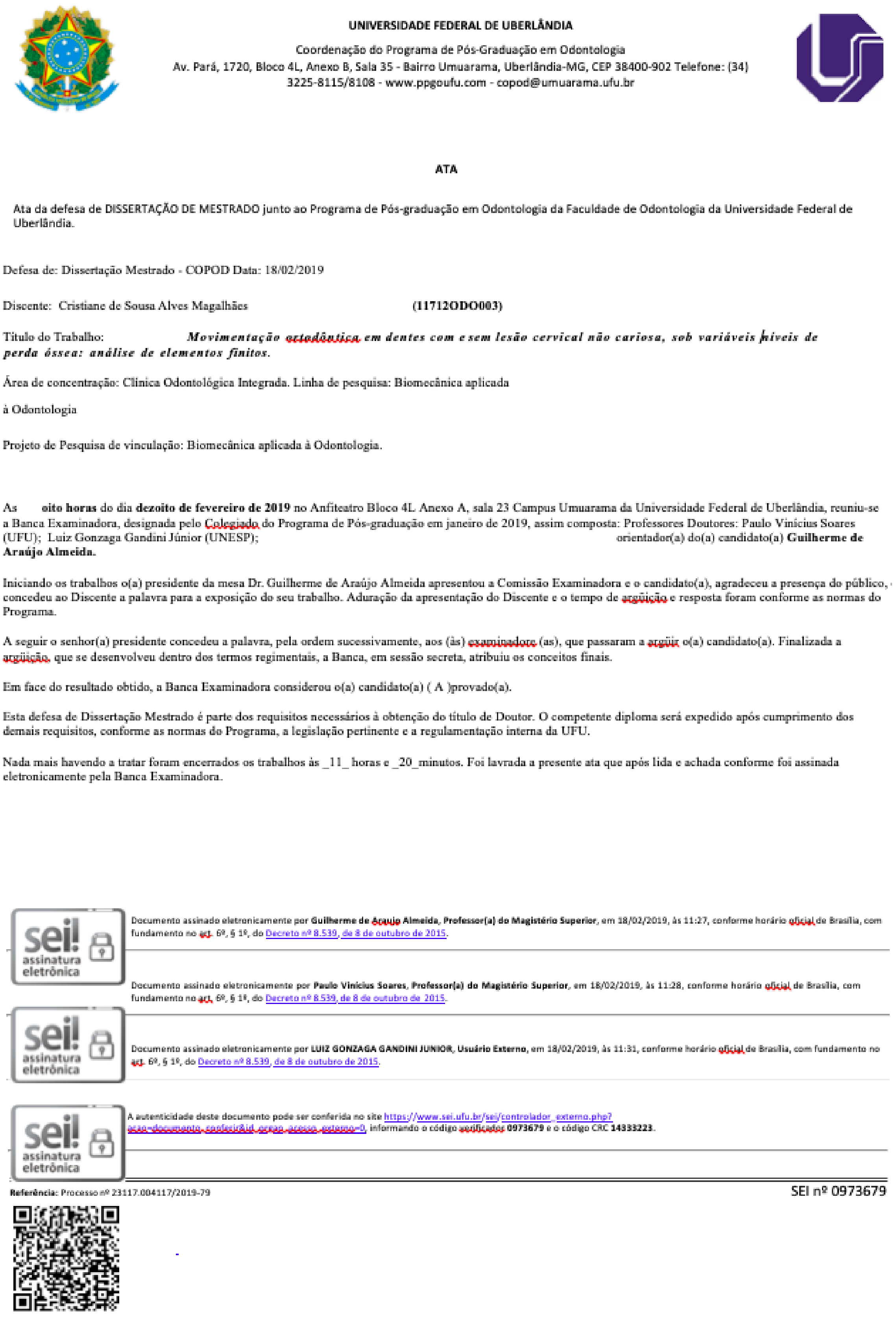

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**ATA**

Ata da defesa de DISSERTAÇÃO DE MESTRADO junto ao Programa de Pós-graduação em Odontologia da Faculdade de Odontologia da Universidade Federal de Uberlândia.

Defesa de: Dissertação Mestrado - COPOD Data: 18/02/2019

Discente: Cristiane de Sousa Alves Magalhães **(11712ODO003)**

Título do Trabalho: ***Movimentação ortodôntica em dentes com e sem lesão cervical não cariosa, sob variáveis níveis de perda óssea: análise de elementos finitos.***

Área de concentração: Clínica Odontológica Integrada. Linha de pesquisa: Biomecânica aplicada

à Odontologia

Projeto de Pesquisa de vinculação: Biomecânica aplicada à Odontologia.

As **oito horas** do dia **dezoito de fevereiro de 2019** no Anfiteatro Bloco 4L Anexo A, sala 23 Campus Umuarama da Universidade Federal de Uberlândia, reuniu-se a Banca Examinadora, designada pelo Colegiado do Programa de Pós-graduação em janeiro de 2019, assim composta: Professores Doutores: Paulo Vinícius Soares (UFU); Luiz Gonzaga Gandini Júnior (UNESP); orientador(a) do(a) candidato(a) **Guilherme de Araújo Almeida.**

Iniciando os trabalhos o(a) presidente da mesa Dr. Guilherme de Araújo Almeida apresentou a Comissão Examinadora e o candidato(a), agradeceu a presença do público, concedeu ao Discente a palavra para a exposição do seu trabalho. Aduração da apresentação do Discente e o tempo de argüição e resposta foram conforme as normas do Programa.

A seguir o senhor(a) presidente concedeu a palavra, pela ordem sucessivamente, aos (às) examinadore (as), que passaram a argüir o(a) candidato(a). Finalizada a argüição, que se desenvolveu dentro dos termos regimentais, a Banca, em sessão secreta, atribuiu os conceitos finais.

Em face do resultado obtido, a Banca Examinadora considerou o(a) candidato(a) ( A )provado(a).

Esta defesa de Dissertação Mestrado é parte dos requisitos necessários à obtenção do título de Doutor. O competente diploma será expedido após cumprimento dos demais requisitos, conforme as normas do Programa, a legislação pertinente e a regulamentação interna da UFU.

Nada mais havendo a tratar foram encerrados os trabalhos às _11_ horas e _20_minutos. Foi lavrada a presente ata que após lida e achada conforme foi assinada eletronicamente pela Banca Examinadora.

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# Dedicatória

Vitórias são só possíveis quando se tem **Deus** no comando de nossas vidas, então, primeiramente, ao Pai Maior, dedico esse momento, já que, foi Ele quem me deu ânimo e coragem para não desistir.

Aos meus pais, **Antônio e Cledes**, pela compreensão, ao serem privados em muitos momentos da minha companhia e atenção. Também pelo profundo apoio, estimulando-me nos momentos mais difíceis. Obrigada por desejarem sempre o melhor para mim, pelo esforço que fizeram para que eu pudesse superar cada obstáculo em meu caminho e chegar aqui e, principalmente, pelo amor imenso que vocês têm por mim.

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**SUMÁRIO**

## LISTA DE ABREVIATURAS E SIGLAS

MEF- Método de Elementos Finitos

LCNC- Lesão Cervical Não Cariosa

JCE – Junção Cemento Esmalte

EX- Movimento Ortodôntico de Extrusão

IN- Movimento Ortodôntico de Intrusão

CMA- Crista Marginal Vestibular do Osso Alveolar

RCC- Região Cérvico Vestibular da Coroa

VAR- Vestibular do Terço Apical da Raiz

# *RESUMO*

## RESUMO

O objetivo deste estudo foi analisar o efeito biomecânico de Lesões Cervicais Não Cariosas (LCNC) e perda óssea em pré molar, durante a movimentação ortodôntica. Através de Tomografia Cone Beam da maxila, utilizada para a construção de modelos tetraédricos do primeiro(14) e segundo pré-molares(15) e do primeiro molar(16) hígidos e com boa saúde periodontal. Foram gerados 12 modelos conforme a combinação de dois fatores: 1- coroa dentária do dente 15 (hígida, com LCNC, e LCNC restaurada), 2- nível de perda óssea (ausente, ¼, ½ e ¾). Estas condições foram avaliadas por meio de elementos finitos(MEF), mediante a aplicação de forças extrusivas(EX) e intrusivas(IN). O movimento EX apresentou maiores valores de tensão comparado a IN, em todas as situações, mesmo sob a aplicação de forças menores. As LCNCs promoveram maiores valores de tensão em todas as regiões avaliadas: crista marginal vestibular do osso alveolar(CMA), região cérvico vestibular da coroa(RCC), vestibular do terço apical da raiz(VAR). Nos dentes com LCNCs restauradas as tensões tenderam a aproximarem dos valores apresentados pelas coroas hígidas, em ambos os movimentos. A quantidade de perda óssea mostrou forte influência na intensidade das tensões geradas em todas as combinações estudadas. Concluiu-se que, a presença de LCNC gera tensões em seu interior, principalmente no movimento de extrusão; as LCNC restauradas tendem a apresentar valores de tensão em seu interior semelhante a um dente hígido; e, que quanto maior a quantidade de perda óssea alveolar, maior a quantidade de tensão gerada na raiz e no alvéolo, principalmente ao nível da crista óssea marginal.

Palavras-chave: Análise de Elementos Finitos, Extensometria, Lesão Cervical Não Cariosa, Movimentos ortodônticos, Perda Óssea.

# *ABSTRACT*

## ABSTRACT

The objective of this study was to analyze the biomechanical effects of pre-molar NCCLs and bone loss in premolar, during orthodontic movement. Cone beam CT scan of the maxilla was used to construct of tetrahedral models of the first (14) and second premolars (15) and first molar (16), sound and periodontally healthy. Twelve models were generated from combinations of two factors: 1- crown condition of tooth 15(sound, with unrestored NCCL, with restored NCCL) 2- level of bone loss (without, ¼, ½ and ¾). Finite element analysis (FEA) was used to evaluate these combinations under extrusive (EX) and intrusive (IN) loads. EX produced greater tension than IN, in all situations and even under lighter loads. NCCLs were associated with greater tension regardless of region: marginal alveolar bone crest (MAC), crown buccal cervical region (CBC), buccal apical third of the root (BAR). Tension in the restored NCCL teeth was similar to that of the sound teeth, regardless of movement type. Bone loss strongly affected tension in all situations. It is concluded that NCCLs generate internal tension that is greatest under EX, while restored NCCLs produce internal tension that is similar to that of sound teeth and finally, greater alveolar bone loss is associated with greater tension in the root and alveolus, especially at the level of the marginal bone crest.

Keywords: Bone Loss, Finite Element Analysis, Non-Carious Cervical Lesion, Orthodontic Movement, Strain Gauge Test.

# *INTRODUÇÃO E REFERENCIALTEÓRICO*

## 1- Introdução e Referencial Teórico

A procura de pacientes adultos pelo tratamento ortodôntico tem aumentado consideravelmente, devido melhoras no planejamento, materiais e redução no nível de desconforto.

Dentre algumas alterações degenerativas encontradas nesses pacientes são, as Lesões Cervicais Não Cariosas (LCNC) um processo patológico caracterizado por uma perda lenta e irreversível da estrutura dentária mineralizada na junção cemento-esmalte (JCE), não relacionada a presença de microorganismos(Wood et al, 2009; Brandini et al, 2012).As LCNCs são encontradas em pacientes jovens e adultos,(Borcic et al, 2004; Smith et al, 2008),entretanto têm uma maior prevalência nos indivíduos adultos(Borcic et al, 2004; Smith et al, 2008; Que et al, 2013), por estarem expostos há um maior tempo aos fatores etiológicos(Smith et al, 2008;Que et al, 2013).Os dentes mais comumente acometidos por essas lesões são os pré-molares, seguidos pelos caninos, primeiros molares, incisivos e, finalmente os segundos molares que apresentam a menor taxa(John et al, 2006; Smith et al, 2008; Que et al, 2013).

Há inúmeras controvérsias entre os autores em relação a etiologia das LCNCs (Bartlett & Shah, 2006; Wood et al, 2008).A literatura mais atual mostra que os três mecanismos distintos que fazem parte deste processo são a tensão, biocorrosão e fricção, que agem de forma conjunta na estrutura do dente(Piotrowski et al, 2001;Smith et al, 2008; Grippo et al, 2012). (Figura 1)

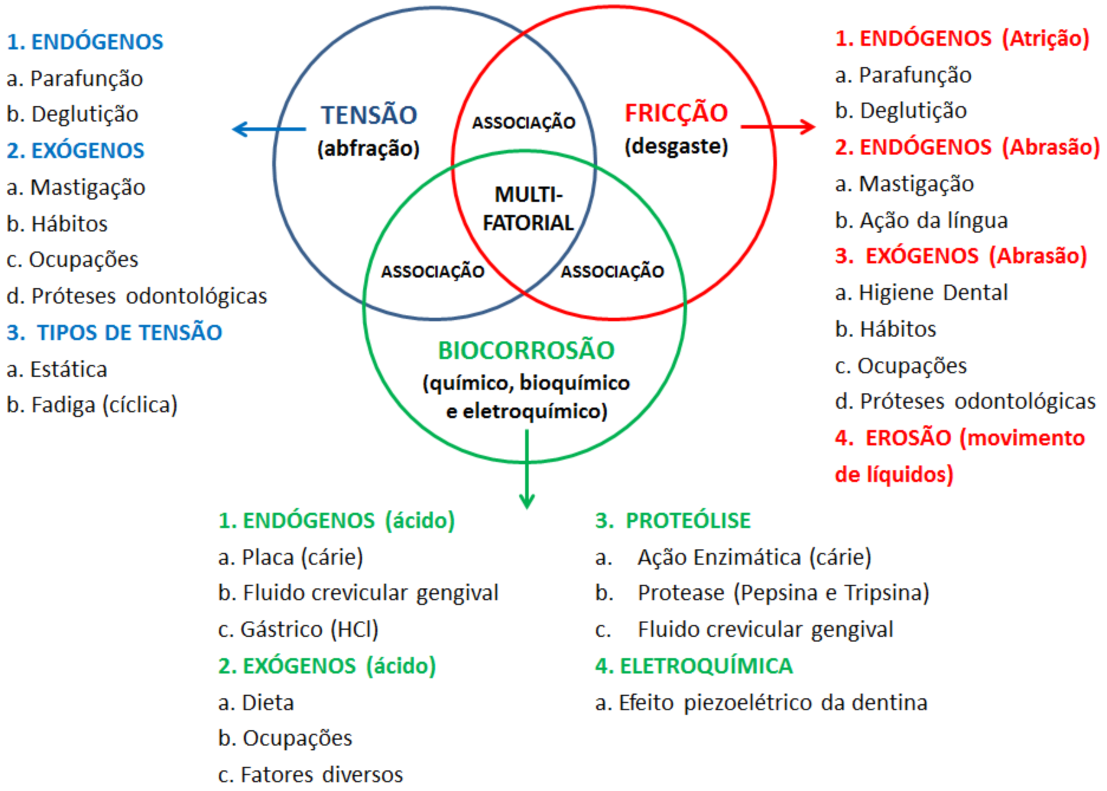

**Figura 1.** Diagrama de Venn, representando os fatores envolvidos na formação de lesões cervicais não cariosas

Estudos tem mostrado que a região cervical dental é mais susceptível a ação de fatores etiológicos das LCNCs, como a tensão (Lee & Eakle, 1984; Soares et al, 2003),pois o esmalte na região cervical, próximo a JCE é bastante fino e o cemento e a dentina não são muito resistentes(Rees,2002; Soares et al, 2013). O enfraquecimento da estrutura dental na região cervical pode ser por meio da concentração de tensão que é resultante de carregamentos oclusais que podem ocorrer em vários locais da estrutura dental durante os contatos interoclusais, como consequência das funções orais, parafunções, e trauma oclusal, que alteram a distribuição de tensões (Rees, 1998; Benazzi et al, 2014). Dessa forma, carregamentos oclusais em altas intensidades e aplicados fora do longo eixo do dente, resultam em maiores índices de tensão na região da JCE (Rees, 2003; Rees, 2006).Essas tensões geradas podem levar a deslocamentos deflexivos e deformações suficientes para promover o rompimento das ligações químicas entre os cristais dos componentes de esmalte e dentina(Lee & Eakle, 1984;

Rees, 1998). Esse fenômeno causado pela flexão dental (Grippo 1991; Rees, 2006) caracterizado pela desorganização dos cristais(Lee & Eakle, 1984; Soares et al., 2003)é denominado de abfracão, que em latim significa fratura à distância(Grippo, 1991).

Outro tipo de problema comumente encontrado em pacientes adultos são as perdas ósseas, segundo alguns autores, podemos considerar apto ao tratamento ortodôntico aquele paciente cujos problemas periodontais encontram-se controlados, sem sangramento gengival a sondagem e com boa higiene bucal, mesmo que o periodonto encontre-se reduzido, sem que isso signifique mais deteriorização do tecido de sustentação(Artun & Urbye, 1998; Boyd et al, 1998).

No processo fisiológico que ocorre durante o tratamento ortodôntico, o ligamento periodontal desempenha um papel crucial na regulação da movimentação ortodôntica, uma vez que a microvasculatura e o fluxo sanguíneo contido no ligamento, podem ser parcial ou completamente comprimidos devido à sua exposição a certo nível de pressão, ajustando o fluido intersticial periodontal (Danz et al, 2016). Essa pressão pode causar a disfunção ou necrose do ligamento periodontal, seguido por uma cascata de eventos, direcionando a movimentação via recrutamento de osteoclastos e osteoblastos promovendo reabsorção óssea de forma indesejada (Liao et al, 2016).

Sendo o movimento do dente em regiões fora do processo alveolar desfavorável, a distribuição da força em tecidos circundantes as raízes é controlada pela magnitude da força, e pela relação momento/força no centro de resistência da raiz, sendo sua magnitude baixa, evitando assim a hialinização(Burstone & Pyputniewicz,1980; Roberts & Chase, 1981).Com a perda óssea progressiva , o centro de resistência move-se para apical, e as forças que atuam sobre a coroa geram deslocamento(Melsen et al, 1989;Cardaropolli et al, 2001),embora a resposta tecidual possa ser igual

(Kokich & Spear,1997),tornando o dente mais susceptível inclinação dentária do que movimento de corpo.(Ong & Wang, 2002)

Neste contexto, surgiu a hipótese de se realizar uma pesquisa onde a indagação é: qual o papel do tratamento ortodôntico em dentes com e sem lesão cervical não cariosa, sob diferentes níveis de perda óssea?

# *PROPOSIÇÃO*

## 2- Proposição

O objetivo deste estudo foi avaliar o comportamento biomecânico de segundo pré molar superior por meio do método de elementos finitos e extensometria com diferentes variáveis:

1- região cervical(Hígido, Lesão Cervical Não Cariosa e Lesão Restaurada)

2- perda óssea (ausente, 1/4, 1/2, 3/4)

# *CAPÍTULO 1*

# Capítulo 1

Referência do Artigo segundo normas do programa:

Magalhães CSA, Almeida GA. Influence of non-carious cervical lesion and bone loss associated with orthodontics movements: finite elements analysis

# Influence of non-carious cervical lesion and bone loss associated with orthodontics movements: finite elements analysis

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b. Professor, Department of Pediatric Dentistry and Orthodontics, Federal University of Uberlândia, Uberlândia, Minas Gerais, Brazil.

## Abstract:

**Introduction:** The objective of this study was to analyze the biomechanical effects of NCCLs and bone loss in premolar, during orthodontic movement. **Methods:** Cone beam CT scan of the upper jaw was used to construction of tetrahedral models of the first (14) and second premolars (15) and first molar (16) sound, periodontally healthy. Twelve models were generated from combinations of two factors: 1- crown condition of tooth 15(sound, with unrestored NCCL, with restored NCCL) 2- level of bone loss (without, ¼, ½ and ¾), crown condition of tooth 15(sound, with unrestored NCCL, with restored NCCL). Finite element analysis (FEA) was used to evaluate these combinations under extrusive (EX) and intrusive (IN) loads. **Results:** EX produced greater tension than IN, in all situations and even under lighter loads. NCCLs were associated with greater tension regardless of region: marginal alveolar bone crest (MAC), crown buccal cervical region (CBC), buccal apical third of the root (BAR). Tension in the restored NCCL teeth was similar to that of the sound teeth, regardless of movement type. Bone loss strongly affected tension in all situations. **Conclusions:** NCCLs generate internal tension that is greatest under EX, while restored NCCLs produce internal tension that is similar to that of sound teeth and finally, greater alveolar bone loss is associated with greater tension in the root and alveolus, especially at the level of the marginal bone crest.

Keywords: Bone Loss, Finite Element Analysis, Non-Carious Cervical Lesion, Orthodontic Movement, Strain Gauge Test.

## INTRODUCTION

Advances in orthodontic diagnostics, techniques, and materials as well as reductions in discomfort and treatment length have made orthodontics accessible to all age groups, including adults (1,2,3). A non-carious cervical lesion (NCCL) is a significant degenerative change that is associated with the slow and irreversible loss of mineralized dental structure at the cementum-enamel junction and the presence of microorganisms (4,5). These lesions have a multifactorial etiology that involves the concentration of stress (biomechanical load), friction (friction and abrasion) and biocorrosion (acid-induced chemical degradation)(6). NCCLs are most common in the vestibular region of upper premolars and more prevalent in adults (4,7), given their longer exposure to etiological factors. (7)

When an orthodontic force is applied to a tooth with an NCCL, the force is greatest within the lesion (8,9). This may deflect the crown, reduce the overall rigidity of the tooth and likely affect the biomechanics between the alveolar bone and related root structures (10,11).

Another degeneration commonly found in adults is alveolar bone loss (12). This condition may cause progressively greater root exposure that can compromise the insertion of a dental device by apically displace its center of resistance (13,14). Furthermore, when exposed to occlusal forces and/or orthodontic movement, root deflection may occur where the root contacts the marginal crest of the alveolar bone.

Given these types of degeneration in adult patients, extrusion (EX) and intrusion (IN) orthodontic movements in monoradicular teeth deserve special attention. First, because these movements cause vertical displacement of teeth within an ever-decreasing bone structure (15,16) and second, because orthodontic loads are applied to a tooth crown and not to the tooth's center of resistance, potentially causing either lingual inclination from extrusive movement or buccal inclination from intrusive movement (12,17).

Thus, the objective of this study was to use FEA and strain gauge test to evaluate the influence of NCCLs and different types of bone loss on the pattern of tension and deformation in upper second premolars under orthodontic loads. The null hypothesis of this study was that different types of bone loss and structural change in the cervical region do not influence the biomechanical behavior of a dental device under orthodontic load.

## MATERIALS AND METHODS

This study was approved by the Ethics Committee of the Federal University of Uberlândia, Brazil (#86043117.9.0000.5152). A single patient was selected with all permanent teeth, "normal occlusion" and healthy periodontium.

### Orthodontic Load Test

A model of the upper arch was obtained by passively attaching double self-ligating brackets (Damon 022, Ormco, Washington, USA) to teeth 16 and 14, and a single bracket on tooth 15, according to the precepts of the Straight-Wire technique (18) (Figure 1).

To achieve a load similar to that used in the literature (19), the following wire types and diameters were tested: NiTi 0.014” (Flexy NiTi, Orthometric, Marilia, Brazil), NiTi 0.012” (Flexy NiTi, Orthometric, Marilia, Brazil) Thermoactivated NiTi 0.012” (Termoativado Flexy NiTi Thermal 35°,Orthometric, Marilia, Brazil). The loads generated by the deflection of these wires were measured using a Mecmesin force gauge (Mecmesin Ltda., Sterling, USA) and a 25N load (Figure 2). The EX movement was created by inserting the wire in the brackets of teeth 16 and 14, such that the wire on tooth 15 was placed under the cervical bracket wings. The IN movement was created by inserting the wire in the brackets of teeth 16 and 14 such that the wire passed under the incisal wings of the tooth 15 bracket. The results were submitted to Two-Way ANOVA and Tukey tests and then compared to the results of other studies(19). Thermoactivated NiTi 0.012” was chosen based on the results of this comparison and the values generated by IN.

## Finite Element Analysis

Linear and elastic three-dimensional finite element analysis was performed using a model based on tomographic representations of the dentin, pulp, enamel, periodontal ligament, cortical bone and trabecular bone of teeth 14, 15 and 16. The images (.DICOM) captured by cone beam computed tomography (Classic i-CAT®, Imaging Sciences, Hatfield, PA) were processed in Invesalius CTI software (Renato Archer, Campinas, Brazil) to produce delimitations of the external anatomy, which were then saved as *.STL files (Stereolitograficos). The *.STL files of the enamel, dentin, pulp and bone were exported to Solidworks CAD software (Dassalts Systems, Paris, France) to make models that represented a sound tooth (SO), and that were used to simulate the various combinations of teeth with or without NCCLs and with varying levels of bone loss. To create the models, the three regions of the tooth, cervical margin, prosthetic equator and marginal ridges were first traced.

In the *.STL file, several reference points were selected in strategic regions that were used to generate interconnected curves. Model surfaces, brackets and wires were created using these curves and significant anatomical reference points. Twelve models were generated to represent the various combinations of the two factors under consideration: 1 - tooth condition (sound, unrestored NCCL and NCCL restored with composite resin - CR) and 2- bone loss level (without, ¼, ½ and ¾).

The NCCL was created by using CAD to subtract a cavity from the enamel and dentin, measuring 2.5mm deep by 2.5 mm wide, that covered the entire distal-mesial region. The various levels of bone loss were created in a 11.9 mm space between the cementum-enamel junction and the root apex of tooth 15. In this region, CAD was used to remove the following quantities of alveolar bone: 2.97mm for ¼ bone loss; 5.95mm for 1/2 loss and 8.92mm for 3/4 bone loss. The recovered material was restored by following the points and curves of the cervical profile. These data were exported to Femap software (Siemens PLM Software, Plano, USA) to generate 10-node tetrahedral meshes. All dental structures and restorative materials were considered homogeneous, with linear and elastic properties, and isotropic structures (20,21,22,23,24,25) (Table I)

The modeled tooth 15 bracket was submitted to EX and IN loads using load values established through the previously described orthodontic load test. The models were fixed to the base and lateral surfaces of the cortical and medullary bones to prevent model displacement. The result was post-processed using the Von Mises criterion (MPa).

## Strain Gauge Test in vivo

A transparent addition-silicone (Elite Transparent, Zhermack, Badia Polesine, Italy), which allowed light to pass through the photopolymerizer, was used to transfer mold a plaster model with bonded brackets - as described in the orthodontic load test. This procedure was used so that the position of the brackets in the plaster model could be faithfully reproduced on the patient's teeth (16, 15 and 14).

Next, the brackets were removed from the plaster model, cleaned by blasting with fine aluminum oxide, and transferred to transfer silicone. After transfer to the silicone wall, the brackets were attached to the buccal surface of teeth 16, 15 and 14 using orthodontic resin (Transbond XT, 3M, Ribeirao Preto, Brazil) and as described in the orthodontic load test. Simultaneously, self-ligating brackets were attached to the lingual of teeth 16 and 14.

Once the brackets were bonded, a 0.020" thick stainless-steel wire (CrNi 0.020”, Morelli, Sorocaba, Brazil) was passively installed in the brackets of 16 and 14 to securely anchor these teeth and restrict movement to tooth 15 (Figure 3).

A strain gauge (PA-06-060BA-120-C2, Excell Sensores, Itatuba, Brazil) with active grid area of 1.5 mm², electrical resistance of 120Ω and copper wires soldered to its terminals, was attached to the long axis of the buccal surface of tooth 15 (Figure 3), in order to measure its deformation before the movements the EX and IN.

EX was generated by inserting a segment of Thermoactivated NiTi 0.012” in the slots of the brackets on teeth 16 and 14, such that the Thermoactivated NiTi 0.012” wire was positioned under the cervical wings. IN was produced by inserting a similar wire segment into the bracket slots of teeth 16 and 14, such that the wire was placed under incisal wings.

The strain gauge wires were connected to a Data Acquisition System (ADS2000, Lynx, Sao Paulo, Brazil) using the Wheatstone half bridge scheme, while another strain gauge was attached to tooth 25, to compensate for dimensional changes caused by temperature and to act as a passive sample (26).

The data were transfered to computer using acquisition software, signal transformations and data analysis (AqDados 7.02 and AqAnalisys, Lynx). During orthodontic movement, microdeformation (μs) data was collected every 0.25 seconds. For verification, the maximum and mean deformation values (from 30 seconds of loading) of each simulated movement were compared to values obtained by FEA.

## RESULTS

### Orthodontic Load Test

The results of the orthodontic load tests for each wire diameter and movement type (EX and IN) were submitted to statistical analysis (Table II). Nitinol 0.014" wire produced the greatest force regardless of movement type while Nitinol 0.012"wire produced intermediate results. Thermoactivated NiTi 0.012" wire produced the lowest and closest values to those recommended in the literature (19) and was therefore chosen for the current study.

### Finite Element Analysis

Figures 4 A, B and C and 5 A, B and C show the tension distributions, according to the Von Mises criterion, for all the models. According to the Von Mises criterion, the higher the value presented, the greater the accumulated tension. Mean tension was calculated from values obtained at 10-nodes in three distinct regions: marginal alveolar bone crest (MAC), crown buccal cervical region (CBC) and buccal apical third of the root (BAR) (Tables III and IV).

Figures 4B and 5B show that EX caused lingual displacement while IN caused buccal displacement. Both displacements increased with greater levels of bone loss.

EX produced greater tension than IN in all samples and regardless of cervical region integrity or level of bone loss (Tables III and IV, Figures 6 and 7).

NCCLs generated greater tension in the cervical region regardless of periodontal state or orthodontic movement. This tension was greatest at the base of the NCCL (EX, 0.247MPa and IN, 0.165MPa) and in the alveolus region (EX, 0.083MPa and IN, 0.062MPa). In the restored models, tension was evenly distributed across the dental surface (EX, 0.165MPa and IN, 0.082MPa) and was similar to that of the sound tooth (EX, 0.148MPa and IN, 0.082MPa) (Tables III and IV, Figures 6 and 7).

In the periodontium, tension was found in the root and around the alveolus in all the simulations of this study (Figures 4, 5, 6 and 7, Tables III and IV). However, as bone loss increased, tensions also increased in the root, specifically near the marginal crest of the alveolus and especially under EX (EX, 0.298MPa and IN, 0.132MPa), even though the EX force was lower (Figures 4, 5, 6 and 7, Tables III and IV).

Furthermore, when bone loss reached ¾, tension from both movements (EX and IN) migrated to the interproximal regions (Figures 4C and 5C).

### *In vivo* validation using Strain Gauge Test

Figure 8 shows the deformation values during the *in vivo* strain gauge test. The highest individual and highest mean tooth deformation values were found under EX (EX, 38.8 μS and IN, 3.10 μS).

Figure 9 shows that the FEA and strain gauge test results for both movement types were similar, thereby validating FEA.

## DISCUSSION

The null hypothesis was rejected because different types of bone loss and structural change in the cervical region influenced the distribution of tension and deformation during orthodontic movement.

Two of the most significant degenerative tooth changes in adults are NCCLs (27,28) and alveolar bone loss (39). Both progress with age (1,3). Given that orthodontic treatment in adults is relatively frequent (1,2), the objective of the present study was to evaluate the influence of these degenerations on alveolar tooth structure while under EX and IN loads.

Thus, a series of steps were taken to reproduce clinical realities as accurately as possible. These steps included the definition of wire type by analyzing orthodontic loads (19, 32), careful reproduction of the positioning of brackets in the buccal cavity, exactly as they were in the plaster model, and by the installation of 0.020"wire round stainless steel wire on the lingual side of non-target teeth to focus, as much as possible, the deformation evaluations on the second upper right premolar.

An *in vivo* strain gauge test was used to validate the FEA deformation data (Figs 8 and 9) under EX and IN loads. Even though the results of the strain gauge test and FEA (Fig 9) were not numerically similar, the patterns of the results were similar, thus validating both analyses.

While the dental movements chosen for this study were essentially vertical, they were also accompanied by inclination given that the loads were applied to the tooth crown (33,34).

The front view of EX (Fig. 4A) shows that there is relatively constant bracket tension, regardless of bone condition. Tension was also observed in the cervico-buccal region of the tooth crown, in all the simulations of this study, and mainly inside the NCCL. Interestingly, this deformation within the lesion predominated over other areas of tension and increased with progressively greater stages of bone loss (Figures 4 and 6 and Table III).

Tension was highest in the cervical region of the crown during EX loading and at the ¼ bone loss level. However, at ½ and ¾ bone loss, the data from the sound tooth and the restored NCCL showed that periodontal condition became a determining factor given that the highest tensions migrated to the vestibular region of the apical third of the root and were no longer found in the cervico-buccal region of the crown. On the other hand, when an NCCL was present, the highest tensions were found in the interior of the NCCL, regardless of bone condition. This suggests that it is important to restore an NCCL before applying an EX load, especially when alveolar bone loss has reached half the root length in the first upper premolars (Figures 4 and 6 and Table III).

When force is applied to the buccal surface of the crown, a tooth will mostly move towards the occlusal plane but will also undergo slight lingual tipping (Fig. 4B). Thus, when an orthodontic load is applied to a monoradicular tooth, the most significant deformation should occur in the lingual region of the alveolar bone crest and in the buccal portion of the root, close to the bone margin (33). Nevertheless, the results of the current study did not corroborate this expected outcome. The largest deformations in the alveolus region occurred on the buccal surface and increased at the ¼ and ½ levels of bone loss, regardless of crown health. This was probably due to the association between the alveolar tension caused by EX and the displacement of the tooth's center of resistance towards the root apex, which increased buccal displacement of the apical section of the root (Figures 4 A and C).

Conversely, when bone loss reached ¾ of its original structure, deformations were displaced from both the radicular portion and the surrounding alveolar ridge to the interproximal surfaces. In these cases, given that the brackets were positioned passively, and that tooth movement in the mesio-distal direction was consequently impossible, these deformations were probably the result of interproximal deflection of the entire dental structure, which is caused by the specific anatomy of the tooth under study, by possible morphological NCCL asymmetry, and the strong influence of bone loss.

The IN frontal view shows that the same types and locations of tension occurred as in EX, but at a lower level (Fig 5A, B and C); even though the applied force was greater. Figure 5 A, shows that tension is present in the bracket, in the cervical-vestibular region of the crown, the interior of the NCCL (when present) and in the vestibular of the root, near the marginal ridge.

The expected vertical displacement in the apical direction, usually accompanied by mild buccal tipping, was increasingly stronger with greater bone loss and especially so in the in the presence of an NCCL (26) (Figure 5 B).

Once again, there was greater tension on the interproximal surfaces in the presence of an NCCL and in the presence of bone loss, possibly due to its own anatomy or to the deflection of the dental structure caused by the presence of the lesion (Figures 5 A, B and C).

Unlike in EX, the tensions generated by IN were predominantly higher in the cervico-buccal region of tooth 15 when bone loss was at ½. When alveolar bone resorption reached ¾, tension in the buccal region of the root, at the level of the bone margins began to predominate over other areas of tension. This suggests that IN loads cause proportionally less tooth inclination, resulting in fewer and less-intense areas of tension.

The results of this study show that NCCLs increase overall tooth tension (Fig 4 A, B, C and Fig 5 A, B, C). Tables III and IV show that deformation increases when NCCLs are present, which may in turn impact tooth integrity (35).

Conversely, deformations in a tooth with a restored NCCL approach the values (Tables III and IV) and behaviors (Figures 4 and 5 and Table III and IV) of a sound tooth, thereby reinforcing the need to restore these lesions before applying EX and IN loads (36). This treatment requires restorative material that is biomechanically similar to that of the tooth. (37,38). The properties of composite resin are very similar to dentin. Therefore, this material can be used to compensate and dissipate the of tension generated by losses of mineral tissue (35). NCCL restorations prevent contact between lesions and external threats such as attrition and corrosive agents.

The results also show the extent to which bone loss intensifies the tension generated by EX and IN loads. This intensification is caused by the greater distance between the point where force is applied and the tooth's center of resistance (31). Under these conditions, lighter loads should be used to limit deformation intensity in the target alveolar structures (40,41).

The results of this study clearly show that EX generates much greater tensions, even at much lower loads, than does IN. This probably results from the fact that displacement caused by extrusive movements is towards the outside of the alveolus, which reduces tooth stability and apically displaces the center of a tooth's resistance (33). Conversely, intrusion allows a tooth to remain relatively stable within the alveolus, generating less inclination and consequently less tension (34).

The study showed that NCCLs should be restored prior to orthodontic treatment, and especially when associated with alveolar bone loss. Similarly, intrusion should be favored over extrusion because of the lighter forces involved and activation intervals that allow adequate repair of periodontal tissues.

Future studies could expand on the present study by including other types of orthodontic movements.

## CONCLUSION

The results of this study show that:

1- tensions are generated in the interior of NCCLs, mainly under extrusive loads;

2-restored NCCLs produce tension values similar to those of sound teeth;

3-greater the amount of alveolar bone loss, the greater the amount of tension generated in the root and in the alveolus, especially at the level of the marginal bone crest.

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## Attachments

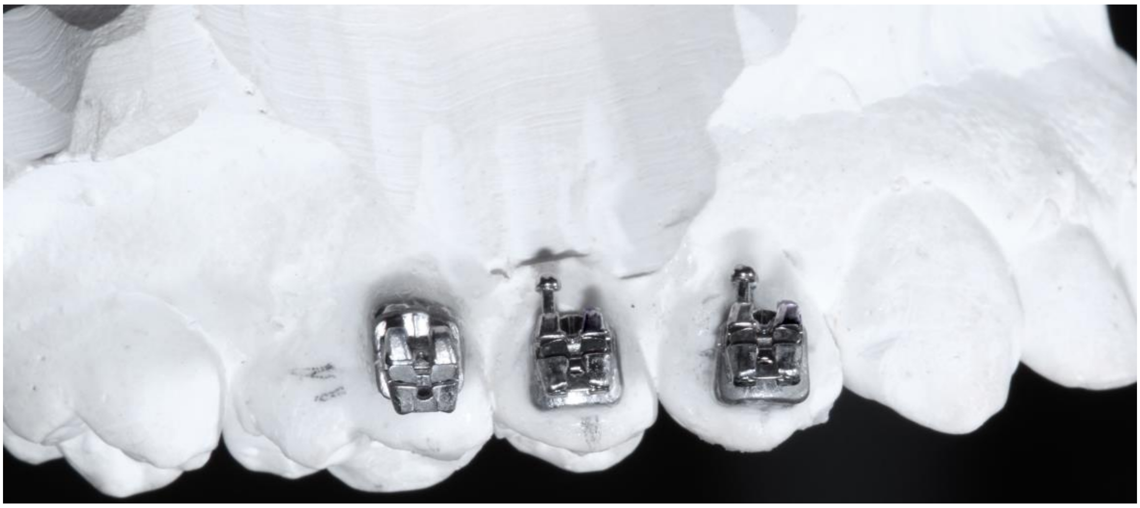

**Fig. 1**- Self-ligating brackets passively bonded to the buccal vestibular of teeth 16, 15 and 14 (Straight-Wire technique).

**Fig. 2-** Measurement of the load generated by wire deflection (Mecmesin force gauge).

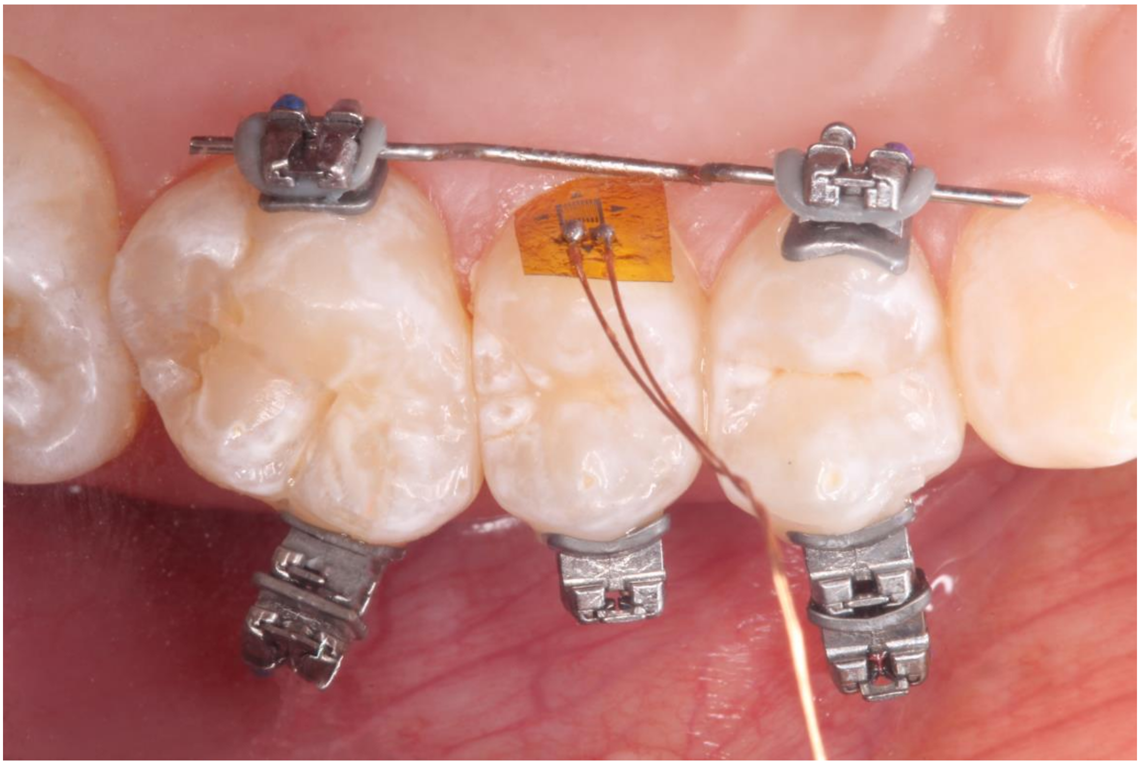

**Fig. 3-** Strain Gauge attached parallel to the long axis of the lingual surface of tooth 15

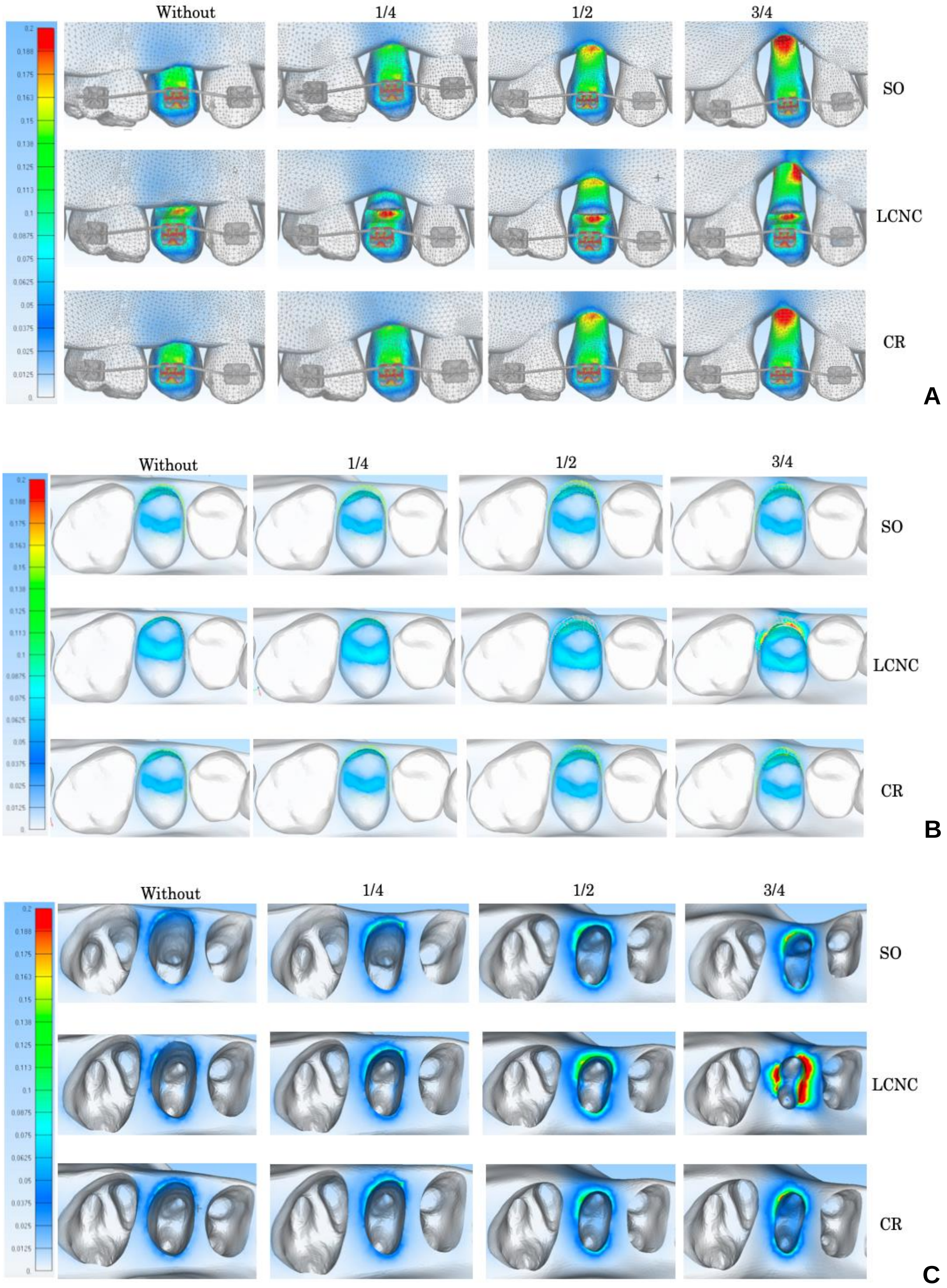

**Fig. 4-** Distribution of tension using Von Mises criteria: EX **A-** buccal; **B**-occlusal; **C**-alveolar

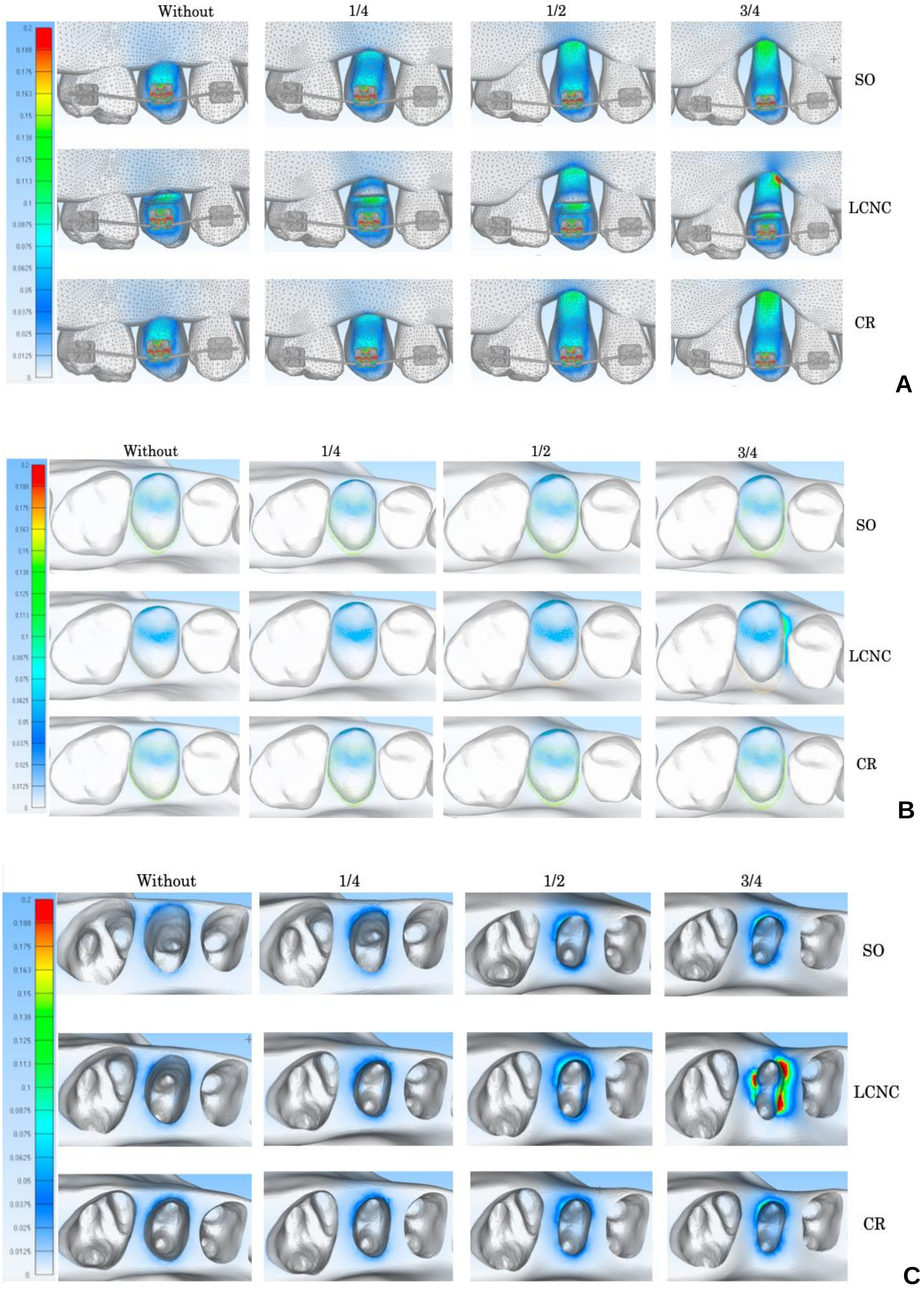

**Fig. 5-** Distribution of tension using Von Mises criteria: IN **A-** buccal; **B**-occlusal; **C**-alveolar

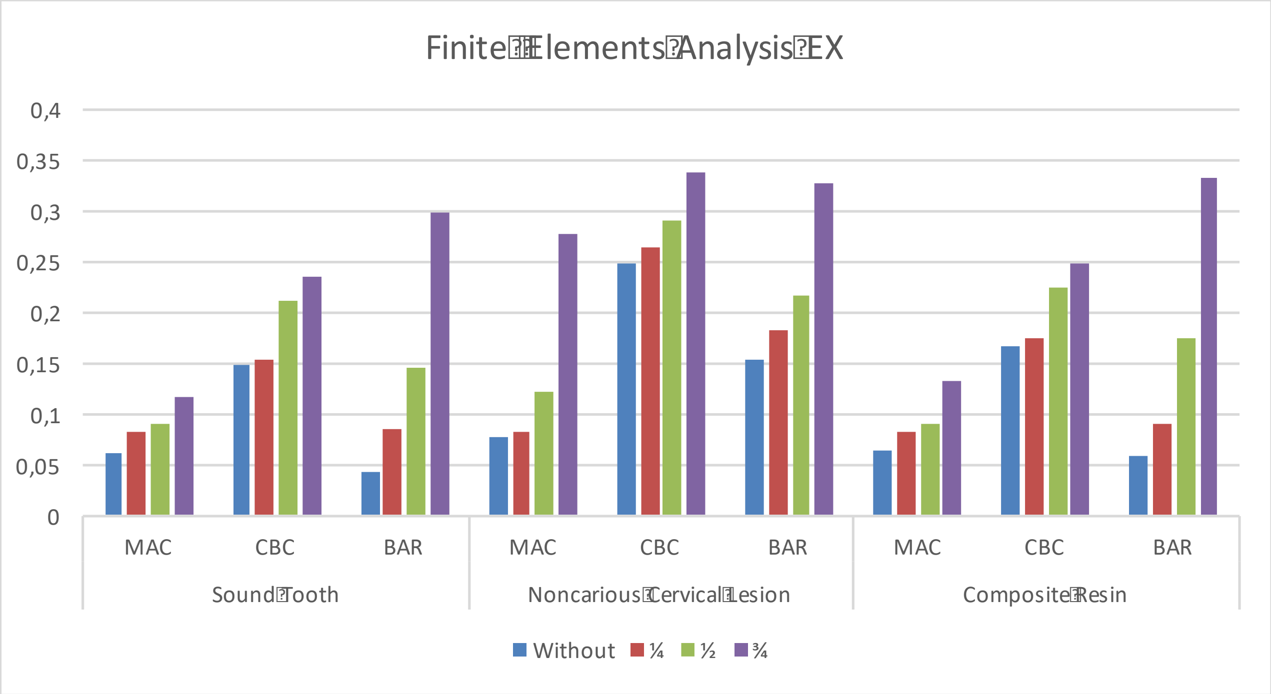

**Fig. 6**- FEA results for EX in MPa. Marginal alveolar bone crest (MAC), crown buccal cervical region (CBC), buccal apical third of the root (BAR).

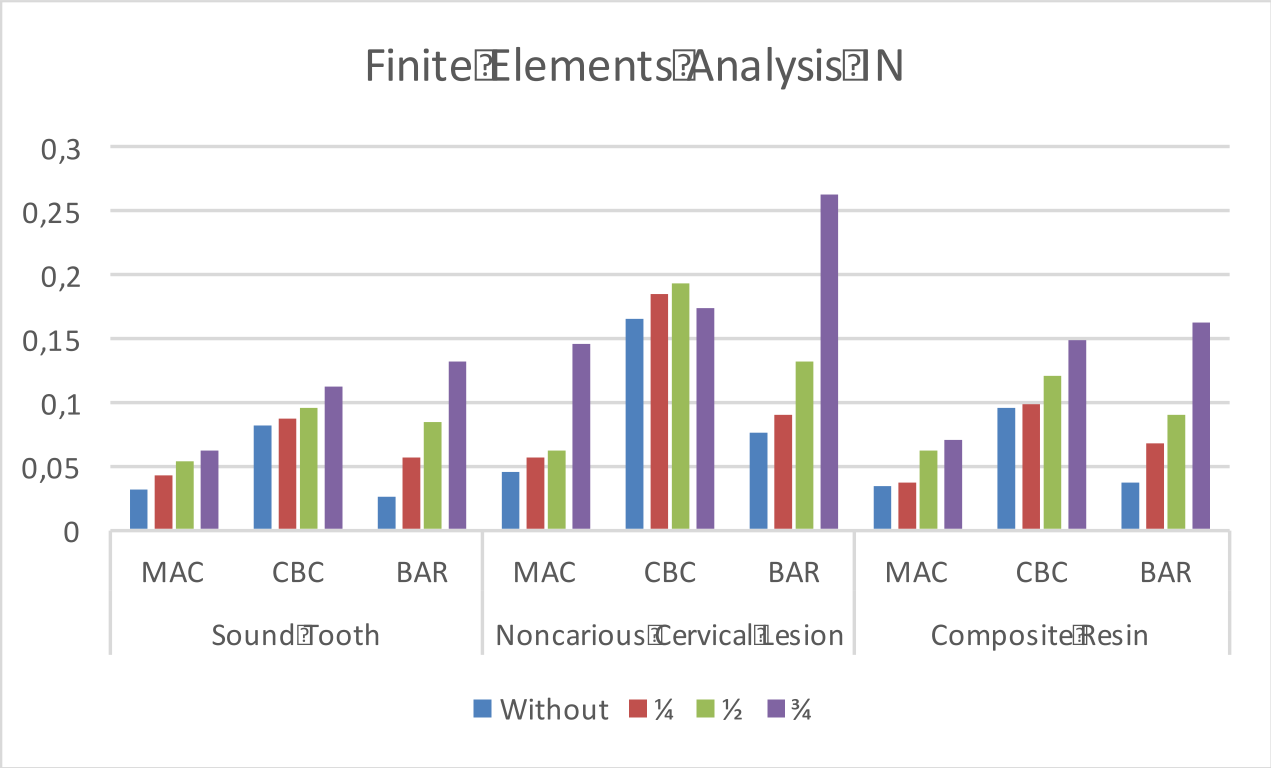

**Fig. 7**-FEA results for IN in MPa. Marginal alveolar bone crest (MAC), crown buccal cervical region (CBC), buccal apical third of the root (BAR).

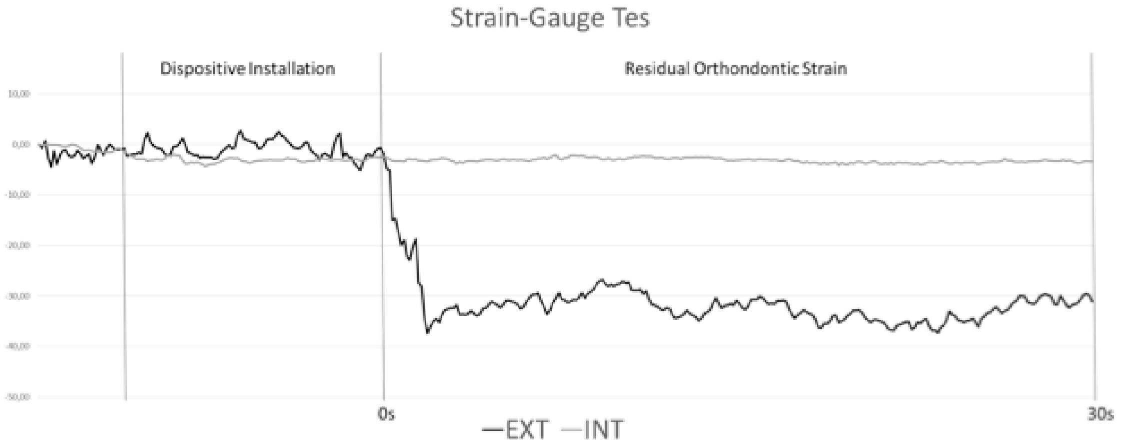

**Fig. 8-** Deformation during the *in vivo* Strain Gauge test

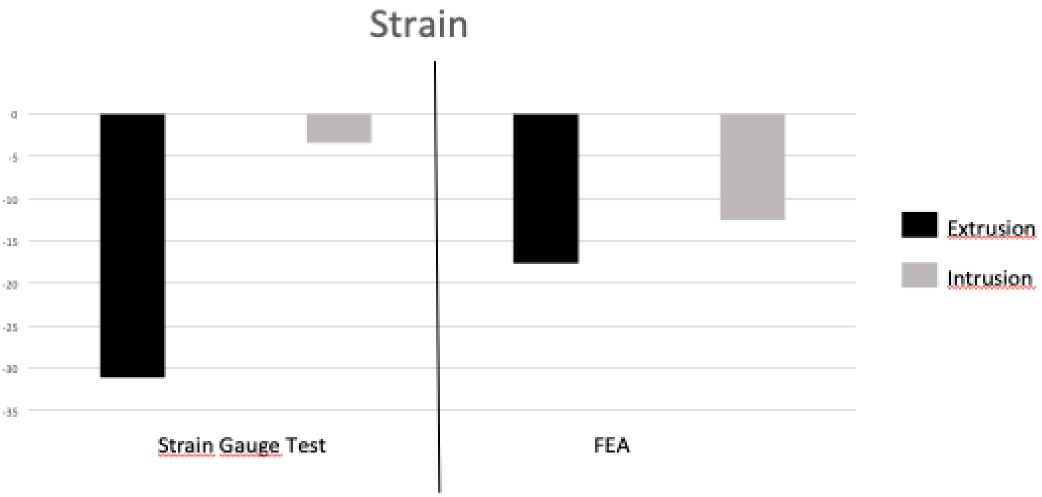

**Fig. 9-** Similarity among results, validating FEA

**Table I:** Isotropic mechanical properties used in the models.

| **Material** | **Elastics Modulus (MPa)** | **Poisson's ratio** |
|---|---|---|
| Enamel | 73.720 | 0.23 |
| Dentin | 17.07 | 0.30 |
| Pulp | 2.07 | 0.45 |
| Periodontal Ligament | 68.09 | 0.45 |
| Cortical Bone | 13.700 | 0.30 |
| Medular Bone | 1.370 | 0.30 |
| Composite Resin | 22.000 | 0.27 |
| Brackets | 200 | 0.3 |

**Table II-** Statistical analysis of EX and IN wire load

| **Orthodontic Wire** | **IN (N)** | **EX (N)** |
|---|---|---|
| Thermoactivated NiTi 0.012" | 0.130 $^{A}$ | 0.046 $^{A}$ |
| NiTi 0.012" | 0.568 $^{B}$ | 0.324 $^{B}$ |
| NiTi 0.014" | 2.318 $^{C}$ | 2.036 $^{C}$ |

Different letters within a column indicate statistically significant differences ($P<0.05$)

**Table III-** Mean tensions in three regions under EX in MPa: marginal alveolar bone crest (MAC), crown buccal cervical region (CBC), buccal apical third of the root (BAR).

| Tooth Condition | Sound | | | NCCL | | | Restored NCCL | | |
|---|---|---|---|---|---|---|---|---|---|
| Periodontal Condition | MAC | CBC | BAR | MAC | CBC | BAR | MAC | CBC | BAR |
| Without | 0.062 | 0.148 | 0.043 | 0.078 | 0.247 | 0.153 | 0.063 | 0.165 | 0.058 |
| ¼ | 0.083 | 0.153 | 0.084 | 0.083 | 0.264 | 0.182 | 0.082 | 0.175 | 0.089 |
| ½ | 0.089 | 0.212 | 0.146 | 0.122 | 0.289 | 0.217 | 0.090 | 0.224 | 0.174 |
| ¾ | 0.117 | 0.235 | 0.298 | 0.276 | 0.338 | 0.327 | 0.132 | 0.249 | 0.331 |

**Table IV-** Mean tensions in three regions under IN in MPa: marginal alveolar bone crest (MAC), crown buccal cervical region (CBC), buccal apical third of the root (BAR).

| Tooth Condition | Sound | | | NCCL | | | Restored NCCL | | |
|---|---|---|---|---|---|---|---|---|---|
| Periodontal Condition | MAC | CBC | BAR | MAC | CBC | BAR | MAC | CBC | BAR |
| Without | 0.032 | 0.082 | 0.025 | 0.045 | 0.164 | 0.075 | 0.035 | 0.095 | 0.037 |
| 1/4 | 0.042 | 0.088 | 0.057 | 0.057 | 0.185 | 0.089 | 0.038 | 0.097 | 0.068 |
| 1/2 | 0.053 | 0.095 | 0.083 | 0.063 | 0.193 | 0.132 | 0.063 | 0.121 | 0.091 |
| 3/4 | 0.062 | 0.113 | 0.132 | 0.146 | 0.174 | 0.264 | 0.069 | 0.147 | 0.163 |

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# *ANEXO*

## 5-Anexo

UNIVERSIDADE FEDERAL DE
UBERLÂNDIA/MG

### COMPROVANTE DE ENVIO DO PROJETO

**DADOS DO PROJETO DE PESQUISA**

**Título da Pesquisa:** Efeito de forças ortodônticas em pré molares com lesões cervicais não cariosas e perda óssea

**Pesquisador:** Guilherme de Araújo Almeida

**Versão:** 1

**CAAE:** 86043117.9.0000.5152

**Instituição Proponente:** Universidade Federal de Uberlândia/ UFU/ MG

**DADOS DO COMPROVANTE**

**Número do Comprovante:** 025941/2018

**Patrocinador Principal:** Financiamento Próprio

Informamos que o projeto Efeito de forças ortodônticas em pré molares com lesões cervicais não cariosas e perda óssea que tem como pesquisador responsável Guilherme de Araújo Almeida, foi recebido para análise ética no CEP Universidade Federal de Uberlândia/MG em 22/03/2018 às 18:16.

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