Nathália de Oliveira Domingos

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Orientador: Prof. Dr. Guilherme de Araújo Almeida

Banca examinadora:
Prof. Dr. Guilherme de Araújo Almeida
Prof. Dr. Luiz Renato Paranhos
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Uberlândia, 2024

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D671 2024

Domingos, Nathalia de Oliveira, 1995-
Efeito de configurações de attachments na distalização de dentes póstero-superiores com alinhadores: estudo de elementos finitos [recurso eletrônico] / Nathalia de Oliveira Domingos. - 2024.

Orientador: Guilherme de Araújo Almeida .
Dissertação (Mestrado) - Universidade Federal de Uberlândia, Pós-graduação em Odontologia.
Modo de acesso: Internet.
Disponível em: http://doi.org/10.14393/ufu.di.2024.369
Inclui bibliografia.

1. Odontologia. I. , Guilherme de Araújo Almeida,1961-, (Orient.). II. Universidade Federal de Uberlândia. Pós-graduação em Odontologia. III. Título.

CDU: 616.314

Bibliotecários responsáveis pela estrutura de acordo com o AACR2:

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Programa de Pós-Graduação em:	Odontologia				
Defesa de:	Dissertação de Mestrado Acadêmico, nº 446, PPGODONTO				
Data:	Três de Julho de Dois Mil e Vinte e Quatro	Hora de início:	08:30	Hora de encerramento:	10:10
Matrícula do Discente:	12222ODO010				
Nome do Discente:	Nathália de Oliveira Domingos				
Título do Trabalho:	Efeito de configurações de attachments na distalização de dentes póstero-superiores com alinhadores: estudo de elemento finitos				
Área de concentração:	Clínica Odontológica Integrada				
Linha de pesquisa:	Tratamento das Deformidades e dor Oro-facial e das disfunções temporomandibulares				
Projeto de Pesquisa de vinculação:	Tratamento das Deformidades e dor Oro-facial e das disfunções temporomandibulares				

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Referência: Processo nº 23117.041659/2024-90 SEI nº 5500041

AGRADECIMENTOS

Por todo o tempo dispensado e ajuda fornecida na realização deste trabalho, agradeço a todos os meus familiares e amigos pelo apoio incondicional.

Ao meu querido companheiro de vida, que me deu todo suporte e força em toda a jornada, sempre me incentivando e acalmando, meu esposo Arthur Aurélio Pedrosa Silva.

Àquela que por mim sacrificou planos, enfrentou obstáculos, me transformou num reflexo de sua integridade e me ensinou a sempre ser forte, minha querida mãe, Daniela Cristina de Oliveira Silva.

Àquela que devo todo carinho e reconhecimento, minha professora da vida, me acolheu e incentivou na dedicação aos estudos, e sempre esteve presente, minha querida avó, Deise Aparecida de Oliveira Silva.

Ao meu professor e orientador Guilherme de Araújo Almeida por todo ensinamento, respeito e motivação necessária que foi dada, e pela oportunidade de me acolher como sua aluna e responsabilidades passadas.

À Faculdade de Odontologia, ao Programa de Pós-Graduação, ao respectivo corpo docente e equipe, pelo acolhimento e oportunidade que me foi dada, contribuindo com o meu crescimento.

Agradeço a Deus, o qual sempre esteve presente para me amparar e iluminar no caminho percorrido, e fortalecer em todas as situações difíceis.

SUMÁRIO

LISTA DE ABREVIATURAS

MEF - Método de elementos finitos

CBCT - Tomografia computadorizada de feixe cônico

STL - *Stereo Lithography*

MPO - Miniparafuso ortodôntico extra-alveolar

SA – Sem *attachment*

AV – *Attachment* vertical

AVH – *Attachment* vertical e horizontal

PC – *Precision cut*

BT - Botão

GA - Gancho

mm - Milímetros

N – Newtons

MPa – Mega pascal

LIST OF ABREVIATIONS

FEM - Finite element method

CBCT - Cone beam computed tomography

STL - Stereo Lithography

NA – No attachment

VA – Vertical attachment

VHA – Vertical and horizontal attachment

PC – Precision cut

BT - Button

HO - Hook

mm - Millimeters

N – Newtons

MPa – Mega pascal

RESUMO

O objetivo deste trabalho foi estudar a influência de *attachments* na distalização dos dentes póstero-superiores com uso de alinhadores e ancoragem com miniparafuso ortodôntico extra-alveolar (MPO). Foi selecionada uma tomografia computadorizada de paciente com 18 anos de idade, dentição permanente completa e má oclusão classe II, divisão 1. Foram construídos 9 modelos de elementos finitos da arcada superior contendo alinhadores e ancoragem com MPO para simular a distalização do segundo molar, variando configurações de *attachments* (SA, sem *attachments;* AV*, attachments* verticais; AVH, *attachments* verticais+horizontais) e dispositivos para inserção da força de ancoragem no canino (BT, botão; GA, gancho; e PC, *precision cut*). Os deslocamentos foram mensurados por referência da ponta de cúspide mésio-vestibular no segundo molar, ponta da cúspide do canino e incisal do incisivo central superior, nos planos sagital (eixo Y), vertical (eixo Z) e coronal (eixo X). No eixo sagital, o segundo molar apresentou movimentação distal, enquanto os dentes canino e incisivo central movimentação vestibular, com tendência dos modelos com AVH e AV apresentarem maior vestibularização dos dentes anteriores. No eixo vertical, os dentes apresentaram tendência à intrusão, com exceção do modelo AV+PC que tendenciou à extrusão evidente. No eixo coronal, o segundo molar tendenciou à lingualização, e os dentes anteriores à mesialização, exceto o incisivo central no modelo AV+PC que apresentou distalização. Portanto, a não utilização de *attachments* indica ser a melhor opção, independente do dispositivo para ancoragem no canino; utilizando *attachments*, independente da configuração, há tendência de aumentar a vestibularização dos dentes anteriores, desfavorecendo o tratamento.

Palavras-chaves: aparelhos ortodônticos removíveis; má oclusão classe II de Angle; análise de elementos finitos.

ABSTRACT

This study investigated the influence of attachments on distalization of upper posterior teeth using aligners and extra-alveolar orthodontic mini-screw anchorage. A computed tomography scan of an 18-year-old patient with complete permanent dentition and class II division 1 malocclusion was selected. Nine finite element models of the upper arch containing aligners and mini-screw anchorage were constructed to simulate the distalization of the second molar, altering attachment configurations (NA, no attachments; VA, vertical attachments; VHA, vertical + horizontal attachments) and devices for force application on the canine (BT, button; HO, hook; and PC, precision cut). Displacements were measured with reference to the mesiobuccal cusp tip of second molar, the cusp tip of canine, and the incisal edge of upper central incisor in the sagittal (Y-axis), vertical (Z-axis), and coronal (X-axis) planes. In the sagittal axis, the second molar exhibited distal movement, as the canine and central incisor displayed buccal movement, with a tendency for models with VHA and VA to have greater buccal movement of anterior teeth. In the vertical axis, the teeth showed a tendency for intrusion, except for the VA+PC model, which tended to evident extrusion. In the coronal axis, the second molar tended to lingualize, and the anterior teeth to mesialize, except for the central incisor in the VA+PC model, which presented distalization. Therefore, not using attachments seems the best option, regardless of the anchorage device on the canine; using attachments, regardless of configuration, tends to increase vestibular movement of the anterior teeth, which is unfavorable for treatment.

Keywords: removable orthodontic appliances; angle class II malocclusion; finite element analysis.

1. INTRODUÇÃO E REFERENCIAL TEÓRICO

Os alinhadores são aparelhos contemporâneos amplamente utilizados para tratar má oclusões, sendo uma boa opção terapêutica, pois são estéticos e fáceis de serem usados. O tratamento com alinhadores era recomendado para casos mais simples, porém com o avanço das pesquisas foi evidenciado que é possível tratar casos mais complexos de má oclusões.[1] Dentre as má-oclusões tratadas, incluem-se as classes II dentárias, que são frequentemente encontradas nos consultórios pelos ortodontistas, representando cerca de 38% das má-oclusões no Brasil.[2] Nesta má oclusão, os dentes superiores estão em posição mesial, anteriorizados, em relação à arcada inferior, e o tratamento pode ser executado por meio de extrações de pré-molares superiores ou por distalização dos dentes póstero-superiores – sendo que a movimentação dos dentes deve, idealmente, ser translatória (sem inclinações), com nenhuma ou mínima perda de ancoragem dos dentes anteriores.[3]

Vários estudos têm demonstrado a correção da má oclusão de classe II com uso de alinhadores,[4-8] e para otimizar a movimentação dentária, estudos demonstraram que é possível utilizar dispositivos como miniparafusos ortodônticos (MPO), o que ampliou as indicações de uso de alinhadores ortodônticos, mesmo de certa complexidade que os alinhadores sozinhos não seriam capazes de gerenciar de maneira previsível. Além disso, pode ser combinado com o MPO o uso de dispositivos no canino, como botão, *precision cut (*recorte no alinhador na região do canino), ou ganchos, com inserção de uma força de ancoragem anterior, que ajudará no controle da perda de ancoragem dos dentes anteriores. [9-11]

Attachments são incrementos de resinas anexados aos dentes, comumente utilizados com os alinhadores, e sua utilização é indicada para ancorar o alinhador e aprimorar a movimentação dentária.[12,13] Estudos demonstram que seu uso melhora a distribuição das tensões e deslocamento dos dentes, além de minimizar a inclinação dentária (produzindo translação do dente), e prevenir perda de ancoragem anterior,[3,14-16] entretanto, outros autores têm afirmado que sua presença ou ausência não influencia na movimentação dentária com uso de alinhadores. [4,6,17,18] Várias configurações de *attachments* têm sido propostas pelos ortodontistas e pelas empresas de alinhadores,[3,6,11,19-26] porém ainda não há uma escolha empírica sobre as diversas configurações, além disso, ainda não há um consenso na literatura sobre o uso de *attachments* e seus efeitos para distalização de dentes superiores posteriores, combinados com dispositivos como *precision cut*, botão ou gancho para inserção da força de ancoragem do canino ao MPO.

Uma das formas de dirimir as dúvidas seria a utilização da metodologia de elementos finitos (MEF), que consiste em uma técnica numérica usada para estudar a biomecânica e pode simplificar as respostas fisiológicas do complexo dento-alveolar às forças ortodônticas, sendo que o modelo pode ser usado com confiança para compreender biomecânica de tais dispositivos e do movimento dentário que eles induzem.[24] Apesar de alguns estudos terem avaliado a biomecânica do movimento dentário com alinhadores e a influência dos *attachments* nos padrões de deslocamento dental,[14,15,23-28] nenhum avaliou o efeito das diferentes configurações de *attachments* e dispositivos para ancoragem na distalização do segundo molar e seus efeitos na maxila. Portanto, o objetivo deste trabalho foi estudar a influência de *attachments* na distalização dos dentes superiores posteriores com uso de alinhadores e ancoragem com MPO em conjunto com dispositivos no canino.

2. CAPÍTULO ÚNICO

ARTIGO 1 - Efeito de configurações de attachments na distalização de dentes póstero-superiores com alinhadores: estudo de elementos finitos

Artigo a ser enviado para o periódico Dental Press

Nathália de Oliveira Domingos, Guilherme de Araújo Almeida

Effect of attachment configurations on the distalization of posterior-superior teeth with aligners: finite element study

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Effect of attachment configurations on the distalization of posterior-superior teeth with aligners: finite element study

ABSTRACT

This study investigated the influence of attachments on distalization of upper posterior teeth using aligners and extra-alveolar orthodontic mini-screw anchorage. A computed tomography scan of an 18-year-old patient with complete permanent dentition and class II division 1 malocclusion was selected. Nine finite element models of the upper arch containing aligners and mini-screw anchorage were constructed to simulate the distalization of the second molar, altering attachment configurations (NA, no attachments; VA, vertical attachments; VHA, vertical + horizontal attachments) and devices for force application on the canine (BT, button; HO, hook; and PC, precision cut). Displacements were measured with reference to the mesiobuccal cusp tip of second molar, the cusp tip of canine, and the incisal edge of upper central incisor in the sagittal (Y-axis), vertical (Z-axis), and coronal (X-axis) planes. In the sagittal axis, the second molar exhibited distal movement, as the canine and central incisor displayed buccal movement, with a tendency for models with VHA and VA to have greater buccal movement of anterior teeth. In the vertical axis, the teeth showed a tendency for intrusion, except for the VA+PC model, which tended to evident extrusion. In the coronal axis, the second molar tended to lingualize, and the anterior teeth to mesialize, except for the central incisor in the VA+PC model, which presented distalization. Therefore, not using attachments seems the best option, regardless of the anchorage device on the canine; using attachments, regardless of configuration, tends to increase vestibular movement of the anterior teeth, which is unfavorable for treatment.

Keywords: removable orthodontic appliances; angle class II malocclusion; finite element analysis

INTRODUCTION

Aligners are contemporary devices widely used to treat malocclusions.[1] Among the malocclusions, dental class II represents about 38% of the malocclusions in Brazil.[2] The treatment of this malocclusion can be performed through extractions of upper premolars or distalization of the posterior upper teeth, and in its execution, the distal movement should be ideally translational (without inclinations), with no or minimal loss of anchorage on anterior teeth.[3]

Several studies have demonstrated the correction of class II malocclusion with the use of aligners,[4-6] and to optimize the movement, studies have shown that it is possible to use devices like orthodontic mini-screws combined with devices on the canine for insertion of anterior anchorage force such as precision cut (cutout in the aligner in the canine region), button or hooks.[7,8] Additionally, the use of attachments is common and indicated to anchor the aligner and improve tooth movement.[9] Studies reveal that their use improves the distribution of stresses and tooth displacement, minimizing tooth inclination, and preventing anterior anchorage loss,[10-12] however, other authors have noticed that their presence or absence does not influence tooth movement with the use of aligners. [4,6,13,14] Many attachment configurations have been proposed by orthodontists and aligner companies,[3,6,8,15-20] but there is still no empirical choice regarding the different configurations, furthermore, there is no consensus in the literature on the use of attachments and their effects on the distalization of posterior upper teeth combined with devices such as precision cut, button or hook for the insertion of canine anchorage force to the mini-screw.

An approach to resolving these uncertainties would be the use of the finite element methodology (FEM), and although some studies have evaluated the biomechanics of tooth movement with aligners and the influence of attachments on dental displacement patterns,[10,11,17-22] none have evaluated the effect of different attachments configurations and anchorage devices on the distalization of the second molar and their effects on the maxilla. Therefore, the aim of this study was to evaluate the influence of attachments on the distalization of posterior upper teeth with the use of aligners and mini-screw anchorage combined with devices on the canine.

METODOLOGY

This study was submitted and approved by the Research Ethics Committee of the Federal University of Uberlândia (CAAE 68334822.0.0000.5152). A cone-beam computed tomography (CBCT) scan of an 18-year-old female patient with Class II, division 1 malocclusion and complete permanent dentition up to the second molars was selected from the image bank of Guima Assessoramento Odontológico Ltda. (R. Prof. Mario Porto, 225 - Lídice, Uberlândia - MG). The CBCT scan was acquired using a Planmeca Promax 3D Max unit (Helsinki, Finland) in extended field of view mode (14.5 cm × 13.0 cm).

To analyze biomechanical behavior, the range of orthodontic tooth movement was measured in virtual numerical models. Three-dimensional (3D) finite element models of the maxillary arch were generated from the CBCT scan. DICOM files were exported to Invesalius CTI software (Renato Archer, Campinas, Sao Paulo, Brazil) for segmentation and reconstruction of the structures. The maxilla was segmented up to the height of the zygomatic bone. Different structures, including cortical bone, cancellous bone, enamel, and dentin, were delimited by image density.[23,24] A 0.2 mm thick periodontal ligament[25] was defined around the tooth roots using Boolean operations.[23]

After segmentation, the 3D triangular mesh surface of each maxillary structure was exported in Stereo Lithography (STL) format. The aligner, precision cuts, hooks with 4mm high, buttons, and rectagunlar attachments with 3 mm high, 1 mm thick, and 2 mm wide, were designed using 3-Matic software (version 18.0; Materialise, Leuven, Belgium). The STL file of the 12 x 2 mm mini-screw was provided by the manufacturer (Extra-alveolar mini-screw #5593, Peclab, Belo Horizonte, Brazil). The mini-screw was positioned on the zygomatic crest, 11 mm above the mesiobuccal cusp of the maxillary second molar. The aligner thickness was set at 0.75 mm, exclusively covering the crowns of the maxillary teeth. Buttons, precision cuts, and hooks were positioned in the center of the cervical region of the maxillary canines.

The STL files were imported into Femap software (Siemens PLM Software, Plano, Texas, USA), and the volumetric meshing process of the model was performed with 10-node tetrahedral elements, resulting in an average of 775,945 nodes and 490,227 elements. The model was then imported into ANSYS software (ANSYS, Pennsylvania, USA) for structural analysis, maximum and minimum stress data, and displacement of dental structures. In defining the boundary conditions, a smooth contact interface was defined at the interfaces and the top of the bone structure, except for the palatine bone, which was rigidly fixed in the x, y, and z axes. The entire upper portion of the maxilla, apart from the palate, was fixed due to its fibrous articulation with the different bones of the face, characterizing it as a synarthrosis joint, which allows little or no mobility.

The interfaces between the different structures were considered bonded to prevent relative movement along all interfaces of the model. On the other hand, the attachments, buttons, and hooks of each contact were considered rigid. Furthermore, the contact between the tooth crowns and the aligner is frictional, with a coefficient of friction of 0.2.[17] All materials were considered linear-elastic, isotropic, and homogeneous. For each material, the Poisson's ratio and modulus of elasticity obtained from the literature were used, as shown in Table 1.

Table 1. Modulus of elasticity e Poisson's ratio of materials

Material	Modulus of elasticity (Mpa)	Poisson's ratio (v)	Reference
Tooth	19 600	0.30	Gomez et al.[17]
Periodontal ligament	50	0.45	Patiño et al. [26]
Cortical bone	13 700	0.30	Patiño et al. [26]
Cancelous bone	1 370	0.30	Patiño et al. [26]
Aligner	528	0.36	Gomez et al.[17]
Attachments	12 500	0.36	Gomez et al.[17]
Mini-screw	110 000	0.30	Patiño et al. [26]
Button	206 000	0.30	Ji et al.[20]
Hook (stainless steel)	200 000	0.30	Patiño et al. [26]

Nine finite element models were generated (Figure 1) according to the two factors under study: attachments at 3 levels (no attachments - NA, vertical attachments - VA, and vertical and horizontal attachments - VHA) and anchorage devices at 3 levels (precision cut - PC, button - BT, and hook - HO):

Model 1: aligner and mini-screw, NA+PC;

Model 2: aligner and mini-screw, NA+BT;

Model 3: aligner and mini-screw, NA+HO;

Model 4: aligner and mini-screw, VA+PC;

Model 5: aligner and mini-screw, VA+BT;

Model 6: aligner and mini-screw, VA+HO;

Model 7: aligner and mini-screw, VHA+PC;

Model 8: aligner and mini-screw, VHA+BT;

Model 9: aligner and mini-screw, VHA+HO.

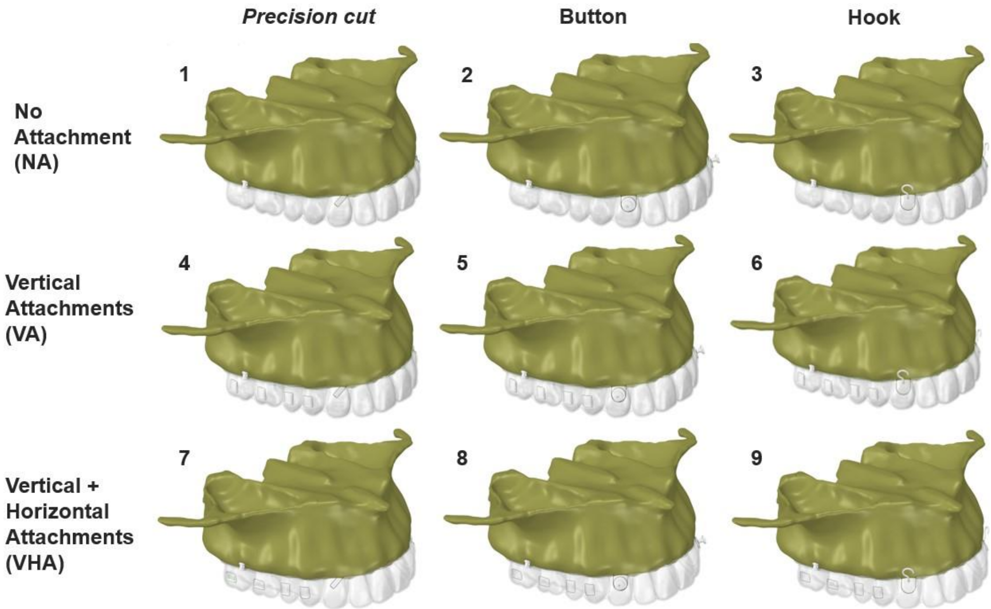

Figure 1. Finite element models of the maxillary arch containing aligners and anchorage with extra-radicular orthodontic mini-screws, with three attachment configurations (no attachments - NA, vertical attachments - VA, vertical + horizontal attachments - VHA) and three anchorage devices on the canine (button - BT, hook - HO, and precision cut - PC).

The models were submited to an anchorage force of 1.66 N from the mini-screw to the anchorage device on the canine, in addition to a distal displacement of 0.2 mm (Y-axis +) to move the maxillary second molar distally.

Data analysis was performed comparatively according to the quantitative scales generated in the models in specific areas. The results were expressed using the Von Mises criterion, presenting maximum and minimum stresses to represent tensile and compressive forces, measured in MPa. Displacements were measured with reference to the mesiobuccal cusp tip of the second molar, the cusp tip of the canine, and the incisal edge of the maxillary central incisor, and were expressed by displacement vectors, indicating the direction and magnitude of movement in the X (coronal), Y (sagittal), and Z (vertical) planes.

RESULTS

Initial displacement tendency of the mesiobuccal cusp tip of the second molar and the cusp tips of the canine and maxillary central incisor under the combinations of attachments and anchorage devices used are shown in the lateral view (Figure 2) and occlusal view (Figure 3), and the values in mm are expressed in Table 2, and Figures 4, 5, and 6.

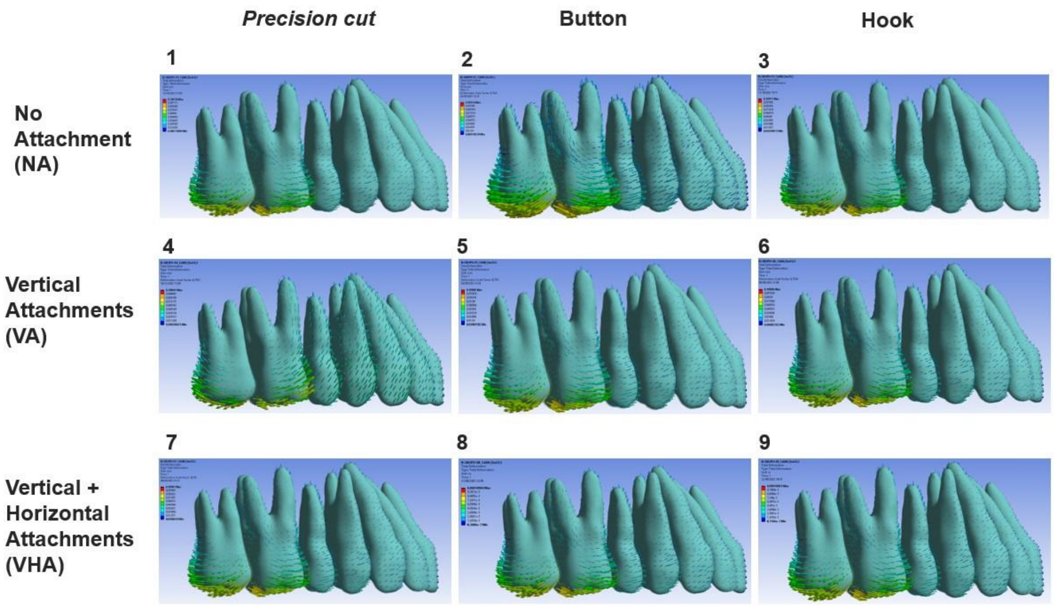

Figure 2. Lateral view of the tooth movement trend of the maxillary arch in models 1 to 9, expressed in vector arrows and measured in MPa.

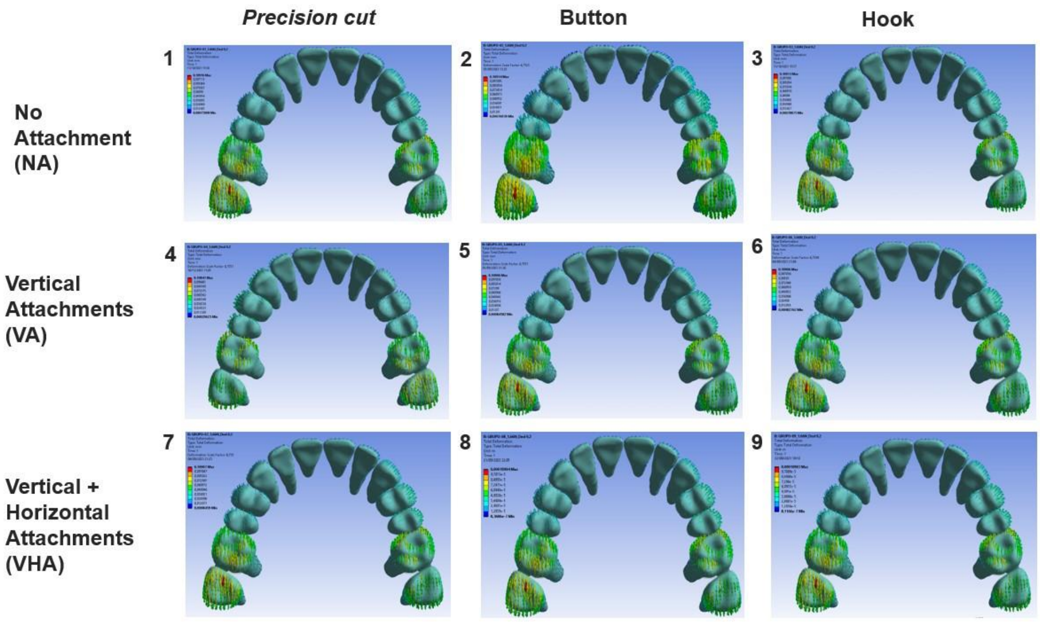

Figure 3. Occlusal view of the tooth movement trend of the maxillary arch in models 1 to 9, expressed in vector arrows and measured in MPa.

Table 2. Values (in mm) of the initial movement trend of the second molar, canine, and central incisor teeth, for models 1 to 9, in the Y, Z, and X axes.

	Second Molar			**Canine**			**Central Incisor**		
Models/Axes	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**
1 (NA+PC)	0,058	0,002	0,003	-0,012	0,021	0,021	-0,004	0,009	0,010
2 (NA+BT)	0,057	0,001	0,003	-0,013	0,021	0,021	-0,004	0,009	0,010
3 (NA+HO)	0,057	0,001	0,003	-0,013	0,021	0,021	-0,005	0,01	0,011
4 (VA+PC)	0,063	-0.021	0,008	-0,014	0,007	0,003	-0,004	0,005	-0,008
5 (VA+BT)	0,057	0,001	0,003	-0,014	0,021	0,022	-0,005	0,009	0,010
6 (VA+HO)	0,057	0,001	0,003	-0,015	0,022	0,022	-0,006	0,01	0,010
7 (VHA+PC)	0,057	0,001	0,003	-0,014	0,022	0,022	-0,005	0,009	0,010
8 (VHA+BT)	0,057	0,002	0,004	-0,015	0,022	0,022	-0,006	0,010	0,010
9 (VHA+HO)	0,057	0,002	0,003	-0,016	0,022	0,022	-0,007	0,010	0,010

Y axis - sagittal

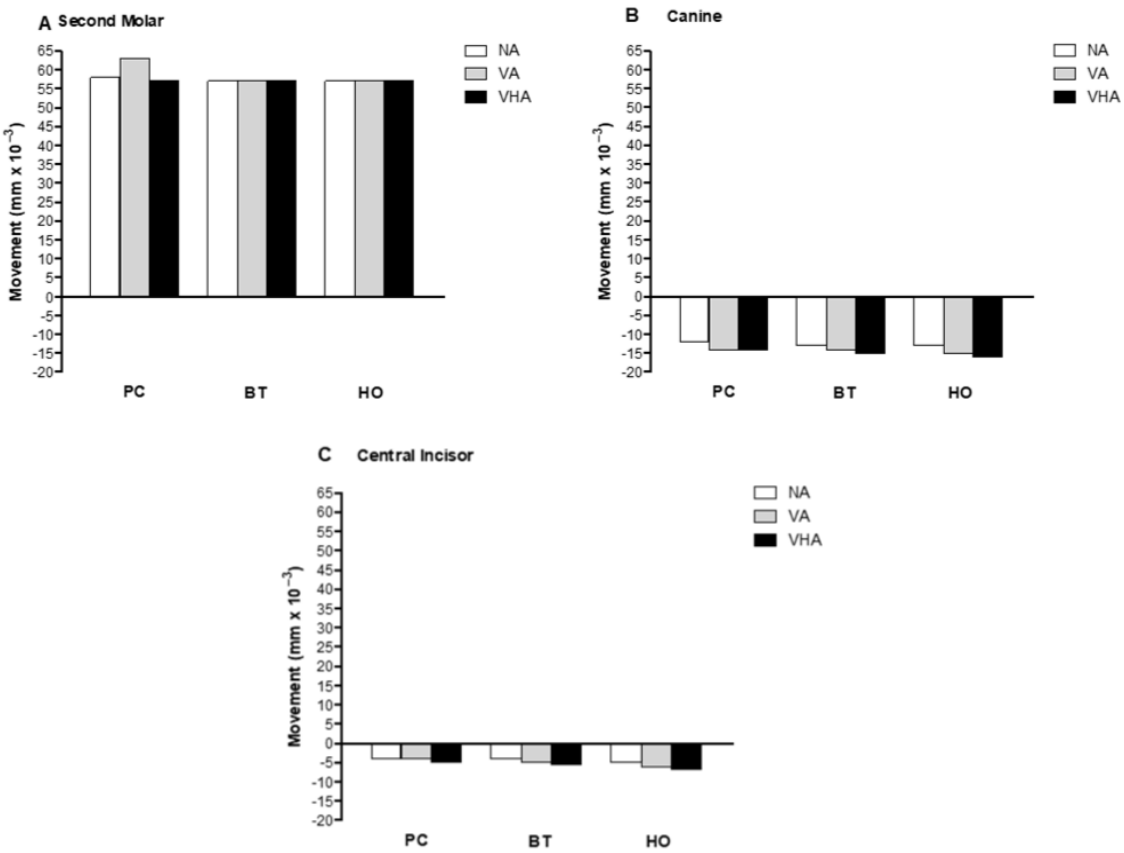

Figure 4. Comparison of Y-axis (sagittal) movement values for the second molar (**A**), canine (**B**), and central incisor (**C**) teeth, in models 1 to 9, with precision cut (PC), button (BT), and hook (HO), and the different attachment configurations (NA, VA, and VHA).

Z axis - vertical

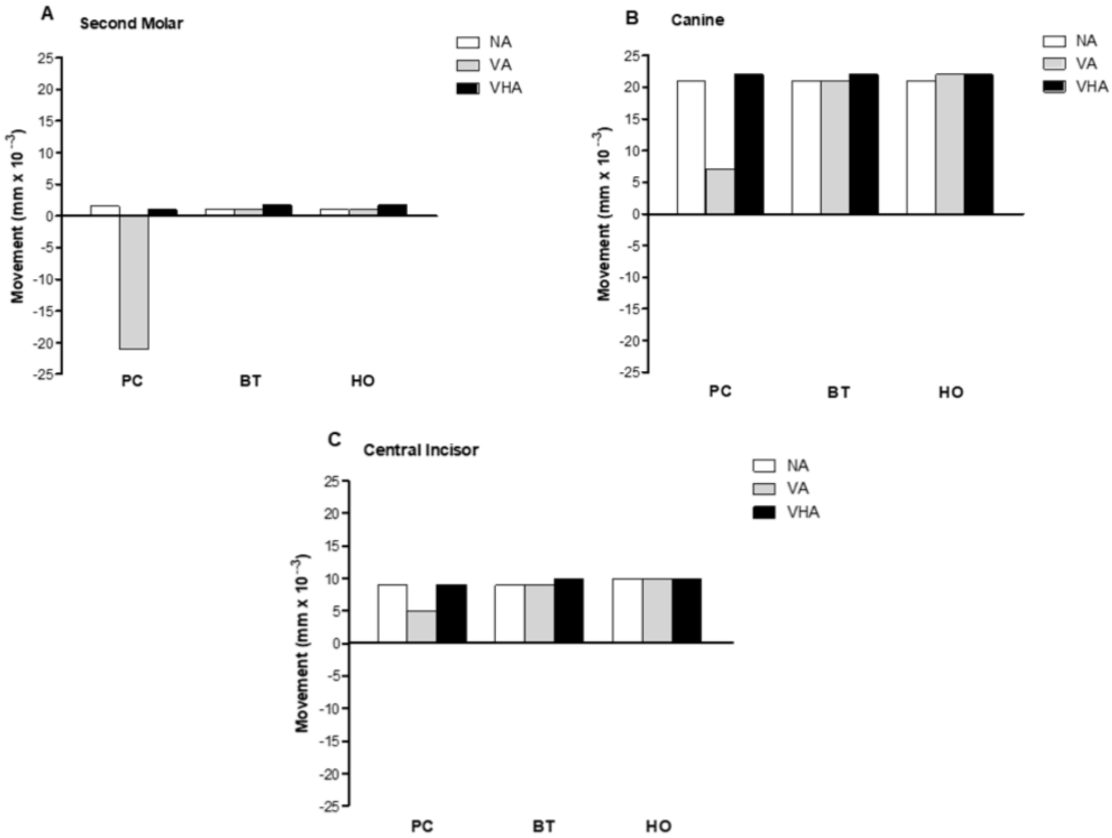

Figure 5. Comparison of Z-axis (vertical) movement values for the second molar (**A**), canine (**B**), and central incisor (**C**) teeth, in models 1 to 9, with precision cut (PC), button (BT), and hook (HO), and the different attachment configurations (NA, VA, and VHA).

X axis - coronal

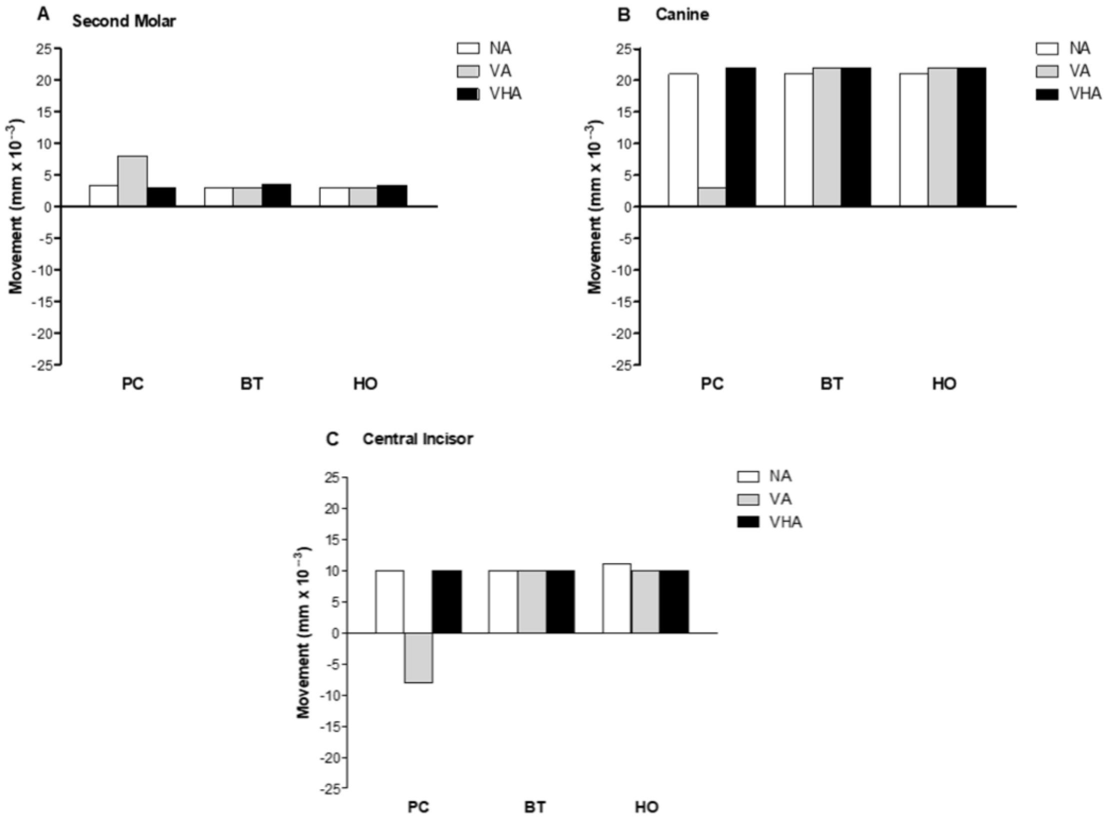

Figure 6. Comparison of coronal (X-axis) tooth movement values for second molar (**A**), canine (**B**), and central incisor (**C**) across models 1 to 9, utilizing precision cut (PC), button (BT), and hook (GA) methods, and varying attachment configurations (NA, VA, VHA).

Analysis of Y-axis movement values reveals a distalization tendency for the second molar, while the canine and central incisor tended towards vestibular movement. The greatest movement was observed in the second molar, followed by the canine and central incisor, respectively (Figures 2, 3, and 4). The VA+PC model tended to exhibit greater distalization than other models (Figure 4A). Furthermore, models with VHA and VA showed increased vestibularization of the anterior teeth, respectively (Figures 4B and 4C).

Regarding tooth movement on the Z-axis, a tendency towards intrusion was observed, except for the VA+PC model, which exhibited a clear tendency towards extrusion (Figures 2, 3, and 5). It was also noted that the

VA+PC model demonstrated less intrusive movement in the canine and central incisor compared to other models (Figures 5B and 5C).

Considering tooth movement on the X-axis, the second molar tended towards lingualization, while the anterior teeth tended towards mesialization, except for the central incisor in the VA+PC model, which tended towards distalization (Figures 2, 3, and 6). It is noteworthy that the VA+PC model showed a lesser tendency for mesialization in the canine (Figure 6B), but a significant tendency for lingualization in the second molar (Figure 6A).

Table 3. Percentual (%) comparison between the immediate upper second molar movement on sagittal axis and anchorage loss of canine and central incisor according to each model.

	Movement of upper teeth (%)			**Anchorage loss (%)**
Models	**Second molar**	**Canine**	**Central incisor**	**Canine + central incisor**
1 (NA+PC)	+78.38%	-16.22%	-5.4%	-21.62%
2 (NA+BT)	+78.38%	-16.22%	-5.4%	-21.62%
3 (NA+HO)	+76%	-17.33%	-6.67%	-24%
4 (VA+PC)	+77.78%	-17.28%	-4.94%	-22.22%
5 (VA+BT)	+75%	-18.42%	-6.58%	-25%
6 (VA+HO)	+73.08%	-19.23%	-7.69%	-26.92%
7 (VHA+PC)	+75%	-18.42%	-6.58%	-25%
8 (VHA+BT)	+73.45%	-19.33%	-7.22%	-26.55%
9 (VHA+HO)	+71.52%	20.07%	-8.41%	-28.48%

The percentage of upper tooth movement in the sagittal axis, as well as the percentage of anterior anchorage loss, is shown in Table 3. It is observed that the models with NA and the VA+PC model demonstrated the greatest movement of the second molar and the minimal movement of the canines and central incisor, resulting in a lower percentage of anterior anchorage loss.

DISCUSSION

This study evaluated the biomechanics and influence of the presence or configurations of attachments on the distalization of maxillary posterior teeth using aligners and anchorage with mini-screw combined with devices on the canine, through FEM.

The choice to study FEM was established since the method can predict the results of forces and moments applied to teeth, simplifying the understanding of the biomechanics of such devices and the consequent tooth movement they induce, with the advantage of being used prior to clinical tests, without harming the patient.[18]

The results of the present study indicate that the non-use of attachments, regardless of their configuration and the use of a device for inserting the anchorage force in the canine, indicates better tooth movement. Considering sagittal movement, models with NA had less vestibular movement, with a tendency to preserve anterior anchorage. Previous studies have found that the use of attachments did not show a difference in tooth movement when compared to non-use,[4,6,9,13,14,27] while others have found that movement was improved with the use of attachments.[3,10-12,28-31] Some studies have also reported that, with the use of attachments, it was possible to achieve bodily tooth movement and control anterior anchorage.[10,11,15,17]

Considering that in distalization the ideal movement of the posterior teeth should be bodily, and essentially devoid of extrusion or lingual movement, and in the anterior teeth there should be no loss of anchorage,[3] our results contradict some of these studies, depending on the combination of the absence or configuration of attachments, along with the specificity of each anchorage mechanics adopted. The likely explanation for the models with NA showing less vestibular movement is that the use of attachments causes a greater area of resistance to movement in the teeth. Then, in the distalization of molars with attachments, there is greater resistance with increased movement of the anterior teeth, intensifying the loss of anchorage, which would accentuate the overjet of the class II malocclusion, wich is unfavorable to the treatment. To optimize the indication of models with VHA and VA, a possibility would be to consider increasing the resistance to the movement of the anterior teeth, reinforcing the anterior anchorage. When using attachments, regardless of their configuration, there is a tendency to increase the vestibularization of the anterior teeth.

Furthermore, regarding sagittal movement, the reaction force of distalizing the molar with aligners can cause labial inclination of the anterior teeth.[32] Previous studies have reported vestibular movement for the anterior teeth,[14,15,20-22] and movement of the posterior and anterior teeth in opposite directions.[15,19,21,22,33] The present study corroborates these findings regarding the vestibularization of the anterior teeth, and that the teeth presented movement in opposite directions. The likely explanation is that aligners transmit force through deformation, so that the anterior teeth move in the opposite direction due to the reciprocal force created by the distalization of the molar.

Regarding movement on the vertical and coronal axes, the present study observed a tendency for intrusive movement in the second molar, as well as intrusion and mesialization of the anterior teeth. This aligns with the findings of previous studies that reported intrusive movement with uncontrolled tipping for the molar,[15,20] and intrusion and mesialization for the anterior teeth.[14,15,20-22] However, other studies have shown a tendency for slight extrusion of the second molar during its distalization[22] and vestibular inclination and clockwise rotation.[19,21,33] The results of the present study do not corroborate these findings, as a tendency for intrusive and lingual movement was observed in the second molar. These discrepancies can be explained by the differences in the designs of the studies using FEM, in which these previous studies analyzed the distalization of the second and first molars, while the present study analyzed only the distalization of the second molar. Furthermore, these studies investigated other configurations and arrangements of attachments. [19,21,22,33]

In the present study, different movement was observed in the VA+PC model, which despite demonstrating, along with the NA models, a lower percentage of anterior anchorage loss, exhibited significant extrusive and lingual movement for the second molar, less mesial and intrusive movement for the canine, and distal movement in the central incisor. This difference in movement can be explained by the combination of the use of vertical attachments with traction in the precision cut. Rectangular vertical attachments have a larger force transmission area in the sagittal direction, producing more precise distal movement.[20] In the present study, it is believed that the use of traction in the precision cut produced possible deformation in the plastic of the aligner in the anterior region, and combined with the use of vertical attachments on the molars, resulted in greater resistance to molar movement due to the force area. Therefore, the movement response in the anterior teeth will be different, as the plastic may tend to deform with the application of force, and the posterior teeth are resisting the applied force. The use of precision cut increases the probability of aligner deformation with the application of forces, stemming from a possible deformation originating from the properties of the plastic itself,[10,11] while increasing the thickness of the aligner may be an alternative to control undesirable effects and optimize its indication.

This study presents some limitations, as it represents, through the design used with FEM, only the application of force during the initial phase of distalization of the maxillary second molar, demonstrating the initial tendency of movement, and measured at a specific point on the crown of the second molar, canine and central incisor, without evaluating the root apices, therefore not being able to confirm whether there was inclination or bodily tooth movement. However, its use allowed us to highlight, in this study, the importance of not using attachments when considering different traction devices and to demonstrate the effects of their presence and different configurations. Clinical factors including patient cooperation, periodontal health, and root length can impact the results. Thus, future clinical studies are recommended to assess the pattern of tooth movement, in addition to other experimental and computational studies to assess the influence of aligner thickness, the increase in anterior anchorage on undesirable side effects, and the action of reciprocal force on the posterior and anterior teeth.

CONCLUSION

The use of attachments, regardless of their configuration, shows a tendency to increase the vestibular movement of the anterior teeth, independent of the device used for canine anchorage, in the simulation of distalizing the upper posterior teeth with aligners and mini-screw anchorage.

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ANEXOS

UNIVERSIDADE FEDERAL DE UBERLÂNDIA

UFU Comitê de Ética em Pesquisa — Plataforma Brasil

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Distalização dos dentes posteriores superiores com alinhadores sobre influência de diferentes pontos de tração: estudo de elementos finitos

Pesquisador: Guilherme de Araújo Almeida

Área Temática:

Versão: 2

CAAE: 68334822.0.0000.5152

Instituição Proponente: FACULDADE DE ODONTOLOGIA

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 6.052.443

Apresentação do Projeto:

Este parecer trata-se da análise das respostas às pendências do referido projeto de pesquisa.

As informações elencadas nos campos "Apresentação do Projeto", "Objetivo da Pesquisa" e "Avaliação dos Riscos e Benefícios" foram retiradas dos documentos Informações Básicas da Pesquisa nº 2043202. e Projeto Detalhado (Projeto.pdf), postados em 20/04/2023.

INTRODUÇÃO - "O estudo "Distalização dos dentes posteriores superiores com alinhadores sobre influência de diferentes pontos de tração: estudo de elementos finitos" é um estudo laboratorial com finalidade de estudar a biomecânica de distalização dos dentes superiores posteriores com uso alinhadores sobre influência de diferentes dispositivos no ponto tração e da presença de attachments."

METODOLOGIA - "Será realizado no Laboratório de Elementos Finitos do Centro de Pesquisa Odontológico Biomecânico (CPBIO), situado no bloco 4L da Universidade Federal de Uberlândia. Será convidado a participar da pesquisa, para fornecimento de dados de exame, um paciente jovem que já tenha feito um exame de tomografia. Não será aplicado nenhum tipo de intervenção no paciente, apenas o uso de dados tomográficos do prontuário. A partir da tomografia será replicado um modelo de elementos finitos da arcada superior, com uso de alinhadores e

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