UNIVERSIDADE DE SÃO PAULO
FACULDADE DE ODONTOLOGIA DE BAURU

LORENA VILANOVA FREITAS DE SOUZA

Three-dimensional evaluation of maxillary molar distalization with skeletal anchorage

Avaliação tridimensional da distalização de molares superiores com ancoragem esquelética

BAURU
2020

LORENA VILANOVA FREITAS DE SOUZA

Three-dimensional evaluation of maxillary molar distalization with skeletal anchorage

Avaliação tridimensional da distalização de molares superiores com ancoragem esquelética

Tese constituída por artigos apresentada à Faculdade de Odontologia de Bauru da Universidade de São Paulo para obtenção do título de Doutor em Ciências no Programa de Ciências Odontológicas Aplicadas, na área de concentração Ortodontia.

Orientador: Prof. Dr. José Fernando Castanha Henriques

BAURU

2020

Vilanova Freitas de Souza, Lorena

Three-dimensional evaluation of maxillary molar distalization with skeletal anchorage / Lorena Vilanova Freitas de Souza -- Bauru, 2020.

125 p. : il. ; 31cm.

Tese (Doutorado) – Faculdade de Odontologia de Bauru. Universidade de São Paulo

Orientador: Prof. Dr. José Fernando Castanha Henriques

Comitê de Ética da FOB-USP
Protocolo nº: 43930715.8.0000.5417
Data: **18 de setembro de 2015**

ERRATA

FOLHA DE APROVAÇÃO

DEDICATÓRIA

Aos meus pais.

Dedico este trabalho, os que o antecederam e

tudo que ainda está por vir

À minha irmã.

O meu melhor presente, minha alma gêmea.

AGRADECIMENTOS

A Deus pelo privilégio de uma vida cercada de amor, pessoas e oportunidades que tornaram isto possível.

Gratidão eterna aos meus pais Azenira e Jorge por uma vida inteira de dedicação, paciência e amor.

Agradecimento especial à minha mãe Alzenira, por ser minha maior inspiração. Por ser extraordinária. Rara.

À minha irmã Larissa. Minha alma gêmea, melhor amiga e melhor companhia durante toda minha vida.

A toda minha familia e amigos pelo amor e por comemorarem comigo cada conquista.

Um agradecimento especial ao Arón, esse ser inexplicável e surpreendente. Meu melhor presente dessa jornada. Obrigada por tanto cuidado, paciência e amor. Amo você.

Às grandes amigas que Bauru me deu. Deborah, Vanessa e Flávia. Vocês fazem parte das minhas melhores memórias.

À minha turma de mestrado que foi excepcional. Arón Aliaga, Camila Massaro, Deborah Brindeiro, Fabiola Alvarez, Felicia Miranda, Ludmila Mangiliardo, Patricia Negreiros, Raquel Poletto, Ricardo Rengifo, Rodolfo Francisco, Sorileé Pujols.

À minha querida turma de Doutorado. Arón Aliaga, Camila Massaro, Carol Gambardela, Deborah Brindeiro, Diego Tonello, Fabiola Alvarez, Felícia Miranda, Ludmila Mangialardo, Paula Cotrin, Raquel Poletto, Wilana Moura. Obrigada por darem mais leveza às obrigações, pela união e por não soltarem a mão de ninguém. Terei sempre um pouco de cada um no meu coração.

Às turmas de mestrado e doutorado pela troca de experiências. Em especial ao Sílvio, pela parceria, força e ajuda imensuráveis.

Agradecimento especial ao meu estimado orientador Prof. José Fernando Castanha Henriques, que sempre teve minha imensa admiração. É uma honra tê-lo como orientador. Obrigada pelos ensinamentos, pela gentileza, pelo respeito e pelo carinho sempre.

À professora Daniela que é uma gigante sem jamais perder a doçura. Tem a capacidade de nos fazer se apaixonar pela ortodontia e desejar ir além. Será sempre uma grande inspiração.

Ao professor Guilherme por ser incansável e nos estimular a dar o melhor de nós. Ao professor Arnaldo, professor Marcos e professor Renato por nos acolherem e dividirem conosco tanto conhecimento.

Agradecimento especial aos professores da Universidade de Michigan, professor Antônio Ruellas, professora Lúcia Cevidanes e professora e amiga Marília Yatabe e família. Gratidão imensa por me permitirem tamanha experiência acadêmica e de vida ao lado de vocês.

À Mayara Patel e ao Roberto Grec que foram muito importantes quando comecei a dar os primeiros passos aqui dentro. Vocês são grandes referências.

À banca examinadora deste trabalho, por aceitarem o convite e por toda a atenção e tempo disponibilizado.

Com muito carinho agradeço aos funcionários e amigos do Departamento de Ortodontia, Cleo, Daniel, Sérgio, Vera e Wagner, pela colaboração e disponibilidade em ajudar sempre. Em especial ao Sérgio que foi um grande parceiro de trabalho.

Aos meus pacientes, pelos quais tenho um carinho imensurável. Vocês transformam nossas vidas. Obrigada pela confiança, pelo carinho e por fazerem parte do meu aprendizado.

À Universidade Federal de Sergipe onde tudo começou.

À Faculdade de Odontologia de Bauru da Universidade de São Paulo na pessoa do diretor Prof. Dr. Carlos Ferreira dos Santos.

À Capes. O presente trabalho foi realizado com apoio da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Código de Financiamento 001

ABSTRACT

ABSTRACT

Three-dimensional evaluation of maxillary molar distalization with skeletal anchorage

Introduction: This study aimed to evaluate the changes after maxillary molar distalization with direct skeletal anchorage, based on cephalometric superimposition of digital dental models evaluations and finite element analysis (FEA). **Methods**: The sample included 23 patients (9 males, 11 females; mean age 13.21 ±1.54 years) treated with the miniscrew anchored Cantilever and 26 patients treated by the First Class skeletally anchored First Class. Lateral cephalograms before and after molar distalization were evaluated with the Dolphin software. Superimposition of digital dental models using an open-source software was performed in Cantilever sample. FEA was performed to comparisons between buccal and palatal distalizing methods with skeletal anchorage. **Results:** In Cantilever sample, all maxillary teeth showed distal movement and palatal (incisors) or distal (posterior teeth) angulation showing statistically significance for the maxillary first premolar and maxillary first and second molars. The vertical changes were minimal. The first and second molars showed crown distal rotation of 19.31 ± 5.71º and 10.17 ± 3.84º, respectively. There was increase in intermolar distance. When Cantilever with direct skeletal anchorage was compared to First Class with indirect anchorage, the maxillary incisor showed palatal inclination (0.75 ± 2.57º) in the Cantilever group, and labial inclination (2.85 ± 3.53º) and protrusion (1.41 ± 1.40mm) in the First Class group. The maxillary first premolar showed distal angulation (4.15 ± 4.87º) and distal movement (1.09 ± 1.54mm) in the Cantilever group and mesial angulation (11.20 ± 24.19º) and mesial movement (2.62 ± 2.08mm) in the First Class group. Regarding FEA, tipping movements were predominant in first and second molars with both modalities, due to the higher displacements values at coronal levels than at apical regions. In the palatal appliance the palatal root showed slight greater displacement than in cantilever appliance, especially regarding distal movement. **Conclusions:** The miniscrew anchored cantilever was effective for maxillary molar distalization with minimal side effects. Three-dimensional displacement was observed for all teeth. Distal movement was progressively greater from anterior to posterior teeth. Both Cantilever and First Class appliances corrected the Class II molar relationship with similar molar distal angulation. Indirect anchorage does not provide absence of anchorage loss. The FEA showed

predominantly tipping movements in both distalization methods and the von mises stress showed different patterns between appliances

Key words: Malocclusion, Angle Class II; Orthodontic appliances; Cephalometry; Dental models.

RESUMO

RESUMO

Avaliação tridimensional da distalização de molares superiores com ancoragem esquelética

Introdução: Este estudo teve como objetivo avaliar as alterações após distalização dos molares superiores com ancoragem esquelética direta, a partir da avaliação cefalométrica e de modelos digitais e da análise de elementos finitos (AEF). **Métodos:** A amostra incluiu 23 pacientes (9 homens, 11 mulheres; idade média de 13,21 ± 1,54 anos) tratados com o Cantilever ancorado diretamente em mini-implante e 26 pacientes tratados com aparelho First Class com ancoragem esquelética indireta. Telerradiografias laterais foram avaliadas antes e após a distalização do molar com o software Dolphin Imaging. A sobreposição de modelos digitais utilizando um software aberto foi realizada na amostra do Cantilever. A AEF foi realizada para comparações entre os métodos de distalização por vestibular e por palatino, ambos com ancoragem esquelética. **Resultados:** Na amostra do Cantilever, todos os dentes superiores apresentaram movimento distal e inclinação para palatino (incisivos) ou mesioangulação (dentes posteriores), sendo estatisticamente significante a alteração ocorrida no primeiro pré-molar superior e no primeiro e segundo molar superior. As mudanças verticais foram mínimas. O primeiro e o segundo molares apresentaram rotação vestibulodistal da coroa de 19,31 ± 5,71º e 10,17 ± 3,84º, respectivamente. Houve aumento da distância intermolar. Quando o Cantilever com ancoragem esquelética direta foi comparado ao First Class ancoragem indireta, o incisivo superior apresentou inclinação palatalina (0,75 ± 2,57º) no grupo Cantilever, e inclinação vestibular (2,85 ± 3,53º) e protrusão (1,41 ± 1,40 mm) no grupo do First Class. O primeiro pré-molar superior apresentou angulação distal (4,15 ± 4,87º) e movimento distal (1,09 ± 1,54mm) no grupo Cantilever e angulação mesial (11,20 ± 24,19º) e movimento mesial (2,62 ± 2,08mm) no grupo do First Class. Em relação à AEF, os movimentos de inclinação foram predominantes no primeiro e no segundo molar em ambos os métodos de distalização, uma vez que maiores valores de deslocamento foram encontrados no nível coronal que nas regiões apicais. No aparelho de distalização por palatino, a raiz palatina apresentou deslocamento ligeiramente maior do que no aparelho por vestibular, principalmente em relação ao movimento distal. **Conclusões:** O Cantilever ancorado a mini-implante foi eficaz para a distalização dos molares superiores com poucos efeitos colaterais. Deslocamento tridimensional foi

observado para todos os dentes após distalização. O movimento distal foi progressivamente maior dos dentes anteriores para os posteriores. Os aparelhos Cantilever e First Class corrigiram a relação molar de Classe II com angulação distal molar semelhante, porém ancoragem indireta não promove absoluta ancoragem. A AEF mostrou movimentos predominantemente de inclinação nos dois métodos de distalização e o Von Misses Stress mostrou padrões diferentes entre os aparelhos.

Palavras-Chave: Má oclusão de Classe II; Aparelhos ortodônticos; Cefalometria; Modelos dentários.

LIST OF ILLUSTRATIONS

ARTICLE 1

Figure 1 - Miniscrew anchored Cantilever. A, sagittal view. B, occlusal view. ... 44

Figure 2 - Intraoral photographs of patient. A, before treatment. B, cantilever positioned. C after distalization. D, treatment whit fixed appliances. E, treatment concluded. 45

Figure 3 - Skeletal, soft tissue and dentoalveolar variables. A, A. SNA; B.SNB; C. ANB; D. A-PTV; E. B-PTV; F. FMA; G. SN.GoGn; H. SN.Occlusal plane; I. Nasolabial angle; J. SL-S line. B, A. Mx1-PTV; B. Mx4-PTV; C. Mx6-PTV; D. Mx7-PTV; E. Mx1-PP; F. Mx4-PP; G. Mx6-PP; H. Mx7-PP; I. Md6-PTV; J. Overjet; K. Overbite; I. Molar relationship. C, A. Mx1.SN; B. Mx4.SN; C. Mx6.SN; D.Mx7.SN; E. Md6.MP. 46

Figure 4 - Superimposed models and ilustration of measurements. A, occlusal view. Intermolar distance was evaluated using mesiovestibular cusps (line 1) and distopalatal cusps (line 2). B, sagittal view. Linear displacements were calculated by distances between point 1 and point 2 in three dimensions. Molar distal angulation was calculated by angle formed between line 3 and line 4 on vertical plane. C, occlusal view. Molar rotation was calculated by angle between line 1 and line 2 on transverse plane. 47

Figure 5 - Mean superimposition of all cephalometric tracings 48

ARTICLE 2

Figure 1 - Distalization appliances. A, miniscrew anchored cantilever; sagittal view. B, skeletally anchorared First Class; occlusal view. 68

Figure 2 - Skeletal, soft tissue and dentoalveolar variables. A, A. SNA; B.SNB; C. ANB; D. Co-A; E. Co-Gn; F. FMA; G. SN.Gn; H. LAFH; I. SN.Occlusal plane; J. Nasolabial angle; K. SL-S line; L. IL-S line . B, A. Mx1-PTV; B. Mx4-PTV; C. Mx6-PTV; D. Mx7-PTV; E. Mx1-PP; F. Mx4-PP; G. Mx6-PP; H. Mx7-PP; I. Md6-PTV; J. Overjet; K. Overbite; I. Molar relationship. C, A. Mx1.SN; B. Mx4.SN; C. Mx6.SN; D.Mx7.SN; E. Md6.MP. 69

Figure 3 - Mean superimposition of cephalometric tracing in Cantilever group. 70

Figure 4 - Mean superimposition of cephalometric tracing in First Class group. 71

ARTICLE 3

Figure 1 - Distalization appliances. A-B, sagittal and occlusal view of Cantilever. C-D, sagittal and occlusal view of palatal appliance........ 87

Figure 2 - Finite element models. 88

Figure 3 - Displacement in x plane. A, occlusal view; B, Buccal view; C, palatal view. 89

Figure 4 - Displacement in y plane. A, occlusal view; B, Buccal view; C, palatal view. 90

Figure 5 - Displacement in z plane. A, occlusal view; B, Buccal view; C, palatal view. 91

Figure 6 - Three-dimensional displacement. A, occlusal view; B, Buccal view; C, palatal view. 92

Figure 7 - Stress distribution. A, occlusal view; B, Buccal view; C, palatal view. 92

Figure 8 - Stress distribution in alveolar bone. Oclusal view. A, model with cantilever appliance. B, model with First Class appliance. 93

LIST OF TABLES

ARTICLE 1

Table I - Initial (T1), post distalization (T2) and treatment changes (T2-T1). Cephalometric measurements and statistical analysis. 49

Table II - 3D linear displacements obtained by superimposition of maxillary digital dental models. Descriptive statistics. 50

Table III - Rotation, angulation and intermolar changes obtained by superimposition of maxillary digital dental models. Descriptive statistics. 51

ARTICLE 2

Table I - Comparison of sex, Class II malocclusion severity, and erupted maxillary second molars distributions, initial and final ages and treatment times... 72

Table II - Pretreatment intergroup cephalometric comparison. 73

Table III - Intergroup treatment changes comparison. 74

ARTICLE 3

Table I - Material properties applied to the various components of the model. 95

Table II - Displacement after application of distalizing force (unit 10^{-3}mm)....... 96

LIST OF ABBREVIATIONS AND ACRONYMS

T1	Pretreatment.
T2	After maxillary first molar distalization.
TADs	Temporary anchorage devices.
3D	Three-dimensional.
CBS	Cranial base superimposition.
MS	Maxillary superimposition.
CAPES	Coordenação de Aperfeiçoamento de Pessoal de Nível Superior.
SN	Sella to Nasion line.
SNA	SN to NA angle.
SNB	SN to NB angle.
ANB	NA to NB angle.
A-Nperp	Linear distance from A point to a Nasion perpendicular line.
P-Nperp	Linear distance from Pogonion point to a Nasion perpendicular line.
FMA	Frankfurt and mandibular plane angle.
SN.GoGn	SN to GoGn angle.
SN.OP	SN to occlusal plane angle.
PTV	Pterygoid vertical line.
Mx1	Maxillary incisor.
Mx4	Maxillary first premolar.
Mx6	maxillary first molar.
Mx7	Maxillary second molar.
PP	Palatal plane.

Md6	Mandibular molar.
MP	Mandibular plane.
NLA	Nasolabial angle.
UL	Upper lip.
LL	Lower lip.
R-L	Right-left.
A-P	Antero-posterior.
S-I	Superior-inferior.
V	Vestibular.
P	Palatal.
6	Maxillary first molar.
7	Maxillary second molar.
FAPESP	Fundação de Amparo à Pesquisa do Estado de São Paulo.
Co-A	Condylion to A-point distance.
Co-Gn	Condylion to gnathion distance.
SN.Gn	SN to SGn angle.
LAFH	ANS, anterior nasal spine to menton distance.
FEA	Finite element analysis.
CTI	Information Technology Center.
CAD	Computer-aided design.
FEMAP	Finite Element Modeling And Postprocessing.
MBC	Mesiobuccal cusp.
MPC	Mesiopalatal cusp.
PR	Palatal root.

TABLE OF CONTENTS

1 INTRODUCTION 21

2 ARTICLES 25

2.1 ARTICLE 1 - Three-dimensional changes after maxillary molar distalization with miniscrew anchored cantilever: A prospective clinical study................... 27

2.2 ARTICLE 2 - Direct versus indirect skeletal anchorage for maxillary molar distalization 53

2.3 ARTICLE 3 - Finite element analysis of two skeletally anchored maxillary molar distalization methods.. 75

3 DISCUSSION.. 99

4 FINAL CONSIDERATIONS 103

REFERENCES 107

APPENDICES.. 113

ANNEXES.. 119

1 Introduction

1 INTRODUCTION

Several protocols have been proposed for Class II malocclusion treatment. In nonextraction protocol, maxillary molar distalization could be used to correct molar relationships in patients with discrepancy between tooth size and arch length in the maxillary arch and minor skeletal discrepancies.[1] Maxillary molars can be moved distally by force systems that require patient compliance including headgear[2] and Wilson maxillary bimetric distalizing arch system.[3] However, protocols that require minimal dependence on patient compliance may produce more predictable results.[4-6]

For this reason, for over a decade, various appliances and intraoral devices for maxillary molars distalization have been proposed as an alternative to reduce the need for patient collaboration. Most of these devices consist generally of an anchorage unit, usually comprising premolars or deciduous molars and an acrylic Nance button, and an active unit which varies according to the type of appliance. The active components of force can be repelling magnets,[7] superelastic nickel-titanium archwires,[8] coil springs on continuous archwire or on a sectional archwire (Jones jig[9] and distal jet[10] appliances), springs in beta titanium alloy (pendulum),[11], and vestibular screws combined with palatal nickel-titanium coilspring (First Class).[12]

These intraoral distalizers are practical resources for correct the molar relationship in a short period of time. These appliances are easy to install and promote distal movement of the maxillary molars without the effect of orthopedic maxilla restriction.[10,13] However, in most of these intraoral methods, the major disadvantage is the undesirable reciprocal anchorage loss, as can be seen by mesial crown movement, tipping and extrusion of incisor and premolar.[1,13-15] In addition, molar tipping is frequently observed in most of the cases.[5,16-18]

In order to obtain a total anchorage resistance and to control the line of action of the distal force, some authors have been developed different systems with skeletal anchorage by miniplates or miniscrews.[19-26]

Although some studies have shown a decrease or absence of anchoring loss with the use of miniscrews, the effects caused by distal movement of molars including distal tipping or extrusion have not yet been solved.[23,27]

The achievement of an ideal force system is challenging and the bodily movement is directly related to the force vector and the center of resistance. In an ideal situation, the direction of force should be as close as possible to the center of resistance of the molar.[23] For this reason, an appliance that allows the adjustment of the force application in relation to the vertical position of the miniscrew is necessary. Thus, the desired line of action of the distal force should be placed closer to the center of resistance of maxillary molars.[23]

The aim of this study is to evaluate the changes after maxillary molar distalization with skeletal anchorage, based on cephalometric, superimposition of digital models and and finite element analysis (FEA).

2 ARTICLES

2 ARTICLES

The articles presented in this thesis were written according to the American Journal of Orthodontics and Dentofacial Orthopedics instructions and guidelines for article submission.

ARTICLE 1 - Three-dimensional changes after maxillary molar distalization with miniscrew anchored cantilever: A prospective clinical study

ARTICLE 2 - Direct versus indirect skeletal anchorage for maxillary molar distalization

ARTICLE 3 - Finite element analysis of two skeletally anchored maxillary molar distalization methods

2.1 ARTICLE 1

Three-dimensional changes after maxillary molar distalization with miniscrew anchored cantilever: A prospective clinical study

ABSTRACT

Introduction: This prospective study aimed to evaluate the skeletal, dentoalveolar and soft tissue changes after maxillary molar distalization in Class II patients, based on cephalometric and superimposition of digital dental models evaluations. **Methods:** The sample included 20 patients (9 male, 11 female; mean age 13.21 ±1.54 years) treated with the miniscrew anchored Cantilever. Lateral radiographs and dental models obtained before (T1) and immediately after molar distalization (T2) were evaluated with the Dolphin software and performing superimposition of digital dental models using an open-source software, respectively. Descriptive statistics was obtained for all measurements and intragroup change comparisons were performed with dependent t test or with Wilxocon test, depending on normality ($P<0.05$). **Results:** The mean distalization time was 0.43 ± 0.13 years. All maxillary teeth showed distal movement and palatal (incisors) or distal (posterior teeth) angulation showing statistically significance for the maxillary first premolar and maxillary first and second molars. The distal movement progressively increased from the incisors to the molars. The vertical changes were minimal and only the first molar showed a small intrusion. The first and second molars showed crown distal rotation of 19.31 ± 5.71º and 10.17 ± 3.84º, respectively. The increase of the maxillary intermolar distance was greater when the mesiovestibular cusps where considered when compared to the increase when the mesiopalatal cusps were considered (2.63 ± 1.56 mm; 1.09 ± 1.86 mm, respectively). **Conclusion:** The miniscrew anchored Cantilever was effective for maxillary molar distalization with minimal side effects. Three-dimensional displacement was observed for all teeth. Distal movement was progressively greater from anterior to posterior teeth.

Keywords: Malocclusion, Angle Class II; Orthodontic Appliances; Cephalometry; Dental Models.

INTRODUCTION

To overcome the disadvantages that extraoral appliances and intermaxilar elastics because of the need of patient compliance, many clinicians use different intraoral distalization appliances to distally move the maxillary molars in Class II malocclusion treatment without extractions. Conventional distalizers show reciprocal anchorage loss[1-4] and great molar tipping. [5-8]

Temporary anchorage devices (TADs) have become widely used and helpful in this type of orthodontic mechanics. Some authors have been developed different intraoral distalization systems with skeletal anchorage involving miniplates or miniscrews.[9-16] Miniscrews have become versatile and are commonly used because of the ease of insertion and removal, the possibility of immediate activation, and the minimal invasiveness, in contrast to miniplates that require greater surgical procedures.[17]

Although some studies have shown a decrease or absence of anchorage loss with the use of miniscrews, the effects caused by distal movement of molars including distal tipping or extrusion have not yet been solved.[13,18] To control the effects in maxillary molar distalization with miniscrews, it is necessary the understanding of the appliances biomechanics.

The achievement of an ideal force system is challenging and the bodily movement is directly related to the force vector and the center of resistance. In an ideal situation, the direction of force should be as close as possible to the center of resistance of the molar. For this reason, an appliance that allows the adjustment of the force application in relation to the vertical position of the miniscrew is necessary. Thus, the desired line of action of the distal force should be placed closer to the center of resistance of maxillary molars.[13]

Tooth movements after distalization mechanics have been commonly analyzed on cephalometric radiographs and less usually on dental models.[19-21] (Few studies have reported three-dimensional analysis to evaluate maxillary molar distalization using superimposition of maxillary dental models. Some described a complex methodology,[22,23] others based their superimpositions in few points either in the papilla area[24] or around the palatal rugae,[25] and other used an additional software to quantify changes.[26] Recently, a new method for superimposition of maxillary digital models using an open-source software has been reported as reliable for normal changes evaluation.[27]

Therefore, the purpose of this prospective clinical study was to evaluate the skeletal, dentoalveolar and soft tissue changes after maxillary molar distalization with the miniscrew anchored cantilever in patients with Class II malocclusion based on cephalometric and superimposition of digital dental models assessments.

MATERIAL AND METHODS

This prospective study was approved by the Ethics in Research Committee of Bauru Dental School, University of São Paulo, Brazil (protocol number 43930715.8.0000.5417). Informed consent was signed by all patients and their legal guardians permitting the treatment was executed.

Sample size calculation was performed based on an alpha error of 5% and beta of 10% to achieve a test power of 90% to detect a mean change of 1.75 mm for the maxillary molar distalization, with a previous reported standard deviation of 1.5 mm.[8] A minimum of 12 patients was necessary.

The patients´ selection criteria included: a minimum of ¼ cusp bilateral Class II molar relationship,[28] all permanent teeth up to the first molars erupted, no severe mandibular crowding, and no previous orthodontic treatment. Patients with craniofacial anomalies or syndromes were excluded.

The sample consisted of 20 patients (9 males, 11 females; mean age 13.21 ±1.54 years). Six patients presented ¼ Cusp; 7, ½ Cusp; 4, ¾ Cusp; and 3, Full Cusp Class II molar relationships. All patients were treated with the cantilever with miniscrew anchorage (Fig 1). An orthodontic miniscrew (8-mm length, 1.5-mm diameter; Morelli, Sorocaba, SP, Brazil) buccally placed between the maxillary first molars and second premolars, with an oblique of 20 to 30º, was used as skeletal anchorage. A cantilever made of 1.0-mm stainless steel wire (Morelli, Sorocaba, SP, Brazil) was inserted and soldered into the circular tube on the maxillary first molar band. After the appliance was cemented, a NiTi closed coil spring (Morelli, Sorocaba, SP, Brazil) from the miniscrew to the cantilever was used as active unit. The height of the cantilever in relation to the miniscrew was adjusted to deliver a horizontal force as close as possible to the center of resistance of the maxillary first molar (Figs 1 and 2). The coil spring was activated once a month to deliver 200g of force. The mean of distalization time was 0.43 years

(±0.13) and the maxillary first molars were distalized until achieve a super Class I molar relationship (Fig 2).[29]

Cephalometric evaluation

All cephalograms obtained before (T1) and after molar distalization (T2) were digitized and digitally evaluated using Dolphin Imaging software 11.5 (Version 11.5, Dolphin Imaging and Management Solutions, Chatsworth, CA, USA). The software corrected the magnification factor of the radiographic images that varied between 9.1% and 9.4%. A total of 27 variables were measured to evaluate the skeletal, dentoalveolar and soft tissue changes (Figs 3A-C). Bilateral structures of interest were averaged.

Digital dental model evaluation

Dental models at T1 and T2 were scanned using a R700 3D scanner (3Shape A/S, Copenhagen, Denmark) and stored as .STL files. These files were converted to .VTK files using SlicerCMF 4.1 software (www.slicer.org). The image analysis was performed in the same software and followed the steps reported by a previously validated method:[27]

1. **Orientation:** The T1 dental models were oriented using the midpalatal raphe, the occlusal plane (defined passing from the first molars to the central incisors), and the (incisal line) in the occlusal (axial), lateral (sagittal) and frontal (coronal) views, respectively.
2. **Approximation:** The T2 models were approximated to the oriented T1 model by a first superimposition of corresponding landmarks placed at the tip of the buccal cusps of first premolars and at the middle of incisal edge of central incisors, on both sides.
3. **Superimposition** (registration): A total of 9 landmarks were placed at the posterior limit of the incisive papilla, at the medial edges of the second palatal rugae, at the medial and lateral edges of the third rugae and at 10 mm distal to the medial edge of third rugae. In addition, regions of interest (20-mm each) were defined around the landmarks placed at the middle edge of the second and third palatal rugae, and around the most posterior landmarks. These procedures were performed for the oriented T1 model and for the approximated T2 model. Subsequently, the software superimposed (registered) the approximated T2 model to the oriented T1 model by

matching the coordinates of the corresponding landmarks and the respective regions of interest.

4. **Quantitative 3D assessment:** Landmarks were placed in the oriented T1 and registered T2 models at the tip of the mesiobuccal and distobuccal cusps of the second molars, mesiobuccal, distobuccal and mesiopalatal cusps of first molars, buccal cusp of the first and second premolars, cusp of canines and at the middle of incisal edge of lateral and central incisors, bilaterally. Finally, the displacements in mm in the coordinates X (right-left), Y (antero-posterior), and Z (superior-inferior) as well as the 3D displacement between T1 and T2 were provided by the software using the Q3DC tool. Forward, inferior and lateral displacements had positive values. Backward, superior and medial displacements had negative values.[27] Lines connecting landmarks placed at the mesiobuccal and distobuccal cusps of the molars were defined at T1 and at T2. Then, the angles between the two lines were calculated to evaluate rotation (yaw) and mesiodistal angulation (pitch) of first and second molars. Additionally, the inter-first molar distances were calculated using landmarks placed at the mesiobuccal and mesiopalatal cusps of the first molars, individually in T1 and T2. (Figs 4A-C)

Error study

Lateral cephalograms and dental models of 50% of the sample were randomly selected and the measurements were repeated by the same examiner after a minimum of 15-day interval. The random errors were evaluated with Dahlberg's formula,[30] and the systematic errors were estimated with dependent t tests at $P<0.05$.

Statistical analyses

Treatment changes were calculated as T2-T1. Means and standard deviations were calculated for all measurements at T1, T2 and for T2-T1. The normal distribution of the variables was evaluated with Shapiro-Wilk tests. Inter-stage changes were compared with dependent t tests in case of normality. The Wilcoxon tests, was performed for not normally distributed variables. For dental models measurements, right and left sides were averaged and descriptive statistics was reported. All statistical analyses were performed with the SPSS software (Version 25.0; IBM, Armonk, NY, USA) and the results were considered significant at $P<0.05$.

RESULTS

For the cephalometric analysis, the random errors varied from 0.26 to 1.01 mm and from 0.44 to 1.75 degrees for the linear and angular measurements, respectively. Only two from the 27 variables showed significant systematic error. For the digital dental models assessment, the random errors varied from 0.1 to 1.48 mm and from 0.86 to 2.19 degrees for the linear and angular measurements, respectively. Only two of the 41 variables demonstrated significant systematic error.

The cephalometric analysis demonstrated that all maxillary teeth showed distal movement and palatal (incisors) or distal (posterior teeth) angulation showing statistically significance for the maxillary first premolar and maxillary first and second molars (Table I). The maxillary first molar showed a statistically significant intrusion. Statistically significant changes were observed for the overjet and molar relationship. These variables showed a small reduction and a great improvement, respectively (Fig 5).

The maxillary dentoalveolar changes evaluated by superimposition of digital dental models showed a minimal lateral displacement for the anterior teeth and second molars and greater lateral displacements for the premolars and first molars (Table II). The greater changes were observed in the anteroposterior displacement. Except the central incisor, all teeth showed distal movement. The amount of this movement was progressively greater from the lateral incisor to the molars. The first molar distalization was greater when measured using the mesiovestibular cusp than using the mesiopalatal cusp. The vertical changes were minimal and only the first molar showed a small intrusion when the mesiopalatal cusp was considered. The greatest 3D displacement changes were observed for the first and second molars, as well.

After the superimposition of the maxillary digital models, the first and second molars showed a crown distal rotation of 19.31 (± 5.71) and 10.17 (± 3.84) degrees, respectively (Table III). It was observed 8.80 (± 3.79) and 6.46 (± 3.30) degrees of distal angulation for the maxillary first and second molars, respectively. In addition, the increase of the maxillary intermolar distance was greater when the mesiovestibular cusps where considered compared to the increase observed when the mesiopalatal cusps were considered (2.63 versus 1.09 mm).

DISCUSSION

Few authors have reported cephalometric and digital dental model analyses at the same study to evaluate maxillary molar distalization.[20,31,32] One clinical study performed these analyses and evaluated maxillary molar distalization with interradicular buccal miniscrews. However, the distalization was delivered simultaneously with orthodontic fixed appliances therapy.[31] Orthodontic fixed appliances were not included during the distalization phase in the present study. Thereby, it was possible to determine the isolated effects of the distalization mechanics and the potential movements occurred in all teeth with no interference of other forces.[14,26,33]

In this study, cephalometric tracings and digital models were used for three-dimensional analysis.

Cephalometric superimposition has been widely used in orthodontics and can reveal skeletal, soft tissue and dentoalveolar changes in both vertical and sagittal dimensions. Dental models analysis can provide further information since involves the evaluation of all teeth, including transverse and rotational changes assessment.

Superimposition of maxillary digital models needs to be performed using stable regions. Palatal rugae have been described as relatively stable references during growth.[34] The distal limit of the incisive papilla and the medial point of palatal rugae have been reported as being more stable during growth and orthodontic treatment. Medial points of the third palatal rugae were found to be stable enough in untreated patients and in patients treated with premolar extractions and en masse retraction.[35,36]

On this regard, few studies have reported contemporary methods for superimposition of digital dental models to evaluate, specifically, distalization of maxillary molars. One study considered only three points to perform the superimposition; the most anterior point, the most prominent point, and the most posterior point of the incisive papilla area.[24] Other study considered three points along the the third rugae, only.[25] Although other study seems to have considered various landmarks in the palatal rugae, they did not deeply explain their superimposition method in detail and used one software to perform the superimposition and another additional software to quantify the changes.[26] Using only three points in the incisive papilla area or along the third rugae could lead to some rotation of the digital dental models in the axial (yaw), coronal (roll), and in the sagittal (pitch) plane. The use of another software to compute the 3D changes after superimposition limits the procedure making it longer.

In this study, an open-source software was used, and landmarks were placed at stable regions, including the posterior limit of incisive papilla and the medial end of second and third rugae. Additionally, two landmarks were placed at the lateral end of third rugae and two more were placed 10 mm posteriorly to the third rugae in order to avoid the rotation of dental models in the coronal plane (roll) and in the sagittal plane (pitch), respectively, during the superimposition.[27] The same software was used to performed the superimposition and to quantify the 3D changes. In addition, the methodology used in this study was previously validated.

Miniscrews are preferred because they are cheaper and less invasive than other methods.[17] The placement of miniscrews in the buccal interradicular bone is one of the most common approaches used to provide skeletal anchorage. The interradicular space is a potentially advantageous region for insertion, because there is less potential for complications related to soft tissue irritation.[31] In this study, miniscrews of 1.5 mm of diameter were inserted at an oblique angle of 20 to 30 degrees to the long axis of the proximal tooth.[31] The reported success rates of miniscrews range from 80% to 95%.[37]. Among the miniscrews installed in the 20 patients included in this study, 3 from 40 screws (7.5%) were loose and need to be removed. In these cases, second screws were inserted successfully during their next visit. Oral hygiene deficiency was the probable cause of screw failure in these cases.

After maxillary molar distalization, all maxillary teeth showed distal movement. The cephalometric analysis showed statistically significant changes for the maxillary first premolar and maxillary first and second molars (Table I), and this could be expected. A meta-analysis revealed that a spontaneous distal movement of the premolars with no incisor protrusion could only be observed using direct skeletal anchorage, because of stretching of the transeptal fibers.[38]

The first molar distally moved 3.38 mm and 4.54 mm according to the cephalometric and digital models analyses (mesiobuccal cusp), respectively. In this study, cranial base and the pterygoid vertical line (Ptv) were used as references for distal movement measurements in cephalometric evaluation, as most of the previous studies.[2,3,5,8] Nevertheless, distalization could be imperfectly assessed by cranial base superimposition (CBS) in growing subjects, especially in adolescents. Maxillary forward growth could lead to misleading interpretations and represent a measurement bias.[39,40] Cozzani et al. compared dentoalveolar maxillary measurements traced by CBS and maxillary superimposition (MS). A slight difference in the horizontal movements relative to molar and premolar was observed in their study, concluding that CBS could underestimate the amount of molar distalization.[39] Therefore, the slight difference between the both methods used in this study, could be considered with no clinical significance and may be explained by the inner characteristics of each method.

In our study, the second premolars distalized 2.15 mm (±0.91) on average. Kilkis et al. used miniplate at the zygomatic region and reported spontaneously distal movement of second premolar of 1.63 mm (±1.90).[33] Bolla et al. reported 2.7 mm of distal movement of second premolar, measured in dental casts, after using the Distal jet appliance.[5] None study with buccal interradicular miniscrew reported the amount of second premolar distalization. Although interdental miniscrews may limit mesiodistal movement of the adjacent tooth, our results are in the range of the reported with different mechanics.

All teeth anterior to the first molar showed some amount of distal movement. Since this behavior facilitate correction of the malocclusion simplifying the subsequent mechanic, it could be speculated that it might reduce the treatment time with orthodontic fixed appliances.[14]

The maxillary first molar distalization with unilateral force application is commonly associated with rotation of the crown. This occurs around the palatal root and can be evaluated by digital models. On this regard, as the mesiobuccal cusp distalize, it also rotates. Therefore, the amount of distalization may be overestimated when this cusp is used as reference. Few studies have evaluated the amount of molar distal movement using the mesiopalatal cusp.[9,19,41] In digital models the maxillary first molar moved 2.61 mm when measured by the mesiopalatal cusp, within 0.43 years, that means a 0.5 mm distalization rate per month.

Some authors suggest it is more effective to distalize the maxillary first molars before eruption of the second molars.[5,29] However, Flores-Mir et al. showed minimal effect of the maxillary second and third molar eruption stages on molar distalization.[42] In the current study, the amount of distalization of second molars were in accordance with previous studies.[26,39,43]

The significant intrusion of first molar, that the cephalometric analysis showed, could be expected. Some intrusion was also noted in the dental model analysis when evaluating the mesiopalatal cusp of the first molar. The distal movement was followed by distal angulation that consequently promote intrusion of the distal cusp. This could have contributed to see this significant intrusion. This intrusive movement was similar to the reported in previous studies that ranged from 0.3 to 0.76 mm.[14,26,31,33]

Although an effort to exert a force closer to the center of resistance of the molar was performed, distal tipping was observed. Distal tipping varying from 3 to 12 degrees have been reported after distalization with skeletal anchorage.[38] Only one study,[33] used buccal distalizing forces, with no association with orthodontic fixed appliances, and reported 6.4 degrees (± 5.4) of molar distal angulation in cephalometric analysis, similar as in the present study. Even when buccal distalizing forces are delivered using miniscrews associated with fixed appliances a distal angulation between 4.8 to 7.2 degrees, could be expected.[31,43]

Regarding molar rotation, it can be a desirable effect in some cases. According to previous study the majority of patients with Class II malocclusion exhibit maxillary first molars that are rotated mesially around their palatal root.[44] Then, some distal rotation associated to buccal distalization forces, as observed in this study, should be welcome. No other studies reported the amount of molar rotation in buccal distalizing appliances.

The intermolar widths increases were expected, as previously reported after the use of skeletally distalizing appliances.[14,20,21] This is favorable to maintain a proper transverse relationship of the maxillary to mandibular molars.

Overall, the miniscrew anchored cantilever corrected the Class II molar relationship by effectively distalizing the maxillary first molars. Some minimal distal angulation and rotation were observed within the acceptable limits after this type of treatment mechanics. The assessment of lateral cephalograms and the superimposition of maxillary digital dental models were very useful to undertsand the three-dimensional effects of this appliance. Further studies evaluating the comprehensive treatment and the stability after Class II malocclusion correction with this appliance should be performed.

CONCLUSIONS

Based on the cephalometric analysis and the superimposition of maxillary digital dental models evaluated in this study, it could be concluded that:

- The miniscrew anchored cantilever was effective for maxillary molar distalization with minimal side effects and no need for patient compliance.
- Lateral, anteroposterior, supero-inferior and 3D displacements were observed for all teeth.
- The greater changes were observed for the anteroposterior displacement.
- Distal movement was progressively greater from anterior to posterior teeth.

ACKNOWLEDGMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001. The authors would like to thank Dr. Luiz Sergio Vieira for his help in the confection of the appliances.

REFERENCES

1. Haydar S, Üner O. Comparison of Jones jig molar distalization appliance with extraoral traction. Am J Orthod Dentofacial Orthop 2000;117:49-53.

2. Runge ME, Martin JT, Bukai F. Analysis of rapid maxillary molar distal movement without patient cooperation. Am J Orthod Dentofacial Orthop 1999;115:153-157.

3. Mavropoulos A, Karamouzos A, Kiliaridis S, Papadopoulos MA. Efficiency of noncompliance simultaneous first and second upper molar distalization: a three-dimensional tooth movement analysis. Angle Orthod 2005;75:532-539.

4. Antonarakis GS, Kiliaridis S. Maxillary molar distalization with noncompliance intramaxillary appliances in class II malocclusion: a systematic review. Angle Orthod 2008;78:1133-1140.

5. Bolla E, Muratore F, Carano A, Bowman SJ. Evaluation of maxillary molar distalization with the distal jet: a comparison with other contemporary methods. Angle Orthod 2002;72:481-494.

6. Chiu PP, McNamara JA, Franchi L. A comparison of two intraoral molar distalization appliances: distal jet versus pendulum. Am J Orthod Dentofacial Orthop 2005;128:353-365.

7. Brickman CD, Sinha PK, Nanda RS. Evaluation of the Jones jig appliance for distal molar movement. Am J Orthod Dentofacial Orthop 2000;118:526-534.

8. Patel MP, Janson G, Henriques JF, de Almeida RR, de Freitas MR, Pinzan A et al. Comparative distalization effects of Jones jig and pendulum appliances. Am J Orthod Dentofacial Orthop 2009;135:336-342.

9. Gelgör İE, Büyükyilmaz T, Karaman AI, Dolanmaz D, Kalayci A. Intraosseous screw-supported upper molar distalization. Angle Orthod 2004;74:838-850.

10. Kircelli BH, Pektas Z, Kircelli C. Maxillary molar distalization with a bone-anchored pendulum appliance. Angle Orthod 2006;76:650-659.

11. Escobar SA, Tellez PA, Moncada CA, Villegas CA, Latorre CM, Oberti G. Distalization of maxillary molars with the bone-supported pendulum: a clinical study. Am J Orthod Dentofacial Orthop 2007;131:545-549.

12. Önçağ G, Seçkin Ö, Dinçer B, Arikan F. Osseointegrated implants with pendulum springs for maxillary molar distalization: a cephalometric study. Am J Orthod Dentofacial Orthop 2007;131:16-26.

13. Lim S-M, Hong R-K. Distal movement of maxillary molars using a lever-arm and mini-implant system. Angle Orthod 2008;78:167-175.

14. Oberti G, Villegas C, Ealo M, Palacio JC, Baccetti T. Maxillary molar distalization with the dual-force distalizer supported by mini-implants: A clinical study. Am J Orthod Dentofacial Orthop 2009;135:282. e281-282. e285.

15. Papadopoulos MA. Orthodontic treatment of Class II malocclusion with miniscrew implants. Am J Orthod Dentofacial Orthop 2008;134:604. e601-604. e616.

16. Cozzani M, Fontana M, Maino G, Maiono G, Palpacelli L, Caprioglio A. Comparison between direct vs indirect anchorage in two miniscrewsupported distalizing devices. Angle Orthod 2016;86:399–406.

17. Kuroda S, Sugawara Y, Deguchi T, Kyung H-M, Takano-Yamamoto T. Clinical use of miniscrew implants as orthodontic anchorage: success rates and postoperative discomfort. Am J Orthod Dentofacial Orthop 2007;131:9-15.

18. Polat-Ozsoy Ö, Kırcelli BH, Arman-Özçırpıcı A, Pektaş ZÖ, Uçkan S. Pendulum appliances with 2 anchorage designs: conventional anchorage vs bone anchorage. Am J Orthod Dentofacial Orthop 2008;133:339. e339-339. e317.

19. Gelgor IE, Karaman AI, Buyukyilmaz T. Comparison of 2 distalization systems supported by intraosseous screws. Am J Orthod Dentofacial Orthop 2007;131:161. e161-161. e168.

20. Nalçaci R, Biçakçi AA, Ozan F. Noncompliance screw supported maxillary molar distalization in a parallel manner. Korean J Orthod 2010;40:250-259.

21. Miresmaeili A, Sajedi A, Moghimbeigi A, Farhadian N. Three-dimensional analysis of the distal movement of maxillary 1st molars in patients fitted with mini-implant-aided trans-palatal arches. Korean J Orthod 2015;45:236-244.

22. Ashmore JL, Kurland BF, King GJ, Wheeler TT, Ghafari J, Ramsay DS. A 3-dimensional analysis of molar movement during headgear treatment. Am J Orthod Dentofacial Orthop s 2002;121:18-29.

23. Lai EH-H, Yao C-CJ, Chang JZ-C, Chen I, Chen Y-J. Three-dimensional dental model analysis of treatment outcomes for protrusive maxillary dentition: comparison of headgear, miniscrew, and miniplate skeletal anchorage Am J Orthod Dentofacial Orthop 2008;134:636-645.

24. Nalcaci R, Kocoglu-Altan AB, Bicakci AA, Ozturk F, Babacan H. A reliable method for evaluating upper molar distalization: Superimposition of three-dimensional digital models. Korean J Orthod 2015;45:82-88.

25. Griblasky I, Latkauskiene D, Jakobsone G. Evaluation of the posterior maxillary teeth movements during Class II correction: 3-dimensional superimposition of casts. Stomatologija 2018;20:96-101.

26. Duran GS, Görgülü S, Dindaroğlu F. Three-dimensional analysis of tooth movements after palatal miniscrew-supported molar distalization. Am J Orthod Dentofacial Orthop 2016;150:188-197.

27. Garib D, Miranda F, Yatabe MS, Lauris JRP, Massaro C, McNamara Jr JA et al. Superimposition of maxillary digital models using the palatal rugae: Does ageing affect the reliability? Orthod Craniofac Res 2019;22:183-193.

28. Andrews LF. The straight-wire appliance: syllabus of philosophy and techniques. 2nd ed. San Diego, CA: LF Andrews Foundation of Orthodontic Education and Research; 1975.

29. Gianelly AA, Vaitaa AS, Thomas WM. The use of magnets to move molars distally. Am J Orthod Dentofacial Orthop 1989;96:161-167.

30. Dahlberg G. Statistical methods for medical and biological students. New york: Interscience Publications; 1940.

31. Yamada K, Kuroda S, Deguchi T, Takano-Yamamoto T, Yamashiro T. Distal movement of maxillary molars using miniscrew anchorage in the buccal interradicular region. Angle Orthod 2009;79:78-84.

32. Bozkaya E, Tortop T, Yüksel S, Kaygısız E. Evaluation of the effects of the hybrid Pendulum in comparison with the conventional Pendulum appliance. Angle Orthod 2019.

33. Kilkis D, Celikoglu M, Nur M, Bayram M, Candirli C. Effects of zygoma-gear appliance for unilateral maxillary molar distalization: a prospective clinical study. Am J Orthod Dentofacial Orthop 2016;150:989-996.

34. Almeida MA, Phillips C, Kula K, Tulloch C. Stability of the palatal rugae as landmarks for analysis of dental casts. Angle Orthod 1995;65:43-48.

35. Ganzer N, Feldmann I, Liv P, Bondemark L. A novel method for superimposition and measurements on maxillary digital 3D models—studies on validity and reliability. Eur J Orthod 2018;40:45-51.

36. Bailey LTJ, Esmailnejad A, Almeida MA. Stability of the palatal rugae as landmarks for analysis of dental casts in extraction and nonextraction cases. Angle Orthod 1996;66:73-78.

37. Park H-S, Jeong S-H, Kwon O-W. Factors affecting the clinical success of screw implants used as orthodontic anchorage. Am J Orthod Dentofacial Orthop 2006;130:18-25.

38. da Costa Grec RH, Janson G, Branco NC, Moura-Grec PG, Patel MP, Henriques JFC. Intraoral distalizer effects with conventional and skeletal anchorage: a meta-analysis. Am J Orthod Dentofacial Orthop 2013;143:602-615.

39. Cozzani M, Fontana M, Maino G, Maino G, Palpacelli L, Caprioglio A. Comparison between direct vs indirect anchorage in two miniscrew-supported distalizing devices. Angle Orthod 2016;86:399-406.

40. Caprioglio A, Cozzani M, Fontana M. Comparative evaluation of molar distalization therapy with erupted second molar: Segmented versus Quad Pendulum appliance. Prog Orthod 2014;15:1.

41. Kinzinger GS, Gülden N, Yildizhan F, Diedrich PR. Efficiency of a skeletonized distal jet appliance supported by miniscrew anchorage for noncompliance maxillary molar distalization. Am J Orthod Dentofacial Orthop 2009;136:578-586.

42. Flores-Mir C, McGrath L, Heo G, Major PW. Efficiency of molar distalization associated with second and third molar eruption stage. Angle Orthod 2012;83:735-742.

43. Lee SK, Abbas NH, Bayome M, Baik U-B, Kook Y-A, Hong M et al. A comparison of treatment effects of total arch distalization using modified C-palatal plate vs buccal miniscrews. Angle Orthod 2018;88:45-51.

44. Lamons FF, Holmes CW. The problem of the rotated maxillary first permanent molar. Am J Orthod Dentofacial Orthop 1961;47:246-272.

FIGURE LEGENDS

Fig.1 Miniscrew anchored Cantilever. **A,** sagittal view. **B,** occlusal view.

Fig.2. Intraoral photographs of patient. **A**, before treatment. **B**, cantilever positioned. **C** after distalization. **D**, treatment whit fixed appliances. **E,** treatment concluded.

Fig.3. Skeletal, soft tissue and dentoalveolar variables. **A,** A. SNA; B.SNB; C. ANB; D. A-PTV; E. B-PTV; F. FMA; G. SN.GoGn; H. SN.Occlusal plane; I. Nasolabial angle; J. SL-S line. **B,** A. Mx1-PTV; B. Mx4-PTV; C. Mx6-PTV; D. Mx7-PTV; E. Mx1-PP; F. Mx4-PP; G. Mx6-PP; H. Mx7-PP; I. Md6-PTV; J. Overjet; K. Overbite; I. Molar relationship. **C,** A. Mx1.SN; B. Mx4.SN; C. Mx6.SN; D.Mx7.SN; E. Md6.MP.

Fig.4. Superimposed models and ilustration of measurements. **A,** occlusal view. Intermolar distance was evaluated using mesiovestibular cusps (line 1) and distopalatal cusps (line 2). **B,** sagittal view. Linear displacements were calculated by distances between point 1 and point 2 in three dimensions. Molar distal angulation was calculated by angle formed between line 3 and line 4 on vertical plane. **C,** occlusal view. Molar rotation was calculated by angle between line 1 and line 2 on transverse plane.

Fig. 5. Mean superimposition of all cephalometric tracings.

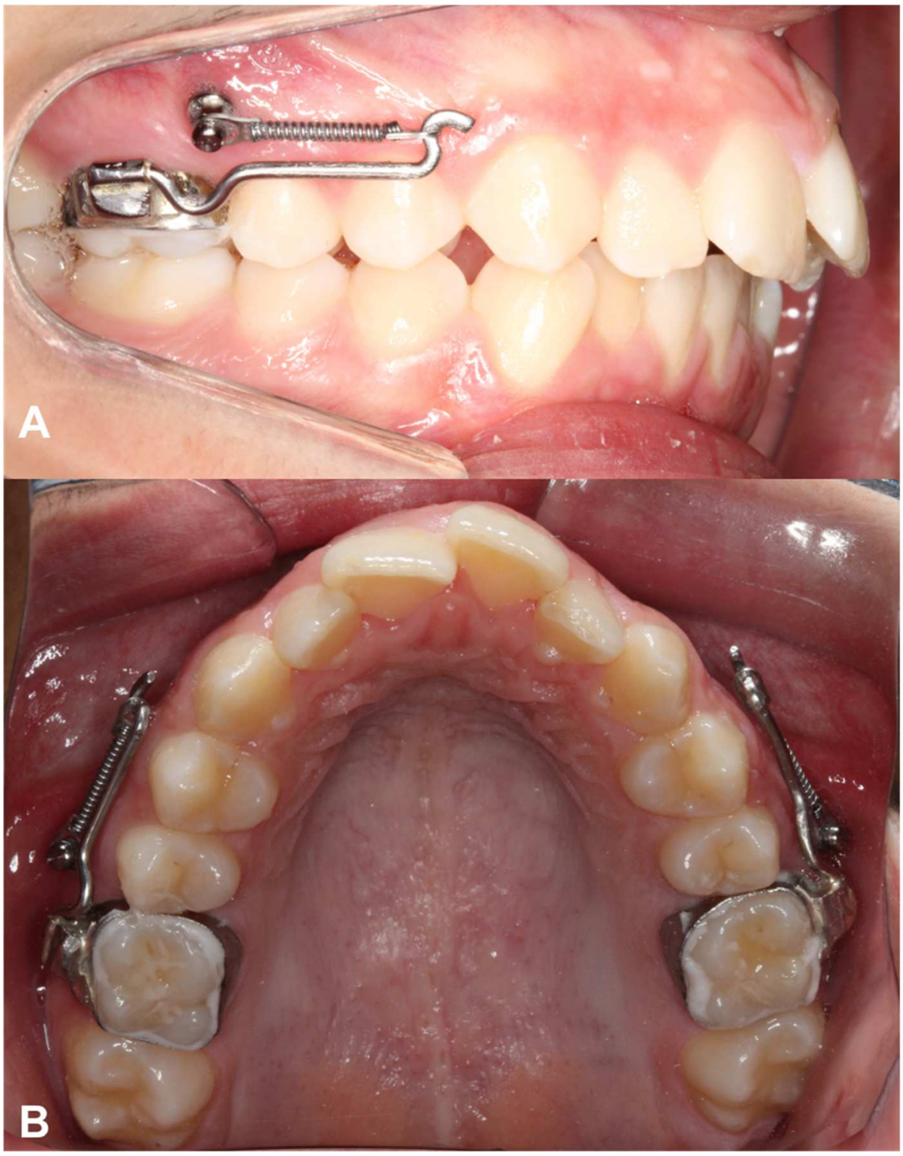


Fig 1.

Fig 2.

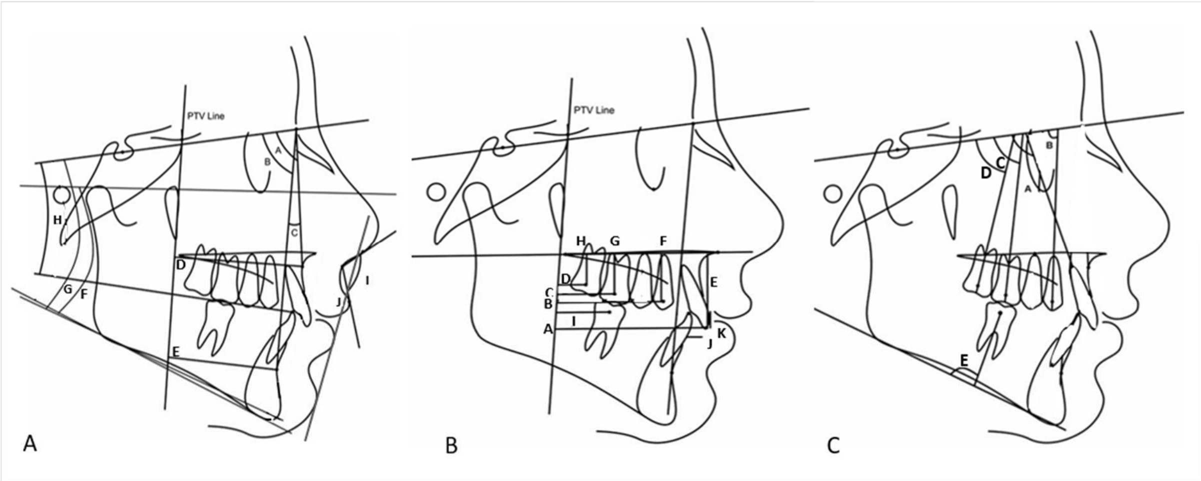


Fig 3.

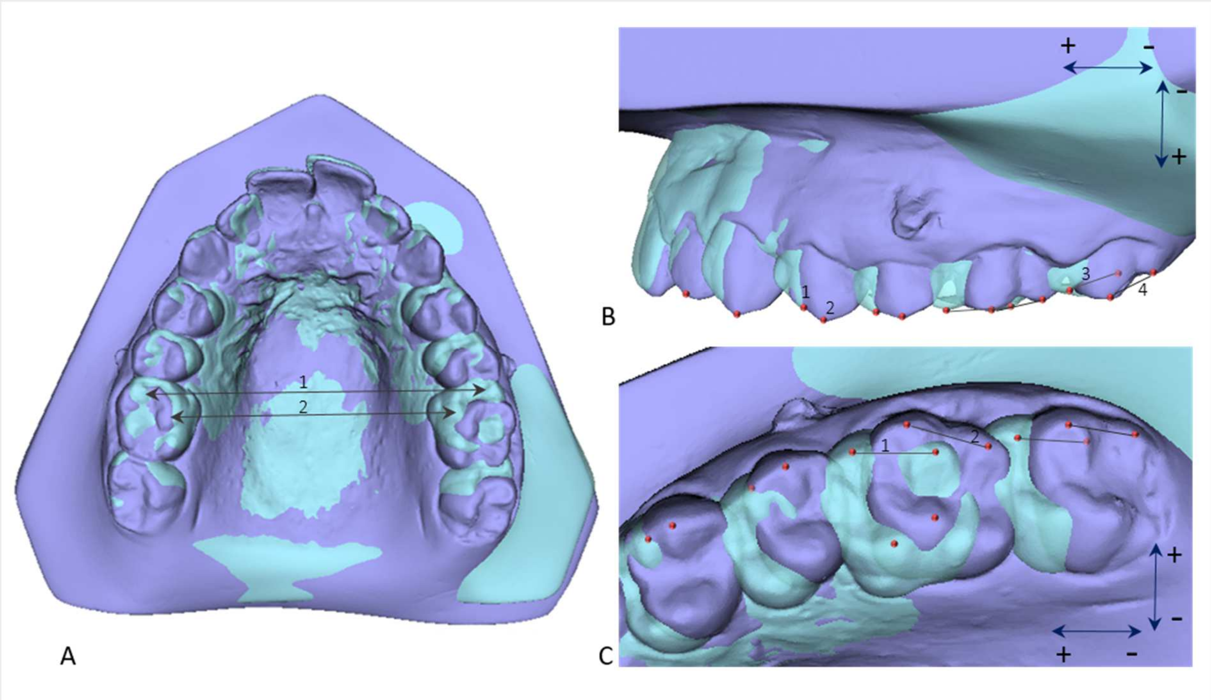


Fig 4.

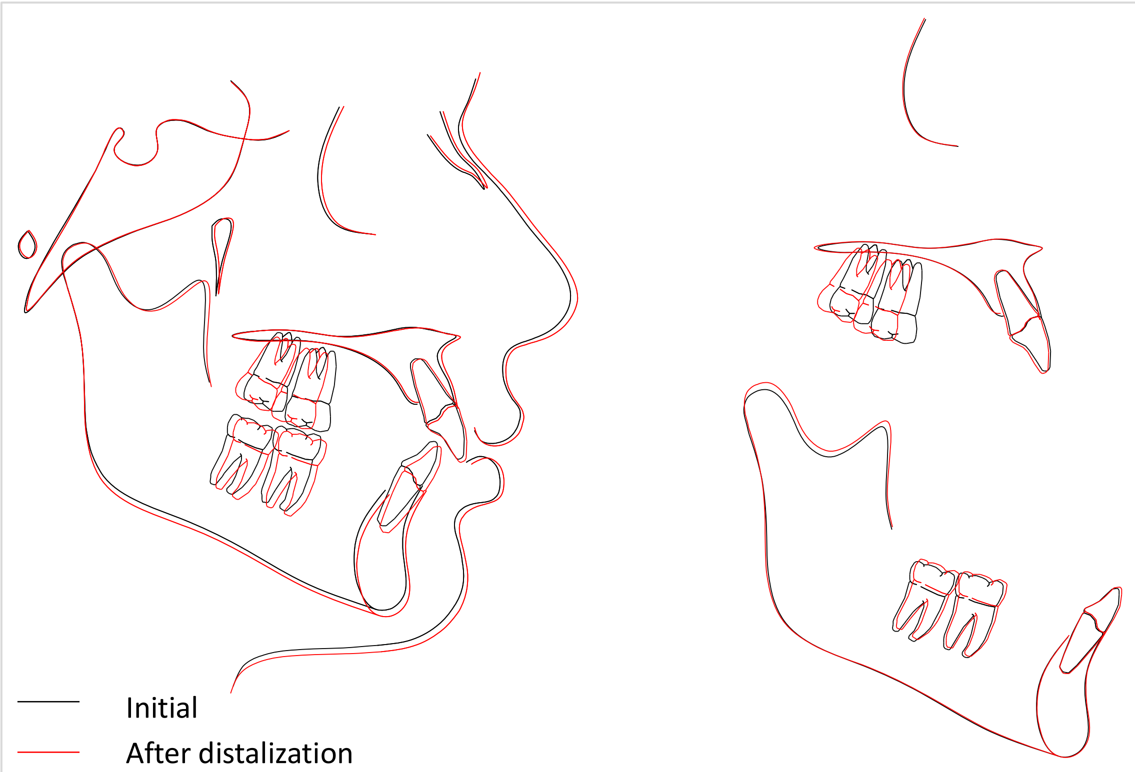


Fig 5.

Table I. Initial (T1), post distalization (T2) and treatment changes (T2-T1). Cephalometric measurements and statistical analysis.

Variable	T1 Mean	T1 SD	T2 Mean	T2 SD	T2-T1 Mean	T2-T1 SD	95%CI Lower	95%CI Upper	P
				Maxillary and madibular skeletal					
SNA	82.25	4.18	82.64	4.16	0.39	4.16	1.03	-0.25	0.219†
SNB	78.06	4.31	78.21	4.35	0.16	4.35	0.61	-0.30	0.483†
ANB	4.21	2.20	4.47	2.07	0.26	2.07	0.64	-0.12	0.163†
A-Nperp	-0.22	2.57	0.34	2.65	0.55	2.65	1.35	-0.25	0.168†
P-Nperp	-7.08	6.22	-5.95	7.11	1.13	7.11	2.69	-0.44	0.148†
				Vertical skeletal					
FMA	25.81	5.14	25.25	5.22	-0.57	5.22	0.19	-1.32	0.136†
SN.GoGn	31.85	6.27	31.63	6.38	-0.22	6.38	0.67	-1.11	0.613†
SN.OP	17.74	6.89	18.13	5.72	0.40	5.72	1.92	-1.13	0.595†
				Maxillary dentoalveolar					
Antero-posterior									
Mx1-Ptv	54.26	4.85	54.21	5.36	-0.05	1.36	0.65	-0.75	0.717‡
Mx4-Ptv	36.14	3.74	34.94	4.19	-1.21	4.19	-0.45	-1.96	0.003†*
Mx6-Ptv	16.29	3.50	12.91	3.51	-3.38	2.51	-2.88	-3.87	0.000†*
Mx7-Ptv	11.79	2.77	9.67	2.83	-2.12	2.83	-1.53	-2.71	0.000†*
Angulation									
Mx1.SN	107.38	7.72	106.37	7.94	-1.02	7.94	0.18	-2.21	0.070‡
Mx4.SN	80.45	5.21	76.16	7.10	-4.29	7.10	-2.09	-6.49	0.001†*
Mx6.SN	72.55	7.02	65.73	8.22	-6.82	8.22	-5.44	-8.19	0.000†*
Mx7.SN	63.14	7.25	54.84	8.36	-8.30	8.36	-5.54	-11.05	0.000†*
Vertical									
Mx1-PP	26.63	2.42	26.93	2.40	0.31	2.40	0.61	0.00	0.050†
Mx4-PP	22.54	2.30	22.78	2.42	0.25	2.42	0.62	-0.13	0.184†
Mx6-PP	20.44	2.41	19.53	2.35	-0.72	2.35	-0.49	-1.34	0.000†*
Mx7-PP	15.58	3.88	15.67	3.89	0.09	3.89	0.82	-0.65	0.810†
				Mandibular dentoalveolar					
Antero-posterior									
Md6-Ptv	13.66	3.97	14.16	3.85	0.50	3.85	1.15	-0.16	0.133†
Angulation									
Md6.MP	92.12	3.52	93.20	4.69	1.08	4.69	3.03	-0.87	0.260†
				Interdental					
Overbite	2.25	1.45	1.94	1.57	-0.31	1.57	0.12	-0.73	0.151†
Overjet	5.79	2.05	5.47	1.85	-0.32	1.85	-0.04	-0.60	0.028†*
Molar relationship	1.75	1.61	-2.94	1.69	-4.69	1.69	-4.08	-5.29	0.000†*
				Soft tissue					
NLA	107.07	8.30	105.68	9.67	-1.40	9.67	1.14	-3.93	0.263†
UL-Sline	1.19	1.25	0.95	1.64	-0.24	1.64	0.19	-0.67	0.260†

†dependent t test; ‡ Wilcoxon.

*Statistically significant at *P* <0.05

Table II. 3D linear displacements obtained by superimposition of maxillary digital dental models. Descriptive statistics.

	R-L				A-P				S-I				3D			
Tooth	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**
1	-0.50	0.75	0.10	0.29	-0.84	1.35	0.01	0.54	-0.69	1.17	0.50	0.47	0.38	2.07	0.98	0.41
2	-0.60	0.75	0.20	0.30	-0.55	1.34	-0.08	0.45	-0.34	1.41	0.54	0.43	0.31	1.65	0.91	0.37
3	-0.31	1.52	0.47	0.41	-2.23	0.66	-0.72	0.76	-0.07	3.36	1.31	0.95	0.51	4.11	1.81	0.99
4	0.26	2.16	1.18	0.58	-3.39	-0.05	-1.48	0.69	-0.16	1.54	0.73	0.45	1.11	4.06	2.19	0.70
5	0.55	3.03	1.58	0.72	-3.98	-0.89	-2.15	0.91	-0.47	1.95	0.51	0.58	1.29	4.83	2.87	1.06
6V	-0.66	2.44	1.29	0.83	-6.73	-2.62	-4.54	1.23	-1.94	1.44	0.15	0.75	3.17	6.79	4.93	1.12
6P	-0.97	1.89	0.62	0.85	-4.83	-0.58	-2.61	1.04	-1.30	1.08	-0.12	0.54	1.12	4.84	2.97	0.99
7	-0.98	1.70	0.53	0.86	-4.86	-2.25	-3.57	0.90	-1.66	1.53	0.22	0.79	2.42	5.24	3.81	0.94

R-L: transversal displacement. A-P: anteroposterior displacement. S-I: vertical displacement. 1. central incisor. 2. lateral incisor. 3. canines. 4. first premolars. 5. second premolars. 6V. first molars using mesiovestibular cusps. 6P. first molars using mesiopalatal cusps. 7. second molars.

Table III. Rotation, angulation and intermolar changes obtained by superimposition of maxillary digital dental models. Descriptive statistics.

	Min	Max	Mean	SD
Rotation				
6	9.56	32.22	19.31	5.71
7	4.59	17.04	10.17	3.84
Mesio Distal Angulation				
6	-15.48	-2.96	-8.80	3.79
7	-13.21	1.17	-6.46	3.30
Intermolar Distances				
6-6(V) T1	45.91	55.34	50.87	2.51
6-6(V) T2	46.86	57.97	53.50	2.69
6-6(V) Change	-0.31	4.87	2.63	1.56
6-6(P) T1	32.63	45.93	40.64	3.11
6-6(P) T2	32.69	45.81	41.73	3.09
6-6(P) Change	-2.55	3.78	1.09	1.86

6. first molars. 7. second molars. (V) mesiovestibular cusps. (P) mesiopalatal cusps

2.2 ARTICLE 2

Direct versus indirect skeletal anchorage for maxillary molar distalization

ABSTRACT

Introduction: This study aimed to compare the effects of direct versus indirect skeletal anchorage for maxillary molar distalization. **Methods:** The Cantilever group comprised 23 patients (9 male; 14 female, mean age of 14.03 years) treated with the miniscrew anchored Cantilever and The First Class group comprised 26 patients (11 male; 15 female) treated with skeletally anchored First Class. Lateral cephalograms were analyzed before and after molar distalization. T tests and Mann-Whitney U tests were used for intergroup comparisons. **Results:** The maxillary incisor showed palatal inclination (0.75 ± 2.57º) in the Cantilever group, and labial inclination (2.85 ± 3.53º) and protrusion (1.41 ± 1.40mm) in the First Class group. The maxillary first premolar showed distal angulation (4.15 ± 4.87º) and distal movement (1.09 ± 1.54mm) in the Cantilever group and mesial angulation (11.20 ± 24.19º) and mesial movement (2.62 ± 2.08mm) in the First Class group. The maxillary first molar distalization and intrusion were significantly greater in the Cantilever group (3.31 ± 1.01mm; -0.75 ± 1.01mm) than in the First Class (1.79 ±1.12; 0.07 ±0.72mm). The Class II molar relationship change was significantly greater in the Cantilever compared to the First Class group. In addition, the treatment time was shorter in the Cantilever group. **Conclusions:** Both appliances corrected the Class II molar relationship with similar molar distal angulation. The miniscrew anchored cantilever showed distal movement of premolars and preservation of incisor sagittal position and a shorter treatment time, while the opposite behavior was observed for the skeletally anchored First Class.

Keywords: Malocclusion, Angle Class II; Orthodontic Appliances, Orthodontic Anchorage Procedures; Cephalometry

INTRODUCTION

Intraoral distalizers are practical resources for the correction of Class molar relationship in a short period of time. These appliances are easy to install and promote distal movement of the maxillary molars without an orthopedic maxilla restriction effect.[1,2] However, in most of these intraoral methods, the major disadvantage is the undesirable reciprocal anchorage loss, as can be seen by mesial crown movement, tipping and extrusion of incisor and premolar.[2-5] In addition, molar tipping is frequently observed in most of the cases.[6-9]

In order to obtain a greater anchorage during mechanics, some authors have been developed different systems using skeletal anchorage by miniplates or miniscrews.[10-17] Based on their reduced invasiveness, ease of insertion and removal, the possibility of immediate loading, and their versatility, the association of miniscrews with distalizing appliances has been increased.[17]

Miniscrews can be direct or indirect skeletal-supported anchorage. In the indirect one, the active component applies the force on the tooth or group of teeth that act as intermediate anchorage elements since they are the ones anchored to the miniscrews.[18].

The main objectives of skeletally anchored molar distalizing therapy are to induce a bodily distal movement and to produce minimal molar distal tipping with no anchorage loss.[19] Many authors have been developed skeletally anchored devices with different designs in order to minimize undesirable effects as the distal tipping and extrusion of the first molars, and protrusion of anterior teeth.[1,6,19] Distalization forces could be applied by the palatal side, buccal side, or bilaterally.

The First Class appliance[19,20] associated with palatal miniscrews delivers bilateral forces to distalize the maxillary molars and uses the second premolars as dental anchorage, these premolars are the ones anchored to the miniscrews. Although its seems a very good option, no studies associating this appliance with skeletal anchorage have been reported. A simple alternative is to perform maxillary molar distalization with distalizers directly anchored to buccal interradicular miniscrews. Some studies reported the use of this approach simultaneously with orthodontic fixed appliances.[21,22] Nevertheless, the isolated distalization effects using these mechanics have not been reported.

Therefore, the aim of this study was to compare the dentoskeletal effects of the miniscrew anchored cantilever (direct anchorage) versus the First Class appliance associated with palatal miniscrews (indirect anchorage) for maxillary molar distalization.

MATERIAL AND METHODS

This study was approved by the Institutional Ethics in Research Committee of Bauru Dental School (Protocol 43930715.8.0000.5417), University of São Paulo, Brazil. Informed consents were obtained from all patients and legal guardians.

A minimum of 21 subject per group was necessary to detect a mean difference of 1.75 mm between the groups for the maxillary first molar distalization, considered as the main outcome, and using a standard deviation of 1.5 mm, as previously reported.[9] Sample size calculation was performed considering an alpha error of 5% and a power of 90%.

The inclusion criteria consisted on the following requirements: to present a minimum of ¼ cusp Class II molar relationship,[23] all permanent teeth up to the first molars erupted, no severe mandibular crowding and no previous orthodontic treatment. were treated at different times. Patients were assigned to treatment when they satisfied the selection criteria. The sample included two groups:

Cantilever Group, comprised 23 patients (9 male; 14 female) treated with the miniscrew anchored cantilever (Fig 1A) at an initial mean age of 13.1 years old (SD 1.52). The cantilever was made of 1.0-mm stainless steel wire (Morelli, Sorocaba, SP, Brazil) welded in the circular tube of the band cemented in the maxillary first molar. It was activated by a closed nickel-titanium (NiTi) coil spring (Morelli, Sorocaba, SP, Brazil) anchored to a buccally positioned miniscrew (8-mm length, 1.5-mm diameter; Morelli, Sorocaba, SP, Brazil), placed between the roots of first molars and second premolars with 20^{o} to 30^{o} of inclination. The height of the miniscrew and cantilever were chosen to apply a force closer to the center of resistance of the molars. The height of the cantilever was manually adjusted, when necessary. The coil spring was activated once a month providing 200g of force.

First Class Group, comprised 26 patients (11 male; 15 female) treated with First Class appliance skeletally anchored to palatal miniscrews (Fig 1B) at an initial mean age of 14.03 years old (SD 1.50). The First Class (Loene®, Florence, Italy) consists of

2 bands on the maxillary first molars and 2 bands on the maxillary second premolars, 2 buccal activation screws (10 mm long) that are soldered to the first molar bands and seated into closed rings welded to the second premolar bands, two 0.010x0.045-in palatally positioned open nickel-titanium coil springs (10 mm long), buccal and palatal tubes.[19] Two miniscrews (6-8 mm length, 1.6-1.8 mm diameter; S.I.N. Implant System, São Paulo, SP, Brazil) were placed anteriorly in the paramedian region of the palate with 45º of insertion. A stainless steel wire (Morelli, Sorocaba, SP, Brazil) was soldered on palatal side of second premolar bands and extended anteriorly until be connected to the miniscrews, promoting an indirect skeletal anchorage. To fixate the extensions to the miniscrews, acrylic resin and a modified acrylic Nance button were used in 12 patients, and in 14 patients, respectively. The patients' guardians activated the appliance by turning the buccally positioned screws a quarter turn in a counterclockwise direction once a day, widening of 0.1 mm.[19]

The Cantilever group was treated exclusively by one operator, and the First Class group was treated by two operators. All treatments were supervised by the same professor. In both groups, the molar relationship was overcorrected until a super Class I relationship was achieved. Each group was treated at different times at the Orthodontic Clinic of Bauru Dental School, University of São Paulo, Brazil.

Lateral cephalograms taken before (T1) and after molar distalization (T2) were digitized and analyzed using the Dolphin Imaging software 11.5 (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA). A total of 29 variables were included in the cephalometric analysis (Fig 2). Bilateral structures were averaged. The software corrected the magnification factor of the cephalograms that varied between 9.1% and 9.4%.

Error study

Thirty per cent of the cephalograms were randomly selected and retraced by the same examiner after a 30-day interval. The random errors and the systematic errors were evaluated using Dahlberg's formula[24] and dependent t tests at $P<0.05$, respectively.

Statistical analyses

Shapiro-Wilk tests were used to evaluated the normal distribution of the variables. Sex distribution were evaluated with the chi-square test. Intergroup comparisons were performed with t tests and Mann-Whitney U tests for variables with and without normal distribution, respectively.

All statistical analyses were performed with SPSS Software (Version 25.0; IBM, Armonk, NY, USA) and the results were considered significant at $P<0.05$.

RESULTS

The random errors varied from 0.28 to 1.02 mm and from 0.61 to 3.48 degrees for the linear and angular variables, respectively. No variables showed significant systematic errors.

The groups were comparable regarding sex distribution, Class II malocclusion severity, presence of second molars and initial mean age (Table I). The Cantilever group presented a significantly smaller final mean age and consequently shorter treatment time than the First Class group.

At pretreatment, the groups were comparable regarding the dentoskeletal and soft tissue characteristics (Table II).

After distalization, the maxillary incisor showed palatal inclination in the Cantilever group and labial inclination in the First Class group (Table III), it also showed a significantly greater protrusion in the First Class group. The maxillary first premolar showed distal angulation and distalization in the Cantilever group and mesial angulation and mesialization in the First Class group (Figs 3 and 4).

The maxillary first molar distalization and intrusion were statistically significant greater in the Cantilever group than in the First Class (Table III). The overjet increased in First Class group and was minimally reduced in the Cantilever group. The Class II molar relationship change was statistically significant greater in the Cantilever compared to the First Class group (Figs 3 and 4).

DISCUSSION

Conventional nonextraction protocols for Class II malocclusion treatment often insufficient due to deficient patient compliance. The use of miniscrews became highly common and are preferred because they are cheaper and less invasive than other temporary anchorage devices (TADs). Miniplates have the disadvantage of the requirement of a mucoperiosteal incision or flap surgery when the plates are placed and removed. Therefore, it is not a minor procedure and the cost increase due to the surgical intervention. [25]

The placement of miniscrews in the buccal interradicular bone is one of the most common approaches used to provide skeletal anchorage in orthodontics. The interradicular space is a potentially advantageous region for insertion, because is relatively comfortable, easy for placement and there is less potential for complications related to the soft tissue.[22,25] Regarding its use for maxillary molar distalization mechanics, it could be argued that the adjacent second premolar would have a limited distal movement. However, 3 mm of distalization per side can be achieved with a properly positioned miniscrew.[26]

Contrary to buccal miniscrews, paramedian miniscrews inserted in the anterior palatal region allows mesiodistal movement of the teeth without significant limitations. However, miniscrew anchored palatal appliances usually require more elaborated desgins and an ideal angulation is not always obtained during manually insertion. Nevertheless, this could be overcome using an implant contra angle handpiece and using an implant motor.[21,27]

The application of force direct to the center of resistance of the tooth is very challenging. Many authors developed different appliance designs associated with miniscrews to control the mesiodistal movement of the molar manipulating the line of action.[15,28] Some studies have reported the use of buccal interradicular miniscrews for molar distalization associated with simultaneously orthodontic fixed appliances.[21,22,29] Others used screws in the infrazygomatic crest to distalize the maxillary dentition.[30] Although they are very good alternatives, they do not allow to evaluate the isolated effects of the maxillary molar distalzation.

In this study, the Cantilever group had buccal direct skeletal anchorage and the First Class group had paramedian palatal indirect skeletal anchorage. Although both mechanics included skeletal anchorage, it does not mean that the anchorage loss would be totally eliminated. This study is important to show the isolated effect of a buccal direct and a palatal indirect skeletal anchorage.

The groups were comparable regarding all dentoeskeletal and soft tissue and other pretreatment characteristics (Tables I and II) which decrease the influence of these factors on treatment changes comparisons.

In this study, the distribution of presence/absence erupted second molars were similar in both groups. The influence of the eruption status of second molars on maxillary first molar distalization is inconclusive. Some authors recommend distalize first molars before eruption of the second molars.[6,31] However, a systematic review showed minimal effect of the maxillary second and third molar eruption stages on first molar distalization.[32] Fortini et al, did not find significant differences in the amount of first molar distalization and distal inclination between subjects with unerupted and those with partially or totally erupted second molars.[19] Other studies also have found no difference in distalization when second molars were or not erupted using different appliances.[7,8]

Both the miniscrew anchored cantilever and the skeletally anchored First Class appliances showed a successful distalization of maxillary first molar to a Class I molar relationship (Table III). However, the different designs of the appliances and the direct or indirect skeletal anchored characteristics lead to some different dental movements.

The distalization time was significantly greater in the First Class group, and the final age of this group was greater than the Cantilever group, as consequence (Table I). The rate of distalization for the Cantilever and First Class groups was 0.5 and 0.2 mm per month, respectively. The distalization rate showed by the First Class group is among the smallest rates reported.[21] Probably the friction between the wire and tube, and the need of a daily activation of the buccal screws, may have reduced the distalization rate on this group.

The bucco-lingual and mesiodistal angulation and sagittal movement of all maxillary teeth anterior to the first molar showed statistically significant differences between groups (Table III). Spontaneous distal movement of the premolars and no incisor protrusion have only been reported using direct skeletal anchorage.[33] In the Cantilever group, the incisor showed palatal inclination and practically remained in a stable position; and the first premolar showed a distal angulation of 4.15 degrees and distal movement of 1.09 mm. It has been already reported that premolars move distally because of the action of transeptal fibers.[11,13,15] It could be thought, that interdental miniscrews might limit distal movement of the adjacent tooth. However; according to some authors, interradicular miniscrews may not interfere with tooth movement when they are obliquely inserted in the alveolar bone with adequate buccolingual thickness.[21,22] Cozzani et al reported 1.9 mm of spontaneous first premolar distalization with miniscrew palatally positioned between maxillary first molar and second premolar. However, there is no clinical studies with buccal interradicular miniscrew that report the amounts of premolar distal movement after maxillary molar distalization.

In contrast, the First Class group showed 2.85 degrees of buccal inclination and 1.41 mm of anterior movement of incisors. Additionally, this group showed 11.2 degrees of mesial angulation and 2.62 mm of mesial movement of first premolars. This could be expected because of the appliance design. Other studies that used indirect skeletal anchorage have shown similar results.[34,35] It might be resulted by the reaction force, in conjunction with other factors, such as movement of the miniscrew due to bone elasticity and the absence of osseointegration or flexibility of the wire that connect the premolar to miniscrew.[33,35]

The Cantilever group demonstrated a slight intrusive movement of first molar while the First Class group remained almost vertically stable. It may be related to the difference in the appliances design. Since the First Class is a more rigid device with bilateral units, smaller vertical effects could be expected.

It has been reported that after distalization, the first molar distal angulation varies from 3 to 12 degrees when skeletal anchorage is used.[33] Although some studies suggest that the line of action of the distal force on the palatal side, applies the force superiorly to the crown of the maxillary first molar and promotes predominantly body movement[1,6,19] the both buccal and palatal groups showed similar molar distal angulation in this current study.

Fortini et. al and Papadopoulos et. al evaluated the First Class appliance and found a mean of first molar distal angulation of 4.6 and 8.56 degrees, respectively. In our study the mean distal angulation was 5.73 in the First Class group. This value was slightly smaller than in the Cantilever group, that presented 6.84. However, this 1.11 degrees of difference was not statistically significant. Indeed, it is also not clinically singnificant.

Regarding the studies that used buccal distalizing forces without the association of fixed appliances during distalization, only one author reported a mean of 6.4 degrees of first molar distal angulation. However, miniplates in zygomatic region were used as anchorage.[36] Yamada et. al and Lee et. al found 4.8 and 7.2 degrees of first molar distal angulation, respectively, with buccal interradicular miniscrew for distalization, when using fixed appliances simultaneously.[21,29] The 6.84 degrees of distal angulation observed in the Cantilever group are within the reported limits.

In this study, the clinical success of maxillary molar distalization and Class II relationship correction was observed in both groups. However, the amount of distalization and molar relationship improvement were significantly greater in the Cantilever group than in First Class group. The numerical, but no statistically significant, greater initial Class II severity showed in the Cantilever group for the molar relationship variable may have played a role to find these differences.

The overjet reduced minimally in the Cantilever group and increased in First Class group. It was expected since distal movement of all teeth was observed in the group with direct skeletal anchorage in contrast with the group with indirect skeletal anchorage that presented mesial movement of anterior teeth. Fewer undesirable effects simplify subsequent mechanic. Consequently, it is possible to assume that the following treatment time with fixed appliance would be reduced.[15]

Further studies comparing the three-dimensional dentoalveolar effects between these appliances by means of superimposition of maxillary digital dental models should be performed to complement the results of the present study. In addition, future comparisons regarding cephalometric changes and treatment efficiency between the appliances after full comprehensive treatment with orthodontic fixed appliances should be done.

CONCLUSIONS

Based on the results of this study, it could be concluded that:

- The miniscrew anchored cantilvever (direct anchorage) and the skeletally anchored First Class (indirect anchorage) were effective for maxillary molar distalization and successfully corrected the Class II molar relationship with similar molar distal angulation.
- Indirect anchorage does not provide absence of anchorage loss;
- The miniscrew anchored cantilever showed distal movement of premolars, preservation of incisor position and a shorter treatment time, while the opposite behavior was observed for the First Class with indirect skeletal anchorage.

ACKNOWLEDGMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001 and by grant #: 2009/04843-7 and 2011/17126-1, São Paulo Research Foundation (FAPESP). The authors would like to thank Dr. Luiz Sergio Vieira for his help in the confection of the appliances.

REFERENCES

1. Carano A, Testa M. The distal jet for upper molar distalization. J Clin Orthod 1996;30:374-380.

2. Haydar S, Üner O. Comparison of Jones jig molar distalization appliance with extraoral traction. Am J Orthod Dentofacial Orthop 2000;117:49-53.

3. Runge ME, Martin JT, Bukai F. Analysis of rapid maxillary molar distal movement without patient cooperation. Am J Orthod Dentofacial Orthop 1999;115:153-157.

4. Mavropoulos A, Karamouzos A, Kiliaridis S, Papadopoulos MA. Efficiency of noncompliance simultaneous first and second upper molar distalization: a three-dimensional tooth movement analysis. Angle Orthod 2005;75:532-539.

5. Antonarakis GS, Kiliaridis S. Maxillary molar distalization with noncompliance intramaxillary appliances in class II malocclusion: a systematic review. Angle Orthod 2008;78:1133-1140.

6. Bolla E, Muratore F, Carano A, Bowman SJ. Evaluation of maxillary molar distalization with the distal jet: a comparison with other contemporary methods. Angle Orthod 2002;72:481-494.

7. Chiu PP, McNamara JA, Franchi L. A comparison of two intraoral molar distalization appliances: distal jet versus pendulum. Am J Orthod Dentofacial Orthop 2005;128:353-365.

8. Brickman CD, Sinha PK, Nanda RS. Evaluation of the Jones jig appliance for distal molar movement. Am J Orthod Dentofacial Orthop 2000;118:526-534.

9. Patel MP, Janson G, Henriques JF, de Almeida RR, de Freitas MR, Pinzan A et al. Comparative distalization effects of Jones jig and pendulum appliances. Am J Orthod Dentofacial Orthop 2009;135:336-342.

10. Gelgör İE, Büyükyilmaz T, Karaman AI, Dolanmaz D, Kalayci A. Intraosseous screw-supported upper molar distalization. Angle Orthod 2004;74:838-850.

11. Kircelli BH, Pektas Z, Kircelli C. Maxillary molar distalization with a bone-anchored pendulum appliance. Angle Orthod 2006;76:650-659.

12. Escobar SA, Tellez PA, Moncada CA, Villegas CA, Latorre CM, Oberti G. Distalization of maxillary molars with the bone-supported pendulum: a clinical study. Am J Orthod Dentofacial Orthop 2007;131:545-549.

13. Önçağ G, Seçkin Ö, Dinçer B, Arikan F. Osseointegrated implants with pendulum springs for maxillary molar distalization: a cephalometric study. Am J Orthod Dentofacial Orthop 2007;131:16-26.

14. Lim S-M, Hong R-K. Distal movement of maxillary molars using a lever-arm and mini-implant system. Angle Orthod 2008;78:167-175.

15. Oberti G, Villegas C, Ealo M, Palacio JC, Baccetti T. Maxillary molar distalization with the dual-force distalizer supported by mini-implants: A clinical study. Am J Orthod Dentofacial Orthop 2009;135:282. e281-282. e285.

16. Papadopoulos MA. Orthodontic treatment of Class II malocclusion with miniscrew implants. Am J Orthod Dentofacial Orthop 2008;134:604. e601-604. e616.

17. Cozzani M, Fontana M, Maino G, Maiono G, Palpacelli L, Caprioglio A. Comparison between direct vs indirect anchorage in two miniscrewsupported distalizing devices. Angle Orthod 2016;86:399–406.

18. Kinzinger G, Wehrbein H, Byloff FK, Yildizhan F, Diedrich P. Innovative Anchorage Alternatives for Molar Distalization—an Overview*. Journal of Orofacial Orthopedics/Fortschritte der Kieferorthopädie 2005;66:397-413.

19. Fortini A, Lupoli M, Giuntoli F, Franchi L. Dentoskeletal effects induced by rapid molar distalization with the first class appliance. Am J Orthod Dentofacial Orthop 2004;125:697-704.

20. Papadopoulos MA, Melkos AB, Athanasiou AE. Noncompliance maxillary molar distalization with the first class appliance: a randomized controlled trial. Am J Orthod Dentofacial Orthop 2010;137:586. e581-586. e513.

21. Yamada K, Kuroda S, Deguchi T, Takano-Yamamoto T, Yamashiro T. Distal movement of maxillary molars using miniscrew anchorage in the buccal interradicular region. Angle Orthod 2009;79:78-84.

22. Kuroda S, Hichijo N, Sato M, Mino A, Tamamura N, Iwata M et al. Long-term stability of maxillary group distalization with interradicular miniscrews in a patient with a Class II Division 2 malocclusion. Am J Orthod Dentofacial Orthop 2016;149:912-922.

23. Andrews LF. The straight-wire appliance: syllabus of philosophy and techniques. 2nd ed. San Diego, CA: LF Andrews Foundation of Orthodontic Education and Research; 1975.

24. Dahlberg G. Statistical methods for medical and biological students. New york: Interscience Publications; 1940.

25. Kuroda S, Sugawara Y, Deguchi T, Kyung H-M, Takano-Yamamoto T. Clinical use of miniscrew implants as orthodontic anchorage: success rates and postoperative discomfort. Am J Orthod Dentofacial Orthop 2007;131:9-15.

26. Miresmaeili A, Sajedi A, Moghimbeigi A, Farhadian N. Three-dimensional analysis of the distal movement of maxillary 1st molars in patients fitted with mini-implant-aided trans-palatal arches. Korean J Orthod 2015;45:236-244.

27. Arcuri C, Muzzi F, Santini F, Barlattani A, Giancotti A. J Oral Maxillofac Surg. Journal of oral and maxillofacial surgery 2007;65:2492-2497.

28. Nalçaci R, Biçakçi AA, Ozan F. Noncompliance screw supported maxillary molar distalization in a parallel manner. Korean J Orthod 2010;40:250-259.

29. Lee SK, Abbas NH, Bayome M, Baik U-B, Kook Y-A, Hong M et al. A comparison of treatment effects of total arch distalization using modified C-palatal plate vs buccal miniscrews. Angle Orthod 2018;88:45-51.

30. Wu X, Liu H, Luo C, Li Y, Ding Y. Three-Dimensional Evaluation on the Effect of Maxillary Dentition Distalization With Miniscrews Implanted in the Infrazygomatic Crest. Implant Dent 2018;27:22-27.

31. Gianelly AA, Vaitaa AS, Thomas WM. The use of magnets to move molars distally. Am J Orthod Dentofacial Orthop 1989;96:161-167.

32. Flores-Mir C, McGrath L, Heo G, Major PW. Efficiency of molar distalization associated with second and third molar eruption stage. Angle Orthod 2012;83:735-742.

33. da Costa Grec RH, Janson G, Branco NC, Moura-Grec PG, Patel MP, Henriques JFC. Intraoral distalizer effects with conventional and skeletal anchorage: a meta-analysis. Am J Orthod Dentofacial Orthop 2013;143:602-615.

34. Kinzinger GS, Gülden N, Yildizhan F, Diedrich PR. Efficiency of a skeletonized distal jet appliance supported by miniscrew anchorage for noncompliance maxillary molar distalization. Am J Orthod Dentofacial Orthop 2009;136:578-586.

35. Gelgor IE, Karaman AI, Buyukyilmaz T. Comparison of 2 distalization systems supported by intraosseous screws. Am J Orthod Dentofacial Orthop 2007;131:161. e161-161. e168.

36. Kilkis D, Celikoglu M, Nur M, Bayram M, Candirli C. Effects of zygoma-gear appliance for unilateral maxillary molar distalization: a prospective clinical study. Am J Orthod Dentofacial Orthop 2016;150:989-996.

FIGURE LEGENDS

Fig.1. Distalization appliances. **A**, miniscrew anchored cantilever; sagittal view. **B**, skeletally anchorared First Class; occlusal view.

Fig.2. Skeletal, soft tissue and dentoalveolar variables. **A,** A. SNA; B.SNB; C. ANB; D. Co-A; E. Co-Gn; F. FMA; G. SN.Gn; H. LAFH; I. SN.Occlusal plane; J. Nasolabial angle; K. SL-S line; L. IL-S line . **B,** A. Mx1-PTV; B. Mx4-PTV; C. Mx6-PTV; D. Mx7-PTV; E. Mx1-PP; F. Mx4-PP; G. Mx6-PP; H. Mx7-PP; I. Md6-PTV; J. Overjet; K. Overbite; I. Molar relationship. **C,** A. Mx1.SN; B. Mx4.SN; C. Mx6.SN; D.Mx7.SN; E. Md6.MP.

Fig.3. Mean superimposition of cephalometric tracing in Cantilever group. Black line (pretreatment), Red line (after distalization of maxillary first molars).

Fig.4. Mean superimposition of cephalometric tracing in First Class group. Black line (pretreatment), Red line (after distalization of maxillary first molars).

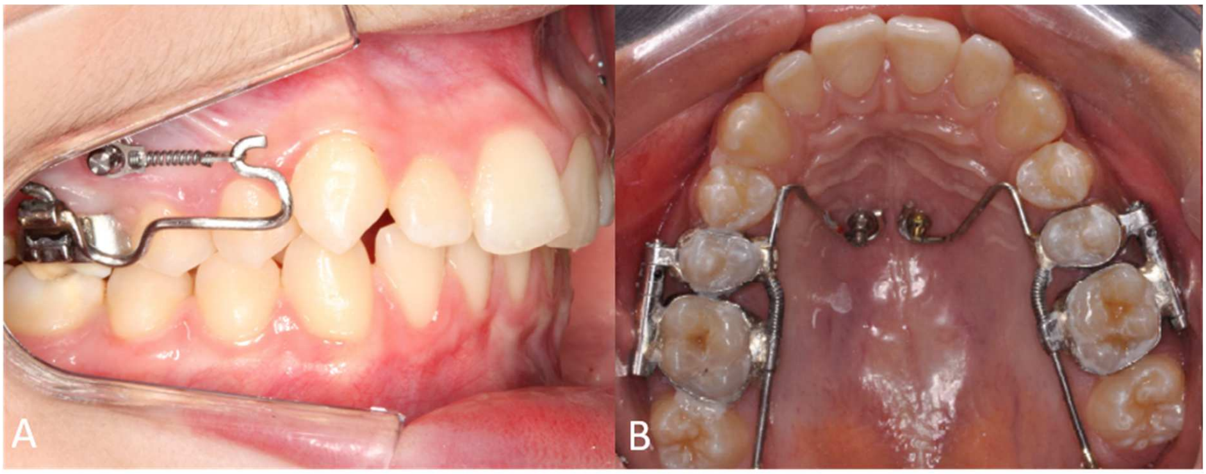


Fig 1.

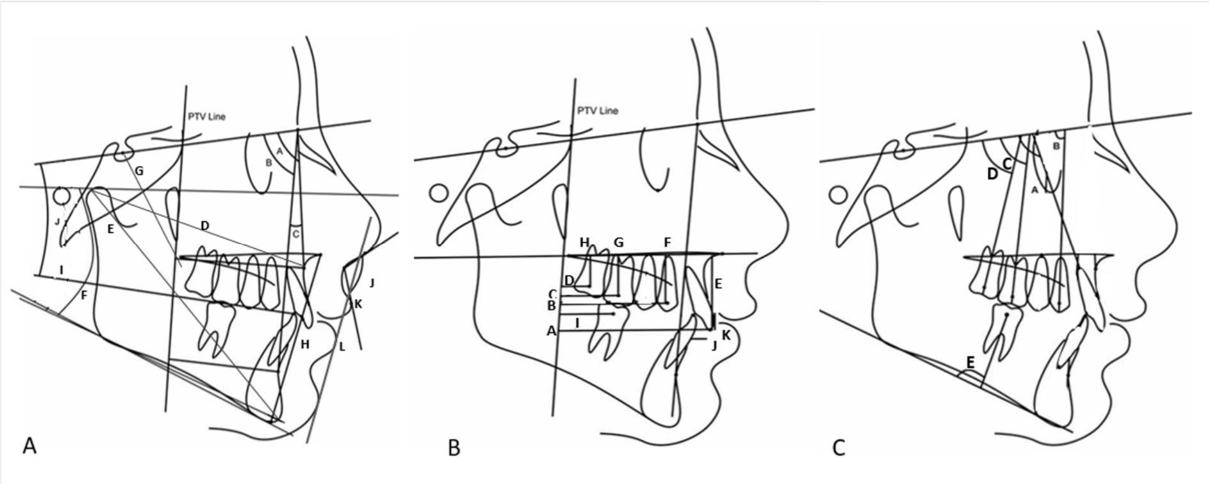


Fig 2.

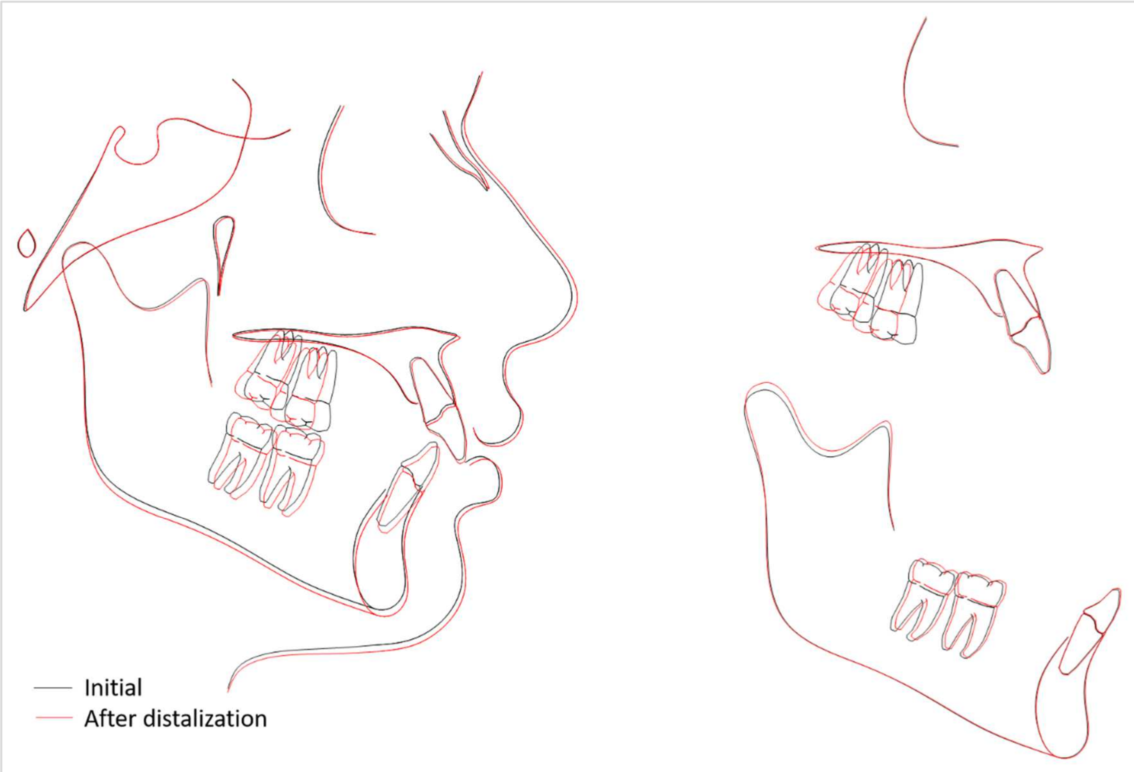


Fig 3.

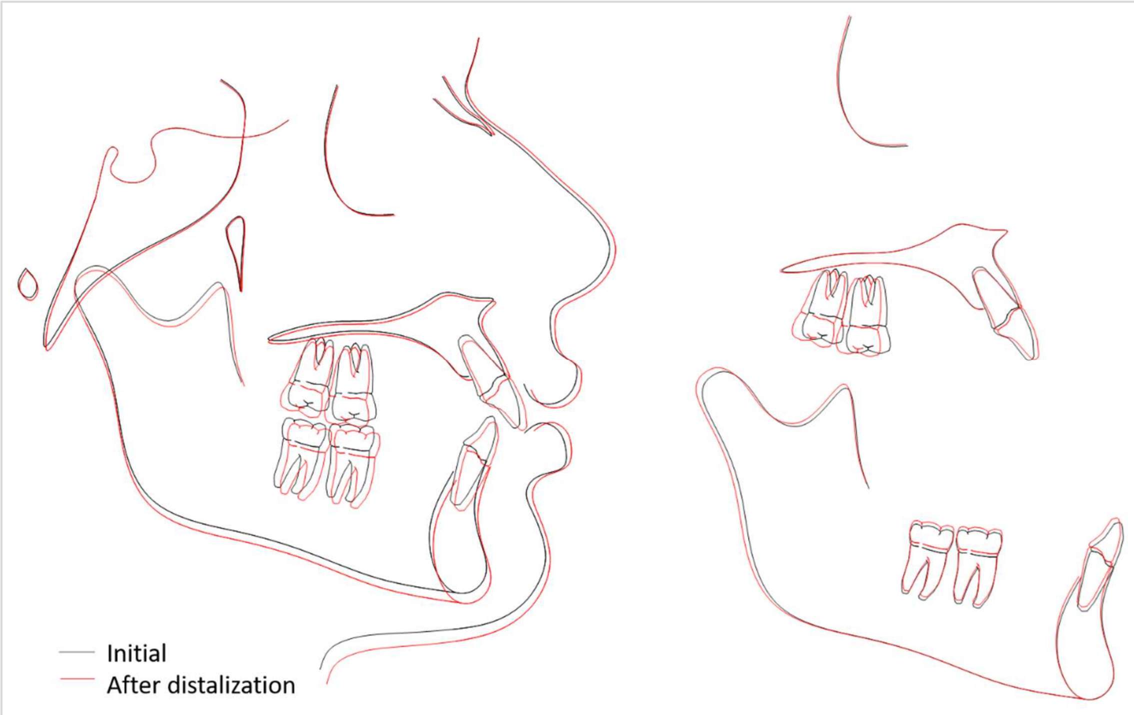


Fig 4.

Table I. Comparison of sex, Class II malocclusion severity, and erupted maxillary second molars distributions, initial and final ages and treatment times.

Variable	Cantilever Group n=23		First Class Group n=26		P
Sex					
Male	9 (39.1%)		11 (42.3%)		0.821€
Female	14 (60.9%)		15 (57.7%)		
Malocclusion severity					
¼ cusp Class II	6 (26.1%)		8 (30.8%)		0.778€
½ cusp Class II	10 (43.5%)		12 (46.2%)		
¾ cusp Class II	3 (13.0%)		4 (15.4%)		
Full cusp Class II	4 (17.4%)		2 (7.7%)		
Presence of second molars					
Erupted	17 (73.9%)		20 (76.9%)		0.807€
Non erupted	6 (26.1%)		6 (23.1)		
	Mean	**SD**	**Mean**	**SD**	
Initial age	13.10	1.52	14.03	1.50	0.054†
Final age	13.45	1.54	14.79	1.45	0.010†*
Treatment time	0.43	0.13	0.76	0.35	0.001†*

€Chi-Square test; † t test

*Statistically significant at *P*<0.05.

Table II. Pretreatment intergroup cephalometric comparison

Variables	Cantilever Group (n=23) Mean	SD	First Class Group (n=26) Mean	SD	Mean difference	95% CI		*P*
				Maxillary and madibular skeletal				
SNA	81.97	3.99	82.36	4.12	-0.39	-2.73	1.95	0.740†
SNB	77.83	4.16	78.32	3.37	-0.50	-2.66	1.67	0.646†
ANB	4.16	2.11	4.04	2.26	0.11	-1.15	1.38	0.856†
Co-A	80.17	5.23	79.72	4.64	0.45	-2.38	3.29	0.749†
Co-Gn	106.85	6.93	107.05	4.78	-0.20	-3.59	3.19	0.905†
				Vertical skeletal				
FMA	25.95	5.28	26.51	4.92	-0.56	-3.49	2.38	0.705†
SN.GN	61.50	4.89	61.75	4.60	0.02	-2.42	2.46	0.464‡
LAFH	67.45	4.81	67.43	3.66	-0.25	-2.98	2.48	0.855†
SN.OP	17.89	6.60	16.52	4.99	1.37	-1.97	4.71	0.394‡
				Maxillary dentoalveolar				
Mx1.SN	107.29	7.36	104.23	6.24	3.06	-0.85	6.97	0.331‡
Mx1-Ptv	53.64	4.81	52.74	4.49	0.90	-1.77	3.57	0.896‡
Mx1-PP	26.66	2.31	27.20	2.78	-0.55	-2.03	0.93	0.461†
Mx4.SN	80.55	5.70	74.21	14.41	6.34	-4.15	16.83	0.249‡
Mx4-Ptv	35.49	3.94	35.45	4.05	0.04	-2.27	2.34	0.974†
Mx4-PP	22.50	2.24	22.47	2.47	0.03	-1.33	1.39	0.968†
Mx6.SN	71.82	6.85	74.47	4.75	-2.65	-6.10	0.80	0.089‡
Mx6-Ptv	15.76	3.56	15.99	3.47	-0.23	-2.25	1.80	0.822†
Mx6-PP	20.36	2.36	20.13	2.08	0.23	-1.04	1.51	0.714†
Mx7.SN	62.43	7.91	64.15	6.21	-1.72	-5.78	2.34	0.399†
Mx7-Ptv	11.50	2.75	11.53	3.16	-0.03	-1.75	1.68	0.968†
Mx7-PP	15.13	4.07	16.33	2.58	-1.20	-3.14	0.74	0.219†
				Mandibular dentoalveolar				
Md6.MP	92.53	3.69	90.28	4.05	2.24	0.00	4.48	0.050†
Md6-Ptv	13.11	4.06	14.38	3.77	-1.27	-3.52	0.98	0.261†
				Interdental				
Overbite	2.30	1.40	1.95	1.55	0.35	-0.50	1.20	0.413†
Overjet	5.95	2.22	4.93	1.60	1.01	-0.09	2.12	0.067†
Molar relationship	1.75	1.54	0.90	1.40	0.85	0.01	1.69	0.050†
				Soft tissue				
NLA	106.76	7.99	105.35	10.66	1.41	-4.07	6.88	0.608†
UL-S line	1.19	1.23	1.12	1.50	0.08	-0.72	0.87	0.848†
LL-S line	1.47	2.16	1.37	1.68	0.09	-1.01	1.20	0.867†

†t test. ‡Mann-Whitney U test.
*Statistically significant at *P* <0.05.

Table III. Intergroup treatment changes comparison

Variables	Cantilever Group (n=23) Mean	Cantilever Group (n=23) SD	First Class Group (n=26) Mean	First Class Group (n=26) SD	Mean difference	95% CI		P
				Maxillary and madibular skeletal				
SNA	0.37	1.32	0.19	1.54	0.18	-0.66	1.01	0.670†
SNB	0.14	0.92	0.07	0.81	0.08	-0.42	0.58	0.753†
ANB	0.25	0.78	0.12	1.25	0.13	-0.48	0.74	0.663†
Co-A	0.45	1.79	1.02	2.07	-0.57	-1.69	0.55	0.098†
Co-Gn	0.97	1.60	1.73	2.75	-0.76	-2.08	0.55	0.111†
				Vertical skeletal				
FMA	-0.60	1.51	0.03	1.77	-0.63	-1.59	0.32	0.088‡
SN.GN	0.30	1.38	0.22	0.76	0.08	-0.55	0.71	0.974†
LAFH	0.87	1.26	1.30	1.97	-0.42	-1.39	0.54	0.207‡
SN.OP	0.58	3.28	-0.88	2.80	1.46	-0.29	3.21	0.100†
				Maxillary dentoalveolar				
Mx1.SN	-0.75	2.57	2.85	3.53	-3.61	-5.40	-1.81	0.000†*
Mx1-PTV	0.02	1.41	1.41	1.40	-1.39	-2.20	-0.58	0.001†*
Mx1-PP	0.22	0.69	-0.07	1.16	0.29	-0.27	0.85	0.188‡
Mx4.SN	-4.15	4.87	11.20	14.19	-5.34	-15.68	-5.01	0.000‡*
Mx4-PTV	-1.09	1.54	2.62	2.08	-3.71	-4.77	-2.64	0.000‡*
Mx4-PP	0.13	0.81	0.68	1.10	-0.55	-1.11	0.01	0.055†
Mx6.SN	-6.84	2.73	-5.73	4.11	-1.11	-3.15	0.92	0.277†
Mx6-PTV	-3.31	1.01	-1.79	1.12	-1.52	-2.14	-0.91	0.000‡*
Mx6-PP	-0.75	1.01	0.07	0.72	-1.11	-1.61	-0.61	0.000†*
Mx7.SN	-8.00	6.13	-7.47	6.22	-0.54	-4.09	3.02	0.763†
Mx7-PTV	-2.16	1.17	-1.78	1.29	-0.38	-1.09	0.34	0.470†
Mx7-PP	0.00	1.49	-0.01	2.08	0.01	-1.04	1.06	0.638†
				Mandibular dentoalveolar				
Md6.MP	0.43	4.42	1.12	3.99	-0.69	-3.11	1.72	0.567†
Md6-PTV	0.44	1.33	0.87	1.10	-0.43	-1.13	0.27	0.223†
				Interdental				
Overbite	-0.33	0.94	-0.57	1.07	0.24	-0.34	0.82	0.415†
Overjet	-0.20	0.67	1.06	1.06	-1.26	-1.77	-0.76	0.000†*
Molar relationship	-4.55	1.25	-2.57	1.34	-1.98	-2.73	-1.23	0.000‡*
				Soft Tissue				
NLA	-1.08	5.48	1.18	6.40	-2.26	-5.70	1.19	0.194†
UL-S line	-0.25	0.90	-0.17	0.98	-0.09	-0.63	0.46	0.750†
LL-S line	-0.37	1.30	-0.34	1.17	-0.02	-0.73	0.69	0.928‡

†t test. ‡Mann-Whitney U test.
*Statistically significant at P <0.05.

2.3 ARTICLE 3

Finite element analysis of two skeletally anchored maxillary molar distalization methods

ABSTRACT

Introduction: The purpose of this study was to evaluate two methods for maxillary molar distalization with skeletal anchorage using finite element analysis. **Methods:** Two three-dimensional models were created: the miniscrew anchored Cantilever appliance, that consisted in a distalization method anchored in a buccal miniscrew placed between the first permanent molar and second premolar; and the miniscrew anchored palatal appliance, that consisted in a distalization method anchored in a miniscrew inserted on the anterior region of the palate. Finite element analysis was used to simulate the distalization methods. **Results:** Greater lateral than distal displacement was observed in the Cantilever appliance for the first molar, while the opposite was observed in the palatal appliance. Greater displacements were observed at crown levels than at apical regions, buccolingual and mesiodistal molar angulations could be with both appliances. Greater stress was observed at buccal crown and cervical regions in the Cantilever appliance and at palatal crown and cervical regions in the palatal appliance. The second molar showed greater stress distribution in the palatal than in the Cantilever appliance. The stress distribution at apical regions were progressively greater from incisors to first molars with both appliances**. Conclusions:** Some buccolingual and mesiodistal angulations are expected after molar displacements with both distalization methods. Greater von mises stress distribution patterns could be expected at the crown and cervical region for the first molars in the buccal side and the palatal side for the Cantilever and for the palatal appliances, respectively

Keywords: Malocclusion, Angle Class II; Orthodontic Anchorage Procedures; Orthodontic Appliances, Finite Element Analysis.

INTRODUCTION

Maxillary molar distalization with intraoral distalizers is considered a conservative method for Class II malocclusion treatment. This protocol requires minimal dependence on patient compliance which produces more predictable results.[1,2] When associated to temporary anchorage devices (TADs), undesirable effects related to distalization with conventional appliances, such as mesial angulation, protrusion and extrusion of premolars and anterior teeth could be solved with skeletally anchored methods.[3,4] Miniscrews are commonly used in orthodontic mechanics and can be inserted in different locations in the maxillary bone. They may be inserted between the roots of maxillary first molars and second premolars at the buccal side[5,6] or either median or paramedian to the midpalatal suture at the anterior palatal region.[4,7]

Many authors have developed skeletally anchored devices with different designs to apply continuous forces to distalize maxillary molars considering their center of resistance.[4,8,9] It is well known that the resultant displacement pattern of an object is associated to the relationship between its center of resistance and the line of force. The appliances associated with skeletal anchorage could deliver the force from the buccal, palatal or from both sides. In addition, the force could be applied directly from the miniscrews to the molars or indirectly, using other teeth that intermediate the delivery of the force and that are anchoraged to the miniscrews.[8,10]

Finite element analysis (FEA) is an experimental method used for the interpretation of force systems, resultant displacement patterns and stress distributions. This engineering technique enables quantitative visualization of an object in three dimensions (3D).[11] Regarding to orthodontics, it complements the evaluation and helps to better understand the clinical effects of different mechanics. Although some studies have used this analysis to evaluate maxillary molar distalization,[12-15] only one of them have evaluated the isolated effects of skeletally anchored distalizers on maxillary molars without association of multibrackets appliances.[13]

Therefore, the aim of this study was to compare the displacement and stress distributions of maxillary molars in two methods of skeletally anchored maxillary molar distalization using finite element analysis.

MATERIAL AND METHODS

A 3D model was generated from a cone beam computed tomography (CBCT) scan (0.3 mm per pixel resolution) of a patient with full permanent dentition up to second molars. To create the 3D model, the DICOM file images were imported and segmented with the use of InVesalius (version 3.1, Renato Archer Information Technology Center - CTI, Campinas, SP, Brazil). Then, the 3D model (.STL file) was exported to Solidworks 3D CAD software (version 2019, Dassault Systemes, Waltham, USA) to create the models. The orthodontic appliances were sketched in this computer-aided design (CAD) system to reproduce the commercially available wire, coil, bands and miniscrews. Two set-ups were modeled: Model 1, the miniscrew anchored Cantilever appliance, that consisted in a buccally positioned cantilever soldered into the tube of the maxillary first molar band, activated by a closed coil spring anchored to the miniscrew located between the maxillary first molar and second premolar (Figs 1A and B). Model 2, the miniscrew anchored palatal appliance, that consisted in a device soldered on the palatal region of maxillary first molar band with an anterior extension that slid distally, by using a closed coil spring, on another parallel a cervical located wire connected to a miniscrew placed on the anterior region of the palate (Figs 1C and D). This second model was based on the design of the Beneslider appliance.[16]

The created models were exported to the Finite Element Modeling And Postprocessing - FEMAP software (version 11.2, Siemens PLM software Inc., Plano, TX, USA), using the .prt (parasolid) extension. The models comprised a total of 770801 tetrahedral elements and 158529 nodes for the Model 1 (Fig 2A) and 799012 tetrahedral elements and 164594 nodes for the Model 2 (Figs 2B). Homogeneous isotropic material properties were assigned for the maxillary bone, teeth, stainless steel (SS) wire and miniscrews using data from previous reports on FEA studies in orthodontics.[12,17,18] The mechanical properties regarding Poisson ratio and Young modulus used in the models are shown in Table I. Boundary conditions were set to fixate the circummaxillary suture system in all directions. A single force vector of 2 newtons (N) was applied parallel to occlusal plane.

The 3D coordinates were based on the occlusal plane: X (transverse plane), Y (anteroposterior plane), and Z (vertical plane). Positive values for X, Y, and Z indicated medial, distal, and upward displacement. The values obtained from teeth displacements were calculated by assessing the tip of the mesiobuccal cusp, the mesiopalatal cusp and the palatal root apex of the molars in each plane of space using the x, y, and z coordinates. Furthermore, the von Mises stress distribution was calculated and quantitatively visualized. Non-linear analysis was performed by the FEMAP software to calculate and visualize the displacements and stress distribution.

RESULTS

Displacements

Lateral displacements were greater in the cantilever appliance for the mesiobuccal and mesiopalatal cusps of the first molar, when compared with the palatal appliance (Table II, Fig 3). The lateral displacements of the first molars palatal root, and second molars (mesiobuccal and palatal cusp, and palatal root) were similar between the appliances.

Distal displacements were slightly greater in the palatal appliance for the mesiobuccal and mesiopalatal cusps and palatal root of the first molar, compared to Cantilever appliance (Table II, Fig 4). The distal displacements of second molars were similar between both appliances.

Greater lateral than distal displacement was observed in the Cantilever appliance for the first molar, while the opposite was observed in the palatal appliance (Table II, Figs 3 and 4)

Intrusive displacement was observed for the mesiobuccal cusp of first and second molars in the Cantilever appliance, while extrusive displacement was observed for theses cusps in the palatal appliance (Table II, Fig 5). A slight greater extrusive displacement was observed for the mesiopalatal cusp of first and second molars in the palatal appliance compared to the Cantilever appliance. The palatal roots showed similar extrusive displacements in both appliances.

The 3D displacements for the mesiobuccal and mesiopalatal cusps of first molars were slightly greater in the Cantilever appliance, while the first molar palatal root 3D displacement was slightly greater in palatal appliance (Table II, Fig 6). The 3D displacements for second molars were similar between both appliances.

Stress distribution

First molars showed greater stress than second molars (Fig 7), and the stress was more accentuated at the crown and cervical levels than at apical regions in both models. Greater stress was observed at buccal crown and cervical regions in the

Cantilever appliance and at palatal crown and cervical regions in the palatal appliance. The second molar showed greater stress distribution in the palatal than in the Cantilever appliance. The stress distribution at apical regions were progressively greater from incisors to first molars with both appliances.

The pattern of stress distribution on alveolar bone was different between the appliances (Fig 8). In the Cantilever appliance, the stress was greater at the mesiobuccal root region and spread around the buccal and distal sides of first molar and anteriorly around of second premolar. In the palatal appliance, the stress was greater at the mesial and distal sides of palatal root region and spread to the buccal region of first molar, palatal region of second premolar and posteriorly to the palatal region of second molar.

DISCUSSION

One of the main challenges in orthodontics is to obtain the precise control of teeth movements. In order to understand such difficulties, many methods have tried to simulate the effect of the forces applied on the teeth.[11] The finite element analysis (FEA) is a digital model that allows the reproduction of a clinical situation and calculate and exhibit the displacement and stress that tissues, as teeth and alveolar bone, suffer when exposed to simulated forces. The use of this analysis has been increasing in orthodontics with different mechanics; even more with the association temporary anchorage devices.[12,13]

Previous studies have evaluated maxillary molar distalization using finite element analysis.[12-15] The majority of them evaluated distalization methods in association with orthodontic fixed appliances simultaneously. However, no finite element study evaluated the isolated distalization effects using buccal versus palatal miniscrews. In this study, two appliances that uses direct skeletal anchorage were evaluated: the miniscrew anchored Cantilever (model 1) and the miniscrew anchored palatal appliance (model 2).

These devices applied unilateral (buccal or palatal) continuous forces to distalize maxillary molars. Although they eliminate the collateral effects observed with conventional or with indirect skeletal anchored distalizers on the anterior teeth, they do not eliminate some side effects on molars which might undergo distal angulation, extrusion and rotation when unilateral forces are used.[9] Some studies have recommended the application of the distal force on the palatal side for maxillary molar distalization, because the force application become closer to the molar center of resistance and promotes predominantly body movement.[1,8,19] However, no previous studies compared the isolated effects of palatal and buccal distalizers with direct skeletal anchorage using finite element analysis.

Finite element analysis evaluates only the initial effect of the appliances on the teeth and surrounding tissues by means of initial displacement and initial stress distribution. It does not represent changes that occur over time as in the cases of continuous forces and do not include the bone remodeling that is observed during orthodontic tooth movement.[12,13] This must be considered when interpreting the results of this study.

The results obtained for displacements should be interpreted from a qualitative, and not so specifically from a quantitative, point of view since they correspond only to the early movement of the tooth.[11] Although, the displacements observed by the two appliances were minimal in terms of millimeters, it gives us an idea of what it could be expected when applying the forces using these appliances.

Because greater displacements were observed at crown levels than at apical regions in this study (Table II), buccolingual and mesiodistal angulations could be expected for first and second molars with both appliances. Previous studies also demonstrated greater tipping movements even when fixed appliances were included during distalization.[12-14]

The greater lateral than distal displacement observed in the Cantilever appliance for both mesiobuccal and mesiopalatal cusps of first molars (Table II) demonstrated a tendency of buccal tipping or distal rotation around the palatal root. Contrary to the Cantilever appliance, the palatal appliance showed greater distal than lateral displacement of both first molar cusps. This demonstrates a greater distal movement with the palatal appliance immediately after the application of the force. It does not mean that the palatal appliance would have a greater distalization than the Cantilever appliance after the distalization phase. Curiously, the slight transverse displacement of the first molar cusps in palatal appliance was in lateral direction, as occurred with the cantilever appliance. However, clinical studies with palatal distalizing forces reported mesial rotation.[1,7,20] Then, it would be expected a medial displacement. Because the finite element method evaluates only the initial movement of the tooth. It could be expected that mesial rotation could occurred after the distalization phase and for this reason it was not observed in this study.

The differences observed in the vertical displacement for the first molar suggest a tendency of buccal tipping with the Cantilever appliance, since the mesiobuccal cusp showed intrusive movement in contrast to the mesiopalatal cusp and palatal root. In the palatal appliance, the slight greater extrusion of the mesiobuccal than the mesiopalatal cusp suggest only a minimal buccal tipping. According to Yu et al. most favourable outcome in palatal distalizing methods were found when compared to buccal distalizing methods.[15]

Regarding second molar, the amount of transverse and anteroposterior movement was more similar in both appliances, as expected since they receive the distal force by the contact with the distal surface of the first molar. However, the distal movement of the palatal root was smaller, suggesting no body movement. In previous study, the second molar demonstrated uncontrolled distal and buccal tipping and extrusion of the mesiopalatal cusp as well.[13]

The differences and similarities discussed above for both appliances reflected in the 3D displacements that was slight different for the first molars and similar for second molars between the both appliances.

The greater stress observed at the crown and cervical regions for first molars was expected since they were the regions where the appliances were soldered (Fig 7). Similar results were observed in previous study that compare three different appliances.[13] The side where the force was applied showed greater stress than the opposite side, in each appliance. The stress spread apically and, in smaller magnitude, to their respective roots. Greater stress distribution patterns were observed for the first molars in the buccal side and the palatal side for the cantilever and for the palatal appliances, respectively. This was expected because of the design of each appliance.

The second molar showed greater stress distribution with the palatal appliance than with Cantilever appliance. This could be associated to the greater distal displacement observed for the palatal appliance (Table II). Then, the second molar probably received more indirect force because of the contact point with first molar. It has been reported significant positive correlations between the average stresses and the total displacements of buccal teeth under direct anchorage. While greater positive correlations exist between stress and displacement along the sagittal and vertical plane, negative correlations were observed in the transverse plane.[12]

The progressively greater stress distribution from incisors to first molars at their apical region observed with both appliances, were expected and reflects clinical findings reported with direct skeletally anchored distalizers.[4,19]

In Cantilever appliance, the stress was distributed between the mesio- and distobuccal roots area in the alveolar bone, was predominant around buccal roots area and spread to the buccal and distal sides of first molar and anteriorly around of second premolar. In the palatal appliance, the stress was more concentrated around the palatal root alveolus showing greater stress than the Cantilever appliance. It spread to the buccal region of first molar, palatal region of second premolar and posteriorly to the palatal region of second molar.

The pattern of stress distribution on alveolar bone was different between appliances, since it was influenced by the area size on which the force is applied. Therefore, as the anatomy and size of buccal roots and palatal root are different, the stress distribution did not present the same pattern.

This study gives an idea of what expect after initial force application with the both appliances. This could help clinicians to complement the understanding of isolated distalization mechanics involving direct skeletal anchorage and force application from different sides. Then, any associated mechanics as orthodontic fixed appliances or aligners could have a more predictable planning. Clinical evaluations of these appliances are necessary to overcome the FE limitation regarding the time effect and individual variability.

CONCLUSIONS

- Some buccolingual and mesiodistal angulations are expected after molar displacements in the transverse, sagittal and vertical plane with both distalization methods.
- The stress distribution at apical regions were progressively greater from incisors to first molars with both distalization methods.
- Greater von mises stress distribution patterns could be expected at the crown and cervical region for the first molars in the buccal side and the palatal side for the Cantilever and for the palatal appliances, respectively
- The stress distribution on alveolar bone depend on the region on which the force is applied

ACKNOWDELEGMENTS:

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

REFERENCES

1. Bolla E, Muratore F, Carano A, Bowman SJ. Evaluation of maxillary molar distalization with the distal jet: a comparison with other contemporary methods. Angle Orthod 2002;72:481-494.

2. McSherry P, Bradley H. Class II correction-reducing patient compliance: a review of the available techniques. J Orthod 2000;27:219-225.

3. da Costa Grec RH, Janson G, Branco NC, Moura-Grec PG, Patel MP, Henriques JFC. Intraoral distalizer effects with conventional and skeletal anchorage: a meta-analysis. Am J Orthod Dentofacial Orthop 2013;143:602-615.

4. Oberti G, Villegas C, Ealo M, Palacio JC, Baccetti T. Maxillary molar distalization with the dual-force distalizer supported by mini-implants: A clinical study. Am J Orthod Dentofacial Orthop 2009;135:282. e281-282. e285.

5. Kuroda S, Hichijo N, Sato M, Mino A, Tamamura N, Iwata M et al. Long-term stability of maxillary group distalization with interradicular miniscrews in a patient with a Class II Division 2 malocclusion. Am J Orthod Dentofacial Orthop 2016;149:912-922.

6. Yamada K, Kuroda S, Deguchi T, Takano-Yamamoto T, Yamashiro T. Distal movement of maxillary molars using miniscrew anchorage in the buccal interradicular region. Angle Orthod 2009;79:78-84.

7. Nalçaci R, Biçakçi AA, Ozan F. Noncompliance screw supported maxillary molar distalization in a parallel manner. Korean J Orthod 2010;40:250-259.

8. Carano A, Testa M. The distal jet for upper molar distalization. J Clin Orthod 1996;30:374-380.

9. Lim S-M, Hong R-K. Distal movement of maxillary molars using a lever-arm and mini-implant system. Angle Orthod 2008;78:167-175.

10. Gelgor IE, Karaman AI, Buyukyilmaz T. Comparison of 2 distalization systems supported by intraosseous screws. Am J Orthod Dentofacial Orthop 2007;131:161. e161-161. e168.

11. Bouton A, Simon Y, Goussard F, Teresi L, Sansalone V. New finite element study protocol: Clinical simulation of orthodontic tooth movement. International Orthod 2017;15:165-179.

12. Ammoury MJ, Mustapha S, Dechow PC, Ghafari JG. Two distalization methods compared in a novel patient-specific finite element analysis. Am J Orthod Dentofacial Orthop 2019;156:326-336.

13. Kang J-M, Park JH, Bayome M, Oh M, Park CO, Kook Y-A et al. A three-dimensional finite element analysis of molar distalization with a palatal plate, pendulum, and headgear according to molar eruption stage. Korean J Orthod 2016;46:290-300.

14. Sung E-H, Kim S-J, Chun Y-S, Park Y-C, Yu H-S, Lee K-J. Distalization pattern of whole maxillary dentition according to force application points. Korean J Orthod 2015;45:20-28.

15. Yu I-J, Kook Y-A, Sung S-J, Lee K-J, Chun Y-S, Mo S-S. Comparison of tooth displacement between buccal mini-implants and palatal plate anchorage for molar distalization: a finite element study. Eur J Orthod 2014;36:394-402.

16. Wilmes B, Drescher D. Application and effectiveness of the Beneslider: a device to move molars distally. World J Orthod 2010;11:331-340.

17. del Castillo McGrath MG, Araujo-Monsalvo VM, Murayama N, Martínez-Cruz M, Justus-Doczi R, Domínguez-Hernández VM et al. Mandibular anterior intrusion using miniscrews for skeletal anchorage: A 3-dimensional finite element analysis. Am J Orthod Dentofacial Orthop 2018;154:469-476.

18. Feng Y, Kong W-D, Cen W-J, Zhou X-Z, Zhang W, Li Q-T et al. Finite element analysis of the effect of power arm locations on tooth movement in extraction space closure with miniscrew anchorage in customized lingual orthodontic treatment. Am J Orthod Dentofacial Orthop 2019;156:210-219.

19. Cozzani M, Fontana M, Maino G, Maino G, Palpacelli L, Caprioglio A. Comparison between direct vs indirect anchorage in two miniscrew-supported distalizing devices. Angle Orthod 2016;86:399-406.

20. Miresmaeili A, Sajedi A, Moghimbeigi A, Farhadian N. Three-dimensional analysis of the distal movement of maxillary 1st molars in patients fitted with mini-implant-aided trans-palatal arches. Korean J Orthod 2015;45:236-244.

FIGURE LEGENDS

Fig.1. Distalization appliances. **A-B,** sagittal and occlusal view of Cantilever. **C-D,** sagittal and occlusal view of palatal appliance

Fig.2. Finite element models

Fig.3. Displacement in x plane. **A,** occlusal view; **B,** Buccal view; **C,** palatal view.

Fig.4. Displacement in y plane. **A,** occlusal view; **B,** Buccal view; **C,** palatal view.

Fig.5. Displacement in z plane. **A,** occlusal view; **B,** Buccal view; **C,** palatal view.

Fig.6. Three-dimensional displacement **A,** occlusal view; **B,** Buccal view; **C,** palatal view.

Fig. 7. Stress distribution. **A,** occlusal view; **B,** Buccal view; **C,** palatal view.

Fig.8. Stress distribution in alveolar bone. Oclusal view. **A,** model 1. **B,** model 2.

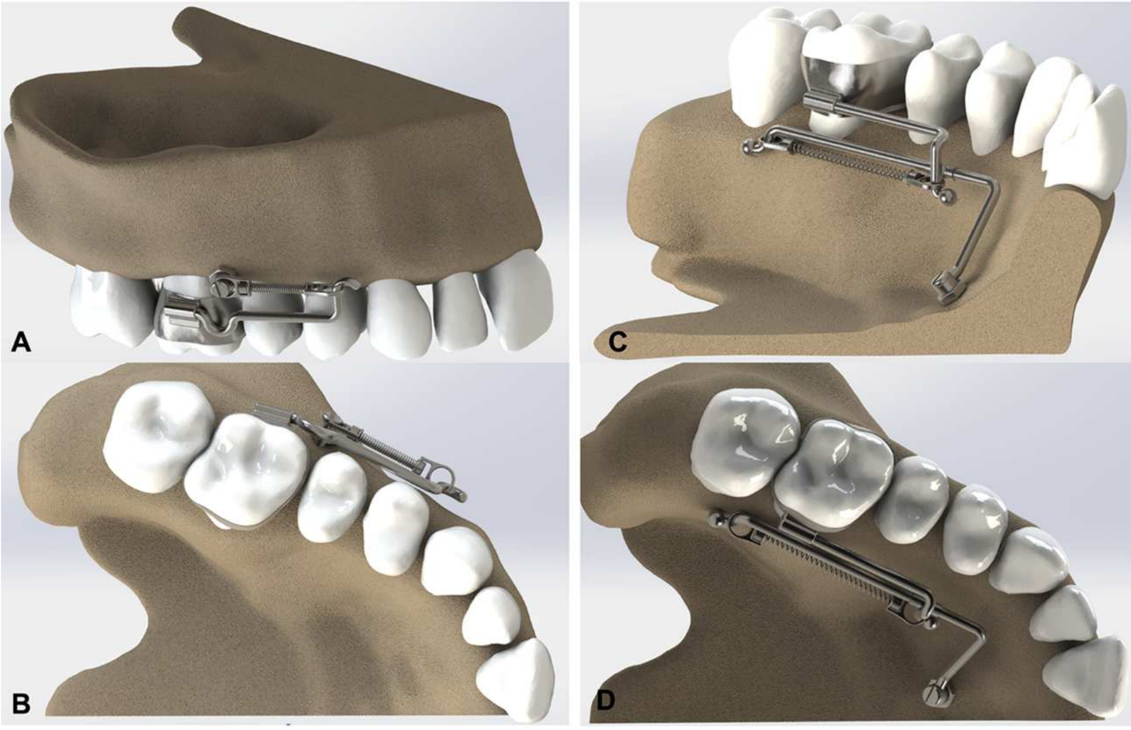


Fig 1.

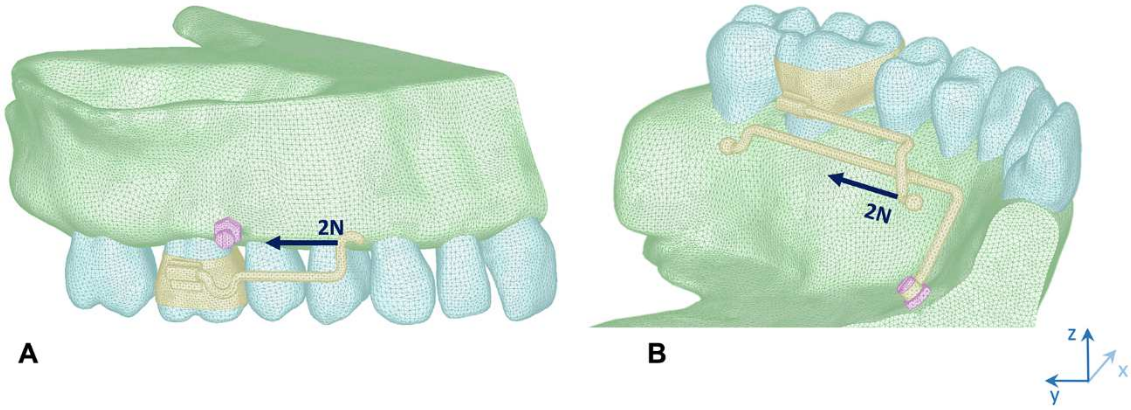
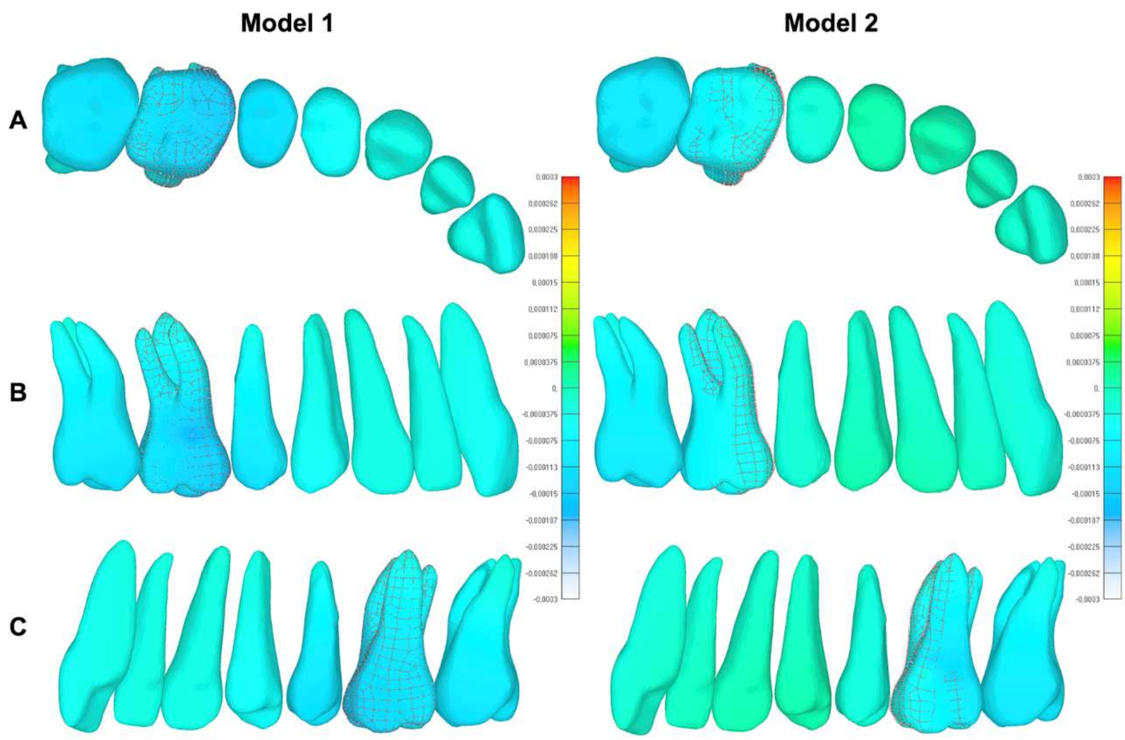


Fig 2.



Model 1
Model 2
A
B
C
0,0003
0,000262
0,000225
0,000188
0,00015
0,000112
0,000075
0,0000375
0,
-0,0000375
-0,000075
-0,000113
-0,00015
-0,000187
-0,000225
-0,000262
-0,0003

Fig 3.

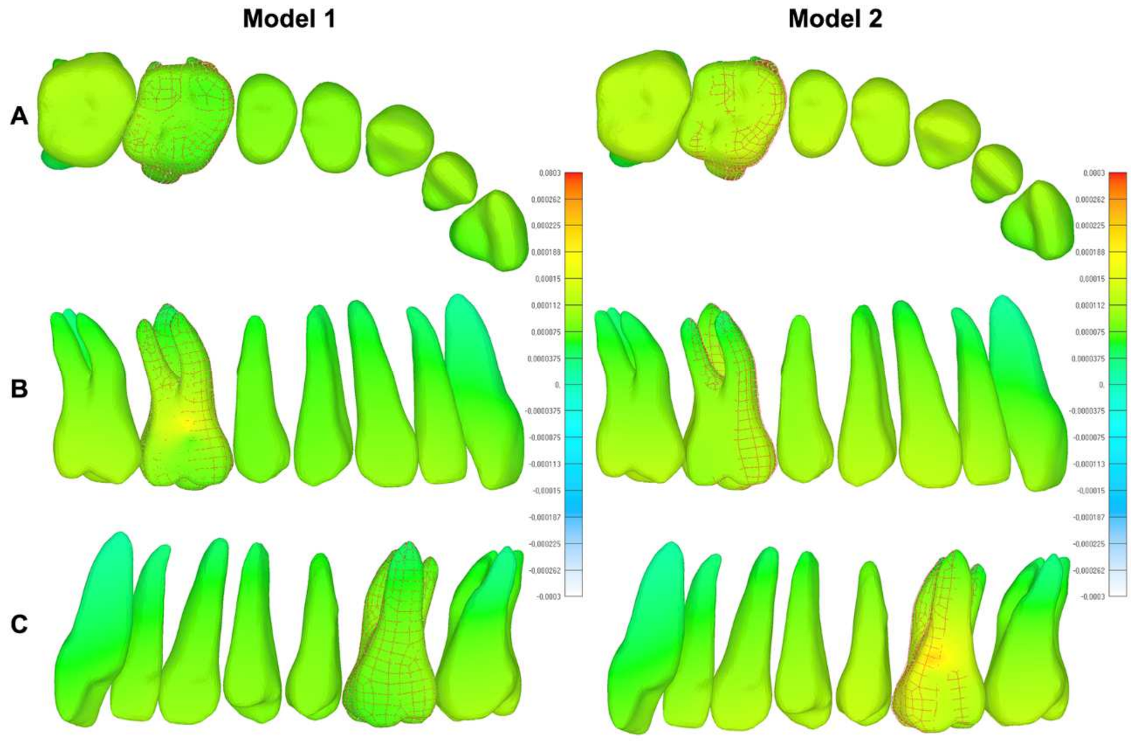

Model 1
Model 2
A
B
C
0.0003
0.000262
0.000225
0.000188
0.00015
0.000112
0.000075
0.0000375
0.
-0.0000375
-0.000075
-0.000113
-0.00015
-0.000187
-0.000225
-0.000262
-0.0003

Fig 4.

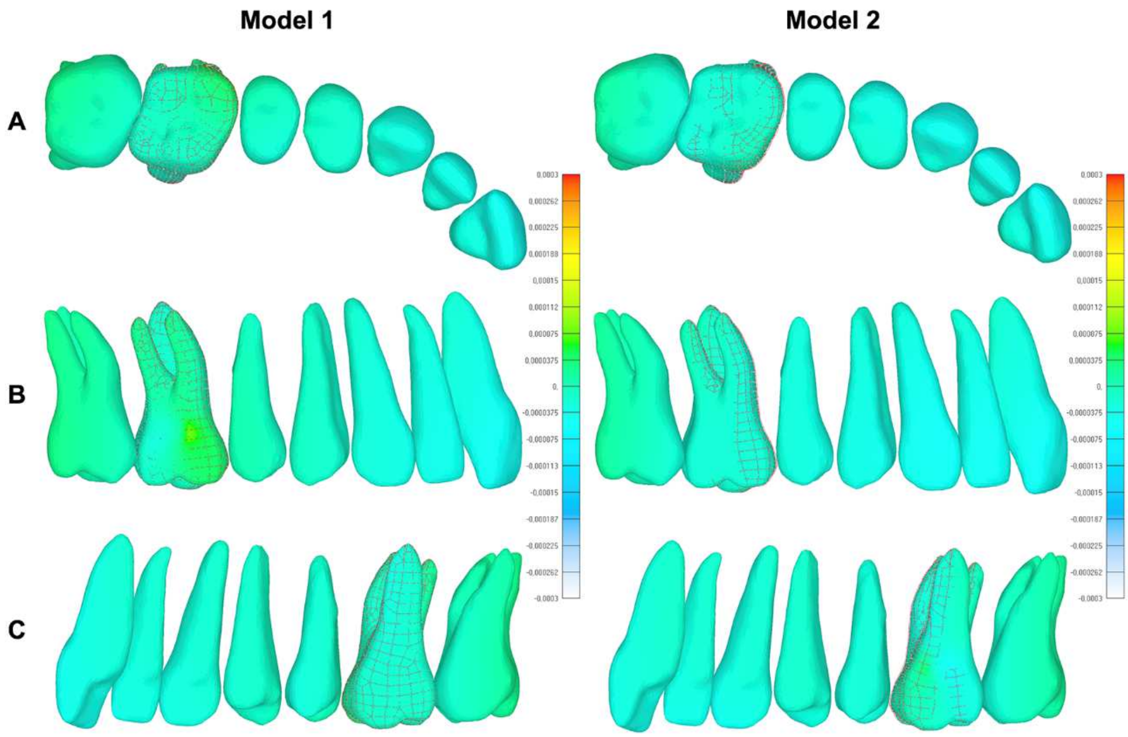

Model 1
Model 2
A
B
C
0.0003
0.000262
0.000225
0.000188
0.00015
0.000112
0.000075
0.0000375
0.
-0.0000375
-0.000075
-0.000113
-0.00015
-0.000187
-0.000225
-0.000262
-0.0003

Fig 5.

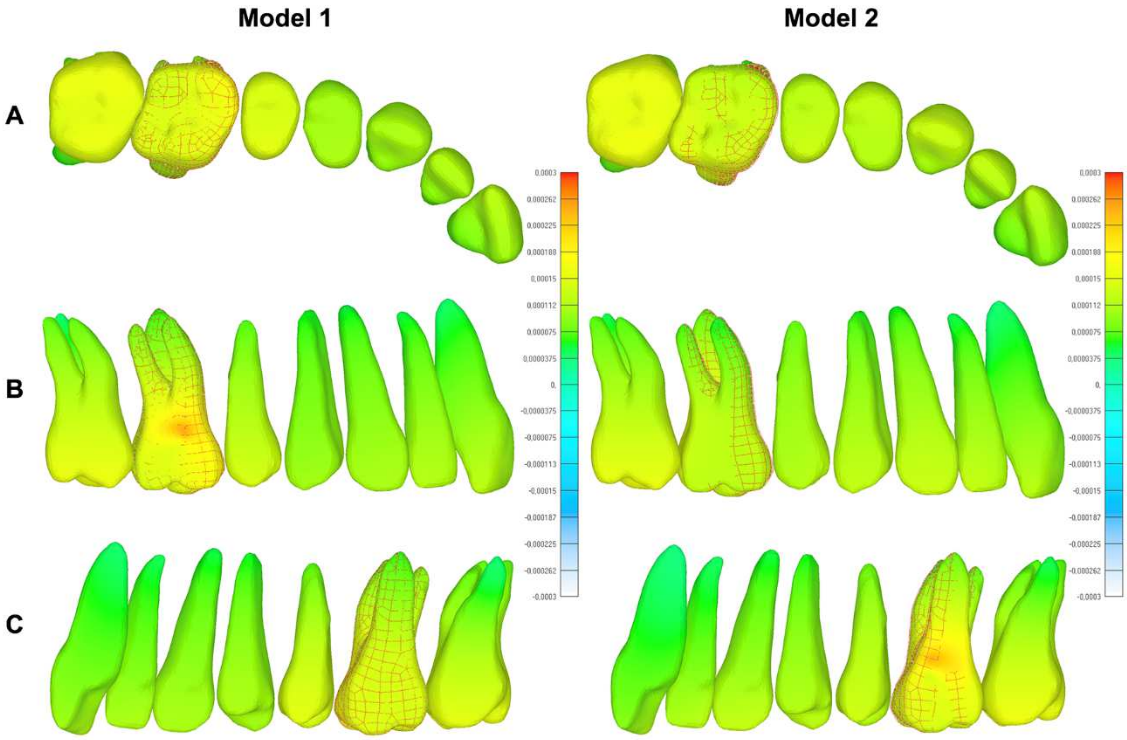

Model 1
Model 2
A
B
C
0,0003
0,000262
0,000225
0,000188
0,00015
0,000112
0,000075
0,0000375
0.
-0,0000375
-0,000075
-0,000113
-0,00015
-0,000187
-0,000225
-0,000262
-0,0003

Fig 6.

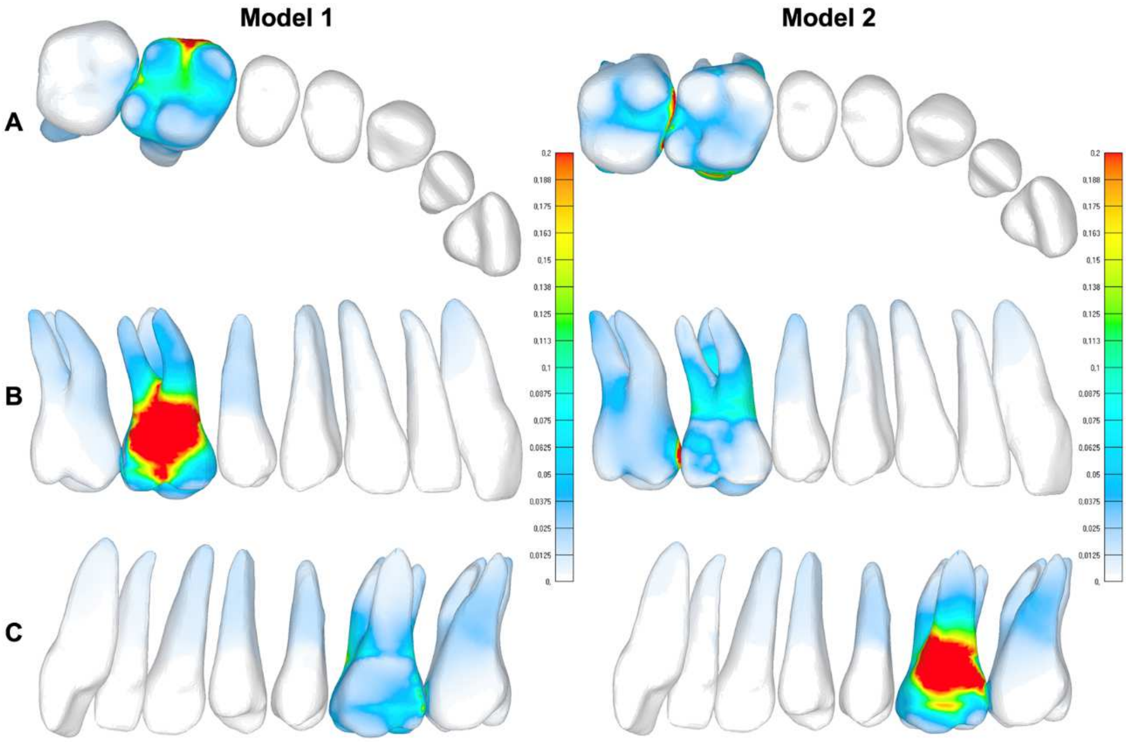


Fig 7.

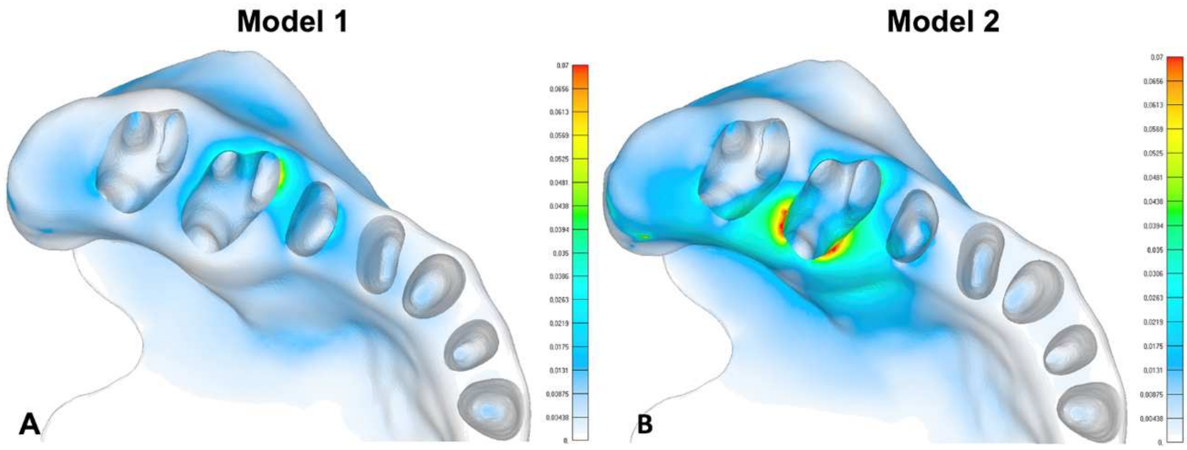

Model 1
Model 2
A
B
0.07
0.0656
0.0613
0.0569
0.0525
0.0481
0.0438
0.0394
0.035
0.0306
0.0263
0.0219
0.0175
0.0131
0.00875
0.00438
0

Fig 8.

Table I. Material properties of the models´ components.

	Young's Module (MPa)	Poisson ratio
Teeth	20 000	0.30
Miniscrew	114 000	0.34
SS wire	200 000	0.30
Bone	1500	0.30

Table II. Displacement after application of distalizing force (unit 10^{-3} mm)

	Miniscrew anchored Cantilever Model 1				Miniscrew anchored palatal appliance Model 2			
	X(R-L)	**Y (A-P)**	**Z (S-I)**	**3D**	**X (R-L)**	**Y (A-P)**	**Z (S-I)**	**3D**
16 MBC	-0.149	0.084	0.040	0.173	-0.057	0.117	-0.020	0.125
16 MPC	-0.134	0.077	-0.009	0.157	-0.066	0.129	-0.018	0.138
16 PR	-0.040	0.047	-0.018	0.065	-0.046	0.066	-0.016	0.081
17 MBC	-0.117	0.113	0.004	0.163	-0.103	0.123	-0.025	0.162
17 MPC	-0.116	0.108	-0.011	0.158	-0.105	0.126	-0.026	0.165
17 PR	-0.029	0.034	-0.012	0.045	-0.038	0.038	-0.011	0.055

MVP, mesiobuccal cusp; MPC, mesiopalatal cusp; PR, palatal root. Positive values for X, Y, and Z indicate medial, distal, and intrusive displacement, respectively. Negative values for X, Y, and Z indicate lateral, mesial, and extrusive displacement, respectively.

3 DISCUSSION

3 DISCUSSION

In this study, cephalometric tracings, digital models and finite element analysis (FEA) were used for three-dimensional analysis of mamxillary molar distalizations with skeletal anchorage.

Cephalometric superimposition has been extensively used in orthodontics to evaluate skeletal, soft tissue and dentoalveolar changes in both vertical and sagittal dimensions. Dental models analysis can provide further information including transverse and rotational changes assessment. Studies comparing direct measurements made from dental casts with those made from digitized dental models have shown that the latter method had a highly accuracy for dental model analysis.[14,28] Few studies have reported contemporary methods for superimposition of digital dental models to evaluate, specifically, distalization of maxillary molars. In this study, an open-source software was used, the methodology used was previously validated.[29]

Lateral, anteroposterior, supero-inferior and 3D displacements were observed for all teeth. The first molar distally moved 3.38 mm and 4.54 mm according to the cephalometric and digital models analyses (mesiobuccal cusp), respectively. All teeth anterior to the first molar showed some amount of distal movement. Since this behavior facilitate correction of the malocclusion simplifying the subsequent mechanic, it could be speculated that it might reduce the treatment time with orthodontic fixed appliances.[24]

When cantilever with direct anchorage was compared to First Class with indirect anchorage, botah were effective for correction of the Class II molar relationship with similar molar distal angulation. However, indirect anchorage does not provide absence of anchorage loss. The bucco-lingual and mesiodistal angulation and sagittal movement of all maxillary teeth anterior to the first molar showed statistically significant differences between direct and indirect anchorage. Spontaneous distal movement of the premolars and no incisor protrusion have only been reported using direct skeletal anchorage.[30]

The use of this FEA also has been increasing in orthodontics with different mechanics. Previous studies evaluated molar distalization using finite element.[31-34] However, no finite element studies evaluated the isolated distalization effects using buccal miniscrew versus palatal miniscrew.

The application of force direct to the center of resistance of the tooth is very challenging. Different authors developed different appliance designs with direct or indirect skeletal anchorage to control the movement of the molar manipulating the line of action.[23,24] Although some studies suggest that the line of action of the distal force on the palatal side promotes predominantly body movement,[5,12,35] the both Cantilever and First Class showed similar molar distal angulation in this current study. Also, the FEA in this study showed predominantly tipping movements in first and second molars with both modalities, due to the higher displacements values at coronal levels than at apical regions. In the palatal appliance, the palatal root showed slight greater displacement than in cantilever appliance, especially regarding distal movement. Previous studies also demonstrated greater tipping movements even when fixed appliances were included during distalization.[31-33]

This FEA study provides an instantaneously observation of the initial stresses and displacements when the tooth is submitted to a distal force. The results may not reflect exact clinical outcomes, which are influenced by the cumulative effects of continuous bone reactions and rebounding of the archwire related to secondary displacement of the teeth. The time-dependent (continuous/dynamic) FE approach should help in exploring such changes to yield accurate mathematical simulations of the biologic processes of tooth movements over time (including bony reactions).[33]

Further studies comparing the three-dimensional dentoalveolar effects between different appliances by means of superimposition of maxillary digital dental models and FEA should be performed to complement the results of the present study. In addition, long-term stability after treatment for molar distal movement achieved with skeletal anchorage devices in nonextraction cases should be evaluated in future researches in large samples. This is a theme for future studies in orthodontics.

4 FINAL CONSIDERATIONS

4 FINAL CONSIDERATIONS

The miniscrew anchored Cantilever produced lateral, anteroposterior, supero-inferior and 3D displacements in all teeth. The distal movement was progressively greater from anterior to posterior teeth. When compared to the First Class with palatal indirect skeletal anchorage, both were effective for maxillary molar distalization and successfully corrected the Class II molar relationship with similar molar distal angulation. However, indirect anchorage did not eliminate anchorage lose of anterior teeth. Complementary, FEA showed greater displacements and stress distributions values at cervical levels than at apical regions in two different methods of distalization. The stress distribution was associated to the side of force application.

Therefore, the desirable body movement of maxillary molar is a great challenge in orthodontics. The tipping movements seems to be continuously associated to maxillary molars distalization with both buccal and palatal distalizing method. Selection of the device should depend on predictability, minimal undesirable side effects and patient need.

REFERENCES

REFERENCES

1. Runge ME, Martin JT, Bukai F. Analysis of rapid maxillary molar distal movement without patient cooperation. Am J Orthod Dentofacial Orthop. 1999;115:153-157.

2. Kloehn S. Evaluation of cervical anchorage force in treatment. Angle Orthod. 1961;31:91-104.

3. Wilson WL, Wilson RC. Modular orthodontics (Wilson) manual. Denver, Colo.: Rocky Mountain/Orthodontics; 1981.

4. Nanda RS, Kierl MJ. Prediction of cooperation in orthodontic treatment. Am J Orthod Dentofacial Orthop.1992;102:15-21.

5. Bolla E, Muratore F, Carano A, Bowman SJ. Evaluation of maxillary molar distalization with the distal jet: a comparison with other contemporary methods. Angle Orthod. 2002;72:481-494.

6. McSherry P, Bradley H. Class II correction-reducing patient compliance: a review of the available techniques. J Orthod. 2000;27:219-225.

7. Gianelly AA, Vaitaa AS, Thomas WM. The use of magnets to move molars distally. Am J Orthod Dentofacial Orthop.1989;96:161-167.

8. Locatelli R. Molar distalization with superelastic NiTi wire. J Clin Orthod. 1992;26:277-279.

9. Jones RD, White J. Rapid Class II molar correction with an open-coil jig. J Clin Orthod. 1992;26:661.

10. Carano A, Testa M. The distal jet for upper molar distalization. J Clin Orthod. 1996;30:374-380.

11. Hilgers J. The pendulum appliance for Class II non-compliance therapy. J Clin Orthod. 1992;26:706-714.

12. Fortini A, Lupoli M, Giuntoli F, Franchi L. Dentoskeletal effects induced by rapid molar distalization with the first class appliance. Am J Orthod Dentofacial Orthop. 2004;125:697-704.

13. Haydar S, Üner O. Comparison of Jones jig molar distalization appliance with extraoral traction. Am J Orthod Dentofacial Orthop. 2000;117:49-53.

14. Mavropoulos A, Karamouzos A, Kiliaridis S, Papadopoulos MA. Efficiency of noncompliance simultaneous first and second upper molar distalization: a three-dimensional tooth movement analysis. Angle Orthod. 2005;75:532-539.

15. Antonarakis GS, Kiliaridis S. Maxillary molar distalization with noncompliance intramaxillary appliances in class II malocclusion: a systematic review. Angle Orthod. 2008;78:1133-1140.

16. Chiu PP, McNamara JA, Franchi L. A comparison of two intraoral molar distalization appliances: distal jet versus pendulum. Am J Orthod Dentofacial Orthop. 2005;128:353-365.

17. Brickman CD, Sinha PK, Nanda RS. Evaluation of the Jones jig appliance for distal molar movement. Am J Orthod Dentofacial Orthop. 2000;118:526-534.

18. Patel MP, Janson G, Henriques JF, de Almeida RR, de Freitas MR, Pinzan A et al. Comparative distalization effects of Jones jig and pendulum appliances. Am J Orthod Dentofacial Orthop. 2009;135:336-342.

19. Gelgör İE, Büyükyilmaz T, Karaman AI, Dolanmaz D, Kalayci A. Intraosseous screw-supported upper molar distalization. Angle Orthod. 2004;74:838-850.

20. Kircelli BH, Pektas Z, Kircelli C. Maxillary molar distalization with a bone-anchored pendulum appliance. Angle Orthod. 2006;76:650-659.

21. Escobar SA, Tellez PA, Moncada CA, Villegas CA, Latorre CM, Oberti G. Distalization of maxillary molars with the bone-supported pendulum: a clinical study. Am J Orthod Dentofacial Orthop. 2007;131:545-549.

22. Önçağ G, Seçkin Ö, Dinçer B, Arikan F. Osseointegrated implants with pendulum springs for maxillary molar distalization: a cephalometric study. Am J Orthod Dentofacial Orthop. 2007;131:16-26.

23. Lim S-M, Hong R-K. Distal movement of maxillary molars using a lever-arm and mini-implant system. Angle Orthod. 2008;78:167-175.

24. Oberti G, Villegas C, Ealo M, Palacio JC, Baccetti T. Maxillary molar distalization with the dual-force distalizer supported by mini-implants: A clinical study Am J Orthod Dentofacial Orthop. 2009;135:282. e281-282. e285.

25. Papadopoulos MA. Orthodontic treatment of Class II malocclusion with miniscrew implants. Am J Orthod Dentofacial Orthop. 2008;134:604. e601-604. e616.

26. Cozzani M, Fontana M, Maino G, Maiono G, Palpacelli L, Caprioglio A. Comparison between direct vs indirect anchorage in two miniscrewsupported distalizing devices. Angle Orthod. 2016;86:399–406.

27. Polat-Ozsoy Ö, Kırcelli BH, Arman-Özçırpıcı A, Pektaş ZÖ, Uçkan S. Pendulum appliances with 2 anchorage designs: conventional anchorage vs bone anchorage Am J Orthod Dentofacial Orthop. 2008;133:339. e339-339. e317.

28. Nalcaci R, Kocoglu-Altan AB, Bicakci AA, Ozturk F, Babacan H. A reliable method for evaluating upper molar distalization: Superimposition of three-dimensional digital models. Korean J Orthod. 2015;45:82-88.

29. Garib D, Miranda F, Yatabe MS, Lauris JRP, Massaro C, McNamara Jr JA et al. Superimposition of maxillary digital models using the palatal rugae: Does ageing affect the reliability? Orthod Craniofac Res. 2019;22:183-193.

30. da Costa Grec RH, Janson G, Branco NC, Moura-Grec PG, Patel MP, Henriques JFC. Intraoral distalizer effects with conventional and skeletal anchorage: a meta-analysis. Am J Orthod Dentofacial Orthop. 2013;143:602-615.

31. Ammoury MJ, Mustapha S, Dechow PC, Ghafari JG. Two distalization methods compared in a novel patient-specific finite element analysis. Am J Orthod Dentofacial Orthop. 2019;156:326-336.

32. Kang J-M, Park JH, Bayome M, Oh M, Park CO, Kook Y-A et al. A three-dimensional finite element analysis of molar distalization with a palatal plate, pendulum, and headgear according to molar eruption stage. Korean J Orthod. 2016;46:290-300.

33. Sung E-H, Kim S-J, Chun Y-S, Park Y-C, Yu H-S, Lee K-J. Distalization pattern of whole maxillary dentition according to force application points. Korean J Orthod. 2015;45:20-28.

34. Yu IJ, Kook Y-A, Sung S-J, Lee K-J, Chun Y-S, Mo S-S. Comparison of tooth displacement between buccal mini-implants and palatal plate anchorage for molar distalization: a finite element study. Eur J Orthod. 2014;36:394-402.

35. Carano A, Testa M. The distal jet for upper molar distalization. J Clin Orthod. 1996;30:374-380.

APPENDICES

APPENDIX A - DECLARATION OF EXCLUSIVE USE OF THE ARTICLE 1 IN DISSERTATION/THESIS

We hereby declare that we are aware of the article "Three-dimensional changes after maxillary molar distalization with miniscrew anchored cantilever: A prospective clinical study" will be included in the Thesis of the student Lorena Vilanova Freitas de Souza and may not be used in other works of Graduate Programs at the Bauru School of Dentistry, University of São Paulo.

Bauru, March 3rd, 2020.

Lorena Vilanova Freitas de Souza
Author

Signature

José Fernando Castanha Henriques
Author

Signature

Author

Signature

Author

Signature

APPENDIX B - DECLARATION OF EXCLUSIVE USE OF THE ARTICLE 2 IN DISSERTATION/THESIS

We hereby declare that we are aware of the article “Direct versus indirect skeletal anchorage for maxillary molar distalization” will be included in the Thesis of the student Lorena Vilanova Freitas de Souza and may not be used in other works of Graduate Programs at the Bauru School of Dentistry, University of São Paulo.

Bauru, March 3rd, 2020.

Lorena Vilanova Freitas de Souza
Author

Signature

José Fernando Castanha Henriques
Author

Signature

Author

Signature

Author

Signature

APPENDIX C - DECLARATION OF EXCLUSIVE USE OF THE ARTICLE 3 IN DISSERTATION/THESIS

We hereby declare that we are aware of the article "Finite element analysis of two skeletally anchored maxillary molar distalization methods" will be included in the Thesis of the student Lorena Vilanova Freitas de Souza and may not be used in other works of Graduate Programs at the Bauru School of Dentistry, University of São Paulo.

Bauru, March 3rd, 2020.

Lorena Vilanova Freitas de Souza
Author — Signature

José Fernando Castanha Henriques
Author — Signature

Author — Signature

Author — Signature

ANNEXES

ANNEX A. Ethics Committee approval, protocol number 1.235.588 (front).

FACULDADE DE ODONTOLOGIA DE BAURU-USP

Plataforma Brasil

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: AVALIAÇÃO CEFALOMÉTRICA DAS ALTERAÇÕES DENTOESQUELÉTICAS DA MÁ OCLUSÃO DE CLASSE II TRATADA COM DISTALIZAÇÃO DOS MOLARES SUPERIORES COM JONES JIG E COM ANCORAGEM ESQUELÉTICA DIRETA

Pesquisador: LORENA VILANOVA FREITAS DE SOUZA

Área Temática:

Versão: 4

CAAE: 43930715.8.0000.5417

Instituição Proponente: Universidade de Sao Paulo

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 1.235.588

Apresentação do Projeto:

Idem ao Parecer 1.172.917 de 29/07/2015.

Objetivo da Pesquisa:

Idem ao Parecer 1.172.917 de 29/07/2015.

Avaliação dos Riscos e Benefícios:

Idem ao Parecer 1.172.917 de 29/07/2015.

Comentários e Considerações sobre a Pesquisa:

Idem ao Parecer 1.172.917 de 29/07/2015.

Considerações sobre os Termos de apresentação obrigatória:

Idem ao Parecer 1.172.917 de 29/07/2015.

Recomendações:

O pesquisador deve adequar a frase inicial do termo de consentimento livre e esclarecido, já que o mesmo é voltado ao responsável pelo participante da pesquisa menor de idade, deve iniciar com a seguinte frase:"O(a) menor sob sua responsabilidade está sendo convidado(a) a participar da pesquisa: titulo...". E "Todos os procedimentos do estudo serão informados de forma detalhada ao menor através deforma verbal e por meio de um TERMO DE ASSENTIMENTO assinado por este caso

Endereço: DOUTOR OCTAVIO PINHEIRO BRISOLLA 75 QUADRA 9
Bairro: VILA NOVA CIDADE UNIVERSITARIA **CEP:** 17.012-901
UF: SP **Município:** BAURU
Telefone: (14)3235-8356 **Fax:** (14)3235-8356 **E-mail:** cep@fob.usp.br

ANNEX A. Ethics Committee approval, protocol number 1.235.588 (verso).

FACULDADE DE ODONTOLOGIA DE BAURU-USP

Continuação do Parecer: 1.235.588

concorde com a participação no estudo. É importante que você esteja consciente de que a participação neste estudo é completamente voluntária e de que o menor pode recusar-se a participar ou sair do estudo a qualquer momento sem penalidades". No termo de assentimento anexado, consta a frese "Este termo de consentimento encontra-se
impresso em duas vias, sendo que uma cópia será arquivada pelo pesquisador responsável, e a outra será fornecida a você"... Por favor corrigir "termo de consentimento" por "termo de assentimento". As pendências acima não foram completamente atendidas, todavia segue confusão com o Termo de Assentimento. Esclarecemos:

1. Termo de Assentimento convida o "menor" a participar da pesquisa e não os responsáveis.
2. O TCLE que consta na PB está feito para participantes não menores.
3. Falta o TCLE para os responsáveis pelos menores que assinarem o Termo de Assentimento, cada Termo de Assentimento convidado o menor e assinado por ele, deve acompanhar um TCLE assinado pelos responsáveis pelo menor.

Assim sendo, essa pesquisa SE possui participantes maiores de idade e menores de idade necessita de: um TCLE para os participantes maiores de idade (está correto na PB), um Termo de Assentimento destinado aos menores participantes (está incorreto na PB) e um TCLE dirigido aos responsáveis pelos menores (esse TCLE não se encontra na PB). SE a pesquisa não for incluir participantes maiores de idade, deverá ser excluído o TCLE anexado na PB. Incluir no projeto de pesquisa a faixa etária dos participantes para facilitar a emissão do parecer.

PENDÊNCIAS ATENDIDAS. A pesquisadora informa que a faixa etária dos participantes é dos 10 aos 16 anos e anexou Termo de Assentimento e TCLE para os pais.

Conclusões ou Pendências e Lista de Inadequações:

Caso a pesquisadora perceba que um termo de assentimento mais figurativo seja necessário para as crianças de 10 a 12 anos, fazer o termo, e encaminhar ao CEP para aprovação.

Considerações Finais a critério do CEP:

Esse projeto foi considerado APROVADO na reunião ordinária do CEP de 16.09.2015, com base nas normas éticas da Resolução CNS 466/12. Ao término da pesquisa o CEP-FOB/USP exige a apresentação de relatório final. Os relatórios parciais deverão estar de acordo com o cronograma e/ou parecer emitido pelo CEP. Alterações na metodologia, título, inclusão ou exclusão de autores, cronograma e quaisquer outras mudanças que sejam significativas deverão ser previamente

Endereço: DOUTOR OCTAVIO PINHEIRO BRISOLLA 75 QUADRA 9
Bairro: VILA NOVA CIDADE UNIVERSITARIA **CEP:** 17.012-901
UF: SP **Município:** BAURU
Telefone: (14)3235-8356 **Fax:** (14)3235-8356 **E-mail:** cep@fob.usp.br

ANNEX A. Ethics Committee approval, protocol number 1.235.588 (verso).

FACULDADE DE ODONTOLOGIA DE BAURU-USP

Continuação do Parecer: 1.235.588

comunicadas a este CEP sob risco de não aprovação do relatório final. Quando da apresentação deste, deverão ser incluídos todos os TCLEs e/ou termos de doação assinados e rubricados, se pertinentes.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Projeto Detalhado / Brochura Investigador	Projeto_de_Pesquisa_LORENA.pdf	26/08/2015 12:49:52	LORENA VILANOVA FREITAS DE SOUZA	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE.pdf	26/08/2015 12:50:19	LORENA VILANOVA FREITAS DE SOUZA	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TERMO_DE_ASSENTIMENTO.pdf	26/08/2015 12:50:41	LORENA VILANOVA FREITAS DE SOUZA	Aceito
Outros	Comunicado_ao_CEP.pdf	26/08/2015 12:51:31	LORENA VILANOVA FREITAS DE SOUZA	Aceito
Folha de Rosto	Folha_de_rosto.pdf	26/08/2015 12:52:22	LORENA VILANOVA FREITAS DE SOUZA	Aceito
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_492537.pdf	26/08/2015 12:53:18		Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

BAURU, 18 de Setembro de 2015

Assinado por:
Izabel Regina Fischer Rubira Bullen
(Coordenador)

Endereço: DOUTOR OCTAVIO PINHEIRO BRISOLLA 75 QUADRA 9
Bairro: VILA NOVA CIDADE UNIVERSITARIA **CEP:** 17.012-901
UF: SP **Município:** BAURU
Telefone: (14)3235-8356 **Fax:** (14)3235-8356 **E-mail:** cep@fob.usp.br

ANNEX B – Informed consent for children (front)

Universidade de São Paulo
Faculdade de Odontologia de Bauru
Departamento de Odontopediatria, Ortodontia e Saúde Coletiva
Disciplina de Ortodontia

1

TERMO DE ASSENTIMENTO

Você está sendo convidado(a) a participar da pesquisa: "Avaliação cefalométrica das alterações dentoesqueléticas da má oclusão de classe II tratada com distalização dos molares superiores com Jones jig e com ancoragem esquelética direta". Neste estudo pretendemos avaliar e comparar por meio de radiografias as mudanças ocorridas após distalização (movimento do dente para trás) dos molares superiores.

A participação neste estudo é completamente voluntária e você pode recusar-se a participar ou sair do estudo a qualquer momento sem penalidades. Para participar, não haverá custos, nem receberá qualquer vantagem financeira. Não será oferecida remuneração, auxílio para alimentação ou transporte até o local nos dias de atendimento.

Para iniciar o tratamento serão realizadas fotos extrabucais, intrabucais, telerradiografia, radiografia panorâmica e modelos de gesso.

Para o tratamento com distalização, serão instalados dois mini-implantes. Sua instalação é um procedimento rápido, seguro e simples, realizado com anestesia tópica (pomada), podendo gerar o mínimo de desconforto no momento da instalação. O dispositivo confeccionado com fio ortodôntico não gera desconforto. Após a distalização, serão realizadas fotos intrabucais, moldagem e telerradiografia para avaliar os efeitos da movimentação dentária.

As fotos utilizadas neste trabalho, bem como todo procedimento ou dado que possa identificá-lo, serão mantidas em sigilo, e não será liberado sem a permissão do responsável.

O procedimento de moldagem que será realizado pode provocar sensação de ânsia, porém o profissional tomará as devidas providências para reduzir este desconforto, caso necessário.

As tomadas radiográficas são procedimentos comuns realizados respeitando todas as medidas de segurança com a mínima exposição necessária aos raios-x.

Durante as consultas haverá orientação sobre cuidados com a saúde bucal, sobre a necessidade de qualquer tipo de tratamento odontológico que se faça necessário e sobre eventuais questionamentos. É garantido indenização em casos de danos decorrentes dos procedimentos empregados nesta pesquisa.

Após os procedimentos que envolvem a pesquisa, é assegurada a continuidade do tratamento ortodôntico até sua finalização.

Este termo de assentimento encontra-se impresso em duas vias igualmente válidas (uma via para o menor e outra para o pesquisador responsável). Qualquer dúvida poderá contatar o orientador José Fernando Castanha Henriques ou a mestranda Lorena Vilanova Freitas de Souza no telefone (79)9954-3885 ou e-mail lorenavilanova@usp.br

Rubrica do participante menor	Rubrica do Pesquisador responsável

Al. Dr. Octávio Pinheiro Brisolla, 9-75 – Bauru-SP – CEP 17012-901 – C.P. 73
e-mail: veragato@fob.usp.br - Fone (0xx14) 3235-8217 - Fax (0xx14) 3223-4679
http://www.fob.usp.br

ANNEX B – Informed consent for children (verse)

2

Eu, ____, portador(a) do documento de Identidade ___________________ fui informado(a) dos objetivos do presente estudo de maneira clara e detalhada. Declaro que concordo em participar desse estudo. Está claro que a minha vontade será prevalecida. Recebi uma cópia deste termo de assentimento e me foi dada a oportunidade de ler e esclarecer as minhas dúvidas.

Bauru, SP,____ de _____________ de _____ .

_______________________ Assinatura do menor

_______________________ Assinatura do pesquisador

O **Comitê de Ética em Pesquisa – CEP**, organizado e criado pela **FOB-USP**, em 29/06/98 (**Portaria GD/0698/FOB**), previsto no item VII da Resolução nº 466/12 do Conselho Nacional de Saúde do Ministério da Saúde (publicada no DOU de 13/06/2013), é um Colegiado interdisciplinar e independente, de relevância pública, de caráter consultivo, deliberativo e educativo, criado para defender os interesses dos participantes da pesquisa em sua integridade e dignidade e para contribuir no desenvolvimento da pesquisa dentro de padrões éticos.

Qualquer denúncia e/ou reclamação sobre sua participação na pesquisa poderá ser reportada a este CEP.

Horário e local de funcionamento:
Comitê de Ética em Pesquisa
Faculdade de Odontologia de Bauru-USP - Prédio da Pós-Graduação (bloco E - pavimento superior), de segunda a sexta-feira, no horário das **13h30 às 17 horas**, em dias úteis.
Alameda Dr. Octávio Pinheiro Brisolla, 9-75
Vila Universitária – Bauru – SP – CEP 17012-901
Telefone/FAX(14)3235-8356
e-mail: cep@fob.usp.br

Al. Dr. Octávio Pinheiro Brisolla, 9-75 – Bauru-SP – CEP 17012-901 – C.P. 73
e-mail: veragato@fob.usp.br - Fone (0xx14) 3235-8217 - Fax (0xx14) 3223-4679
http://www.fob.usp.br

ANNEX C – Informed consent for children´s legal guardians (front)

1

Universidade de São Paulo
Faculdade de Odontologia de Bauru

Departamento de Odontopediatria, Ortodontia e Saúde Coletiva
Disciplina de Ortodontia

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

O menor sob sua responsabilidade está sendo convidado a participar como voluntário da pesquisa "Avaliação cefalométrica das alterações dentoesqueléticas da má oclusão de classe II tratada com distalização dos molares superiores com Jones jig e com ancoragem esquelética direta", cujos objetivos são avaliar e comparar por meio de radiografias as alterações ósseas, dentárias e de perfil após a distalização (movimento do dente para trás) dos molares superiores.

Todos os procedimentos do estudo serão informados de forma detalhada ao menor de forma verbal e por meio de um TERMO DE ASSENTIMENTO assinado por este caso concorde com a participação no estudo. A participação neste estudo é completamente voluntária e o menor pode recusar-se a participar ou sair do estudo a qualquer momento sem penalidades, pois sua vontade será prevalecida.

Será realizada a documentação convencional para iniciar o tratamento ortodôntico, que consta de fotos extrabucais, intrabucais, telerradiografia, radiografia panorâmica e modelos de gesso.

Para o tratamento com distalização, serão instalados dois mini-implantes. Sua instalação é um procedimento rápido, seguro e simples, realizado com anestesia tópica (pomada), podendo gerar o mínimo de desconforto no momento da instalação. O braço de alavanca confeccionado com fio ortodôntico é um dispositivo simples e que não gera incômodo ao paciente. Após o procedimento de distalização, serão realizadas fotos intrabucais, moldagem e telerradiografia para avaliar os efeitos da movimentação dentária.

As fotos utilizadas neste trabalho, bem como todo procedimento ou dado que possa identificar o menor, serão mantidas em sigilo. O procedimento de moldagem pode provocar sensação de ânsia, porém o profissional tomará as devidas providências para reduzir este desconforto, caso necessário.

As tomadas radiográficas são procedimentos comuns realizados respeitando todas as medidas de segurança com a mínima exposição necessária aos raios-x.

Imediatamente após a distalização, os pacientes serão encaminhados para ortodontia corretiva para alinhamento e nivelamento dos arcos e finalização do tratamento.

Durante as consultas haverá orientação sobre cuidados com a saúde bucal, sobre a necessidade de qualquer tipo de tratamento odontológico que se faça necessário e sobre eventuais questionamentos. Não será oferecida remuneração, auxílio para alimentação ou transporte até o local nos dias de atendimento. É garantido indenização em casos de danos decorrentes dos procedimentos empregados nesta pesquisa.

Os **pesquisadores** envolvidos são a mestranda Lorena Vilanova Freitas de Souza e seu orientador José Fernando Castanha Henriques, com os quais poderá manter contato via **e-mail**: lorenavilanova@usp.br ou **telefone**: (79) 99543885.É assegurado o esclarecimento de dúvidas durante toda pesquisa, bem como será garantido o livre acesso a todas as informações adicionais sobre o estudo.

Pelo presente instrumento que atende às exigências legais, o(a) Sr. (a) ____, portador da cédula de identidade ______________, responsável pelo menor ____ após leitura minuciosa das informações constantes neste TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO, devidamente explicada pelos profissionais em seus mínimos detalhes, ciente dos

Rubrica do Responsável pelo menor	Rubrica do Pesquisador responsável

Al. Dr. Octávio Pinheiro Brisolla, 9-75 – Bauru-SP – CEP 17012-901 – C.P. 73
e-mail: veragato@fob.usp.br - Fone (0xx14) 3235-8217 - Fax (0xx14) 3223-4679
http://www.fob.usp.br

ANNEX C – Informed consent for children´s legal guardians (verso)

Eu, ____, portador(a) do documento de Identidade ____________________ fui informado(a) dos objetivos do presente estudo de maneira clara e detalhada. Declaro que concordo em participar desse estudo. Está claro que a minha vontade será prevalecida. Recebi uma cópia deste termo de assentimento e me foi dada a oportunidade de ler e esclarecer as minhas dúvidas.

Bauru, SP____ de ____________ de _____.

____
Assinatura do menor

____
Assinatura do pesquisador

O **Comitê de Ética em Pesquisa – CEP**, organizado e criado pela **FOB-USP**, em 29/06/98 (**Portaria GD-0698/FOB**), previsto no item VII da Resolução nº 466/12 do Conselho Nacional de Saúde do Ministério da Saúde (publicada no DOU de 13/06/2013), é um Colegiado interdisciplinar e independente, de relevância pública, de caráter consultivo, deliberativo e educativo, criado para defender os interesses dos participantes da pesquisa em sua integridade e dignidade e para contribuir no desenvolvimento da pesquisa dentro de padrões éticos.

Qualquer denúncia e/ou reclamação sobre sua participação na pesquisa poderá ser reportada a este CEP.

Horário e local de funcionamento:
Comitê de Ética em Pesquisa
Faculdade de Odontologia de Bauru-USP - Prédio da Pós-Graduação (bloco E - pavimento superior), de segunda a sexta-feira, no horário das **13h30** às **17 horas**, em dias úteis.
Alameda Dr. Octávio Pinheiro Brisolla, 9-75
Vila Universitária – Bauru – SP – CEP 17012-901
Telefone/FAX(14)3235-8356
e-mail: cep@fob.usp.br