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MANUEL GUSTAVO CHÁVEZ SEVILLANO

"EFEITO DA EXPANSÃO PALATINA SOBRE O PROCESSO PTERIGOIDE, SINCONDROSE ESFENO-OCCIPITAL E SELA TURCA EM CRÂNIOS COM RELAÇÃO ESQUELÉTICA CLASSE II E CLASSE III PELA ANÁLISE DE ELEMENTOS FINITOS (AEF)"

"EFFECT OF THE PALATAL EXPANSION ON THE PTERYGOID PROCESS, SPHENO-OCCIPITAL SYNCHONDROSIS AND SELLA TURCICA IN SKULLS WITH CLASS II AND CLASS III SKELETAL RELATIONSHIP BY FINITE ELEMENT ANALYSIS (FEA)"

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FACULDADE DE ODONTOLOGIA DE PIRACICABA

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Dissertação apresentada à Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas como parte dos requisitos exigidos para a obtenção do título de Mestre em Biologia Buco-Dental, na área de Anatomia.

Dissertation presented to the Piracicaba Dentistry School of the University of Campinas in partial of the requirements for the degree of Master in Buco-Dental Biology, in Anatomy area.

Orientador: Prof. Dr. Felippe Bevilacqua Prado

Este exemplar corresponde à versão final da dissertação defendida pelo aluno Manuel Gustavo Chávez Sevillano orientado pelo Prof. Dr. Felippe Bevilacqua Prado.

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Prof. Dr. FELIPPE BEVILACQUA PRADO

Prof. Dr. PAULO ROBERTO BOTACIN

Prof. Dr. EDUARDO CÉSAR ALMADA SANTOS

RESUMO

A Técnica de Expansão Palatina é usada frequentemente para corrigir a mordida cruzada posterior, atresia transversal maxilar e aumentar o perímetro da arcada dentária. O objetivo deste estudo foi avaliar, pela análise de elementos finitos, o efeito simulado da expansão palatina sobre o processo pterigoide, sincondrose esfeno-occipital e sela turca em dois crânios com relação esquelética tipo Classe II e Classe III, identificando a distribuição das tensões mecânicas nessas estruturas anatômicas. Para isso, foram selecionadas duas Tomografias Computorizadas Cone Beam de dois crânios de 13 anos de idade e com atresia transversal da maxila. Um modelo de elementos finitos de cada crânio foi gerado. Foram obtidas imagens espiraladas em cortes de 0,25 mm de espessura por 1mm de intervalo das estruturas craniofaciais. Uma força de 100 Newton transversal e paralela ao plano oclusal foi aplicada ao nível do primeiro molar e primeiro pré-molar permanente superior do modelo, simulando uma situação clínica da expansão palatina. As imagens scaneadas foram visualizadas com o software Mimics V.17 para a construção dos modelos de referência em formato STL (Stereolitografia). A posterior construção das geometrias em modelos Bio-CAD foi efetuada no software Rhinoceros 3D 5.0. A malha de elementos finitos dos modelos foi construída no software Ansys v.14. Foram incorporadas as propriedades mecânicas do osso, sutura palatina mediana e a sincondrose esfeno-occipital em cada modelo. Os modelos de elementos finitos foram cortados sagitalmente e logo identificados pontos craniométricos para sua avaliação. A tensão equivalente de Von Mises e a Tensão máxima principal foram avaliadas e comparadas em ambos os modelos. Os resultados mostraram que a Técnica de Expansão Palatina teve um efeito direto sobre o processo pterigoide, sincondrose esfeno-occipital e sela turca na Classe II esquelética por protrusão da maxila e na Classe III esquelética por retrusão da maxila. Em geral nós observamos que o modelo Classe III mostrou maiores valores de tensões do que o modelo Classe II especialmente nas estruturas como a sincondrose esfeno-occipital e a sela turca.

Palavras Chaves: Técnica de Expansão Palatina, Análise de Elementos Finitos. Morfologia.

ABSTRACT

The Palatal Expansion Technique is often used to correct the posterior cross bite, maxillary transversal colapse and increase the perimeter of the dental arch. The objective of this study was evaluate by Finite Element Analysis the biomechanics effect on the Pterygoid processes, the Spheno-occipital synchondrosis and the Sella turcica in two skulls with Class II and Class III skeletal relationship, identifying the distribution of mechanical stresses in these anatomical structures. For this, we selected two Computerized Tomography Cone Beam of skulls with 13 years old and maxillary transversal collapse. A finite element model of craniofacial structure of each skull was generated. Spiral images were obtained at 0.25 mm thick by 1 mm slices range of craniofacial structures. A force of 100 Newton horizontal and parallel to the occlusal plane was applied at the level of the first molar and upper first permanent premolar model, simulating a clinical situation of the Palatal Expansion. Images scanned were viewed with Mimics V.17 software for the construction of the reference models in STL format (Stereolithography). The subsequent construction of the geometries of Bio-CAD models were made with the help of Rhinoceros 3D software 5.0. The finite element mesh of the models was built in Ansys V.14 software. The mechanical properties of bone, sutures and the spheno-occipital synchondrosis were incorporated in each model. The finite-elements models were cut sagittally and then identified craniometrics points for the evaluation. The Von-Mises stress and maximum principal stress were evaluated and compared in both models. The results revealed that the Palatal Expansion Technique had a direct effect on the the Pterygoid processes, the Spheno-occipital synchondrosis and the Sella turcica in the Class II skeletal relationship by maxillary protrusion and in the Class III skeletal relationship by maxillary hypoplasia. In general, we observed that the Class III model presented higher values stress than the Class II model, especially in the Spheno-occipital synchondrosis and the Sella turcica structures.

Keywords: Palatal Expansion Technique. Finite Element Analysis. Morphology.

SUMÁRIO

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INTRODUÇÃO

A técnica de expansão palatina é usada frequentemente para corrigir a mordida cruzada posterior, atresia transversal maxilar e aumentar o perímetro da arcada dentária (Haas, 1961; Krebs, 1964; Garret et al., 2008).

Uma vez que existe uma importante relação anatômica entre a maxila e a base do crânio, por meio dos processos pterigoideos de osso esfenoide, a transmissão da força mecânica produzida pelo aparelho de expansão durante a abertura da sutura palatina mediana pode afetar tais estruturas diretas ou indiretamente (Timms,1974; Baydas et al., 2006; Ghoneima et al., 2011).

O terço médio da face e a base do crânio em indivíduos ainda em crescimento ósseo, estão formados por ossos unidos por articulações fibrosas e cartilagíneas, as quais ainda não estão totalmente ossificadas; dentro destas, destacam-se a sutura palatina mediana na maxila e a sincondrose esfeno-occipital na base do crânio (Cruz-Rizzolo & Madeira, 2006). A condição estrutural e configuração morfológica destas estruturas anatômicas fazem que algumas regiões do crânio tenham certa flexibilidade e movimentação quando pressões ou tensões mecânicas são exercidas nelas (Sato, 1991; Lee et al., 1997; Slavicek, 2002).

Vários estudos descrevem os efeitos das tensões produzidas pela força fornecida durante a expansão palatina sobre a sincondrose esfeno-occipital (Gardner & Kronman, 1971; Baydas et al., 2006; Leonardi et al., 2010; Feng et al., 2012; Silvestrini-Viavati et al., 2013) e sobre os processos pterigoides (Timm, 1980; Iseri et al., 1998; Jafari et al., 2003; Holberg & Rudzki-Janson, 2006; Pan et al., 2007; Gautam et al., 2007; Boryor, 2008; Wang et al., 2009; Baldawa & Bhad, 2011; Gautam et al., 2011). No entanto, outros autores dão pouca importância à relação entre a maxila e os processos pterigoideos durante a aplicação deste procedimento ortodôntico (Kudlick, 1973, Provaditis et al., 2008, Lagravere et al., 2010).

Outros autores afirmam que a base do crânio por meio da sincondrose esfeno-occipital influencia no estabelecimento da morfologia facial durante a etapa de crescimento (Enlow, 1975; Anderson & Popovich,1983; Kerr & Adams, 1988; Sato, 1991; Singh et al.,1997; Jeffery, 2005), e que inclusive uma modificação desta sincondrose esfeno-occipital poderia afetar o crescimento do complexo craniofacial (Proff, et al., 2008).

Dentro destas modificações da base do crânio por efeito das forças ortopédicas está o deslocamento da sincondrose esfeno-occipital (Gardner & Kronman, 1971; Leonardi et al., 2010; Silvestrini-Viavati et al., 2013), a modificação do metabolismo ósseo da sincondrose esfeno-occipital (Baydas et al., 2006; Feng et al., 2012) e a alteração da base do crânio na região anterior por efeito da forças ortopédicas tipo protação (Feng et al., 2012).

Sabe-se também que imediatamente depois da aplicação da técnica de expansão palatina existe um abaixamento e avanço anterior da maxila junto com sua região dentoalveolar ocasionando um deslocamento inferior e posterior da mandíbula. Porém, encontrou-se que se trata de um fenômeno temporal e não significativo ao longo prazo (Garib et al.,2005; Lagravere et al., 2005).

A Análise de Elementos Finitos (AEF) permite simular o sistema de forças mecânicas simulando a técnica de expansão palatina, e analisar a resposta do crânio frente às tais cargas mecânicas (Brekemans et al., 1972; Bathe, 1982; Taylor, 1986; Singh, 1997; Camacho et al., 1997; Iseri et al., 1998; Holberg, 2007, Prado et al., 2013, Freire, et al., 2014). Apesar dos efeitos das respostas biomecânicas estarem diretamente relacionados à morfologia craniofacial, não estão muito claros nas diferentes relações esqueléticas Classe II e Classe III, uma vez que a morfologia do terço médio da face e da base do crânio são diferentes (Farronato et al, 2011).

Diante do exposto, embasado na diferencia morfológica dos efeitos da força ortopédica da expansão palatina sobre a base do crânio, o objetivo deste estudo foi avaliar, pela análise de elementos finitos, o efeito simulado da técnica de expansão palatina sobre o processo pterigoide, sincondrose esfeno-occipital e sela turca em dois crânios com relação esquelética tipo Classe II e Classe III, identificando a distribuição das tensões mecânicas nessas estruturas anatômicas.

CAPÍTULO 1: Effect of rapid maxillary expansion on the pterygoid process, spheno-occipital synchondrosis and sella turcica in skulls with Classes II and III skeletal relationship - a finite element analysis study.

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ABSTRACT

Objetive: To evaluate the effect of the RME on the PP, SOS and ST in two dry human skulls with Class II and Class III skeletal relationship, in order to identify the distribution of mechanical stresses in specific points of these anatomical structures by FEA.

Materials and Method: Cone-beam computed tomography of two dry human skulls were used in this study: 1) 13 year-old, female, with Class II skeletal relationship by maxillary protrusion and 2) 14 year-old, male, with Class III skeletal relationship by maxillary hypoplasia. The CAD geometry of two skulls was imported into the Ansys v14 software to build the finite element mesh. For the simulation, a force of 100N in a transverse direction was defined at the palatal surfaces of the first upper molar and first premolar, representing the RME. For analysis of results, von Mises stress and Maximum Principal Stress were evaluated identifying different nodes, which were represented by points according to the areas interest in the study.

Results: In von Mises stress, Class II model showed maximum value in the point 3 (2.077 MPa), similarly for the Class III model (1.707MPa). In Maximum Principal stress, maximum tensile stress was found in Class II model, in point 2 (1.396MPa), and in Class III was in point 3 (1.813MPa).

Conclusions: The Class III model undergoing to RME support higher stress at the skull base than Class II model. The stress on the SO and the ST is relatively higher in the Class III than Class II model.

Keywords: Finite element analysis, Rapid Maxillary Expansion, malocclusion.

INTRODUCTION

Rapid maxillary expansion (RME) is often used to treatment of the posterior dental cross bite, transversal maxillary collapse, increase the perimeter of the dental and skeletal arches and skeletal Class III treatment combined with maxillary protraction[1,2,3]. There is an important anatomical relationship between the maxillary region of the skull base and the pterygoid processes of the sphenoid bone (PP), and the transmission of mechanical stress produced by the appliance expander during the opening of the midpalatal suture may affect structures directly or indirectly[4.]

Several studies describe the effects of the mechanical stresses produced by the force provided by RME on the spheno-occipital synchondrosis (SOS)[5,6,7,8,9], the PP[4,10,11,12] and on the Sella Turcica (ST)[12].

Authors affirmed that SOS influences the skull base in establishing the facial morphology during the growth stage[13,14], and state that a modification of the SOS, by RME, could affect the craniofacial complex growth. Others authors related that RME cause changes only on maxillary region of the skull base for effects of orthopedic forces[16]. In addition, some authors state the morphological changes of ST occurs by natural effect of craniofacial growth[17].

The finite element analysis (FEA) allows simulating the system of mechanical forces that act in RME submitted in skulls, and analyze the response on the neurocranium and viscerocranium of such mechanical loads[10].

We hypothesized that the RME could have a direct effect on skull base, mainly in SOS, in Classes II and III skeletal relationship, leading to a new skeletal equilibrium. The knowledge of these effect presented great importance for the monitoring of the treatment of these skeletal Classes.

The present research evaluate the effect of the RME on the PP, SOS and ST in two dry human skulls with Class II and Class III skeletal relationship, in order to identify the distribution of mechanical stresses in specific points of these anatomical structures by FEA.

MATERIALS AND METHODS

The ethics committee of research of Piracicaba Dental School -State University of Campinas, approved this study (Protocol number: 056/2013).

Computed tomography and modeling for CAD geometry acquisition

Cone-beam computed tomography (CBCT) of two dry human skulls were used in this study: 1) 13 year-old, female, with Class II skeletal relationship by maxillary protrusion and 2) 14 year-old, male, with Class III skeletal relationship by maxillary hypoplasia. Both skulls present a complete permanent dentition and posterior dental cross bite. The CBCT images presented slices thickness with 0.25mm intervals.

CBCT scanned images were imported in the software MIMICS v17 (Materialise, Belgium) and segmented through grayscale threshold to obtain the three-dimensional surface of maxilla and skull base (Figure 1). The selected bone structure was converted into a 3D stereolithography (STL) surface.

The Computer Aided-Design (CAD) geometry was constructed in Rhinoceros 5.0 (McNeel & Associates, Seatle, WA) software (Figure 1). The modeling was performed through the STL surface conversion into NURBS surfaces. The space of median palatine suture (MP) and spheno-occipital synchondrosis (SOS) were filled with solids, corresponding to the connective and cartilage tissues, respectively (Figure 2).

Finite element analysis

Finite element model

The CAD geometry of two skulls was imported into the Ansys v14 (Ansys, Inc, USA) software to build the finite element mesh (Figure 1). Tetrahedral elements were used for mesh generation, resulting in a mesh composed by 344808 elements and 596966 nodes (Class II) and with 390349 elements and 689736 nodes (Class III).

The materials properties were considered linear elastic and isotropic. The structures were assigned following the properties of bone, cartilage for SOS and connective tissue for MP. The properties of each material as (Young modulus and Poisson’s ratio) were used according previous studies[18-20](Table 1).

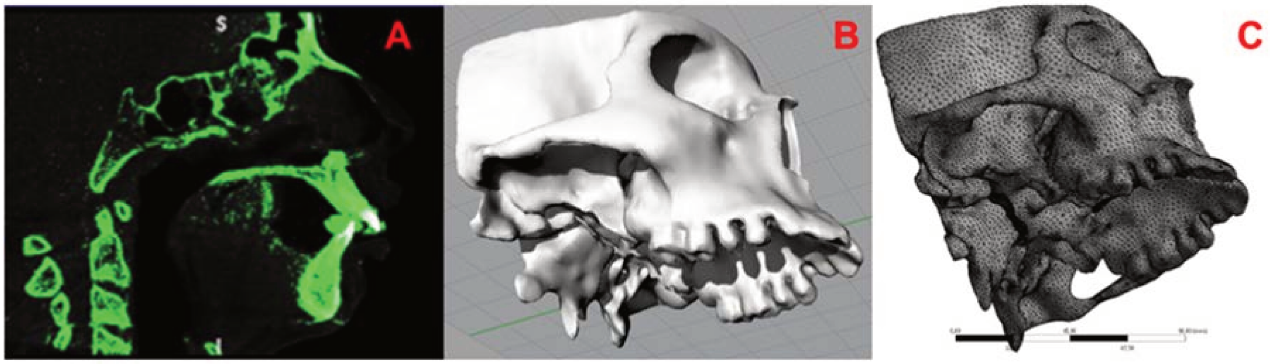

Figure 1. A) CT Image, B) CAD geometric model, C) Finite element mesh

Table 1. Mechanical properties used in study.

Material	Young's modulus(Mpa)	Poisson's ratio
Bone [18]	14000 Mpa.	0.3
Midpalatal suture[19]	1 Mpa.	0.3
Spheno-occipital synchondrosis[20]	24 Mpa	0.3

Boundary conditions and configuration of analyses

The boundary condition was defined by zero-displacement and zero-rotation on the nodes along the foramen magnum margin; the shape and the load was made symmetric around the X-axis (Transverse). For the simulation, a force of 100N[21] in a transverse direction was defined at the palatal surfaces of the first upper molar and first premolar, representing the RME (Figure 2). In order to observe the biomechanical effects on the PP, SOS and ST in the skulls with Class II and Class III skeletal relationship, the finite-elements models were cut sagittally[23].

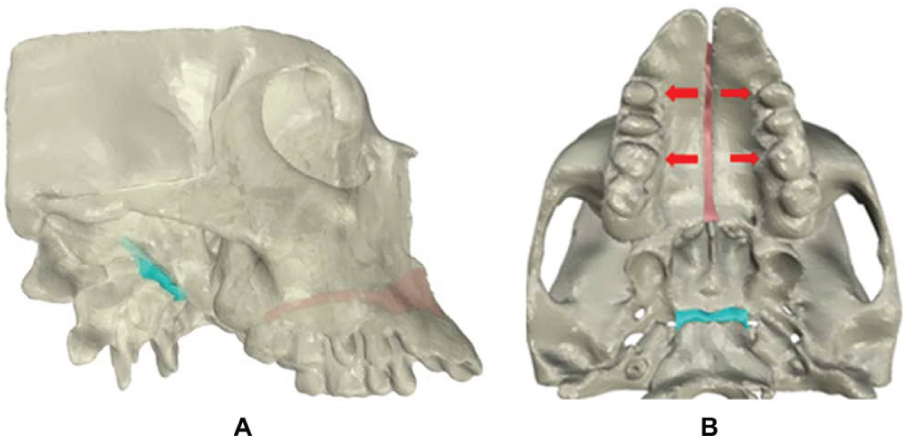

Figure 2. A) The SOS and midpalatal, B) Simulation of the transverse load

Analyses of results

The von Mises stress (VMS) and Maximum Principal Stress (MPS) were evaluated identifying different nodes, which were represented by points according to the areas interest in the study: Sphenobasion anterior - Sba (Point 4), Sphenobasion posterior – Sbp (Point 5), Synchondrosis spheno-occipital inferior - SOi (Point 6), Synchondrosis spheno-occipital superior – Sos (point 7), Sella - S (Point 8) and Sphenoidal point-Sphen (Point 9). Besides we include three points to evaluate the medial pterygoid plate in the lower (Point 1), middle (Point 2) and top (Point 3) zone (Figure 3 and Table 2).

FEA was performed on each model cut. Under specific loading condition, the VMS represents the effective stress in a material and the MPS represents tensile stress and compressive stress on determined regions of interest

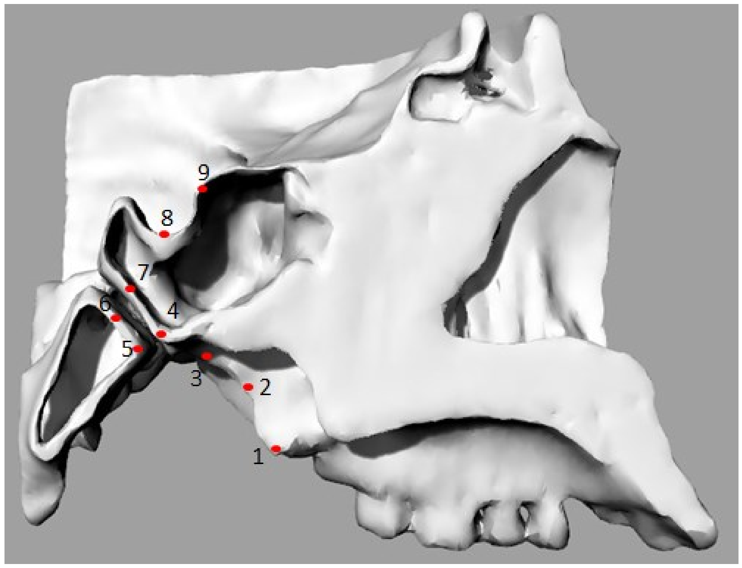

Figure 3. Sites for stress evaluations in the sagittal view

Table 2. Points and Anatomical Structures.

Points	**Selected nodes on**
Point 1	The most inferior and posterior point of the medial pterygoid plate
Point 2	The most posterior and middle point of the medial pterygoid plate
Point 3	The most upper and posterior point of the medial pterygoid plate
Point 4	The most inferior point of the posterior surface of the sphenoid body
Point 5	The most inferior point of the anterior surface of the basilar part of the occipital bone
Point 6	The point of intersection between the S-Ba line and the anterior surface of the basilar of the occipital bone
Point 7	The point of intersectation between the S-Ba line and the posterior surface of the sphenoid body
Point 8	The deepest point of the floor of the sella turcica
Point 9	The uppermost point of the tuberculum sellae

RESULTS

VMS comparison between Class II and Class III skull models

Class II model showed the maximum value of VMS in the point 3 (2.077 MPa), similarly for the Class III model (1.707MPa). In comparison between the two classes, the VMS increased in the medial pterygoid plate, from the inferior region up to superior (points 1, 2 and 3), showing higher stress values in the Class II model than Class III (Figure 4 and Table 3).

In both models anterior region at SOS (Points 4 and 7) showed higher stress concentration than the posterior region (points 5 and 6). VMS in the previous region has close values in both models (Table 3).

ST showed larger stress in Class III model (0.341MPa), than in Class II model (0.193MPa). In S point, the tuberculum sellae also showed higher stress in the Class III model (0.281MPa) than the Class II model (0.177MPa) (Figure 4).

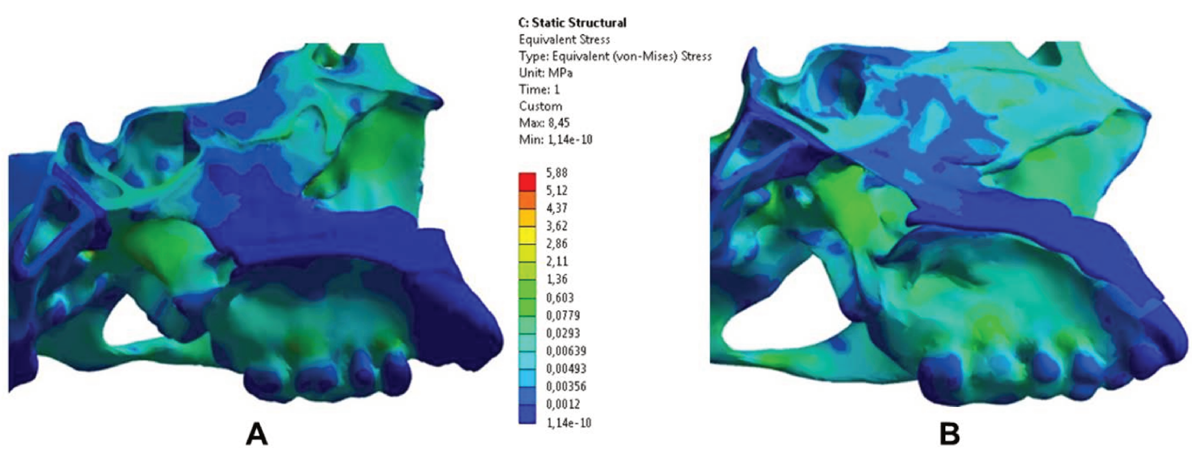

Figure 4. Von Mises stress distribution in Class II model and Class III model

MPS comparison between Class II and Class III skulls models

The MPS presented positive values (tensile stress) and negative values (compressive stress). The maximum tensile stress was found in Class II model, in point 2 (1.396MPa), and in Class III model was in point 3 (1.813MPa) (Table 3).

In both models, higher tensile stress were found in previous region at SOS (Points 4 and 7), as compared with the posterior region (Points 5 and 6) (Table 3). The tensile stress values were higher in Class III model than the Class II model (Table 3).

Compressive stress was found in ST being higher in the Class III model (0.066MPa) than the Class II model (0.008MPa) (Figure 5). The tuberculum sellae showed higher tensile stress in the Class II model (0.183MPa) than the Class III model (0.014MPa) (Figure 5).

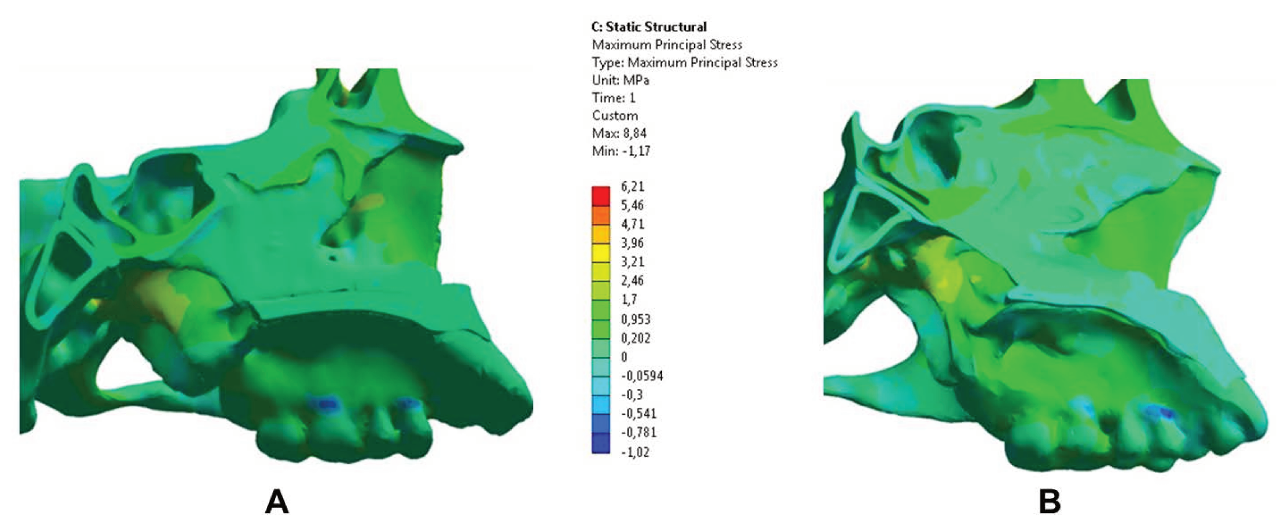

Figure 5. Principal Stress in Class II model and Class III model

Table 3. VMS and MPS values at the anatomical points evaluated

Point	Von Misses stress (MPa)		Maximum Principal stress (MPa)	
	Class II	Class III	Class II	Class III
1	0.050	0.124	0.030	0.127
2	1.466	0.904	1.396	0.885
3	2.077	1.707	1.104	1.813
4	0.324	0.373	0.229	0.435
5	0.143	0.066	0.157	0.069
6	0.036	0.054	0.023	0.066
7	0.212	0.346	0.238	0.387
8	0.193	0.341	-0.008	-0.066
9	0.177	0.281	0.183	0.014

DISCUSSION

RME simulation through FEA has been an effective method used in orthodontics for the study of the forces produced on the craniofacial structures[10, 11,12]. RME is often used to correct the posterior cross bite, maxillary atresia and increase the perimeter of the arch with the consequent relief of dental crowding[1, 2, 3] and can be applied in the treatment of Class II and Class III skeletal relationship.

The RME cause the midpalatal open, and transversals forces are transmitted to the skull base via connection between the maxilla and pterygoid process. Others effects occurring such as the displacement of the SOS[7, 8, 9], bone metabolism modification[5, 28], and changes in anterior region of skull base[17]. The morphology of the skull base is the main factor in establishing the sagittal relationship of the upper and lower jaws[23], however the extent and effects of RME on the skull base in Class II and III skeletal relationship have not been studied or well understood[24].

We do not simulate displacement of the palatal process. We simulated the first stage of RME by application of a lateral force, such as was used by Boryor et al.[21], and Lee et al[22].

Our results showed that in both models in anterior region at SOS (Points 4 and 7) showed higher stress concentration than the posterior region (points 5 and 6). VMS in the previous region has close values in both models. Gardner and Kronman[7] underlined that opening the SOS could be responsible for the forward displacement of the maxilla, and then higher stress concentration in anterior region at SOS. These authors affirmed that this change occurs in the active phase of treatment.

In MPS analysis, we found tensile stress in both models. In Class II model was observed tensile stress in middle part of the medial pterygoid plate (Point 2). In Class III model tensile stress occurs in the top of the medial pterygoid plate (Point 3). This stress distribution agrees with the findings in the study of Holberg et al.[25]. The tensile stress in these points occurs due to lateral bend of the PP during the RME as describe by Jafari et al[11] and Iseri et al[10]. Authors also explain that there is a resistance of the suture opening in the posterior region of the hard palate [2].

In MPS analysis, we observed compressive stress in ST. Our results showed that the compressive stress values were higher in Class III model than the Class II model. Holberg et al.[25] found compressive stress at the SOS during the RME, although the authors not specify the region studied. Ingervall and Thilander[26] found collagen fibers in SOS, arranged in the longitudinal direction of the clivus, which could probably mean preparation for tensile stress distribution. The difference between tensile and compressive stresses distribution around the SOS found in our results could probably related to the elasticity of the SOS[27] that distribute the stress that comes from PP.

In our results, the tuberculum sellae showed higher tensile stress in the Class II model than the Class III model. According to Afrand et al[28] the anterior cranial base is not a stable anatomic structure. Bony tissue of ST remodels and moves backward and downward during craniofacial growth. We could suggested that during the RME an alteration occurs in the morphology of the ST. In addition, Ingervall and Thilander[26] found cartilage regions in ST of skulls in older ages, which could cause lower values of stress in this region.

This study has limitations. In order to be able to simplify and represent the biomechanical procedure the skull models was assumed to be isotropic and linearly elastic[29]. The stress difference found between the skull Class II and Class III models is based on morphology, since that the geometry is fundamental to mechanical response[18].

In general, we observed that the Class III model presented higher values stress than the Class II model, especially in SOS and the ST structures. Considering the limitations of our study, this result is due to a reduction in the quantity of bone manifested such a short cranial base.

CONCLUSIONS

Our results suggested the following conclusions:

- The RME have a direct effect on the PP, SOS and ST in the Class II skeletal relationship by maxillary protrusion and in the Class III skeletal relationship by maxillary hypoplasia.
- The Class III model undergoing to RME support higher stress at the skull base than Class II model.
- The stress on the SO and the ST is relatively higher in the Class III model than the Class II model.

ACKNOWLEDGEMENTS

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CONCLUSÃO

- A Técnica de Expansão Palatina tem um efeito direto sobre o processo pterigoide, sincondrose esfeno-occipital e sela turca na Classe II esquelética por protrusão da maxila e na Classe III esquelética por retrusão da maxila.

.- O modelo Classe III submetido à Técnica de Expansão Palatina recebe maior tensão na base do crânio do que o modelo Classe II.

- As tensões sobre a sincondrose esfeno-occipital e sela turca são maiores no modelo Classe III do que no modelo Classe II.

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*De acordo com a norma da UNICAMP/FOP, baseadas na norma do International Committee of Medical Journal Editors-Grupo de Vancouver. Abreviatura dos periódicos em conformidade com o Medline.

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APÊNDICE 1 – Figura 1

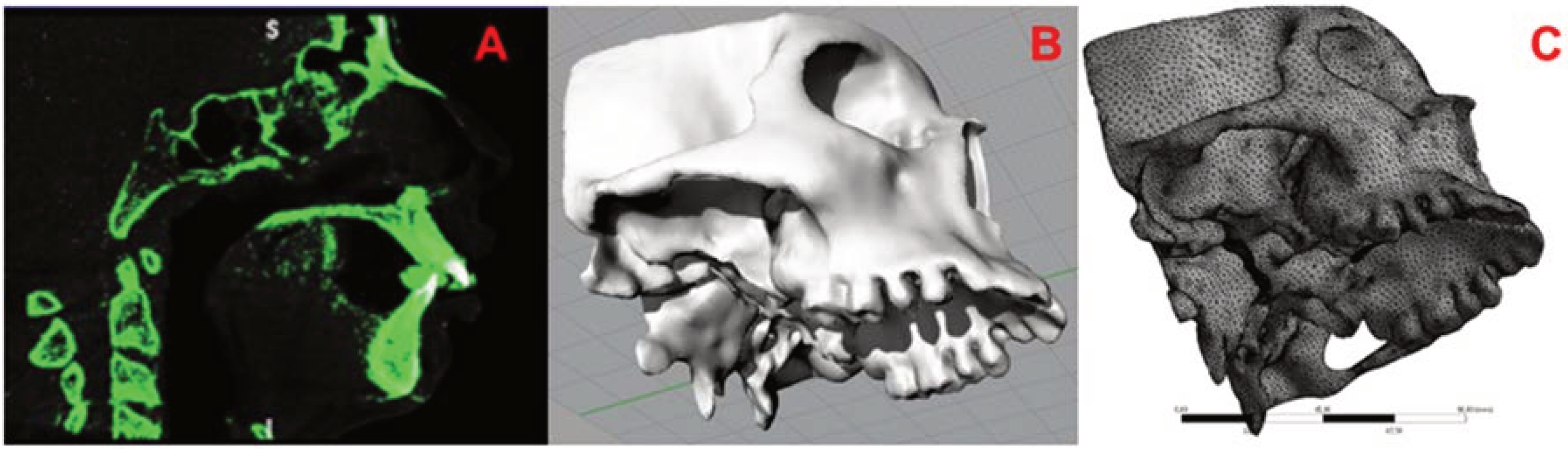

Figura 1. A) Imagem da tomografia com as estruturas selecionadas no software MIMICS v17 (Materialise, Belgium), B) Geometria CAD no software Rhinoceros 5.0 (McNeel & Associates, Seatle, WA), C) Malha de elementos finitos no software Ansys v14 (Ansys, Inc, USA).

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APÊNDICE 2 – Figura 2

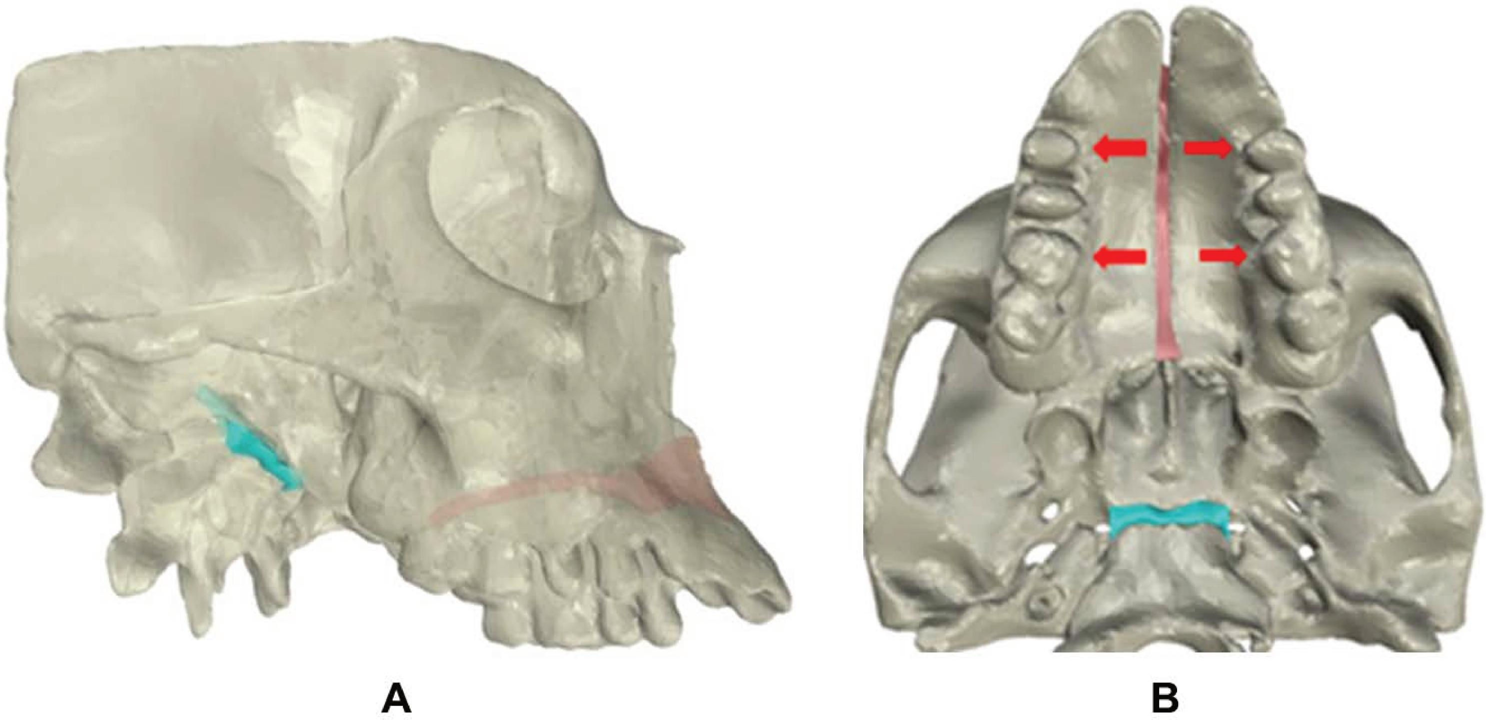

Figura 2. A) Vista lateral do modelo. B) Vista inferior do modelo. As setas indicam a simulação da carga transversal.

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APÊNDICE 3 – Figura 3

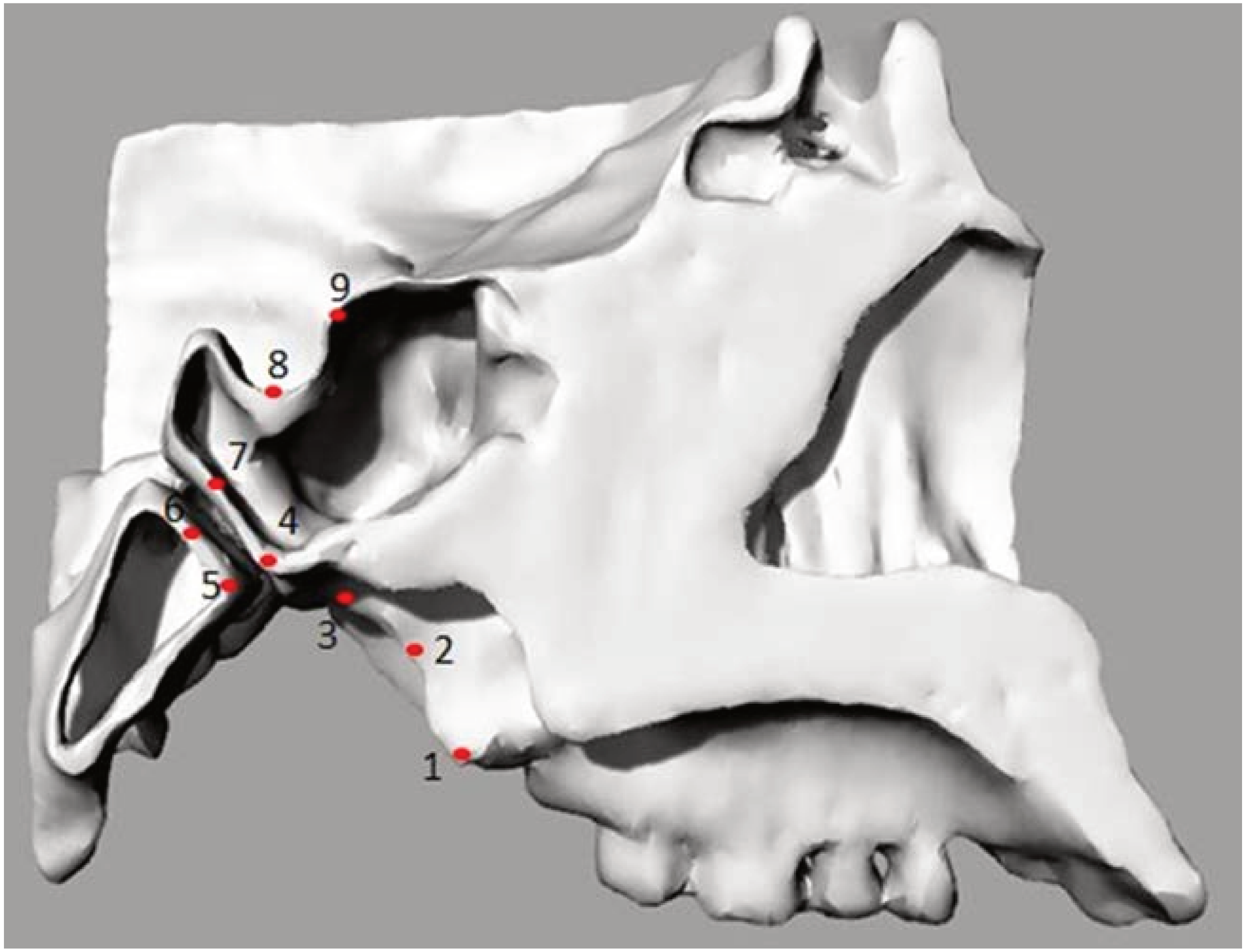

Figura 3. Pontos de tensão avaliados numa vista sagital.

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APÊNDICE 4 – Figura 4

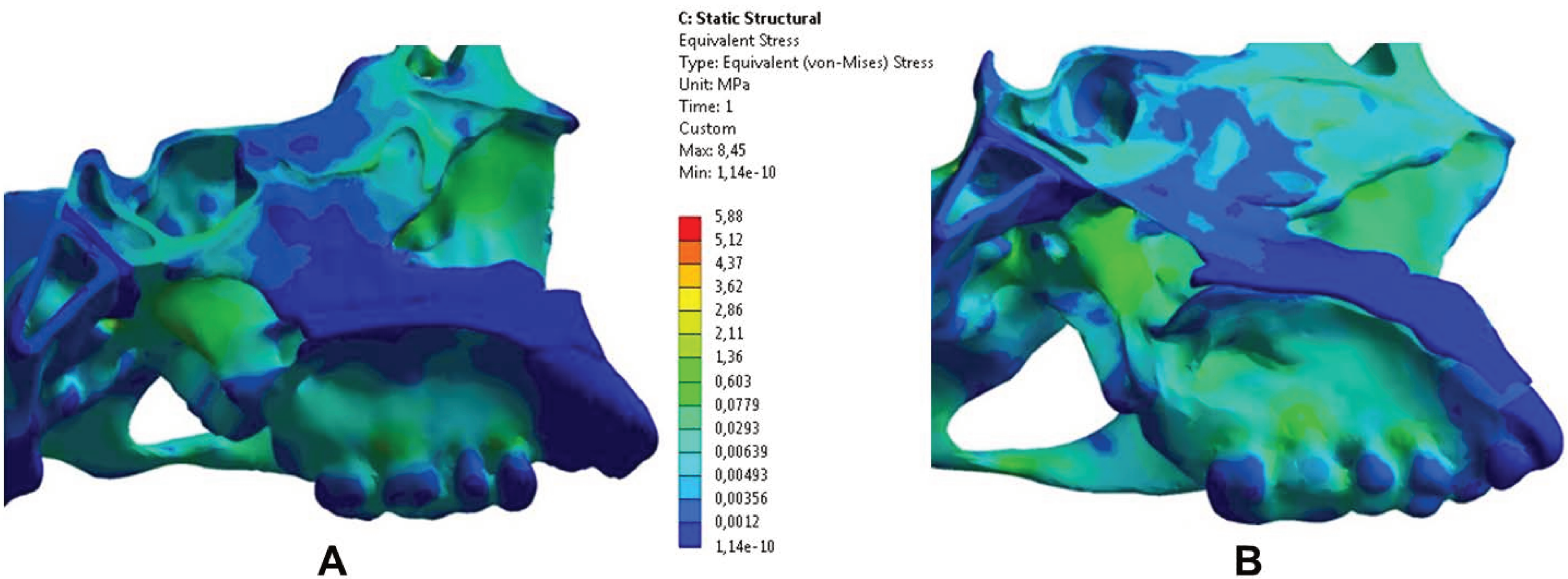

Figura 4. Distribução da tensão de Von mises. A) Modelo Classe II. B) Modelo Classe III.

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APÊNDICE 5 – Figura 5

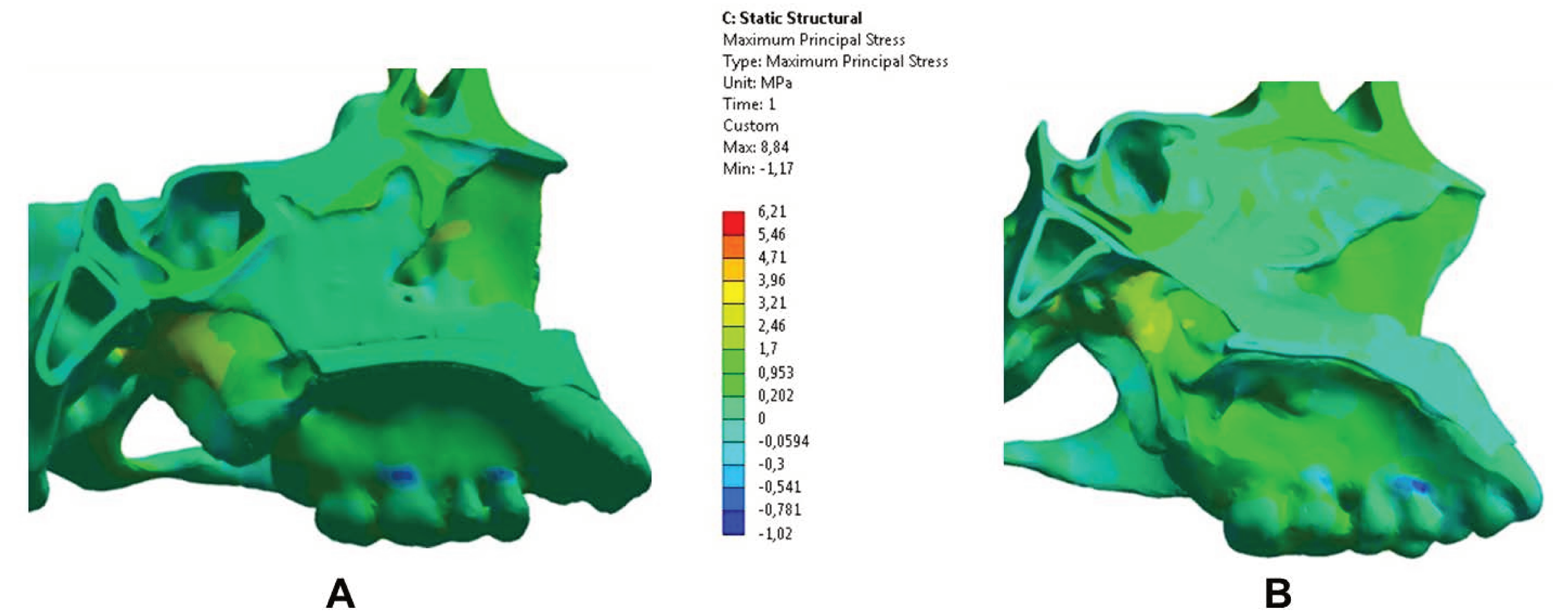

Figura 5. Distribuição da Tensão máxima principal. A) Modelo Classe II. B) Modelo Classe III.

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ANEXO 1 – COMPROVANTE DE SUBMISSÃO DE ARTIGO *ONLINE* – PERIÓDICO ANGLE ORTHODONTIST

THE ANGLE ORTHODONTIST

ONLINE MANUSCRIPT SUBMISSION AND PEER REVIEW

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Detailed Status Information

Manuscript #	041715-260
Current Revision #	0
Submission Date	2015-04-16 14:34:53
Current Stage	Initial QC Started
Title	Effect of rapid maxillary expansion on the pterygoid process, spheno-occipital synchondrosis and sella turcica in skulls with Classes II and III skeletal relationship - a finite element analysis study
Running Title	Effect of RME in Classes II and III skulls
Manuscript Type	Original Article
Special Section	N/A
Corresponding Author	Manuel Chavez Sevillano (San Marcos University)
Contributing Authors	Ana Cláudia Rossi , Alexandre Freire , Felippe Prado
Financial Disclosure	I certify that all financial and material support for this research and work are clearly identified in the manuscript. Details regarding this support have been fully outlined in my cover letter.
Abstract	Objetive: To evaluate the effect of the RME on the PP, SOS and ST in two dry human skulls with Class II and Class III skeletal relationship, in order to identify the distribution of mechanical stresses in specific points of these anatomical structures by FEA. Materials and Method: Cone-beam computed tomography of two dry human skulls were used in this study: 1) 13 year-old, female, with Class II skeletal relationship by maxillary protrusion and 2) 14 year-old, male, with Class III skeletal relationship by maxillary hypoplasia. The CAD geometry of two skulls was imported into the Ansys v14 software to build the finite element mesh. For the simulation, a force of 100N in a transverse direction was defined at the palatal surfaces of the first upper molar and first premolar, representing the RME. For analysis of results, von Mises stress and Maximum Principal Stress were evaluated identifying different nodes, which were represented by points according to the areas interest in the study. Results: In von Mises stress, Class II model showed maximum value in the point 3 (2.077 MPa), similarly for the Class III model (1.707MPa). In Maximum Principal stress, maximum tensile stress was found in Class II model, in point 2 (1.396MPa), and in Class III was in point 3 (1.813MPa). Conclusions: The Class III model undergoing to RME support higher stress at the skull base than Class II model. The stress on the SO and the ST is relatively higher in the Class III than Class II model.
Assistant Editor	Not Assigned
Key Words	finite element analysis, rapid maxillary expansion, malocclusion

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ANEXO 2 – CERTIFICADO DO COMITÊ DE ÉTICA EM PESQUISA DA FOP-UNICAMP

CEP FOP

COMITÊ DE ÉTICA EM PESQUISA
FACULDADE DE ODONTOLOGIA DE PIRACICABA
UNIVERSIDADE ESTADUAL DE CAMPINAS

CERTIFICADO

O Comitê de Ética em Pesquisa da FOP-UNICAMP certifica que o projeto de pesquisa **"Efeito da disjunção palatina sobre a maxila, vômer, processo pterigoide e base do crânio em pacientes com relação esquelética Classe II e Classe III"**, protocolo nº 056/2013, dos pesquisadores Manuel Gustavo Chavez Sevillano e Felippe Bevilacqua Prado, satisfaz as exigências do Conselho Nacional de Saúde - Ministério da Saúde para as pesquisas em seres humanos e foi aprovado por este comitê em 20/09/2013.

The Ethics Committee in Research of the School of Dentistry of Piracicaba - State University of Campinas, certify that the project **"Effect of the rapid maxillary expansion on the maxilla, vomer, pterygoid process and skull base in subjects with Class II and Class III skeletal relationship."**, register number 056/2013, of Manuel Gustavo Chavez Sevillano and Felippe Bevilacqua Prado, comply with the recommendations of the National Health Council - Ministry of Health of Brazil for research in human subjects and therefore was approved by this committee at 09/20/2013.

Prof. Dr. Felippe Bevilacqua Prado
Secretário
CEP/FOP/UNICAMP

Profa. Dra. Lívia Maria Andaló Tenuta
Coordenadora
CEP/FOP/UNICAMP

Nota: O título do protocolo aparece como fornecido pelos pesquisadores, sem qualquer edição.
Notice: The title of the project appears as provided by the authors, without editing.