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Stress Distribution and Displacement Analysis during a Surgically Assisted Rapid Maxillary Expansion using a Bone-Borne Device a Finite Element Study

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Abstract

Introduction: The surgically assisted rapid maxillary expansion (SARME) is a method used for transverse maxillary correction in non-growing individuals or patients who have not achieved successful results with previous conventional treatments. There are several devices associated with SARME. The most common are the Hyrax and Hass expansion appliances. Bone-borne devices have also been reported; however, their high cost often makes their use unfeasible. Methods: Geometrical structures of the maxilla, skull, and bone-borne device were constructed. All materials were assumed to be homogeneous, isotropic, and to have linear elasticity. The maxilla was separated from the skull through a Le Fort I osteotomy and the intermaxillary suture was separated through a mid-sagittal osteotomy. The appliance was activated by 1 mm and the data were graphically analyzed. Results: The highest concentration of applied force was found on the contact region between the plate and the bone, as well as on the uppermost part of the hard palate. We also observed a larger opening in the anterior region in comparison with the posterior region, leading to a "V"-shaped opening.

Keywords: Maxilla, disjunction, bone-borne, osteotomy

1 Introduction and literature review

Transverse maxillary deficiency is often observed in adult patients and can be the cause of unilateral or bilateral crossbite and anterior teeth crowding[1]. Posterior crossbite incidence is nearly 9.4% in the general population. Incidence goes up to 30% among patients who seek assessment for orthognathic surgery.[2] Surgically assisted rapid maxillary expansion (SARME) was introduced in 1938 and its general indications are: skeletal maturity; unilateral or bilateral severe transverse maxillary hypoplasia; anterior teeth crowding; buccal corridor, also known as "black corridor" when patients smile.[3] The advantages of SARME are: crossbite correction, improvement of air passage through the nasal cavity, buccal corridor reduction, and reduced susceptibility to respiratory tract infections.[4]

Several orthodontic devices have been developed to help separate the midpalatal suture. The best known are the Hyrax and Hass expansion devices. They are, in general, cemented on the first premolar and first molar.[5] Other devices have been developed, especially bone-borne devices, in order to optimize the expansion process. However, their high cost often makes their use unfeasible.

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2 Material and Methods

This study was approved by the ethics and research committee of Pontifícia Universidade Católica do Rio Grande do Sul (Pontifical Catholic University of Rio Grande do Sul) - SIPESQ (Porto Alegre; Brazil; Number: 6898). Geometric structures of the maxilla and the skull as a whole were constructed, as well as the device to be studied. Bone structures were built from a DICOM file taken from the CTI database (CenPRA Information Technology Center - Campinas, SP, Brazil). Data have been previously obtained from an adult's skull subjected to a helical computed tomography with a 1 mm width.

Tridimensional geometries of the maxilla, skull, modified bone-borne device and screws were created using Rhinoceros 5.0 software (McNeel-América do Norte, Seattle, WA). Then, geometry was imported to Ansys Workbench V.16.2 software (Ansys Inc., Canonsburg, PA, USA) for finite element (FE) pre-processing. All materials were assumed to be homogeneous, isotropic, and to have linear elasticity.

The bone-borne device used in the study consists of a central expander screw connected to a surgical steel plate, each side is 2 mm wide and has four holes, two of which are used for hard palate bone fixation and the others are used to reinforce the junction between expander screw and plate (figure 1). This device is similar to the device described by Battistetti *et al*.[6]

Figure1

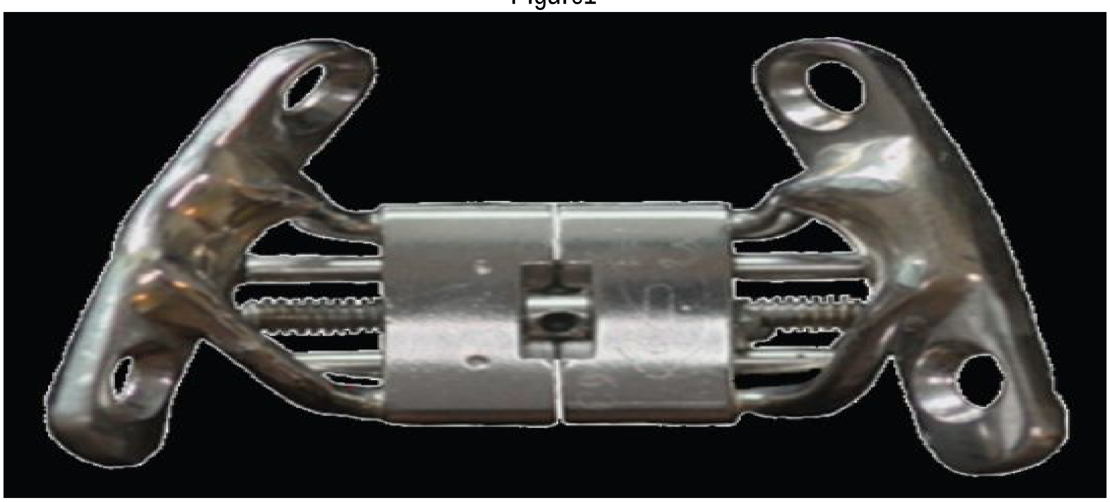


Figure 3

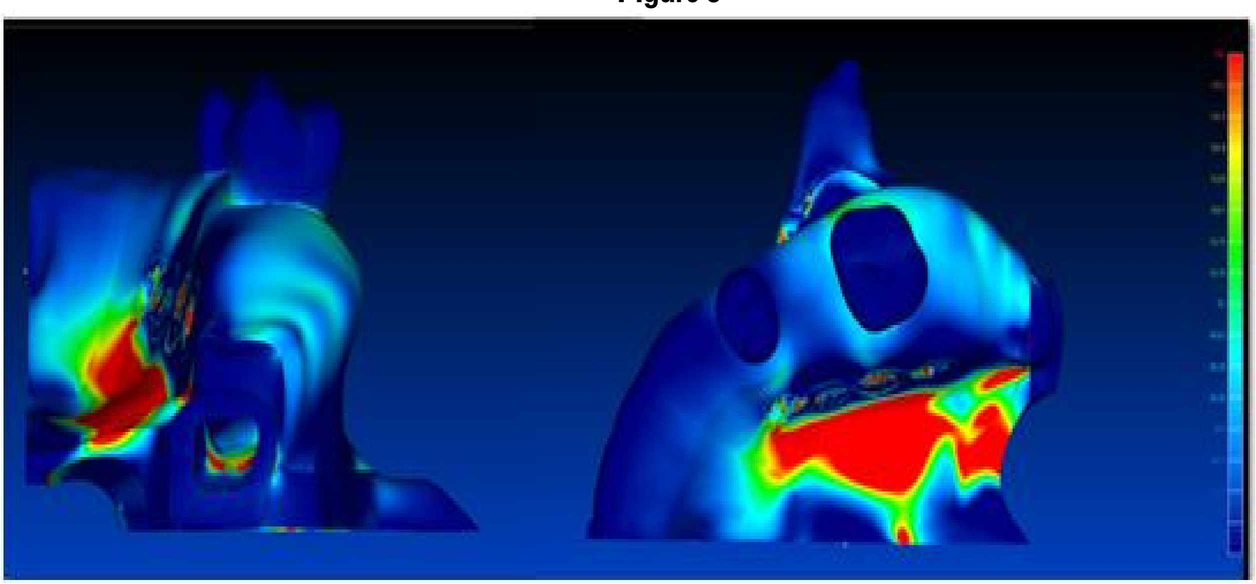
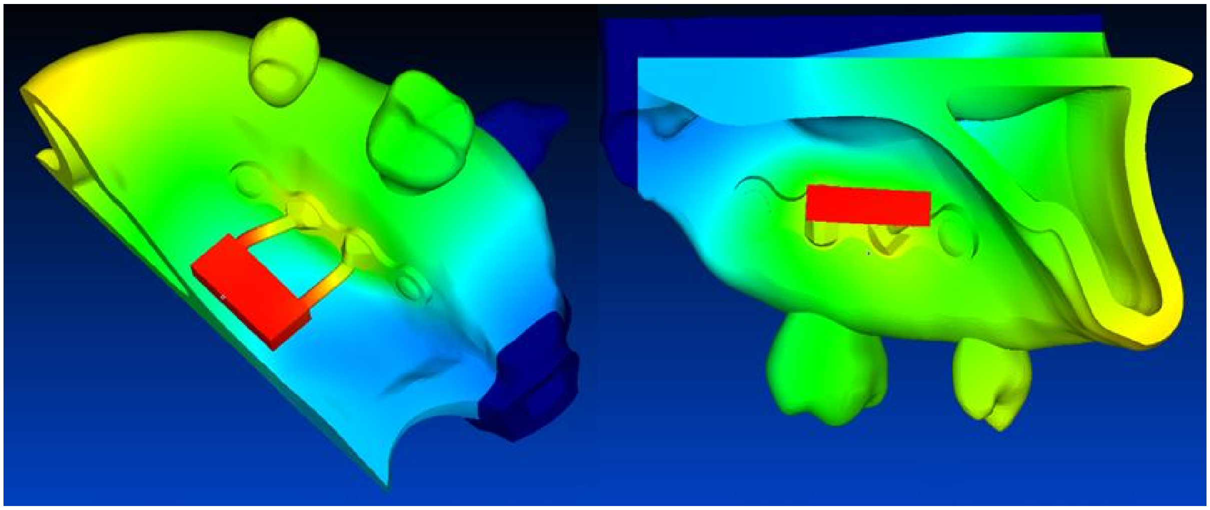
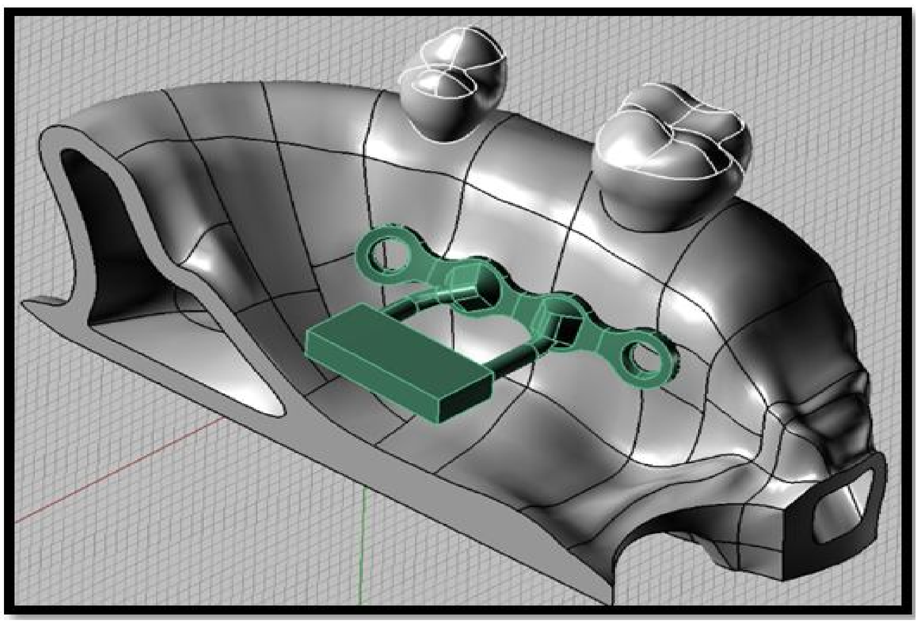


Figure4



A model of finite elements was created for the modified bone-borne device. The device was fixed on the maxilla using two 2.0 mm screws with 6 mm length on each side, adapted to be juxtaposed to bone (figure 2).



The maxilla was virtually separated from the skull through a LeFort I osteotomy, with release of pterygoid plates, and a mid-sagittal osteotomy separated the intermaxillary suture.

A 1 mm opening (0.5 mm each side) was promoted on the expander screw and the resulting forces were graphically analyzed through Ansys Workbench V.16.2. software (Ansys Inc).

Maxilla displacement and stress analysis were simultaneously calculated.

3 Results

The responses of the models created and their variations after load (1 mm) application are similar to those found in *in vivo* studies. The tension distribution model shows that higher maximum tension values are concentrated on the uppermost palatal side of the maxilla and the palatal bone, as well as in the interior of the maxillary sinus. Intermediary values are found in the maxillary tuberosity region and in the alveolar bone at the buccal side. The force suffered by the teeth is virtually null (Figure 3).

Table I

Values corresponding to the colors in the modified bone-anchored appliance model during maximum stress analysis

Dark Blue	Blue	Green	Yellow	Orange	Red
0 to 18.7 Mpa	20 to 65.6 MPa	70 to 105 MPa	110 to 120 MPa	125 to 138 MPa	140 to 150 MPa

Regarding bone movement, there is more displacement in the red areas, and virtually none in the dark blue areas. Areas with intermediary displacement (green, yellow, orange) are represented by the colors, where red and dark blue are the limit.

Table II Values corresponding to the colors in the bone-anchored appliance model during maximum displacement analysis (Value applied to lathe = 0.5 mm)

Dark Blue	Blue	Green	Yellow	Orange	Red
0 to 0.07 mm	0.1 to 0.24 mm	0.28 to 0.4 mm	0.42 to 0.45 mm	0.46 to 0.49 mm	0.5 to 0.56 mm

In the displacement analysis, higher bone movement is seen in the anterior region (0.44 mm) and it decreases towards the posterior region (0.21 mm), resulting in a "V-shaped" opening pattern. The dental region undergoes an intermediary displacement ranging from 0.16 mm to 0.39 mm, which is higher in the premolar region (Figure 4). Linear force transmission was observed, representing, in terms of bone displacement, mostly the movement applied to the expander screw, especially in the anterior maxilla. There was also a slight deformation of the connector arm between expander screw and plate.

4. **Discussion**

The goal of the method of study using finite elements is to transform a geometrically complex structure into a simple structure, with a limited number of elements.[7] Forces applied to the expanding device are conveyed to the maxilla and adjacent structures and the analysis method using finite elements can size this tension in multiple body areas.[8] There are several types of techniques and appliances used for SARME[9] and the variations in the osteotomy models change the level of dissipation regarding the stress that is generated.[10] We look for a technique that presents a balance between maximum maxilla mobility and a minimally invasive surgery to avoid complications. LeFort I osteotomy associated with pterygoid plate release and mid-sagittal osteotomy is considered to be the best way to separate the intermaxillary suture.[10] The first bone-borne devices were described in 1999 and are under constant improvement. They convey force directly to the bone and avoid the undesired effects on teeth and periodontal ligament.[11] The main disadvantage of these devices is their cost, which frequently makes their use unfeasible. This is why the study analyzed the appliance described by Battistetti *et al*., which is a bone-borne device, but much cheaper.

In the force transmission analysis, we observed that the modified bone-borne device conveys forces directly to the hard palate bones, without compromising teeth, periodontal ligament, and alveolar bone, as it is not fixed to the teeth. Thus, all negative effects a bone-borne device causes on teeth and adjacent structures can be avoided.[14] We also observed that the concentration of forces is on the midpalatal suture region, which favors its separation. The displacement analysis showed that the maxilla opening was larger in the anterior region (0.44 mm) in comparison to the posterior region (0.21 mm), resulting in a "V-shaped" opening pattern, because the expansion device was placed in the region of the premolars and first molar. According to Verstraaten[15], a more posterior position of the device makes the opening more parallel. We also observed that tooth displacement occurred to the same degree in relation to the adjacent bone, with no movement in the bone base.

5. Conclusions

It was concluded that the modified bone-borne device presents outstanding efficiency regarding the transmission of forces to the hard palate bones, without compromising tooth structures.
With the use of this device, the separation of the maxillas was more expressive in the anterior region in comparison with the posterior region, resulting in a "V-shaped" opening pattern.

Conclusions: It was concluded that the modified bone-borne device conveys forces very efficiently towards the bone and allows a "V"-shaped maxillary opening

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