

ESTIMATION OF STRAINS IN MIDPALATAL SUTURE: A COMPUTATIONAL BIOMECHANICAL STUDY

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Abstract. Rapid Maxillary Expansion (RME) is a technique very frequently indicated, for the correction of transversal problems in the maxillary arch. During the active phase of this treatment the median palatine suture (MPS) is broken and then it is ossified until reconstitute its original structure. It is reported that the magnitude and frequency of mechanical forces influence the shape and composition of cranial sutures. The most important cyclical force acting on the skull and jaw is the force generated during mastication of food. Thus, the objective of this study is to estimate computationally the deformation in the MPS, during mastication, after the active phase of RME, and correlate them to the mechanobiological cell differentiation theories. The three-dimensional geometry used in the model was extracted from computerized tomography of a 12 year old patient. This geometry was used to construct a finite element model to estimate strains in the MPS. All tissues were considered linear elastic materials with mechanical properties reported in literature. Considering the chewing forces for children who have 6-12 years found in the literature, a force of 35 newtons was applied to the second pre-molar and first molar of the higher hemiarch, in the direction of the long axis of each tooth. After computations, it was obtained that in the outer region, in contact with the jawbone, the SPM showed greater strains, with magnitudes between 0.3% and 7.3%, values close to those needed to stimulate bone synthesis. In the most inner region of the suture, strains were lower, close to 0.1%, only the edges there was strains exceeding 0.5%, values close to those needed to generate cellular resorption. That indicate that the mechanical strains are more favorable for the synthesis of bone close to the previously existent surfaces of bone, and they are the locations where bone could initially appear, as is observed in experimental studies.

Keywords: Rapid Maxillary Expansion, median palatine suture, mastication, mechanobiological cell differentiation.

1. INTRODUCTION

Finite element method (FEM) is a mathematical technique that consists of a discretization of a continuous environment into small elements, which allows study complex problems in areas such as continuum mechanics (Lotti *et al.*, 2006). The FEM has been widely used in orthodontics, because is extremely useful to indicate aspects mechanics of biomaterials and humans tissues that hardly could be measure in vivo (Silva *et al.*, 2008).

Orthodontics is a branch of dentistry that specializes in the prevention and treatment of dental and facial irregularities. One of these irregularities is the facial maxillary atresia, which is a common problem that can culminate to the posterior cross bite (upper posterior teeth are located internally in relation to the lower teeth when they are in contact) (Serpe, 2014). Rapid maxillary expansion (RME) is one of the most recognized medical treatments in orthodontic practice to correct atresic palate (Capelozza Filho *et al.* 1994).

The RME uses a device expander, which exercise transverse forces to the palate in the vestibular direction in order to break the mechanical strength mainly offered by midpalatal suture (MPS) and increase its cross section. The MPS is a tissue present between left maxillary and right maxillary, which is ruptured during the RME. Although the bone reparation starts immediately after active phase of expansion, the full ossification takes 5 to 9 months (Silva filho *et al.*, 2007; Cleall *et al.*, 1965).

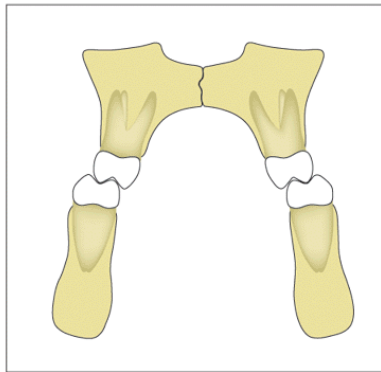


Figure 1. Illustration of posterior cross bite.

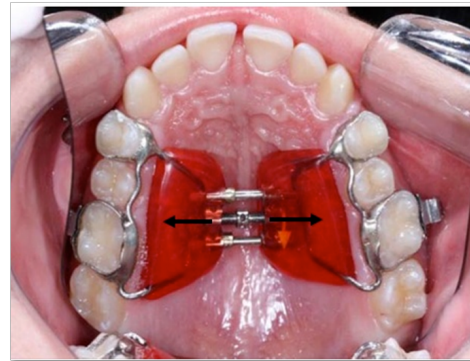


Figure 2. Occlusal photo of the upper arch with device expander type Hass

Experimental evidences indicate that mechanical stimuli have great importance in process of differentiation cell that happens in several processes regenerative such as occur during reparation of MPS. Several theoretical models (Pauwels 1960; Perren 1979; Perren e Cordey 1980; Prendergast *et al.*, 1997) predict how the differentiation of cells occur according mechanical stimuli. About cranial sutures, Paul *et al.* (2008) reports that the stresses generated in chewing and orthopedic loads are absorbed and transmitted by these structures, which regulate the sutural growth according to their intensity and frequency.

Thus, this study aims estimate and correlate with theoretical models of tissue differentiation the strain in MPS during chewing, after RME, by means of a computational model of finite element. This work has purpose to be a first step in the study of the regeneration process of MPS.

2. MECHANOBIOLOGY THEORIES

Mechanical stimuli influence the differentiation of mesenchymal stem cells into several specialized cells defined by Caplan and Boyan (2010) (Figure 1). Hence, various differentiations theories have emerged to explain the relation between cell differentiation and the mechanical environment.

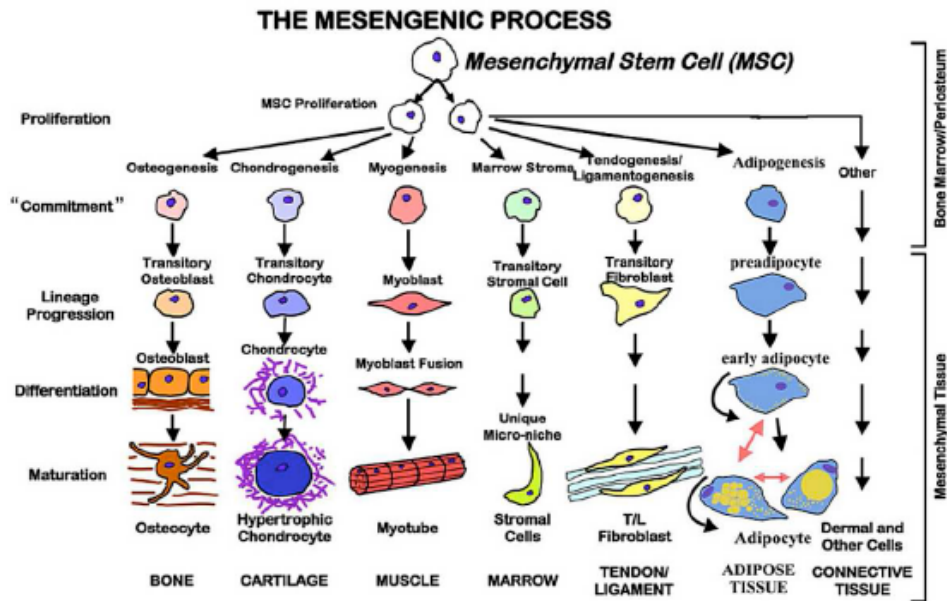


Figure 3. Possible ways of differentiation of mesenchymal stem cells

Much of the understanding of the regulatory effects of forces on tissue differentiation comes from the work of Friedrich Pauwels (Pauwels, 1960), however the theory developed by Prendergast *et al.* (1997) had been widely considered by current computational studies (Checa and Prendergast, 2009; Isaksson *et al.*, 2008; García *et al.*, 2007), is due to ease of obtain yours parameters such as fluid flow, strains and time witch rule tissue synthesis.

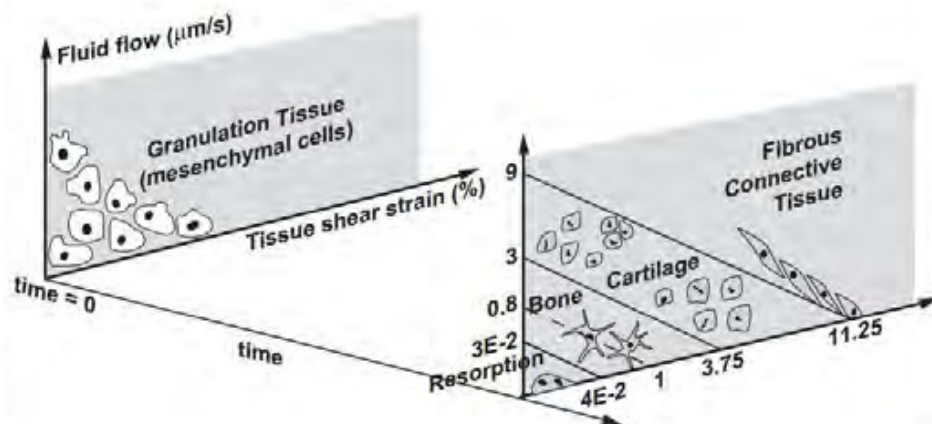


Figure 4. Differentiation law proposed by Prendergast et al. (1997)

3. MATERIALS AND METHODS

For develop this work was used a geometry generated by images of computed tomography Cone beam (TC) of a patient of twelve years old. Details of the development of this geometry can be found in Serp (2014).

From this geometry, is elaborated a finite element model in a commercial software of finite element Abaqus 6.14-1 (Providence, Rhode Island, EUA, 2014). The model generated has a mesh with 612846 elements connected by 151449 nodes. The mesh used passed by refinement process and verification.

The boundary conditions and loads are represented in Figure 3 and 4. Boundary conditions were created in three regions (C, D, E), with aims of represent the limitations of movement that bones of skullcap and cranial base exert in the model. For this, in regions C and E were created conditions which prevent movement in vertical axis. In region D restrictions were applied in three directions (x, y, z). In addition in region F, G and H symmetry conditions were imposed considering a symmetric cranial model and in region B was created a condition which prevents movements in vertical direction to simulate the effect of masseter muscle.

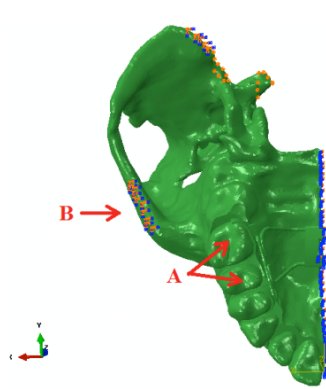


Figure 6. Representation of force (A) and of boundary conditions in region of muscle (B).

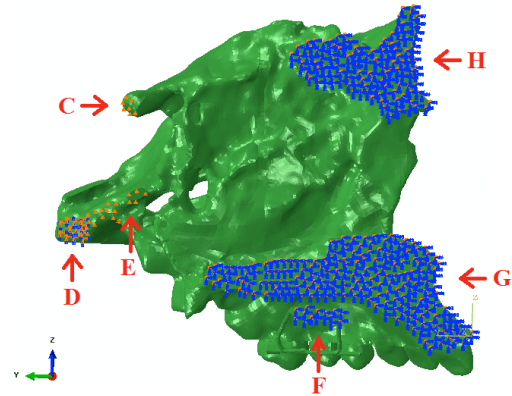


Figure 5. Representation of boundary conditions (C, D, E, F, G, H).

All of material that constitute the parts of model were considered isotropic and elastic linear. The values used were found in studies found in literature (Serpe, 2014).

Table 1. Elastic linear proprieties (Serpe, 2014)

	Elastic Module (MPa)	Poisson Coefficient
Bone (a)	10 000	0.3
Tooth (b)	20 000	0.3
Periodontal Ligament (c)	0.69	0.49
Unit Suture-Bone (d)	1.00	0.49
Expander/ steal (e)	200 000	0.33

The force of chewing was applied in second pre molar and first molar (how are indicated in figure 2, region A), in long axis of each tooth. The intensity of forces of mastication for children 11-15 years old of 70 N was found in the study done by Fields et al. (1986). The intensity of force was divide by 2 and applied on center of first molar and second pre molar. The points of application were chosen supported by studies that propose that during mastication the teeth molars and pre molars are responsible effective in milling of foods (Nankali, 2002). The amplitude of chewing force in function of time has obtained of literature (Gibbs et al., 1981), with a time of a cycle equal 0.692 s. The interval of time of maximum during occlusion is 0.09615 s e o interval of time without force is 0.346 s.



Figure 5. Graphic force x time, Charles et al., 1981.

4. RESULTS

The strains of MPS are represent in figures 6 and 7. On region which is in contact with the maxillary bone, the MPS show higher strains in it al extension (between 0.3% and 7.3%), because how is possible observe on figure 6 the region with strains close to zero is not large. In the other hand the region more intern of suture (plan of symmetry of the model) have lower strains, just on it borders have strains higher than 0.5%. The center of this region is very stable, is due to it show strains close to 0.1% (Figure 7).

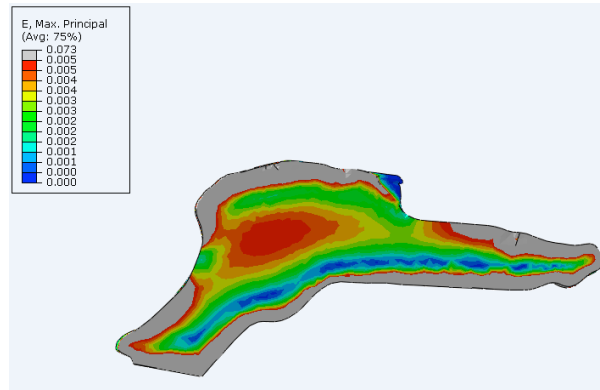


Figure 6. Principal maximum strains on region extern of median palatine suture, during one cycle of mastication

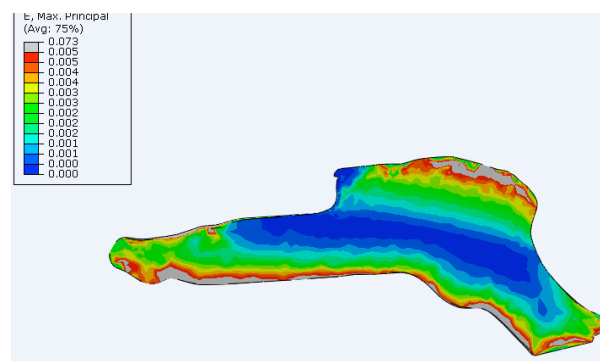


Figure 6. Principal maximum strains on region intern of median palatine suture, during one cycle of mastication

5. DISCUSSION

Although RME is a consolidate method in orthodontic, the regeneration that occurs on MPS after rapid expansion is still unclear. Some computational and experimental studies supported by mechanobiological theories proved that bone healing is rule by frequency and intensity of the mechanical forces (González-Torres, 2011; Gomes-Benito, 2005). Thus is reasonable considered that the ossification of MPS is rule by the mechanical stimuli as well as chemical factors. Therefore the aims of this work are estimate the state of strains on midpalatal suture and correlate with cells differentiation theories.

According to author's knowledge do not exist studies that quantify the strains generate by cyclic forces (mastication forces) and correlate it with sutural remodeling. Majority of works have the aims to qualify the final effect of expansion of MPS or describe the effect of extern forces apply for the complex maxillary-facial.

The model developed on this study was gain by computed tomography that generate a geometry close of the real. The tomography was done in adolescent of twelve years old, which is compatible with the age of people who is submit to RME. The chewing forces used were obtained for the same age group. Furthermore, was included the variation of force on time to have results more realists.

Despite of this, the present model has some limitations. It does not considerate all bones, sutures and muscles of skull. The materials were considerate linear elastic, however suture and bones have comportment viscoelastic. In addition, maxilla and skull are not completely symmetric and were used boundary conditions of symmetry.

Therefore, the strains on MPS during one cycle of chewing are between 0.1% to 0.73%, values that according with cells differentiation theories (Pauwels1960; Perren 1979; Perren e Cordey 1980; Prendergast *et al.* 1997), they are close to the values that stimulate synthesis of bone. However is necessary do other studies that improve the models which used in this work to reach more accurate conclusions.

6. ACKNOWLEDGEMENTS

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