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COMPUTATIONAL MODEL OF THE REMODELLING PROCESS OF MEDIAN PALATINE SUTURE DURING RAPID MAXILLARY EXPANSION: STUDY OF A MECANOBIOLOGY HYPOTHESIS

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Abstract. *This work presents the study of the influence of the mechanical stimuli on the treatment of Rapid Maxillary Expansion (RME). This study is supported by means of Finite Element Method (FEM), which will try to predict the possible consequences of treatment. The model used is presented as a system of equations that show the behavior of cells, and this system is resolved by FEM. The study deals with the remodeling Median Palatine Suture (MPS) during treatment of RME. The proposed system is a model of partial differential equations which is intended to represent the behavior of MPS cells influenced by the presence of mechanical stimuli arising. The main conclusion of the study was that the results obtained in the simulation they were consistent with what was expected in the literature.*

Keywords: *Element Method, Median Palatine Suture, Rapid Maxillary Expansion, Remodeling.*

1. INTRODUCTION

In the past years, many studies have been done regarding orthodontic and orthopedic treatments with a biomechanical and mechanobiology approach. The problem here treated analyzes the stress and strain generated at the craniofacial complex during Rapid Maxillary Expansion (RME). This technique is a procedure which aims to adapt the maxillary in the transversal direction, in other words, it has the function of promoting the separation of the bone ends the Median Palatine Suture (MPS) (SERPE, 2013).

The MPS is a joint formed by a connective tissue, and it is situated between mineralized bones. This articulation is present for all the hard palate, and it is that articulation which promotes the junction between the two maxillary (CONSOLARO; CONSOLARO, 2007). This suture joins two parts of the maxillary, which is divided into right and left maxillary, with the suture length running all of the hard palate (SERPE, 2007).

In orthodontics, the expansion of MPS becomes necessary to correct problems such as the cross-bite.

The MPS is broken quite abruptly during the RME process, and it shows that itself might be able to regroup quickly through the connective tissue repair and the consequent formation of new bone. Therefore it becomes essential at the treatment study (CONSOLARO; CONSOLARO, 2007).

The cellular activity of MPS brings the growth of the hard palate in children up to 13 to 15 years old. Researches indicate that after that age, the sutural growth is given as completed, however, cell death may appears to remain for a few years. As people getting older, the surface of the suture becomes interconnected, which results is an increased resistance of the joint opening.

The study was done from the mechanobiology viewpoint, which the concepts of preventive engineering (predicts the results) was used the Finite Element Method (FEM) as a basic tool for modeling biological system formed by suture.

The proposed hypothesis is tested with a computational model which will serve to analyze how important is the mechanical stimuli effect presented during the RME, observing whether these stimuli influence on the remodeling of MPS.

For this analysis, a comparison will be made between the final results made by a computer simulation and the actual results found at the literature used to do this work.

2. METHODOLOGY

Initially it was developed a geometry in finite element software, Abaqus. A model of the suture in 2D, which allowed us to observe how it behaves MPS with mechanical stimuli arising from the ERM was developed.

Subsequently equations were stipulated attempting to represent the behavior of cells diffusion found in the MPS.

A computer code was created to try to represent the equations that govern the problem, trying to bring all their initial and boundary conditions involved in the real trouble. This code was embedded to the geometry of the problem, and from the software named Tecplot was generated the results obtained with the simulation.

A brief presentation of the real problem is shown below:

2.1 Rapid Maxillary Expansion

The technique consists to use an equipment breaker apparatus palatal to enlarge the transversal dimension of the maxillary by lateral forces, which are applied to the superior and posterior teeth. The purpose of this technique is to achieve the parabolic shape of the upper dental arch. Regarding this purpose, specific breakers is used, as illustrated in Figure 2:

Figure 1: Rapid Maxillary Expansion (RME), Serpe (2007).

At the RME occurs a lateral displacement of the blades bone, due to the dense disorganized fibrous connective tissue. As a result of this displacement, a collision occurs at the bone surfaces. At the surfaces that were touched, a reabsorption bone exists and there is also a decrease in the suture curve. If the proposed expansion occurs repeatedly and alternately respectively, with the areas that are hatched, at the end of the treatment will be obtained a less fibrous connective tissue and unorganized, and also a much less curved shape. (CONSOLARO; CONSOLARO, 2007).

The above statements are observed at the figure 3 below.

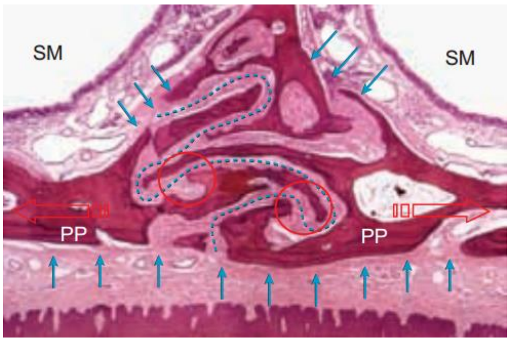


Figure2 – MPS during the RME, Consolaro (2007).

The figure 3, taken from a search about the RME, represents a MPS of a young adult monkey nail, which is very similar to the suture humans.

From this picture, it is possible to see where will happen the possible tissue ruptures during the treatment as indicated by the red circles.

The blue arrows denote the limitations of the periosteum that covers the external bone surface; SM means maxillary sinus and PP is the palatine process of the maxilla (CONSOLARO; CONSOLARO, 2007).

Moments later of have happened the ERM, at the opening region does not occur inflammation because neutrophils and macrophages have not found bacteria to promote the inflammation and a repair and a healing has to occur between 24-48 hours. By passing a few hours, it will be possible to find out:

1) Proliferation of vessels, in order to reconstruct the circulation system;
2) Fibroblasts and undifferentiated cells assume the role of organizing the extracellular matrix;
3) Some osteoprogenitor and osteoblasts cells organized from a primitive form are responsible for the bone deposition in the spaces that are empty. That bone is characterized by being slightly mineralized and still fragile, it is an embryonic type.

A few days later, we may have the formation of a new fibrous connective tissue suture (CONSOLARO; CONSOLARO, 2007).

The whole process can be seen at the figure 4 below:

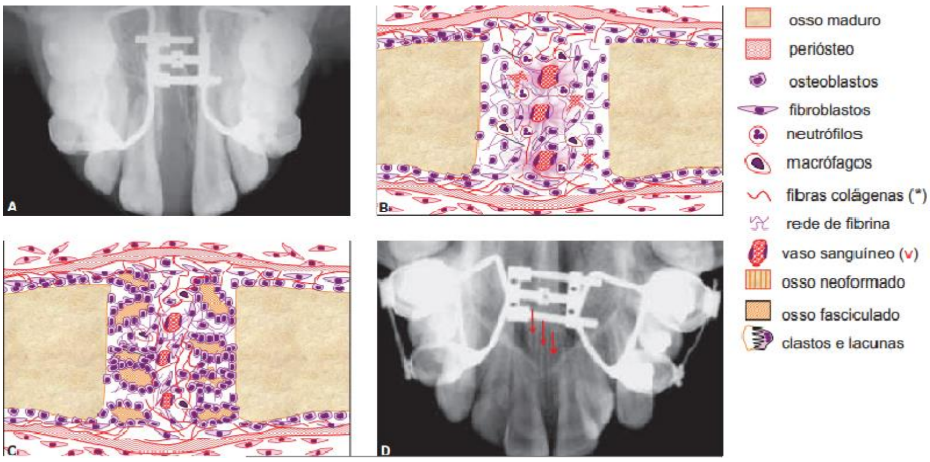


Figure 3 – It represents the MPS tissue formation after the RME, Consolaro (2007)

2.2 Mathematical equations

It will be proposed the equations that govern the remodeling of PMS during the ERM. To do this, it will be considered the cells migration, proliferation, and death regulated by mechanical stimuli (TORRES, 2011).

The system of partial differential equations was based on TORRES, 2011, to represent the behavior of cells of the PMS after RME, subject to the chewing forces. Such a system was solved using the FEM implemented in Abaqus V6.14 using a user subroutine written in the FORTRAN language.

The system of equations below show the evolution of the concentration of stem cells, bone cells, chondrocyte cells, fibroblasts and the presence of vascularization. The following factors were considered (TORRES, 2011):

$$\begin{cases} \dfrac{\partial c_s}{\partial t} + \nabla.(\dot{u}\, c_s) = \nabla.(D_s \nabla c_s) + \alpha \psi c_s - K_s^b M_b(\psi, v, t) c_s - K_s^f M_f(\psi, t) c_s + K c_s \\ \dfrac{\partial c_b}{\partial t} + \nabla.(\dot{u}\, c_b) = K_s^b M_b c_s + K_h^b F_h^b(\psi, v) c_h - K_b^d F_d(\psi) c_b \\ \dfrac{\partial c_h}{\partial t} = -K_h^b F_h^b(\psi, v) c_h - K_h^d F_d(\psi) c_h \\ \dfrac{\partial c_f}{\partial t} + \nabla.(\dot{u}\, c_f) = K_s^f M_f(\psi, t) c_s - K_f^d F_d(\psi) c_f \\ \dfrac{\partial v}{\partial t} + \nabla.(\dot{u}\, v) = \nabla.(D_v(\rho_g, \rho_b, \rho_f) \nabla v) F_v(\psi) - K_v^d F_d(\psi) v \end{cases} \tag{1}$$

Where:

- $\dot{u}$ = velocity field;
- c_s = concentration of stem cells;
- c_f = fibroblast concentration;

- c_b = concentration of bone cells;
- c_h = concentration of chondrocyte cells;
- D_s = diffusion coefficient of stem cells;
- D_v = diffusion coefficient which depends on the densities of the existing tissue;
- ψ = mechanical stimulus;
- M_b = maturation function that indicates that stem cells can differentiate into bone cells;
- M_f = maturation function that indicates that stem cells can differentiate into fibroblasts;
- t = time;
- K = is the constant that represents the rate of differentiation of the cells, and which relies on mechanical stimuli;
- K_s^b = is the rate of differentiation of stem cells into bone cells;
- K_h^b = is the rate of differentiation of chondrocytes cells into bone cells;
- K_b^d = is the death rate of bone cells;
- K_s^f = is the rate of differentiation of stem cells into fibroblasts;
- K_f^d = is the rate of death of the fibroblasts;
- K_v^d = degradation rate;
- M_b = maturation function that indicates that stem cells can be differentiated bone cells;
- $F_h^b(\psi, v)$ = differentiation of the chondrocytes cells function in bone cells;
- $F_{d,h}(\psi)$ = function that determines where cell death occurs.
- ρ = existing density in the callus;

The software Abaqus was also used to create the geometry of the PMS, with the respective properties to characterize materials materials in the suture.

After the development of the code that represents the system of equations, the code was incorporated to the geometry developed in Abaqus, where we finally represent the idealized PMS environment after RME.

The mechanical analysis and cell were made considering the SPM, the periosteum and the blood vessels as poroelastics, and making an approximation of mature bone as a linear elastic model.

3. RESULTS

The first results were obtained from the finite element software, Abaqus.

The geometry's format is based on the dimensions found in the literature, being inspired at the figure 2 represented previously.

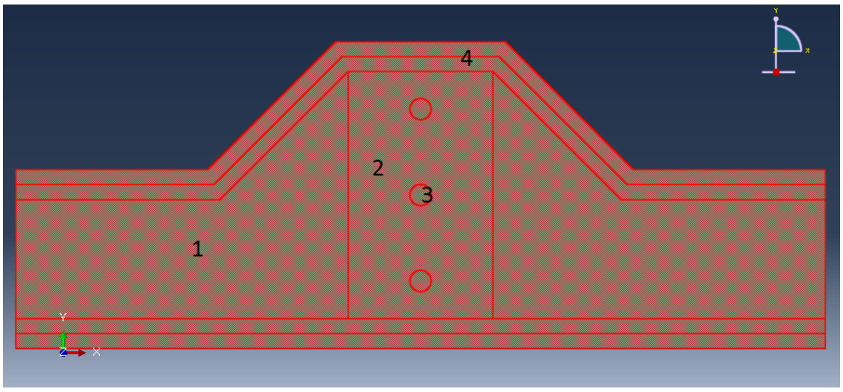
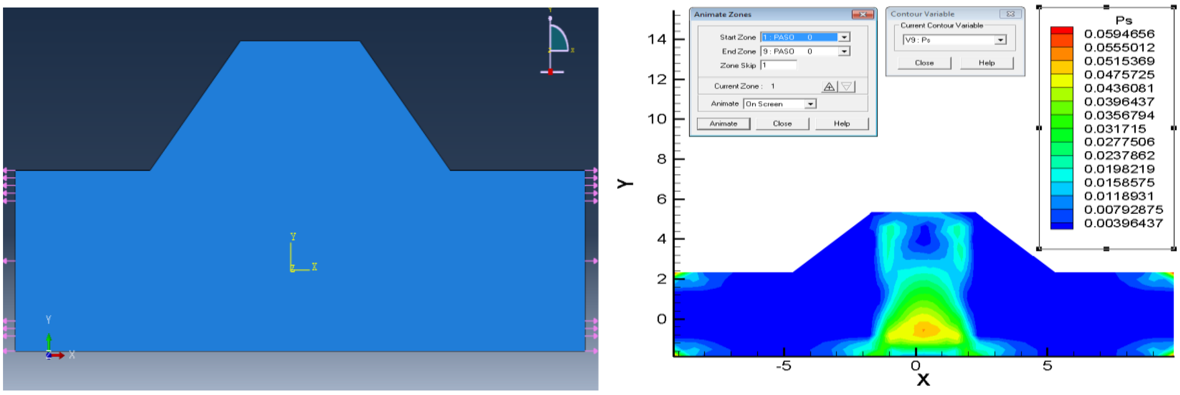


Figure 4 - MPS in normal conditions without applying the RME.

This geometry consists in the MPS (2), blood vessels (3) periosteum (4) and mature bone (1), and then was incorporated the cells as fibroblasts, osteoblasts and blood vessels for a biological analysis of evolution site.

The mesh geometry generated is composed by 959 quads elements and 2940 nodes.

When the MPS is submitted to the treatment of RME, there is the following behavior:

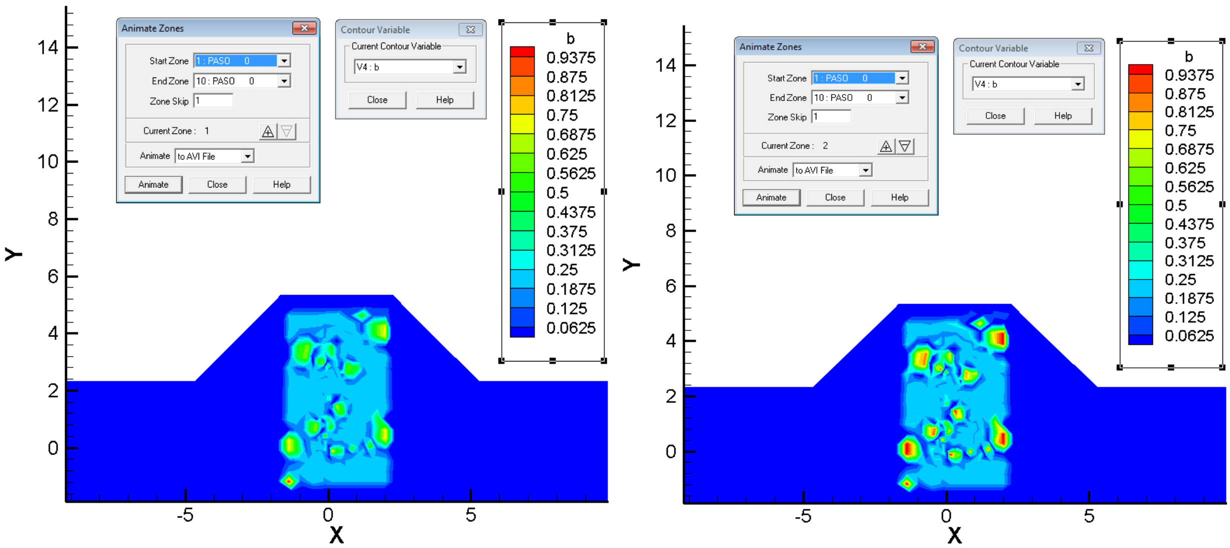


(a) (b)

Figure 5 - (A) used in the Geometry model, (b) Stress in MPa, taken in Tecplot.

As would be expected, analyzing the tensions present in the suture (Figure 5 - b), the largest stress concentration is found at the MPS, and when the geometry is submitted to a traction of 0.1 MPa (Figure 5 - a) at the ends, it tends to fail precisely in the MPS region.

The development of the bone cells can be observed at the Figure 6, where is shown the results from the first two days of evolution after the RME treatment.



(a) (b)

Figure 6 - Representation of MPS 1 day after RME, (b) Representation of MPS 48 h after RME.

After 48 hours it can be observed a higher concentration of bone cells, forming small islands of embryonic bone, which is represented as the red color at the Figure 6 (b).

4. CONCLUSION

In summary, it is possible to conclude that the results obtained from the Figure 6 are quite similar in comparison with the results found in reality, showing a clear difference between the first two days of bone cells concentration.

This result can be compared with the layout shown in Consolaro (2007), which is at the item C of Figure 3.

The similarity between the experimental results and the layout of Figure 3 - item C, is evident.

The hypothesis raised from this study is that the mechanical stimuli at the RME might provide the bone healing at the suture environment, because it is precisely in this region, that it gives the healing.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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