Study Protocol

Comparative Evaluation of the Stress Distribution and Transverse Displacement of the Circummaxillary Sutural System by Four Different Designs of Rapid Maxillary Expansion Appliances using 3D Finite Element model: A Study Protocol

Abstract:

Background: In adolescent patient's Rapid maxillary skeletal expansion (RME) is used with predictable clinical results for correcting transverse maxillary skeletal contraction. During RME, heavy force is directed towards the maxillary skeletal base. These forces also have effect on the palatal bone, adjacent skeletal structures and dentition. Tooth supported RME apply significant pressure on the teeth leading to varying amount of buccal inclination of premolars and molars and dental expansion. Implant assisted expanders take skeletal anchorage thus minimizing or negating the effect of heavy pressure on the teeth and supporting structures. Finite Element Analysis is a form of computer simulation. It is a non-invasive, precise method for obtaining quantitative and comprehensive knowledge about the physiological responses that occur in tissues. It outperforms other experimental methods because it creates a three-dimensional model that allows for simulation and analysis of orthodontic force systems in all three dimensions.

Objective: The present study intends to make an assessment of four different RME designs (Banded HYRAX, Banded MARPE, MSE expander, Orthoeasy PAL expander) in terms of distribution of stress in the circummaxillary Sutural system and resulting displacement of the bones in the craniofacial complex upon activation of the respective appliance.

Methodology: CBCT scan data of an adolescent patient will be taken from archives of a reputed scan centre. 3D skull model will be generated using CBCT data and .stl/ DICOM format will be converted into Finite Element model. The different types of RME appliances will be designed over the FE model. The expanders will be activated and the stresses generated at the sites of interest would be studied.

Results: The study is expected to permit a clinician to select the design of RME appliances, which will produce suitable stress and displacement that will help to increase transverse width of maxilla to correct the underlying skeletal discrepancy.

Conclusion: This study will help to arrive at a conclusion about which designs of RME will best suit clinical application of mechanics for orthopaedic expansion in a particular case.

Keywords: Rapid Expansion, Finite element, Stress, Displacement, Sutures

Introduction:

Rapid palatal expansion has been used with predictable clinical results for correcting transverse maxillary skeletal contraction.[1,2] During rapid palatal expansion, heavy forces applied to the maxillary skeletal base which affect not only the palatal bone and adjacent skeletal structures but also the dentition. As a result of these strong forces, the mid palatal suture breaks and the two halves of the maxillae change laterally. Strong forces directed at the maxillary skeletal base impact not only the palatal bone and surrounding skeletal structures, but also the dentition. The technique is designed to achieve skeletal expansion without buccal inclination of premolars and molars.[2-9]

Richard Courant invented the Finite Element method, a computer simulation technique for analyzing stress distribution in objects. It employs a computational technique for studying statically indeterminate structures with reasonable precision. It outperforms other experimental methods because it creates a three-dimensional model that allows for simulation and analysis of orthodontic force systems in all anatomical dimensions[10].

The present study intends to make an assessment of four different RME deigns in terms of the stress generation in the maxillary complex and resulting displacement of the bones upon activation of the respective appliance.

This study intends to correlate the findings obtained in this investigation to arrive at a conclusion about which of the designs of RME will best suit clinical application of mechanics for orthopaedic expansion in a particular case.

Aim:

The aim of this study is to compare and evaluate the stress distribution in the maxillary complex and the resulting bone displacement for four different RME appliances.

Objectives:

The designs under study are enumerated as follows:

- Banded HYRAX
- Banded MARPE
- MSE expander
- Ortho Easy PAL expander

1) To evaluate the stress distribution in circummaxillary sutural system by the designs mentioned above:

2) To evaluate the transverse displacement in the craniofacial complex produced by the designs mentioned above.

3) To compare the stress for different RME appliances varying in design mentioned above.

4) To compare the displacement for different RME appliances varying in design above mentioned.

Methodology:-

Materials required for the study:

i. Expansion screw

ii. Titanium mini implant

iii.CBCT data of human skull converted into FEM model using ANSYS software

iv. FEM software

- Pre-processor: Altair Hyper Mesh
- Solver: OpriStruct / ANSYS
- Post processor: Altair Hyper View

Method of study:
Source of Data:
A CBCT scan of a normal adolescent skull without any skeletal defects, trauma, lesions etc and with full complement of teeth upto 2nd molar present will be sourced from the archives of a reputed scan centre.

Inclusion Criteria:

- RME design to be included are Banded HYRAX, Banded MARPE, MSE expander and Ortho Easy PAL expander.

- Software generated model of Expansion Screw and Titanium Mini implant.

- The FEM software used will be Altair Hyper Mesh, OpriStruct / ANSYS and Altair Hyper View.

Exclusion Criteria:

- RME design other than the mentioned ones.

- Software generated model other than Expansion Screw and Titanium Mini implant.

- FEM software other than Altair Hyper Mesh, Opri Struct / ANSYS and Altair Hyper View.

Study Design
The data which is in DICOM & .stl format will be converted into a format suitable for finite element modeling. The thickness of the cortical bone, PDL, width of the maxillofacial sutures will be simulated in the FEM model. In the 3D finite element model, the material properties (Young's modulus and Poisson's ratio) of the cortical bone, cancellous bone, tooth, palatal mini-implants, stainless steel (SS) wires, periodontal ligament, and sutures will be prepared according to those defined in previous investigations.[11,12]

Six craniofacial sutural systems will be incorporated in the model for evaluation of von mises stress generated by different designs of rapid maxillary expansion: Internasal, Nasofrontal, Frontomaxillary, Zygomaticomaxillary, Zygomaticofrontal and Zygomaticotemporal. For evaluation of resultant displacement variables evaluated were maxilla, palate, nasal cavity wall, nasal bone, Zygomatic bone and frontal bone. 3D coordinates to assess the displacements (in mm) of aforementioned skeletal structures will be done along the X – transverse axis, Y- sagittal axis, Z – vertical axis. Negative values indicated outward, forward and upward movement of the X, Y, and Z plane respectively.

The different types of RME appliances under investigation will be designed accordingly to their specification over this FEM model. The activation of the appliances will be performed following the standard protocol and resultant forces generated and the stresses produced on nasomaxillary complex will be evaluated using ANSYS 12.0.

Study Outcomes:

The study is expected to permit a clinician to select the design of RME appliances, which will produce suitable stress and displacement that will help to increase transverse width of maxilla to correct the underlying skeletal discrepancy.

Discussion:

The present FEM study intends to make an assessment of four different RME deigns in terms of the distribution of stress in the maxillary complex and resulting displacement of the bones upon activation of the respective appliance. Despite the fact that previous clinical studies have provided extensive information about various RME appliances, the majority of them have been limited in their accurate assessment of the biomechanical impact of heavy forces on the various sutures and internal bony structures of the craniofacial complex.

Lee H,Ting K,Nelson M,Sun N,SungSJ in 2009[13] did the study to assess the changes caused by transverse expansive forces on different mid palatal sutures by creating a 3 dimensional finite element model of maxilla. The effect of transverse orthopedic force was evaluated using three different models of maxilla: The solid model which had maxilla without a mid palatal suture, fused model containing maxilla with suture elements and the patent model which included maxilla without suture elements. It was found that the solid model and the fused model showed similar pattern stress. Study concluded that expansion of maxilla caused by RME can be assessed by changes at various sutural level.

Jafari A, Shetty K, Kumar M in 2003[14] studied the distribution of stress pattern in the craniofacial system during the use of rapid maxillary expansion therapy. Maximum forward displacement was seen in the anterio-inferior border of nasal septum. Pterygoid plates showed maximum displacement laterally in the inferior portion but minimally at the region near the cranial base. There was downward movement of the structures along the vertical axis including ANS and point A. The study concluded that the force dissipation is not just restricted to intermaxillary region but also affects the other craniofacial structures.

Gautam P, Valiathan A, Adhikari R in 2007[15] evaluated the distribution of stress along the craniofacial sutures and the resulting displacement of various craniofacial structures using rapid maxillary expansion device. Computed tomographic scan of a dry human skull at the interval of 2.5mm was used for this study. FE analysis revealed that the RME resulted into anterior and downward displacement of maxilla also the maxilla rotated clockwise in response to the force applied. When the RME was evaluated for stress the frontomaxillary, nasomaxillary and frontonasal sutures experienced maximum Von Mises stress. The study concluded that RME aids in expansion of maxilla in canine and molar region. Also it results in downward and backward rotation of maxilla which helps in correcting mild class III malocclusion. Related studies were reviewed[16].

Conclusion:

This study contemplates to correlate the findings obtained in this investigation to arrive at a conclusion about which of the designs of RME will best suit clinical application of mechanics for orthopaedic expansion in a particular case.

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