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Analysis of Biomechanical Behaviour of Dental Structure in Orthodontics Movement

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Abstract:- Our goal for this research is to determine the perfect translation tooth movement along with determining its Centre of resistance for different size of dental root and to Analyze the effect of Placement of bracket on Orthodontic tooth movement by the Finite Element Analysis. Use of high end imaging Software Materialise Mimics 17.0 an image processing software for 3D design and modeling. Ansys Workbench is used for Finite Element Analysis, Meshing and applying constraints, load and using parametric function to get the perfect value of moment for the translation. Material Properties are taken from previous research paper for better accuracy. Experimenting with various values we attain translation movement and determined Stress and Strain state during Tooth movement.

Key words: *- Finite Element Analysis, Centre of resistance, Translation Movement.*

I. INTRODUCTION

A. Human tooth function is mechanically breaking down items of food by cutting and crushing them in preparation for swallowing and digestion. There are four different types of teeth, namely incisors, canines, molars and premolars. Each type of tooth has a different job. The incisors cut the food, the canines tear the food and the molars and premolars crush the food. The roots of teeth are embedded in the maxilla (upper jaw) or the mandible (lower jaw) and are covered by gums. Teeth are made of multiple tissues of varying density and hardness.

B. Alveolar Bone is the bone of the jaw which forms the alveolus around teeth. Like any other bone in the human body, alveolar bone is modified throughout life. Osteoblasts create bone and osteoclasts destroy it, especially if force is placed on a tooth. As is the case when movement of teeth is attempted through orthodontics, an area of bone under compressive force from a tooth moving toward it has a high osteoclast level, resulting in bone resorption.

C. Periodontal ligament or PDL is a specialized connective tissue that attaches the cementum of a tooth to the alveolar bone. This tissue covers the root of the tooth within the bone. Each ligament has a width of 0.15–0.38mm, but this size decreases over time. The functions of the periodontal ligaments include attachment of the tooth to the bone, support for the tooth, formation and resorption of bone during tooth movement, sensation, and eruption.

D. Trabecular Bone or Spongy bone, is one of two types of bone tissue that form bones. *It* has a higher surface area to mass ratio than cortical bone because it is less dense. This gives it softer, weaker, and more flexible characteristics. The greater surface area in comparison with cortical bone makes cancellous bone suitable for metabolic activity e.g. exchange of calcium ions.

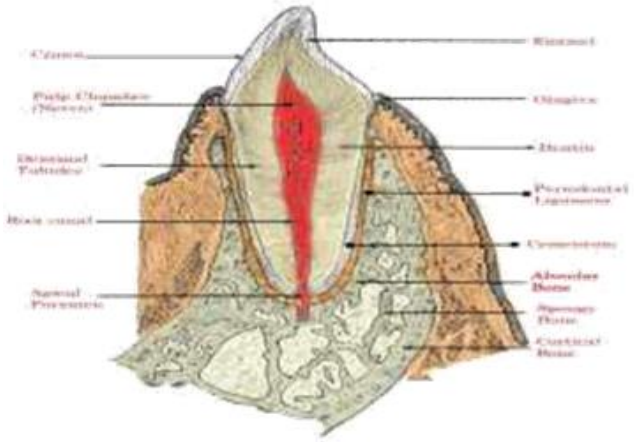

Fig :-1 Tooth Anatomy

E. Materialise Mimics is an additive manufacturing software and technology for medical, dental and additive manufacturing industries. Materialise Mimics is used to create 3D surface models from stacks of 2D image data. These 3D models can then be used for a variety of engineering applications such as 3D measurements, Computer Aided Design: 3-matic, Solid Works, Pro/E...etc., Computational Fluid Dynamics: FLUENT, CFX,...etc., Customized implant design, Finite Element Analysis: ABAQUS, ANSYS,...etc., Rapid Prototyping: EOS, Stratasys, 3D Systems, ZCorp, Dimension, Objet, ... etc., Surgical simulation.

F. Finite Element Analysis is the study of dividing a geometry or a body in multiple small parts (finite), analyze stress, strain, heat and other related engineering factors. Accrue all the information for all the small units and extrapolate it for the entire body. The results will include limiting or yield stress, fracture stress (based on the geometry, shape, relationships to mating mechanisms and size and not

just material properties) and thus help us in designing a part and avoid failure of any sorts.

II. MODELLING

Research involves three different types of dental structure

- Simple Model using Cylinder Structure of tooth and its supporting tissue designed in Pro E Software.
- Intermediate similar structure model of tooth and its supporting tissue in Pro E.
- Final Model of tooth and its supporting tissue using actual Tomography of Human designed in Materialise Mimics Software.

Major part of the research was designing the model of Lateral Incisor tooth, Periodontics Ligament, Cortical and Trabecular bone using Materialise Mimics v17. Initially the 2D image or the Tomography is loaded in the Mimics database, since tomography comprises of slices and sections of a 3D Object we categories the plane in Sagittal, Coronal and Axial planes. So, Mimics basically works on the concept of Mask and Object, where mask is an outline of the 3D object in 2D format and consist of pixels and object is derived from a mask. Mimics need perfection and patience to design an object because every pixel contributes in the making of a complete model. *The best thing of Mimics is that we get an actual model with real shape, dimension and flaws.* We have to consider all the three planes when creating a mask because as you edit in one plane you can see the effect on other planes so it's important to synchronize and edit the mask. *Editing the mask*, it can be done in 2D (on each plane) and 3D. After editing is done the model needs to be smoothened to get the best results in Meshing and Analyzation. And all these above tasks require experimenting with trial and error method for best results. 3-Matic is also 3D modelling Software for giving anatomical shape and all important details, complexity from start to finish. Here we used 3-Matic for fixing, Stitching the Dental Structure and to export in (.)STP Format for Ansys Analysis.

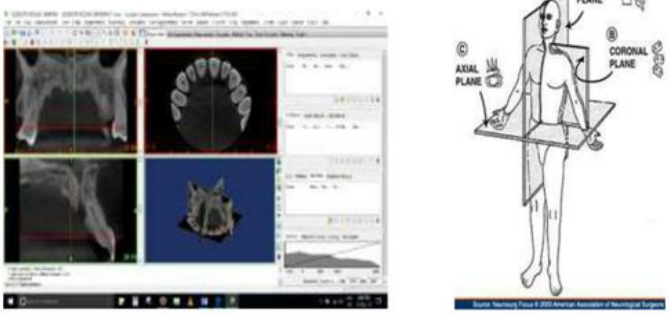

Fig 2:- a. Modelling of Dental Structure in Mimics. Fig. 2 b. Important Planes to ponder.

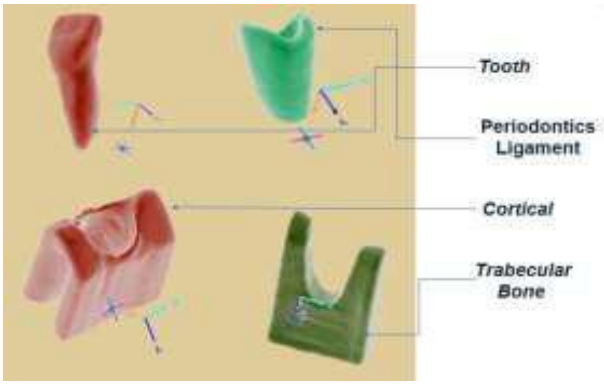

Fig 3:- Final Dental structure designed in Mimics.

III. METHODOLOGY AND ANALYSIS OF DENTAL STRUCTURE

The initial two model is designed to test and analyze the perfect constraint and method so that it can be applied in the final real model. The Dental Model are exported to Ansys Workbench v16.2 in (.)STP format. The steps involved in analysis are explained below.

A. Imported geometry

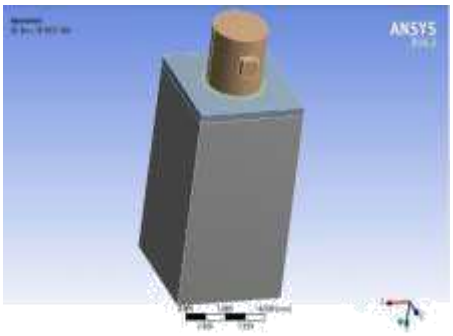

Fig 4:- Initial Model- (Cylinder type) Designed in Pro-E.

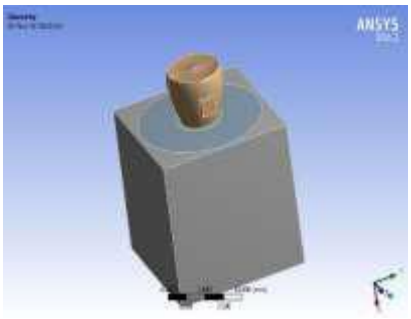

Fig 5:- Intermediate model with similar structure of tooth Anatomy designed in Pro-E.

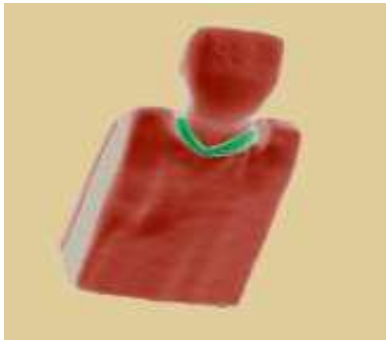

Fig 6:- Final Real Model designed in Mimics.

B. Material Assignment

Properties of Young's Modulus and Poisson's Ratio is taken from research papers.

Dental Structure	Young's Modulus (MPa)	Poisson's Ratio
Incisor tooth	14300	0.34
PDL	175	0.45
Cortical	13700	0.30
Trabecular	1370	0.30
Bracket	200000	0.30

C. Meshing

For quality meshing, Patch Independent method is used for individual component.

3D Models	Number of Elements	Number of Nodes
Initial	106793	180382
Intermediate	339883	512217
Mimics Model	464742	673474

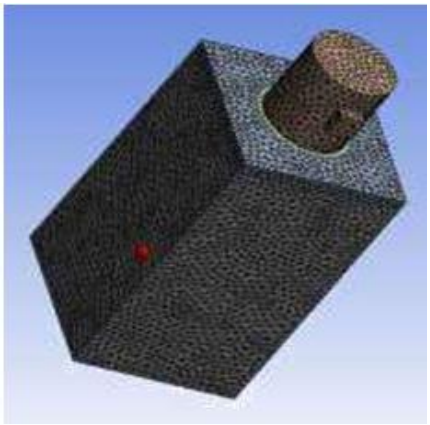

Fig 7:- Initial Model

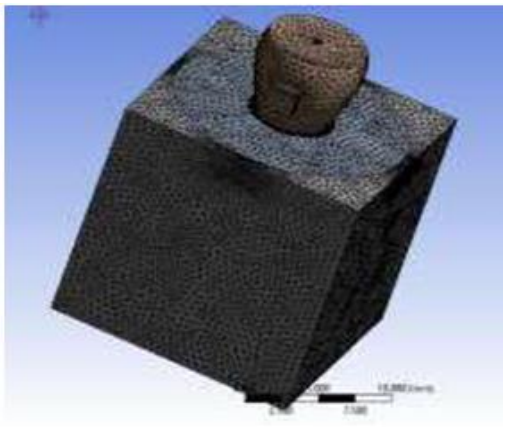

Fig 8:- Intermediate Meshed Model.

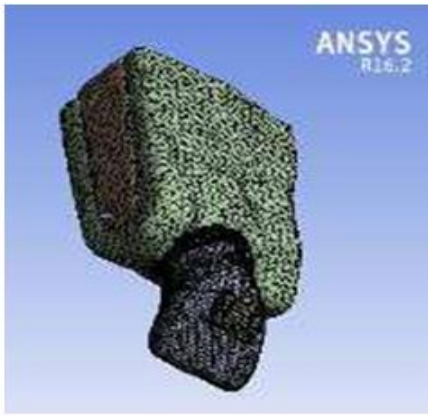

Fig 9:- Mimics model Fined mesh quality.

D. Boundary Conditions

The conditions are applied on the front face of bracket, *Force* of 1 N, Fixed support in the base, Displacement (Unidirectional) and the Moment. We initially tested the boundary conditions on first two model and at last we took the best possible conditions for our final model.

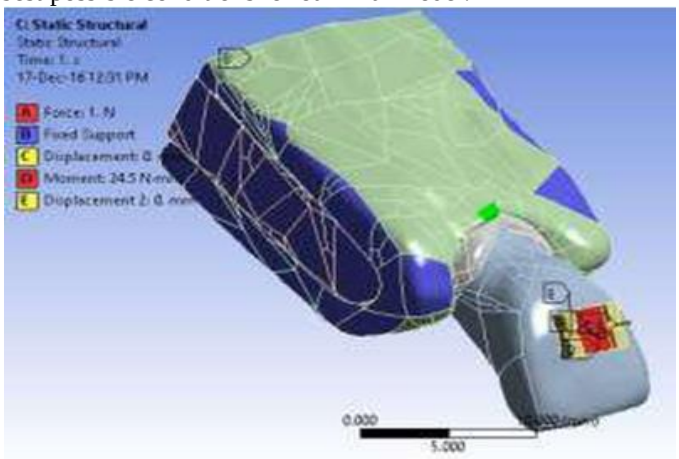

Fig 10:- The boundary conditions applied to the 3D Dental model.

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To get the best Moment to counter the force applied in the tooth brackets, Parameter Function is used between the *Maximum pressure vs Moment.* Experimenting through various Design points to get the best possible Moment for the tooth movement.

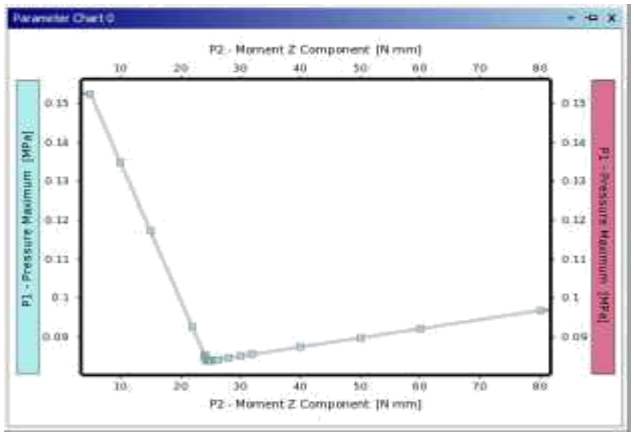

Fig 11:- We get a Parameter chart using various design points in Ansys.

3D Models	Time For 1 Design-Points (sec)
Initial	114
Intermediate	151
Mimics Model	344

Above table shows the time taken by the processor to calculate one updated design point by the respective 3D models.

E. Results and Discussion

This study investigates the total deformation, Equivalent Stress, Equivalent elastic strain and the pressure created on the PDL.

Initial result was the perfect translation moment of tooth in our intermediate model which gave uniform pressure on one side of the PDL, the same input we used for the Mimics model to get results.

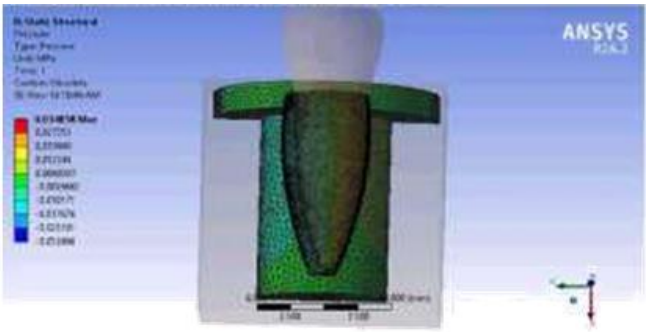

Fig 12:- Intermediate model resulted in translation moment.

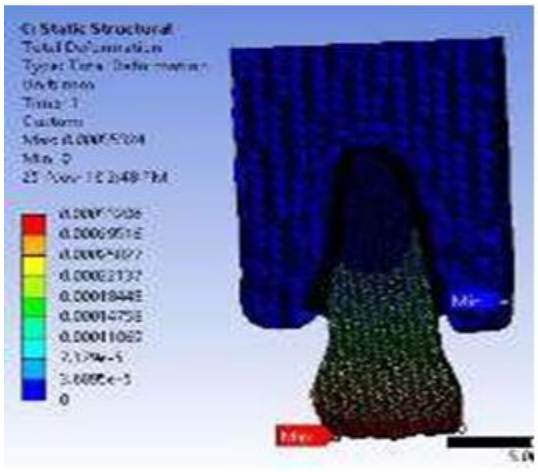

Fig 13:- Total deformation of Tooth which is 0.00035 mm.

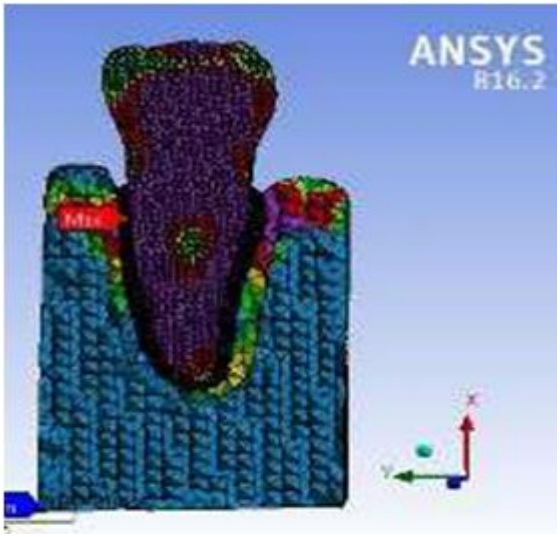

Fig 14:- Analysis which provide Centre of Rotation

IV. CONCLUSION

By this study, we have investigated the biomechanical behavior of the Tooth, Periodontal Ligament, Cortical bone and Trabecular bone and identified the best result for the center of resistance for different types of root size and defined the tooth translating moment.

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