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Allison R. Beckmann

Virginia Commonwealth University

Lena Unterberg

Virginia Commonwealth University

Stefan Raith

Virginia Commonwealth University

Horst Fischer

Virginia Commonwealth University

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Computer Simulation of Tooth Mobility using Varying Material Properties

By Allison R. Beckmann, Lena Unterberg, Stefan Raith, Horst Fischer.

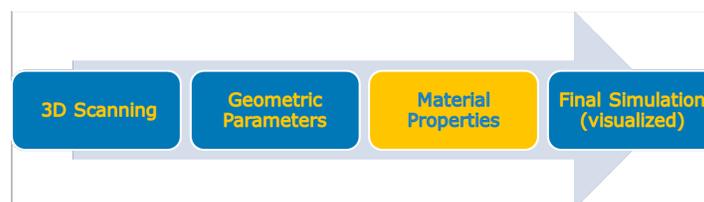
Introduction

Tooth mobility is the major cause of stress on a tooth implant or partial denture and often results in the damage of the device. For many prosthetic devices like dental bridges, a partial denture used for a person who is missing a tooth to give the appearance and function of a tooth, mobility can cause up to double the amount of stress in comparison to a fixed model. Creating a computer simulation of tooth mobility using Finite Element Analysis allows one to understand and predict this movement in order to improve future dental prosthetic devices.

The main cause of tooth mobility within the mouth is the periodontal ligament (PDL). This ligament is a soft biological tissue that surrounds the roots of teeth. The tooth moves when a force like mastication, or chewing, causes the ligament to deform. This deformation is due to the small Young's Modulus of the ligament. The Young's Modulus determines the stiffness of a material. In the case of the PDL, the Young's Modulus is sometimes noted to be 30,000 times smaller than that of dentin, this is the material that makes up the majority of the tooth, and of the alveolar bone, this is the bone in which the tooth lies. The deformation of the PDL is also due to the viscoelastic nature of the ligament. The major elastic component of the ligament is collagen, this material allows the PDL to stretch to a certain limit, and the major viscous component of the ligament is the interstitial fluid between the cells, this allows the material to have a fluid-like nature (4).

Materials and Methods

3D imaging system: The imaging system that can accurately illustrate and separate individual teeth from a scan of either a patient's mandible or maxilla. Usually the scan is created from a mold of the teeth. Python: The programming language used to code the interface and many components of the simulation. Blender: The open source graphics software that displays the simulation interface. ANSYS: The simulation software where the tooth is displayed after the geometric and material properties are chosen for the tooth



Results

Figure 1: This figure displays the interface used to choose the material properties for a scan of the mouth. Specific properties can be chosen for the PDL, Dentin, and Alveolar Bone. The first drop down menu labeled 'Literature Values' allows the user to either choose their material properties manually or from a list of common sources. If the user chooses select their values manually, another down menu labeled 'Type' will appear. This menu allows the user to choose what kind of model they would like to simulate. Currently the options are: linear, bilinear, multilinear, and hyperelastic (neo-Hookean). Once a model is chosen, the user can

then pick values for density, Poisson's Ratio, and Young's Modulus. These values are then saved into an inp file that can be read and processed by ANSYS. Refer to Figure 4 and Figure 5 to see the visualized simulation in ANSYS.

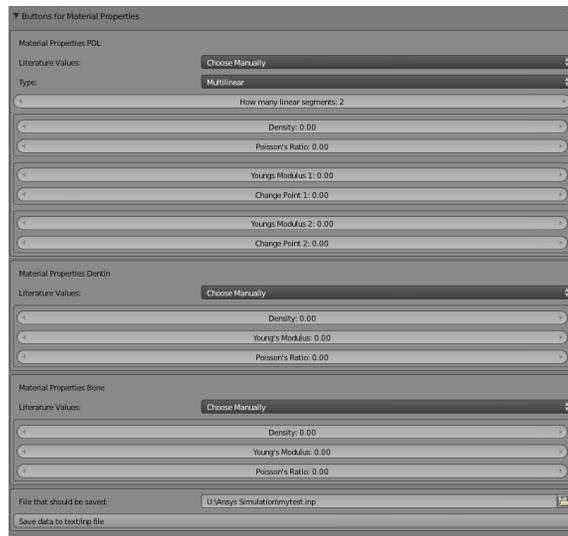


Figure 1:

Curves Formed from Type of Function Chosen for PDL

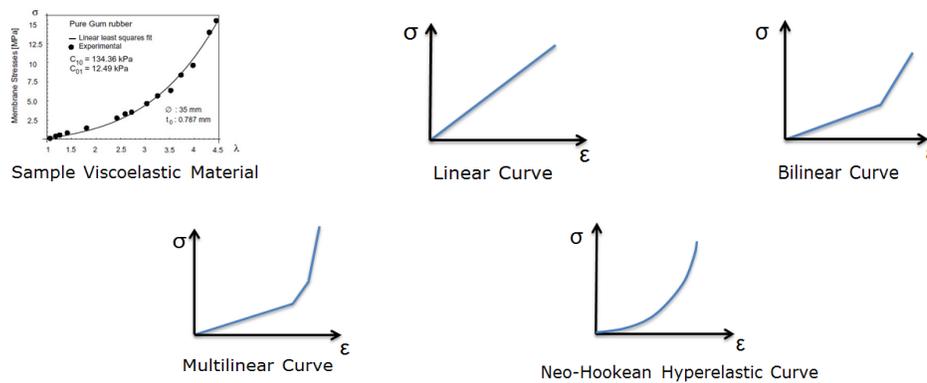


Figure 2: There are different types of functions that are available to describe the behavior of the PDL. The figure on the top left of the screen shows a sample stress-strain curve for a viscoelastic material similar to that of the PDL. Many of the literature values, as shown in Figure 3, use either the linear or bilinear curve to describe the values of Young's Modulus, but this information can also be displayed using other theoretical models. Different models allow the user to more accurately describe the information for stress as the tooth deforms. The neo-Hookean model in particular shows the most similarity to the sample stress strain curve. This type of model is used for predicting behavior of elastic materials undergoing large deformations and is often used to describe biological tissues (9). Using this model could more accurately describe the behavior of the PDL.

Material Property Values

Reference	Material	Young's Modulus (MPa)	Poisson's Ratio	Curve Type
Poope, 2002	PDL	0.05,0.28	0.3	Bilinear
Anderson et al, 1991	PDL	0.07	0.49	Linear
Hohmann et al, 2011	PDL	0.1	0.45	Linear
Yosida et al, 2001	PDL	0.13-0.96	0.49	Linear
Yettram et al, 1977	PDL	0.18	0.49	Linear
Meyer et al, 2010	PDL	0.5	0.47	Linear
Tanne et al, 1987	PDL	0.67	0.49	Linear
Tanne et al, 1998	PDL	0.67	0.49	Linear
Tanne and Sakuda, 1983	PDL	0.7	0.49	Linear
Danielyte and Gaidys, 2008	PDL	0.8, 10	0.49	Bilinear
Jones et al, 2001	PDL	1	0.45	Linear
Farah et al, 1989	PDL	6.9	0.45	Linear
Takahashi et al, 1989	PDL	9.8	0.45	Linear
Rees and Jacobson, 1997	PDL	44	0.49	Linear
Wright, 1975	PDL	49	0.45	Linear
Wilson, 1991	PDL	50	0.45	Linear
Cook et al, 1982	PDL	68.9	0.49	Linear
Ko et al, 1981	PDL	68.9	0.45	Linear

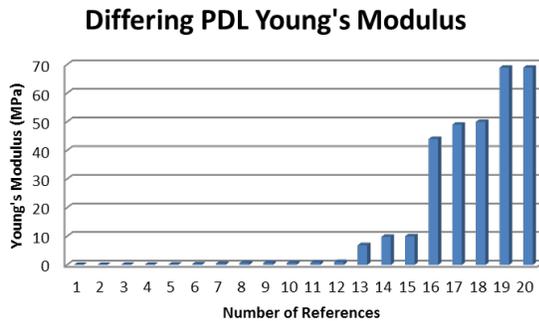


Figure 3: This figure shows a comparison of literature values for Young's Modulus of the PDL. As shown, these values can be drastically different depending on how the modulus is calculated and the assumed behavior of the PDL. All these values may be valid depending on how the user wishes the simulation to be used and are available in the interface with the drop down menu labeled 'Literature Values.' Since the discrepancy between the property values can be so drastic it is important to also allow the user to manually place in any value, therefore the 'Choose Manually' option was created.

PDL with Differing Properties

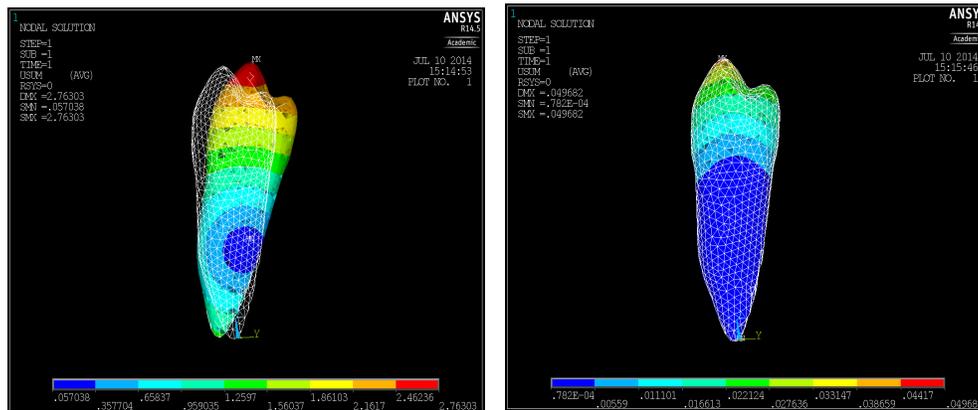


Figure 4: In this figure each tooth is subjected to an occlusal force. The image on the left has a PDL with a lower Young's Modulus of .07MPa (1) and thus undergoes a higher degree of deformation, up to 2.46 mm. The image on the right has a higher Young's Modulus 68.9MPa (2) and thus undergoes a lower degree of deformation, as little as 0.044 mm. The images are not scaled to the same amount, otherwise the image on the right would be entirely dark blue. This figure shows how easily tooth mobility can be compared using different material properties.

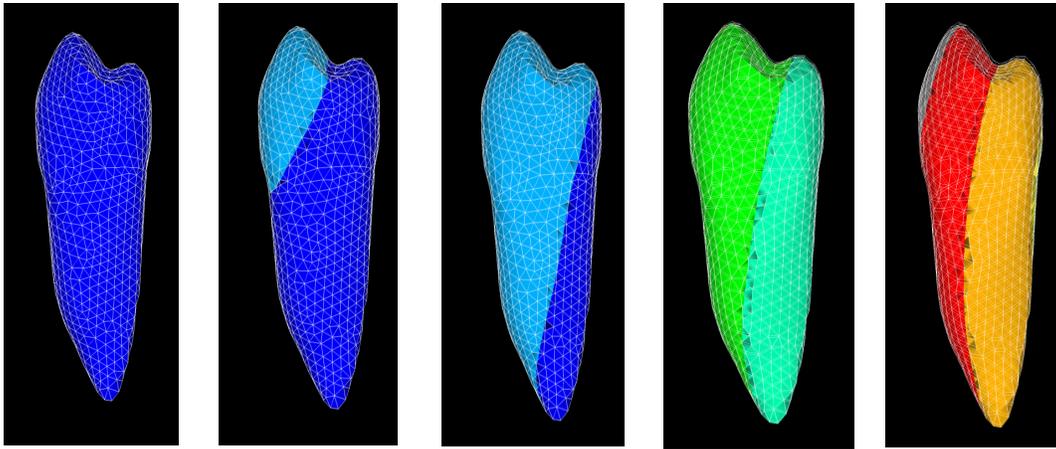


Figure 5: This figure also displays teeth subjected to an occlusal force with differing material properties. In this image the color scale is exact and the deformation is shown by the differing color of the teeth. The red color is a demonstrates the higher degree of deformation, whereas the blue color shows little to no deformation. These represent the literature values (from left to right) of: Cook et al (2), Rees and Jacobson (12), Takashi et al (13), Farah et al (5), and Meyer et al (10).

Conclusions

These results demonstrate that the interface created was the missing link between modeling and the visualized final simulation of the tooth. It creates an easier and more usable way for the user to use the simulation system for real-world application. The ability to use different models like the neo-Hookean model, can create a simulation process that will more accurately demonstrate the movement of teeth. Now, with the new material properties interface, different tooth models can be created and compared with just a few clicks. This will expedite the process of creating the simulation as well as allow the adjustment of the simulation to a variety of tasks

Future Directions

Currently this simulation is still in the development stage and must undergo the process of model verification before it is ready to be used for real-world application. Once a reality, this simulation can be used for a variety of tasks. On an individual basis, it can be used by dentists to simulate how an individual's tooth will move based on the properties of their periodontal ligament. Once this is determined, the dentist can then chose the material that is best for an implant or partial denture. This material will be chosen so that it will last the longest in the patient's mouth. On a more general basis, this simulation can be used for Material's Engineering. Taking the scans of multiple mandibles and maxillae, engineers can determine what type of material would be best for most patients. This might take away the need to use the simulation on an individual basis and will take away the liability on the dentist to determine what type of material is best.

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