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DEPARTMENT OF COMPUTER SCIENCE

Teeth Movement Variations in Orthodontics:
A Finite Element Study on Several Patients

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Objective
- To develop patient-specific finite element (FE) models of human jaw and investigate orthodontic tooth movement variations across a group of patients.
- To investigate the influence of teeth geometries of different patients on the resulting teeth movements.

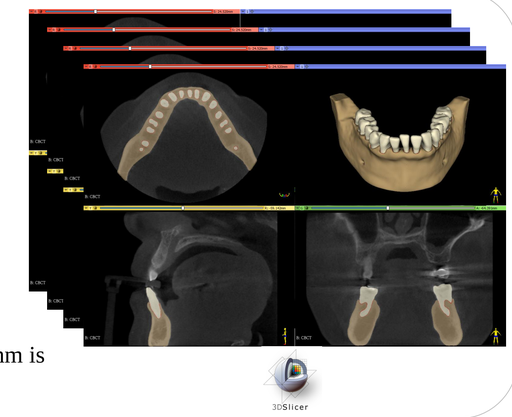
Background
Previous studies on computational modeling of tooth movement in orthodontic treatments are limited to a single model and fail when generalizing the simulation results to other patients. To this end, we consider multiple patients and focus on tooth movement variations under the identical load and boundary conditions both for intra- and inter-patient analyses.

Workflow of the Project

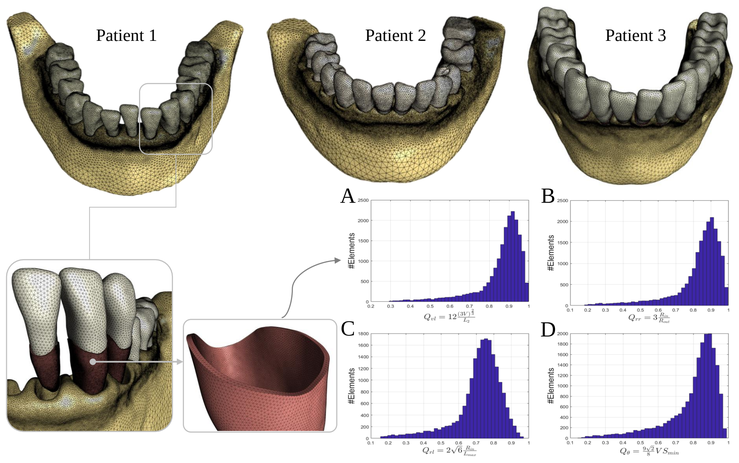
Geometry Reconstruction

Data
- Cone Beam Computed Tomography (CBCT) of three orthodontic patients are used.
- Intraoral scans are obtained from 3Shape Trios.

Segmentation
- Semi-automatic watershed algorithm is applied to segmenting teeth and bone.
- Periodontal ligament (PDL) with uniform width of 0.2 mm is generated around teeth roots.



Patient-Specific Geometries



Volumetric Mesh Generation

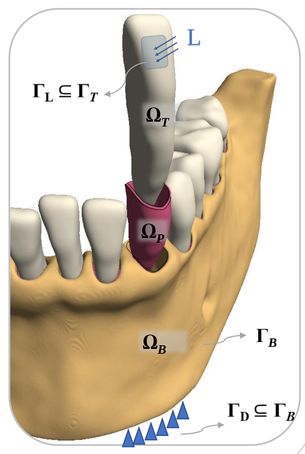
TetGen
- TET4 elements are used.
- The quality of the generated tetrahedral mesh is evaluated using mesh quality histograms.

Setting Up FE Problem

FEBio software packages

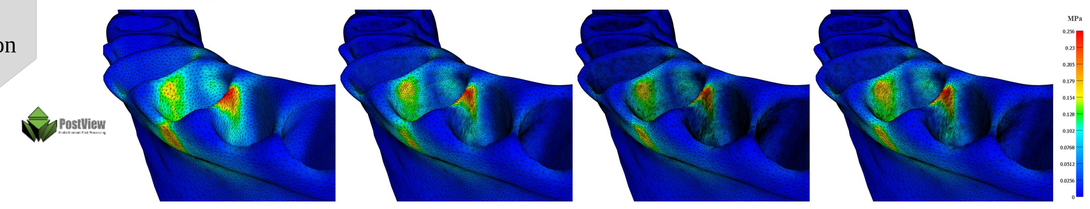
PreView used for generating patient-specific FE problem, by setting
- Boundary conditions
- Loading conditions
- Contact definitions
  - Tied contact in tooth-PDL and PDL-bone interfaces
- Material properties
  - $\boldsymbol{\Omega_T}$ Rigid body with 6 degrees of freedom
  - $\boldsymbol{\Omega_P}$ Mooney-Rivlin Hyperelastic
  - $\boldsymbol{\Omega_B}$ Isotropic elastic

FEBio used for performing nonlinear FE analysis on quasi-static simulations.



Model Verification

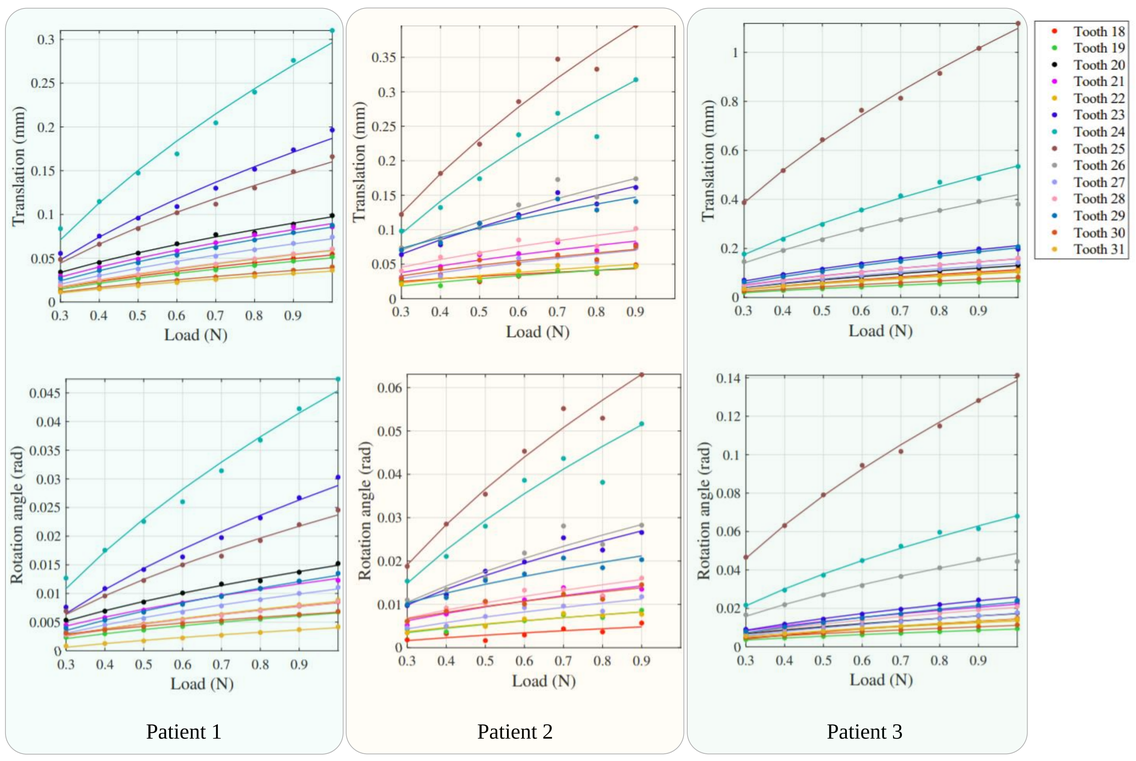
Mesh convergence study



Parameter sensitivity analysis

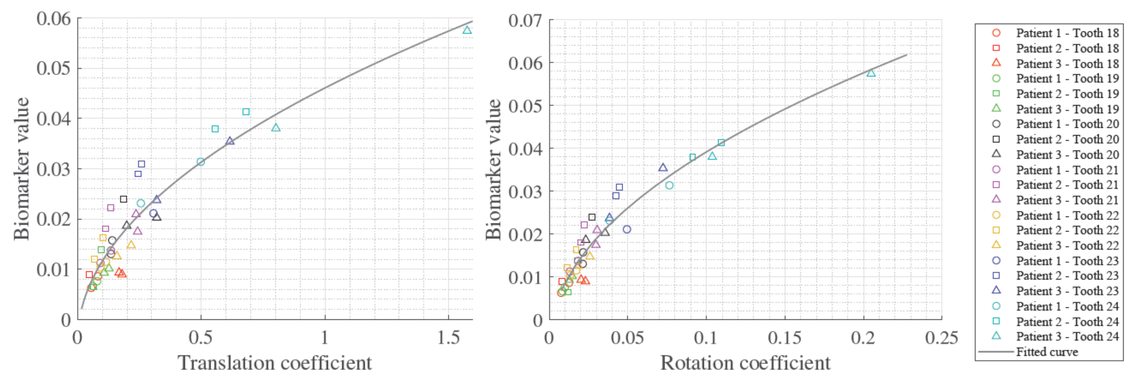
	PDL		Bone		PDL-Bone Tied Contact	
	Young's Modulus	Poisson's Ratio	Young's Modulus	Poisson's Ratio	Augmented Lagrangian	Penalty Factor
Interval of parameter change	0.044 - 0.0938	0.45 - 0.49	1200 - 13700	0.2 - 0.4	0.2 - 0.1	0.25 - 1.75
Relative error in Von Mises stress (%)	2.127	2.127	0.709	3.900	1.418	3.900

Experiments and Results
- Uncontrolled tipping scenario is conducted on the three patients' models.
- An identical force magnitude is applied perpendicular to the surface of each patient's teeth.
- The load magnitude varies from 0.3 N to 1 N.
- The tooth displacement is measured by
  - Translation of the center of mass
  - Rotation of the rigid body tooth (angle θ and axis n)
- Teeth IDs are defined based on the universal numbering (UNN) system.



- The square root function is applied to fit the data from each patient's tooth.
- But the fit coefficients are different for the corresponding teeth of different patients and cannot directly be used for predicting teeth displacement of other patients.

Contributions
✓ Studies have shown that the root length and tooth geometry can affect the initial tooth movement. However, the exact relationship between the crown/root size and tooth displacement is missing.
✓ The ratio of crown height to root volume is proposed as the biomarker causing tooth movement variations together with the applied load.
✓ A square root relation is also found between the proposed biomarker and the coefficients of the fitted functions, that can be used for adjustment/generalization of the model for different patients.



Conclusion
✓ Our study showed that a combination of two clinical biomarkers, i.e., crown height and root volume, could affect the tooth displacement.
✓ We proposed two nonlinear functions for modeling and predicting translation and rotation of different patients' teeth under various load magnitudes.
✓ This is the first time a full dentition intra-patient and inter-patient tooth movement analyses have been considered.

Possible Future Work
✓ Obtaining patient-specific material properties for the PDL tissue by preforming inverse problem. This would involve:
- Applying identical load magnitude to the teeth of different patients
- Calculating the teeth displacements by comparing the intraoral scans of the patient at T_0 and T_1
- Solving the inverse problem to obtain the patient-specific material properties.

References
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