A FLEXIBLE METHOD FOR PRODUCING F.E.M. ANALYSIS OF BONE USING OPEN-SOURCE SOFTWARE

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Background:

- Astronauts may lose up to 9% of load-bearing bone density per month in spaceflight[1]
- Lower chance of fracture in space due to lower loads (0G) [2]
- Higher loads on Earth (1G) result in a higher potential for fracture due to lowered bone density when astronauts return to Earth[2]
- Computational bone strength model can be used to assess bone fracture risk for astronauts

Objective:

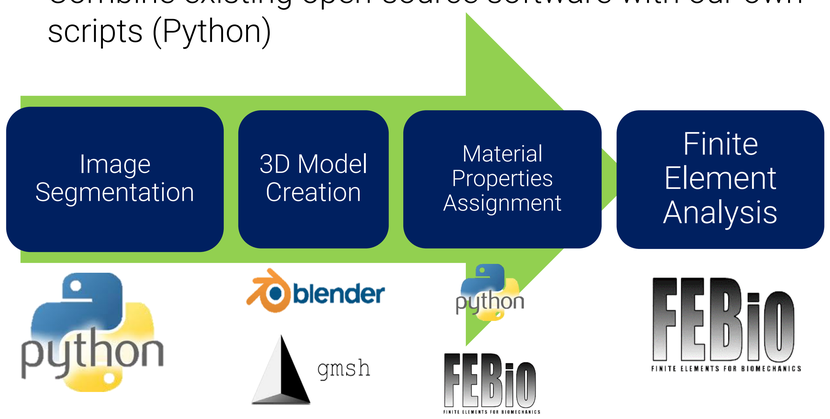
Develop and test an open-source computational bone strength model for acceptable performance in the assessment of pre-flight and post-flight astronaut bone strength studies.

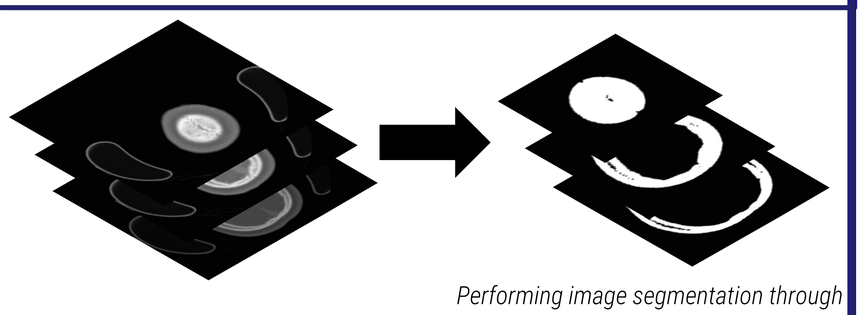
Open Source Advantage :

- Publicly published with a community collaborative mindset, where others are encouraged to view and contribute to the code to advance development
- Allows for expanded future development and input from a large community of experts

Hypothesis:

- Combine existing open-source software with our own scripts (Python)





Performing image segmentation through Python

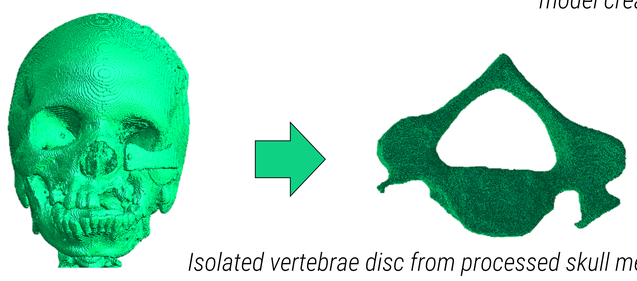
Image Segmentation:

- Python script imports CT scans with visualization toolkit (VTK)
  - Library allows for import of many popular medical image formats
  - Script translates pixel values to Hounsfield values using metadata in original CT scans
- Script isolates bone from medical images with thresholding based on Hounsfield values
- Final image is binary representation of bone regions

3D Model Construction:

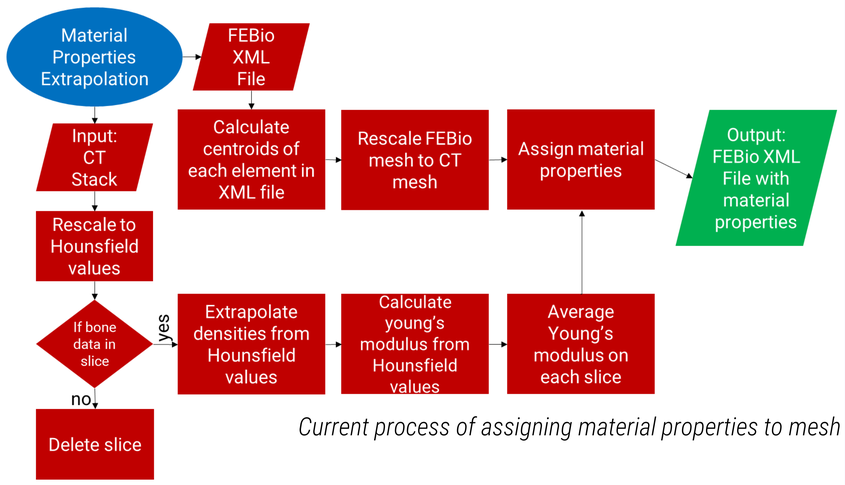
- Python's VTK toolkit includes a Marching Cubes algorithm
  - Creates a 2D surface mesh from binary segmented regions[3]
  - Also smooths mesh and removes unnecessary triangles
- Blender[4] used to repair mesh and isolate any areas of interest
- 2D surface mesh was recreated into a 3D volume mesh with Gmsh[5]

Flowchart showing 3D model creation process

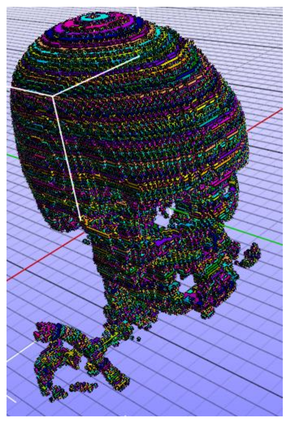


Isolated vertebrae disc from processed skull mesh

Material Properties Assignment:

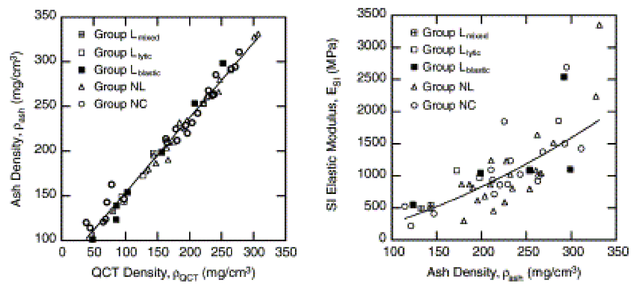


Current process of assigning material properties to mesh



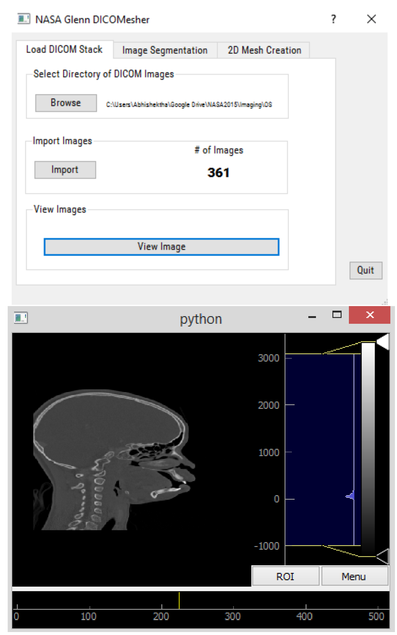
Skull model with dynamically applied material properties

- Original CT scans' Hounsfield values extrapolated into densities and Young's modulus using Keneko et al.'s [6] prior bone ash testing
  - Translates Hounsfield value to bone ash density
  - Extrapolates Young's modulus from bone ash density
- Python script writes material properties to an FEBio XML file for easy import



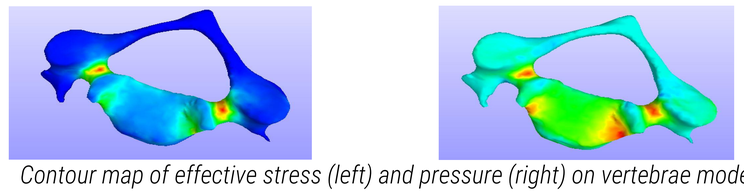
Figures from Keneko et al. [2] showing relationship between Hounsfield value, ash density, and Young's modulus

In-House Developed Interface:



Graphical User Interface for tool

- A Graphical User Interface (GUI) combines process of image segmentation and 2D mesh creation into a centralized tool
- User can select stack of medical images to import and can view stack in three dimensions
- Users can perform image segmentation using their inputted threshold value
- Exports a 2D mesh for next processing step in Blender and Gmsh



Contour map of effective stress (left) and pressure (right) on vertebrae model

Finite Element Analysis (FEA):

- Finite Element Analysis performed through FEBio[7] suite
- Software allows for the graphical fixing of points, defining of loads and boundary conditions
- Allows for graphical viewing of end results

Conclusions:

- No straightforward method to implement existing open-source software into desired product
- A combination of various open source software along with self-developed scripts was needed to complete the segmentation, 3D construction, and FEA analysis tasks

Future Work:

- Need to design and run a selection of test cases to validate our method, including a full end-to-end simulation
- Extend further aspects of tool into interface, allowing for full integration of method into a single location

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