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

Abhishektha Boppana[1], Ryan Sefcik[2], Dr. Jerry G. Myers[3], Dr. Beth Lewandowski[3]

[1]Case Western Reserve University, Cleveland, OH 44106

[2]The Ohio State University, Columbus, OH, 43210

[3]NASA Glenn Research Center, Cleveland, OH, 44135

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:

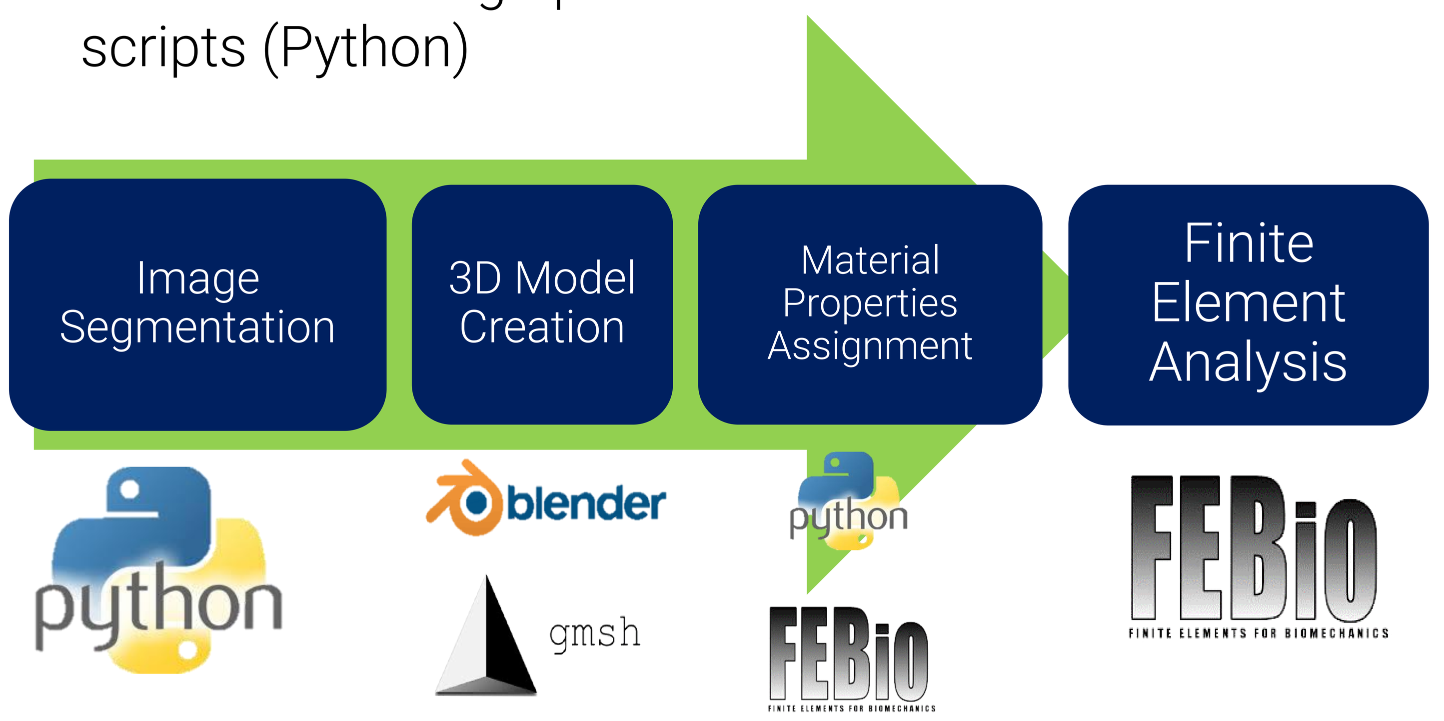
Develop and test an open-source computational bone strength model for acceptable performance in the assessment of pre-flight and post-flight astronaut bone strength studies.

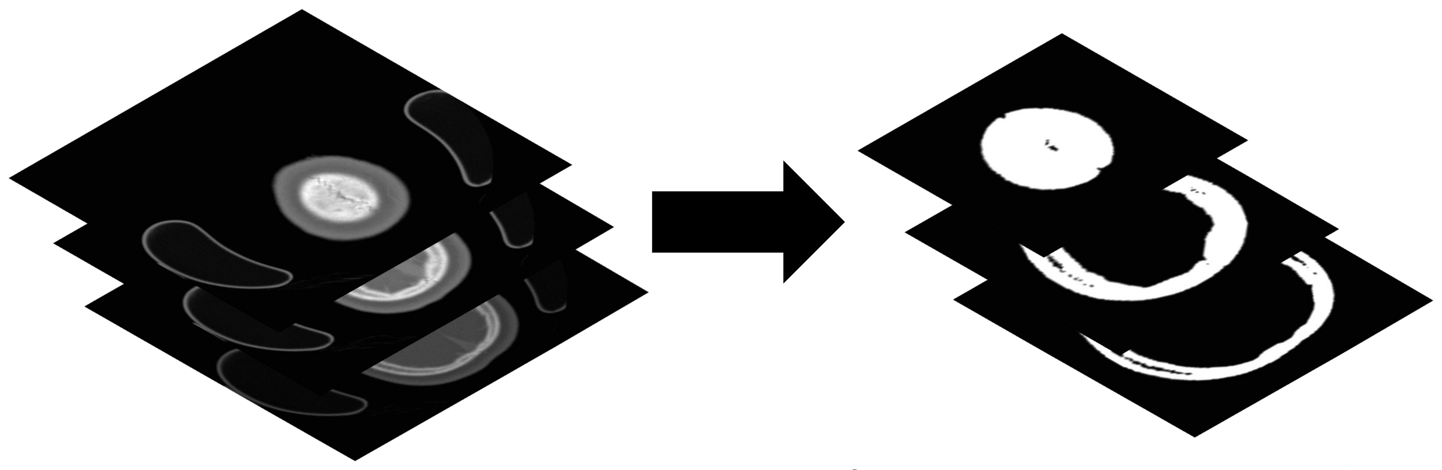
Open Source Advantage :

- 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

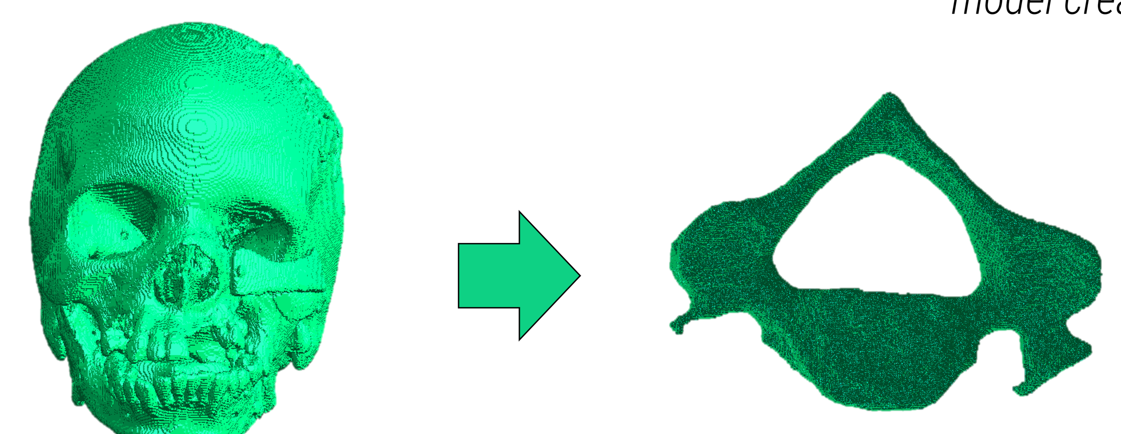
Image Segmentation:

- 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:

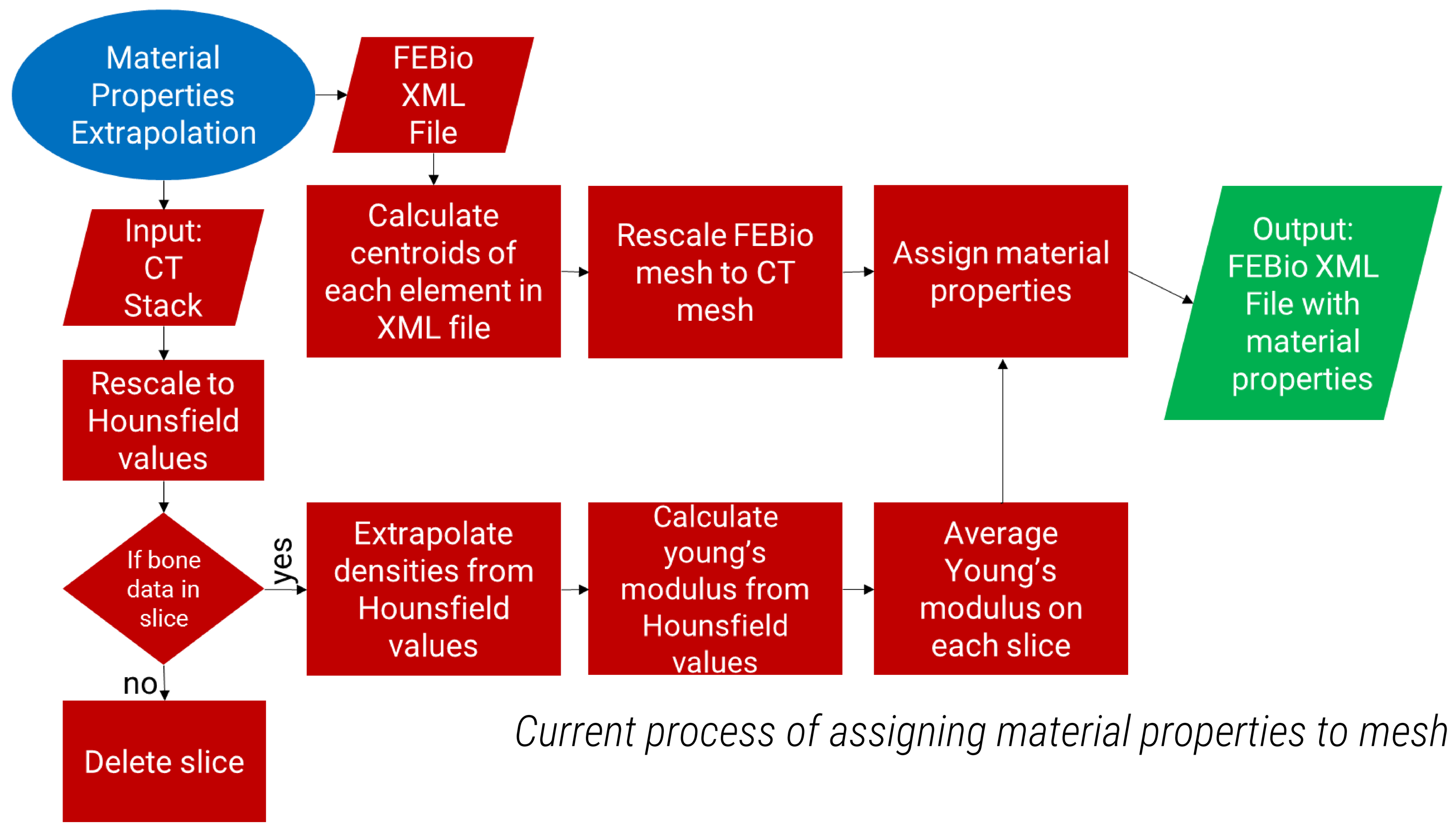
- Python's VTK toolkit includes a Marching Cubes algorithm
    - Creates a 2D surface mesh from binary segmented regions[3]
    - Also smooths mesh and removes unnecessary triangles
- Blender[4] used to repair mesh and isolate any areas of interest
- 2D surface mesh was recreated into a 3D volume mesh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

Flowchart showing 3D model creation process

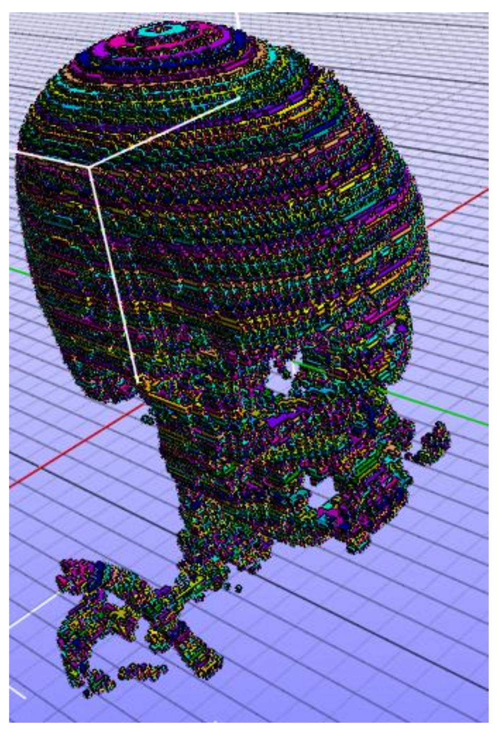


Isolated vertebrae disc from processed skull mesh

Material Properties Assignment:

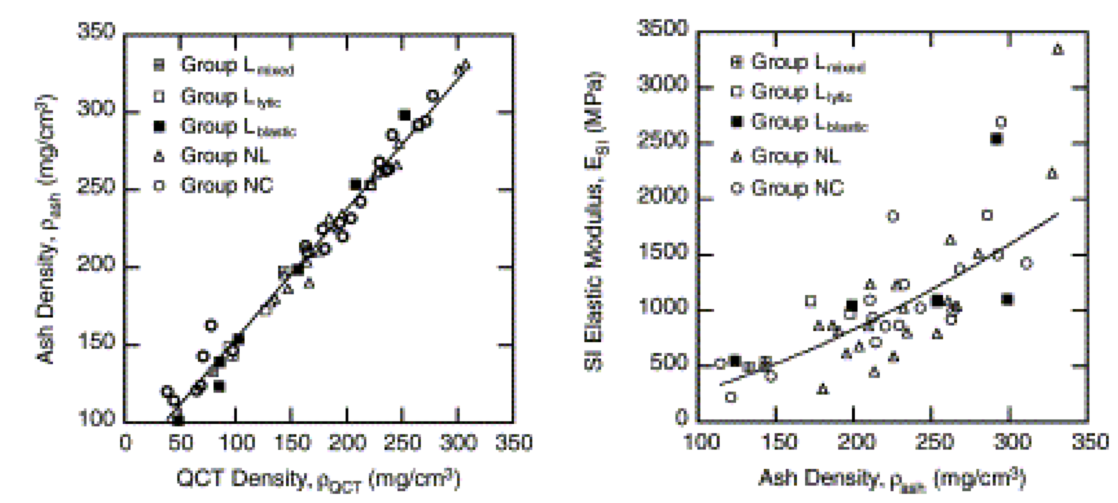


Current process of assigning material properties to mesh



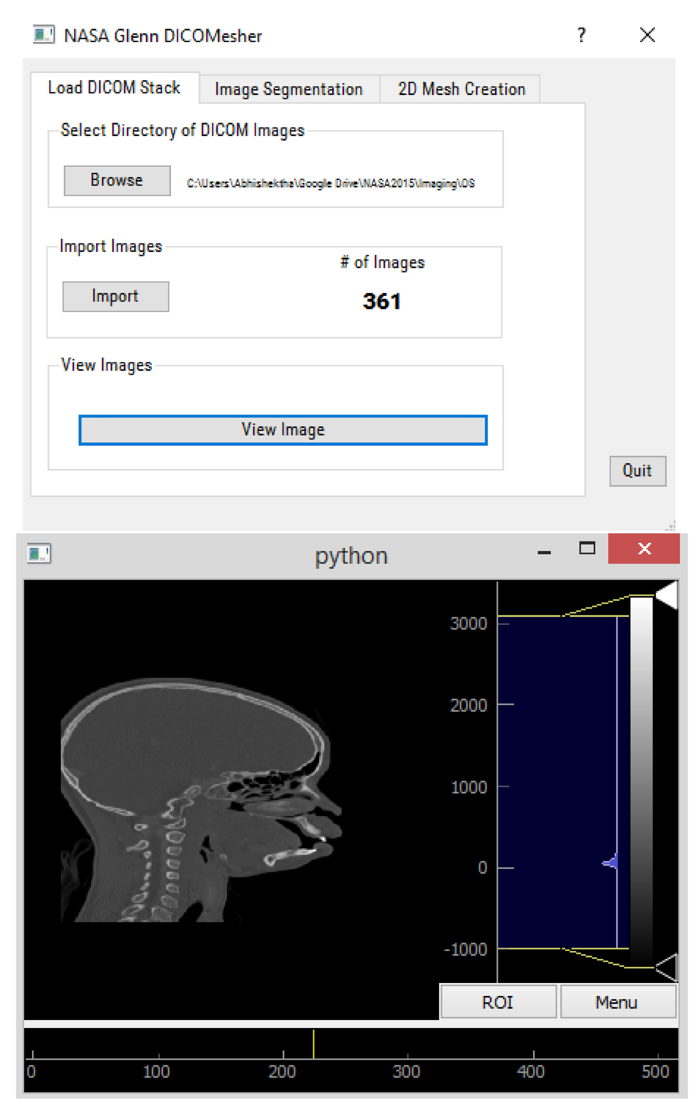
Skull model with dynamically applied material properties

- 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



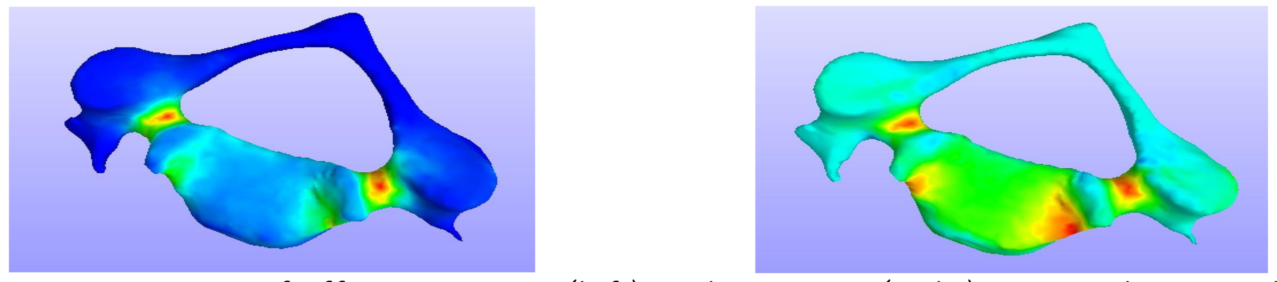
Figures from Keneko et al. [2] showing relationship between Hounsfield value, ash density, and Young's modulus

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

Acknowledgments:

This project was supported by the 2015 NASA Glenn Space Academy

Other Acknowledgements include:

Chris R. Werner (Zin Technologies)

Ohio Aerospace Institute

Ohio Space Grant Consortium

References:

1. Sibonga et al., "Recovery of spaceflight-induced bone loss: Bone mineral density after long-duration missions as fitted with an exponential function," *Bone*, Vol. 41, Issue 6, pp. 973-978, 2007.
2. "Bones in Space", *NASA For Educators* [online], http://www.nasa.gov/audience/foreducators/postsecondary/features/F_Bones_in_Space.html [retrieved 12 January 2016].
3. Narkbuakaew et al., "3D surface reconstruction of large medical data using marching cubes in VTK," National Electronics and Computer Technology Center, Phahon Yothin Rd, Klong Luang, Pathumthani, Thailand, May 2015.
4. Blender Online Community, "Blender – a 3D modelling and rendering package", Blender Foundation,, http://www.blender.org, 2015.
5. C. Geuzaine and J.-F. Remacle, "Gmsh: A 3-D finite element mesh generator with built-in pre- and post-processing facilities," International Journal for Numerical Methods in Engineering, vol. 79, no. 11, pp. 1309-1331, 2009.
6. Keneko et al., "Mechanical properties, density and quantitative CT scan data of trabecular bone with and without metastases," *Journal of Biomaterials*, Vol. 37, Issue 4, pp. 523-530.
7. S. Mass, B. Ellis, G. Ateshian and J. Weiss, "Finite elements for biomechanics," Journal of Biomechanical Engineering, 2011.