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Improvement of Finite Element Models using nanoCT Scans of Bone: A Methodology

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Introduction

As space exploration continues to dive into depths that we have never seen before, we expect humans to be a part of endeavors that are on the order of years of total travel time. Health and safety of these astronauts are of the utmost importance for these trips to ensure a return to Earth that is as smooth as possible. Bones are subject to a vastly different environment in comparison to here on Earth. Within this new environment, Bone often quickly lose density even with current physical and nutritional countermeasures[1]. It is critical that we can quantify such bone strength loss to help improve care and preventative measures for these travelers. One non-invasive method is utilizing finite element analysis of models constructed from CT images of bone to test responses to different loading scenarios. One issue present in current methods is the lack of adequate resolution to ensure that these models are within reasonable error. Further improvements in resolution, such as utilizing novel CT imaging on the nanometer level will help improve the structure obtained with these scans. With these improvements in imaging comes a new challenge on how to process and deal with these models to perform analysis.

Methods

Conversion to MAC/GMC

In order to utilize nanoCT's resolution capability, each determined voxel of the mesh in finite element model must run through MAC/GMC, a micromechanical program developed by NASA. This program helps simplify the cube to have unique material properties for simulation in order to improve the simulation results and maintain model simplicity. To determine the workflow, cubical elements were selected from the tiff stack in order to create a matrix of bone, pore, and air, as the red box in Figure 1 shows. Material properties of bone, pore, and air were denoted in the program and then a matrix of 1, 2, and 3's was created to denote which material was what via thresholding.

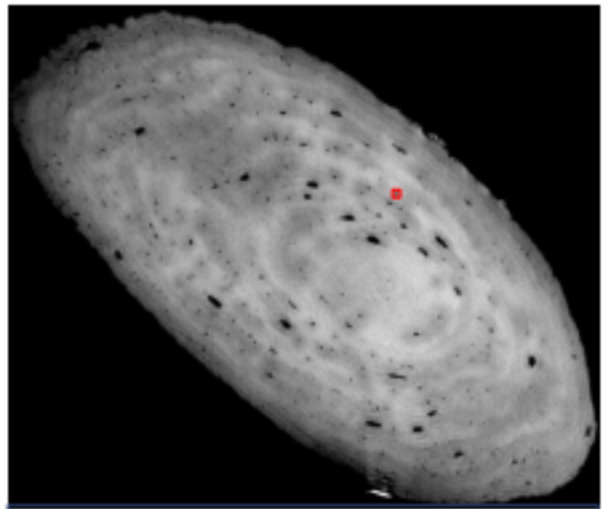

Figure 1. Example of a nanoCT scan of bone. Red box denotes an area selected to convert to a matrix of bone, pore, and air for material property determination.

Discussion

The main goal of understanding the limits and duration of each micromechanical material property run is to determine which mechanism is most viable for simulation. All regular GMC models ran with relative ease, making it suitable for quick testing in simple loads in one direction. If more complex loads are being used, then the HF-GMC model should be used for its consideration of multiple directional factors in its time, with a downside of larger memory usage and time. Applications of this methodology solely focus on a workflow including subroutines that determine material properties per voxel to be applied to a finite element model using in simulation. Utilizing the methodology discovered, this could significantly increase the accuracy of these models as the 50x50x50 cube covers a smaller volume in comparison to conventional CT or microCT methods[2]. When looking for any cause of failure, nanoCT scans along with this methodology may pinpoint never-before-seen issues with space travel, especially a longer duration in space.

Conclusion

nanoCT scans can provide significant increases in resolution that are suitable for improvement of finite element modeling