Bone Microstructural Changes in Rat Tibias exposed to Space Radiation

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Introduction

Human healthcare outside of the Earth's atmosphere has become a greater concern as humans have lived in the International Space station for over two decades. Solar Particle Events (SPE) will be a concern if space travel evolves away from the Earth's orbit. SPE is predicted to cause Acute Radiation Syndrome and other unknown health effects [1]. Currently, NASA limits how long young female astronauts are allowed in space because they are considered higher risk for radiation effects. Bone injury risk is different among the sexes and should be considered when studying radiation since scaling male models to female models based on weight alone is not accurate [2]. It is important to study all types of radiation that astronauts can be exposed to and compare the sex differences. Studying the effects of protracted radiation on bones is vital for the healthcare of deep space astronauts. The goal of this study is to analyze bone health in respect to protracted radiation and sex.

Methods

Study Design

In this study, Long Evans rats were exposed to protracted 5-ion GCR (Galactic Cosmic Radiation) at Brookhaven National Laboratory (n=12). Among these rats, 6 were irradiated with a protracted dose of 50 cGy (n=4 females, n= 2 males), and as a control group, 6 rats were not exposed to any radiation (n=2 females, n=4 males). The rats were euthanized and their hind limbs were collected. Rat tibias were micro-CT scanned (8um resolution) to quantify bone morphometric changes through image processing.

Micro-CT and Image Processing

A way to study bone health is by examining bone volume fraction, connectivity, and thickness. To accurately study the microstructure of the bones, the measurements of the cortical and trabecular bone were calculated separately. The cortical bone and trabecular bone were separated using Mimics. The DICOMS were imported into ImageJ. The BoneJ plugin was used to calculate the bone volume, total volume, and thickness (max, mean) of both the cortical and trabecular bone. Trabecular connectivity was also calculated. A 3D model was rendered showing the changing thickness throughout the bone using a color scale.

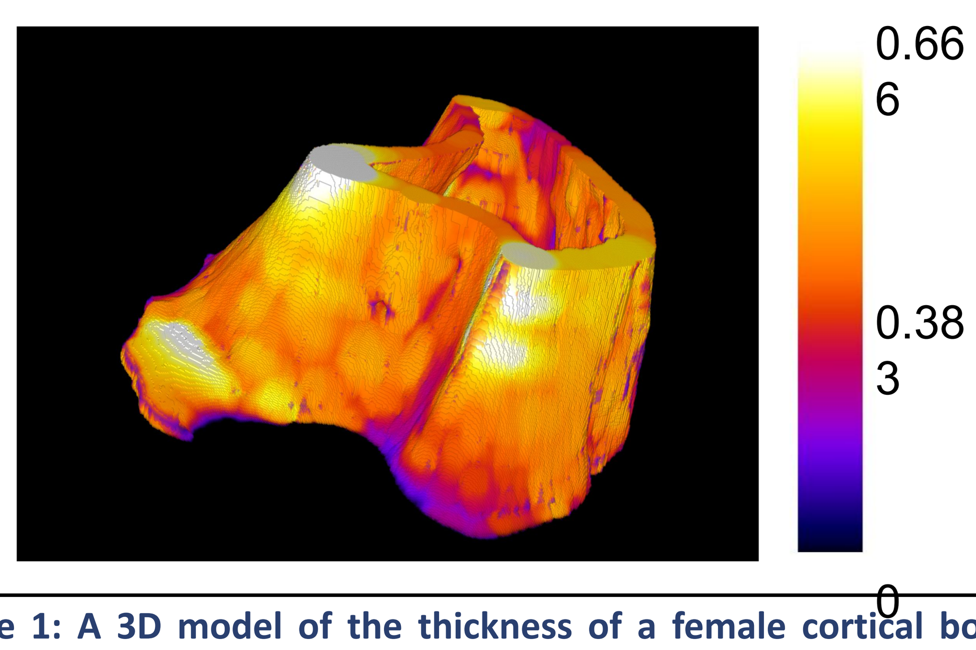

Figure 1: A 3D model of the thickness of a female cortical bone exposed to protracted radiation. The colors are based on the color scale to the right of the model in mm, white being the largest thickness and black being the smallest thickness.

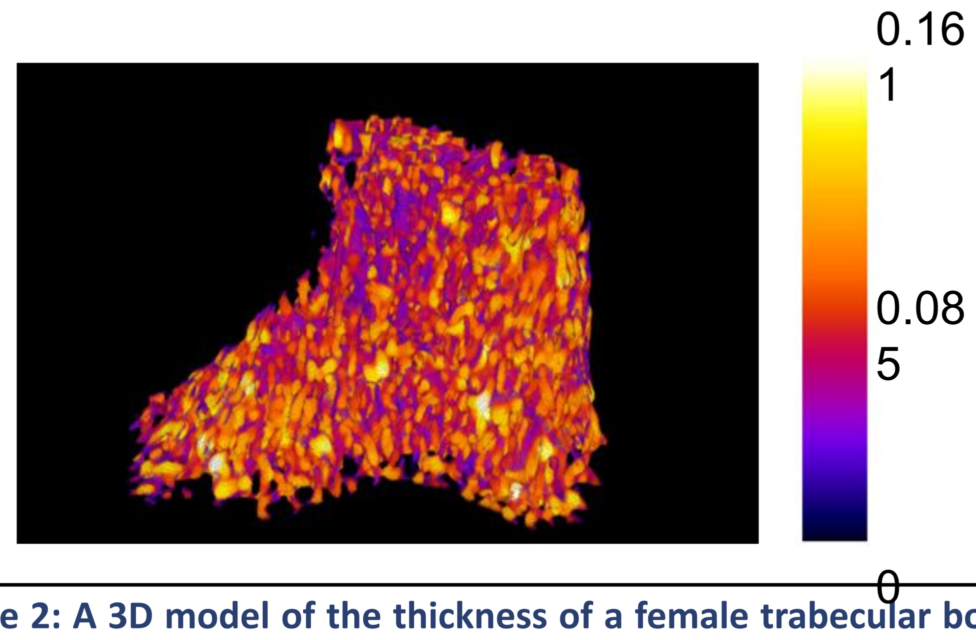

Figure 2: A 3D model of the thickness of a female trabecular bone exposed to protracted radiation. The colors are based on the color scale to the right of the model in mm, white being the largest thickness and black being the smallest thickness.

Statistical Analysis

Statistical analysis was performed using a linear mixed model to evaluate differences for treatment and sex. Exposure to radiation did not cause statistically significant differences with respect to bone volume, thickness (max, mean), or trabecular connectivity. Some microstructural significant differences between male and females were observed. Bone volume was statistically different between the sexes, showing females had decreased cortical bone volumes ($p<0.05$). The increased connectivity in all the females compared to all the males was also significant ($p<0.05$).

Results

There was decreased cortical bone volume ($p=0.0002$) and an increase in trabecular connectivity ($p=0.03332$) in females compared to males, as seen in Figures 3 and 4.

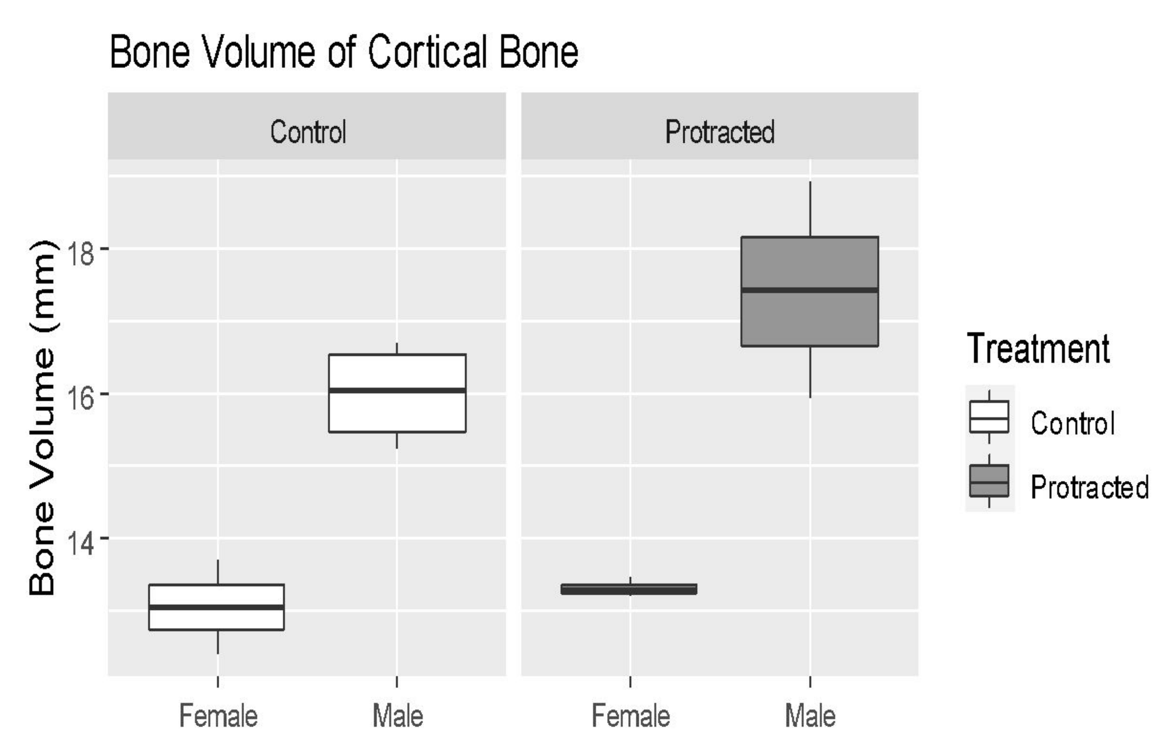

Figure 3: A box and whiskers plot of the cortical bone volume comparing treatment with respect to sex. In the control group, the female cortical bone volumes were lower than male. In the Protracted group, the female cortical bone volumes were lower than males. There was no statistical difference found between control and protracted groups.

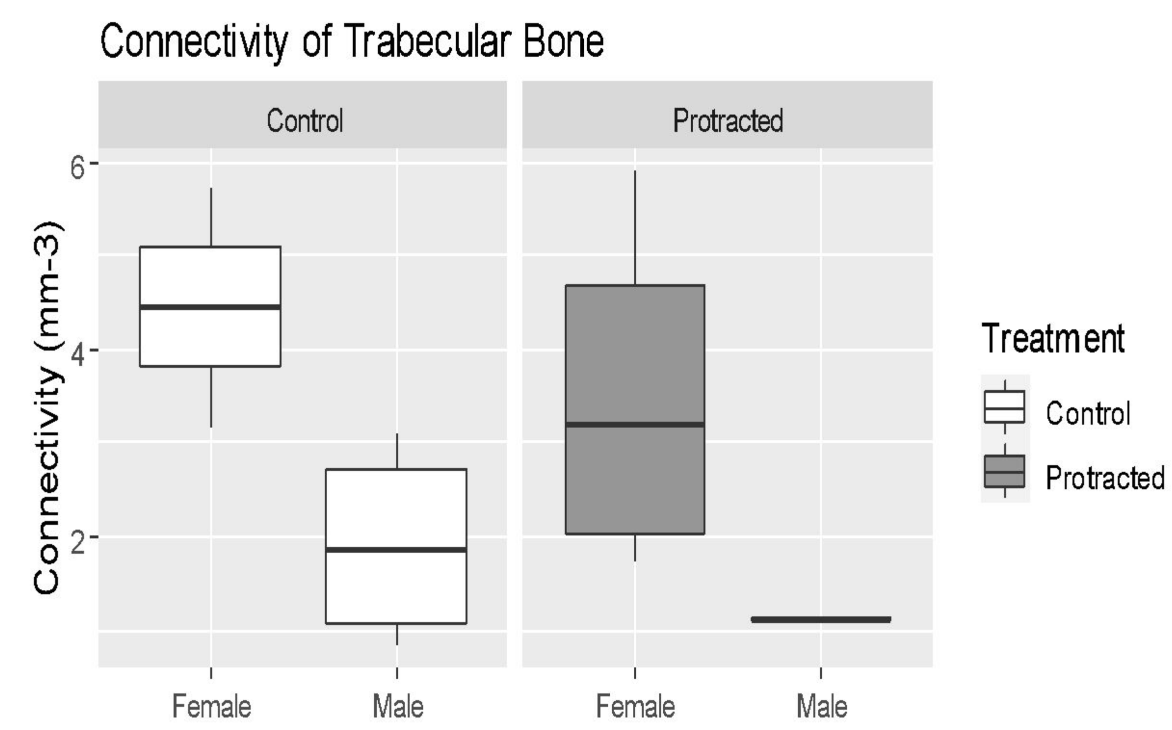

Figure 4: A box and whiskers plot of trabecular connectivity comparing treatment with respect to sex. In the control group, the female trabecular connectivity were higher than male. In the Protracted group, the female trabecular connectivity were higher than males. There was no statistical difference found between control and protracted groups.

Discussion

From these statistics, there were significant differences found between sex but not radiation. A future area of interest is investigating a possible inverse relationship between cortical bone volume and trabecular connectivity and connections between sexes. Connectivity for females was significantly larger than males. Visual analysis confirmed these calculations. In Figure 5, the connectivity in this male specimen not exposed to radiation (C=2.562) was lower than this female specimen also not exposed to radiation (C= 5.737).

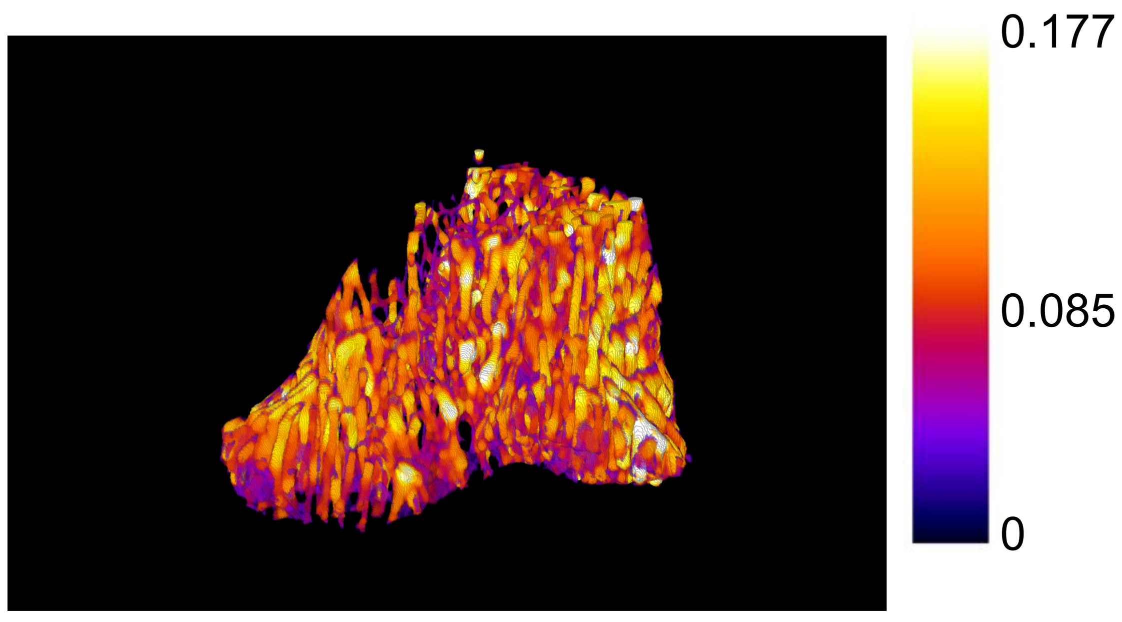

Figure 5: A 3D model of the thickness of a male trabecular bone not exposed to radiation.

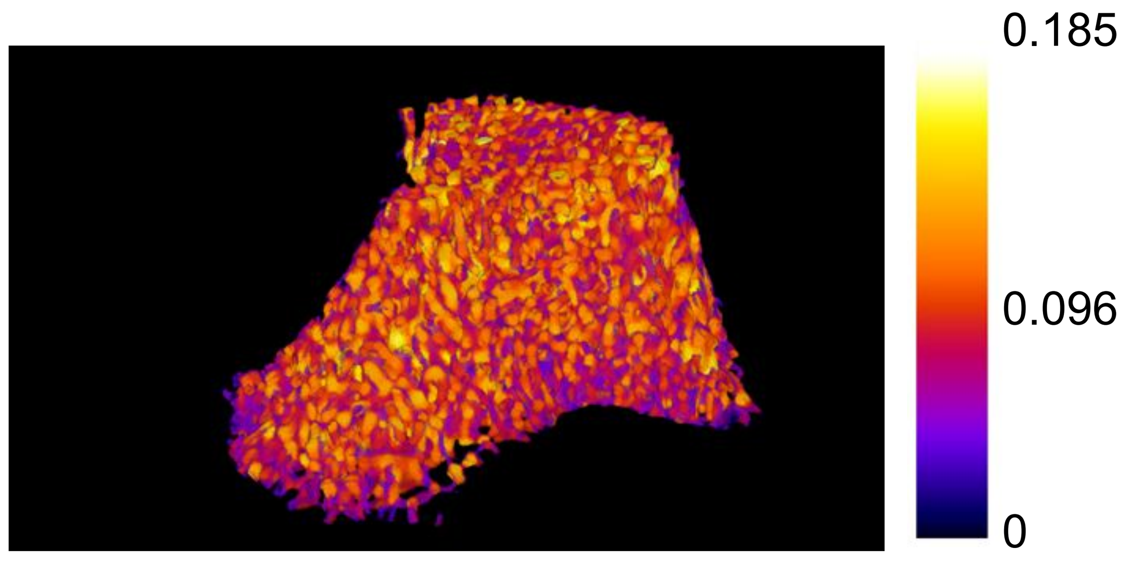

Figure 6: A 3D model of the thickness of a female trabecular bone not exposed to radiation.

One limitation of this study is the small sample size within the groups of this partial cohort due to experimental delays from COVID-19 (n=2 for male irradiated specimens).

Conclusion

There were no significant differences between the bone health of the protracted and control rat bones. There were differences found between male and female microarchitecture. Due to the lack of specimens involved in this study, conclusions were difficult to make. Future work includes finishing analysis of the entire cohort, which should increase statistical power as well as investigating the differences in acute and protracted radiation exposure.

Acknowledgements

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References

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