The Material Properties of Rat Bone Irradiated with Helium Ions

Patricia K. Thomas[1], Gary Dickinson[2], Catherine Davis[3], and Anthony G. Lau[1]

[1]The College of New Jersey, Department of Biomedical Engineering, [2]The College of New Jersey, Department of Biology

Introduction

With several companies working to go to space, and eventually Mars, long distance space travel is becoming more realistic. The journey to Mars takes roughly seven months [1], and with the time in space increasing, so do the health risks associated with the journey. The two main risk factors are the microgravity environment and the radiation. Radiation has been proven to affect the porosity and structure of bone [2] [3]. This study focuses on the effects of radiation at the material level, which had not been previously studied, using spherical micro-indentation.

Methods

Study Design

All animal work was performed following the IACUC protocols set by Johns Hopkins University and Brookhaven National Laboratory, where no live animal work was performed at The College of New Jersey. Long Evans rats (n=75) were completely radiated with varying doses of helium ion radiation. Controls (n=22) were sham irradiated. Entire body radiation was performed at 5 cGy (n=26) and 25 cGy (n=27). 7 days, 30 days, 60 days, 90 days, and 6 months after radiation exposure, animals were euthanized, and their hind limbs were removed and stored in 70% ethanol prior to testing. Bones were dried and embedded in epoxy, as seen in Figure 1. They were then cut with a diamond saw (Figure 2) and polished with a series of polishing papers and cloths using a 0.04 μm silica suspension.

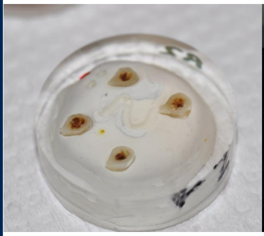

Figure 1: This is the epoxy puck with four bone samples embedded, cut and polished.

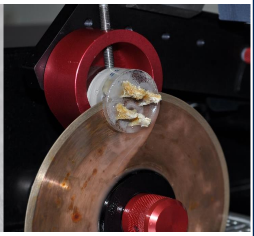

Figure 2: The diamond saw blade used to cut femoral heads off to create flat surface to polish.

Spherical micro-indentation tests were completed using a 300 μm diameter ruby tip with a set depth of 15 μm and a 30 second hold. Tests were performed under a microscope on the cortical bone. Hertz spherical contact was used to calculate the cortical bone elastic modulus from force-displacement data.

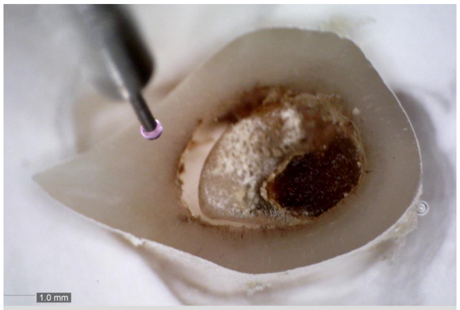

Figure 3: This is the spherical micro-indentation experimental set-up used on bone samples.

Statistical Analysis

The elastic modulus values were averaged per bone. The resulting elastic moduli were then statistically analyzed using a two-way ANOVA test with a post-hoc Tukey test using Origin Pro 2019 (64-bit) where $\alpha=0.05$.

Results

The two-way ANOVA and post-hoc Tukey test showed no statistically significant differences. While the two-way ANOVA showed no differences, there was an increasing trend in elastic modulus as seen in Figure 4. As seen in Figure 5, the elastic moduli increased at 90 days and then decrease at 6 months. The samples were also put into a histogram in order to examine the spreads of each dosage, as seen in Figures 6-8. The means and medians for the irradiated samples were greater than the mean and median for the control samples. However, radiation exposure did increase the variability in the elastic moduli, as seen in Figures 6-8.

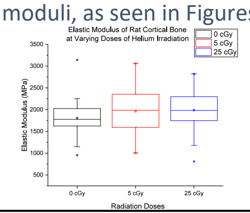

Figure 4: The overall spherical micro-indentation resulting elastic modulus of each bone for each of the helium radiation dosages.

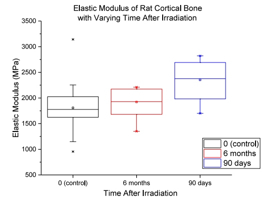

Figure 5: The overall spherical micro-indentation resulting elastic modulus of each bone at each time point after radiation.

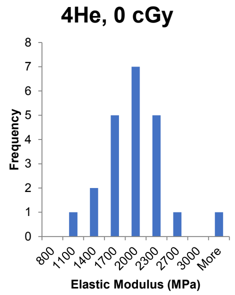

Figure 6: The resulting spread for the control group average elastic modulus per bone in MPa (N=22). This group has a skewness of 0.311.

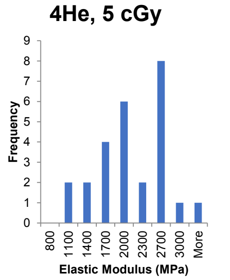

Figure 7: The resulting spread for the 5cGy treatment group average elastic modulus per bone in MPa (N=26). This group has a skewness factor of -0.012.

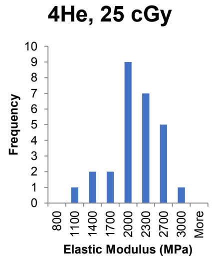

Figure 8: The resulting spread for the 25cGy treatment group average elastic modulus per bone in MPa (N=27). This group has a skewness factor of 0.038.

Discussion

Each histogram was then examined for skewness. The control group without radiation had right skewness of 0.31, while both the 5cGy and 25 cGy irradiated groups had skewnesses of -0.012 and 0.038, respectively. The means and medians of each of the irradiated groups were roughly the same, however they were both higher than the mean and median of the control group. All three groups had large standard deviations that were about the same. Large standard deviations are expected, as the experiment requires working with biological materials. Biological materials are not homogenous nor are they going to be the same across different animals, especially older animals as what were studied in this study. Future work will include adding another length scale with microhardness testing. Microhardness testing all of the previous samples that have undergone spherical micro-indentation will allow for a larger picture regarding the material properties, as the hardness will be obtained. From the hardness the yield stress of the material can be obtained. More samples with varying types of radiation and dosages will also be studied, as space radiation consists of multiple types of ionic radiation. Overall, it was very interesting to see a general increase in the elastic modulus with radiation dosages. This could be due to the radiation destroying the collagen and organic components of the tissue, and cells filled in the gaps with extra inorganic material.

Conclusion

Studying the material properties of the bone that was treated with space radiation is imperative to understanding the full effects of space radiation on the human body. The material properties contribute to the structural properties. Radiation is a health concern with longer space missions, so it is necessary to understand its effects in order to figure out methods of preventing bone degradation or loss.

Acknowledgements

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