Bone Strength Changes in Rats Exposed to Proton Radiation

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Introduction

As we venture into uncharted territories, such as Mars, radiation must be considered an imminent risk. Once outside the Earth's magnetic field astronauts are exposed to a range of particles that can alter their biological makeup (1). Exposure to radiation has been shown to increase bone porosity and thus an increased fracture risk (2). This study will focus on the material properties from head only proton irradiated bone through the use of micro-indentation techniques.

Methods

Study Design

Animal work was performed following IACUC protocols set by John Hopkins University and Brookhaven National Laboratory; no live animal work was performed at The College of New Jersey. Long Evans Rats were irradiated at the femoral head only. Controls were sham irradiated (n=7). Radiation was only given to the head of each animal and were given at doses 10 cGy (n=9), 25 cGy (n=13), and 100 cGy (n=15). These animals were euthanized 6 months after radiation exposure. Bones were stored in 70% ethanol before testing. Bones were dried and embedded in an epoxy. Once dry, they were cut with a diamond saw and polished with am abrasive cloth using 0.04 μm silica suspension.

Figure 1- After embedding and sawing of the femoral head.

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. Bones were indented at the anterior, posterior, lateral, and medial locations of the femoral head. MATLAB was used to fit load relaxation as an exponential decay function, in order to derive the long time and instantaneous shear moduli.

Figure 2- Set up used for spherical micro-indentation

Statistical Analysis

A mixed linear model with a Tukey HSD post-hoc was used (α=0.05). The mixed model was set up with the anatomical location and dosage as fixed effects. Anatomical location and bone were also crossed as a random factor to account for any variance in the overall population. Dosage was nested within bone to account for each bone being a part of one dosage group.

Results

According to the post-hoc, no significant differences in radiation dose were found (Fig. 3-4). No significant differences in anatomical location was found for instant shear modulus (Fig. 5), however, significant differences were found between location (p<.05) in the long-time shear modulus (Fig. 6). A high amount of variation was observed across the sham groups. Although no significant differences were found, it is important to note that both the instantaneous and long-time shear modulus both share a general trend, as radiation dosage increased, both the instantaneous and long-time moduli decreased.

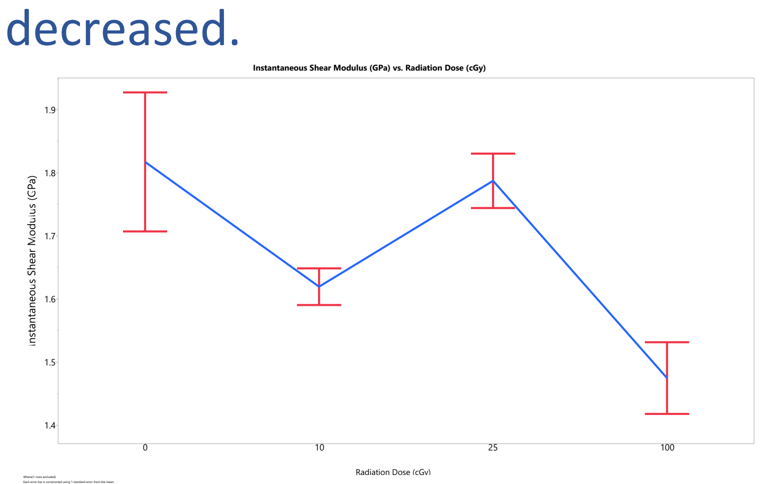

Figure 3- Instantaneous Shear Modulus (GPa) vs. Radiation Dosage(cGy). Red bars represent error bars for according dosage.

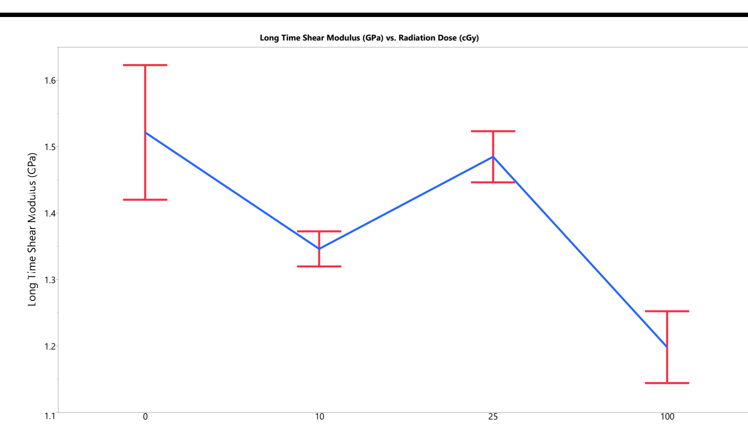

Figure 4- Long Time Shear Modulus (GPa) vs. Radiation Dosage(cGy). Red bars represent error bars for according dosage.

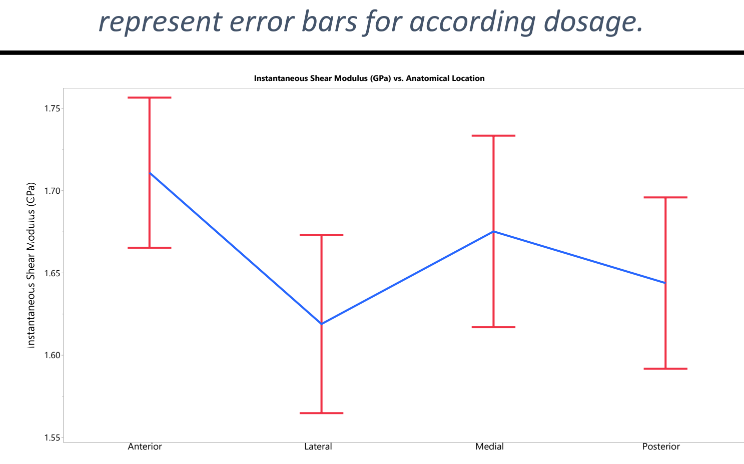

Figure 5- Instantaneous Shear Modulus (GPa) vs. Anatomical Location. Red bars represent error bars for according location.

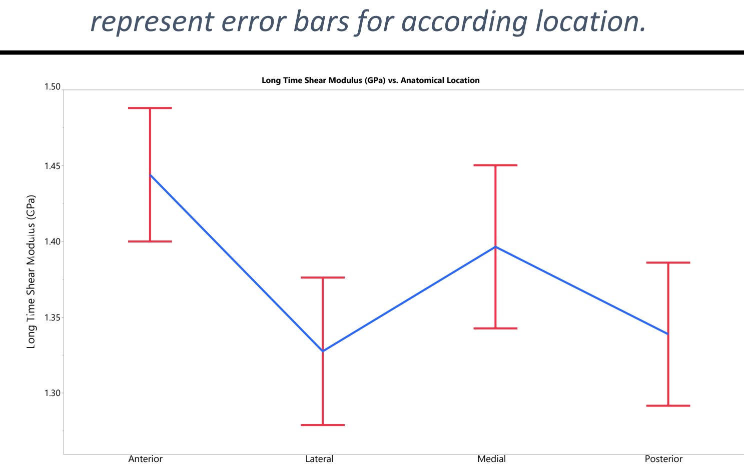

Figure 6- Long Time Shear Modulus (GPa) vs. Anatomical Location. Red bars represent error bars for according location.

Discussion

Overall, the data has shown a downward trend in instantaneous and long-time shear modulus as radiation dosage increases. Using this trend, we can infer that there seems to be an effect on the material properties of proton irradiated bones. It is possible that this downward may be due to a deterioration of the organic matrix, where an increase of crystallization will decrease the elastic properties of bone. Difference in moduli due to anatomical location can be explained by natural load displacement. Most of the anterior part of the femur is typically in compression and must be able to endure higher loads.

Future work should include a combined study consisting of hindlimb suspension (HLS) as well as galactic cosmic radiation (GCR). The combination of these effect is a better representation to represent the environment astronauts will be exposed to in space. Furthermore, a systemic approach should be taken since whole body radiation does not just affect the bone itself. Taking a step back and looking at the systemic responses, will help to focus in what factors are affecting the material and mechanical properties. A focus should be taken at understanding the response of the endocrine system due to radiation. Hormones, such as PTH, indirectly contribute towards the differentiation of osteoclasts, understanding how they behave under irradiated conditions will help to pinpoint the factors directly contributing to the decreased material properties.

Conclusion

Material properties of irradiated bones have been greatly understudied. Understanding the effects at this length scale will help determine the contributing factors of the mechanical properties and assist in gauging failure risks of irradiated bones. The effects of radiation must be understood since it may be more detrimental to bone health than just microgravity alone.

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