

Towards a Personalized Dosimetry Approach for Astronauts: Combining Computational and Biological Modeling to Predict the Topography of the Energy-Dose-Toxicity Landscape for Solar Particle Event Radiation

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INTRODUCTION

The space radiation environment is exceptionally complex and imposes increased dangers of acute and chronic exposure to ionizing radiation. Of particular concern is the possibility of exposure to ionizing radiation in a solar particle event (SPE). A large body of literature exists investigating the absorbed dose to organs that is expected from exposure to an SPE. Due to computational complexity, this work has been largely based on simplified models of radiation transport in matter that rely on a straight ahead approximation with doses to individual organs represented by dose absorbed at average depths in a standard sphere.

METHODS

In this study, we have developed software tools using the Geant4 Monte Carlo simulation framework that use computed tomography scans and provide radiation transport simulations that use the full complement of radiation interaction processes. We have applied this model to predict the expected organ dosimetry for 3 different human CT scans and 2 different SPE. We have also applied this model to help experimentally recreate SPE-like dose distributions in a Yucatan Mini-Pig model to test both the expected biological outcome of Astronaut SPE exposure as well as the efficacy of potential radiation mitigators for SPE radiation.

RESULTS

We found that this simulation accurately predicts measured datasets for experimental set-up with both protons and electrons. The results of these simulations indicate that not only does any particular astronaut's dose to specific organs (ie skin, eyes, lungs, bowel, etc) differ dramatically for different SPE, different astronaut models experience significantly different doses to these organs even with the same SPE exposure. In experiments with Yucatan mini-pigs, clinically and histopathologically observable skin toxicity, including necrotic keratinocytes, presence of melanophages and pigment incontinence peaked on day 14 post irradiation. Blistering began to appear in areas of skin that received dose > 15-20 Gy that healed by day 30 post-irradiation, but decreases in the volume of skin microvasculature were observed at doses as low as 5 Gy. Subacute radiation necrosis was also observed in previously healed areas of skin in days 30-60 post irradiation following doses of 7.5-20 Gy. We also found that the degree of inflammatory complications of skin and internal organs appears to correlate with the degree of radiation-induced leukocyte count suppression. Finally, we have begun to explore the impact of potential radiation mitigators for cutaneous toxicity of SPE-like radiation.

CONCLUSIONS

In conclusion, these studies clearly demonstrate value of our novel computational and biological modeling techniques for two critically interrelated uses: determining the overall dose distribution and dose to specific organ systems for SPE exposed astronauts and helping to ensure that earth based experiments reproduce appropriate dose distributions in order to maximize the applicability of findings from these experiments. These results suggest that a detailed understanding of the dose distribution and physiologic understanding of consequences of this dose will be necessary to predict toxicity in SPE exposed astronauts. In addition, our results suggest that a personalized dosimetry approach for specific astronauts may be valuable in determining the most appropriate course of clinical action in the event of an SPE exposure.

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