JULY 12–16 2020 VIRTUAL JOINT AAPM | COMP MEETING EASTERN TIME [GMT-4]

Monte Carlo Simulations of Minibeam Therapy with Protons and Carbon Ions

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INTRODUCTION

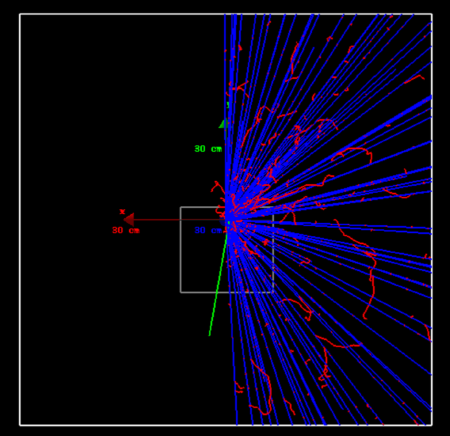
Despite potential benefit of minibeam therapy using particle beams, obstacles remain regarding beam delivery and computational planning tools. For example, dose calculations for the minibeam distributions may require roughly 2 orders of magnitude increase in spatial resolution, and increased computational burden, compared with current standards for radiation therapy. The purpose of this work was to demonstrate feasibility of dose calculation for particle minibeam therapy in anatomically realistic patient anatomy and to investigate the ability to treat deeper brain tumors using carbon-ion minibeams instead of proton minibeams.

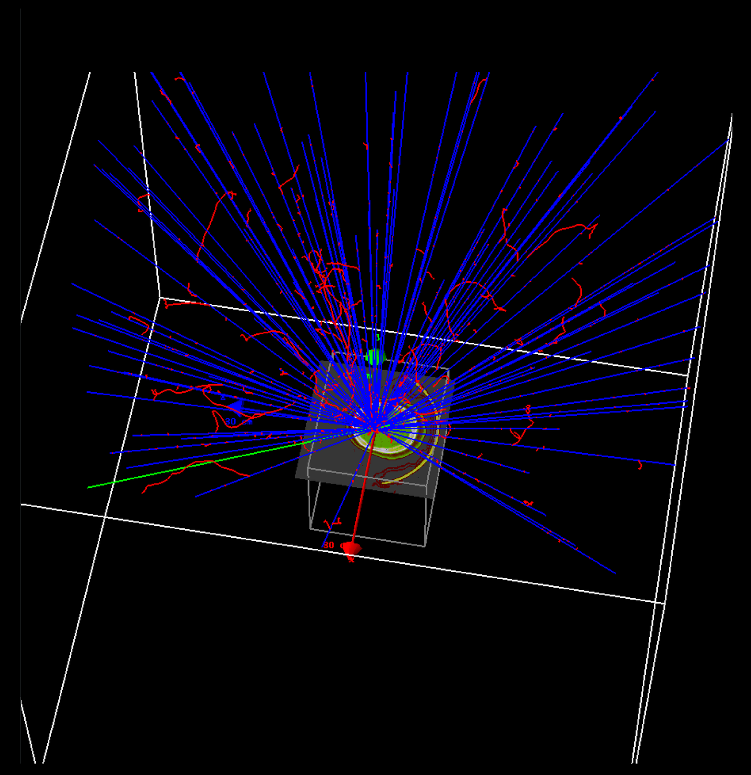
AIM

The purpose of this research was to investigate the physical properties of heavy ion particles as they pertain to external beam therapy treatments in the brain. Given biological benefits of minibeam therapy, certain particle therapies may be more beneficial than others. This project is intended to investigate the differences between carbon ion and proton particle external beam therapies.

METHOD

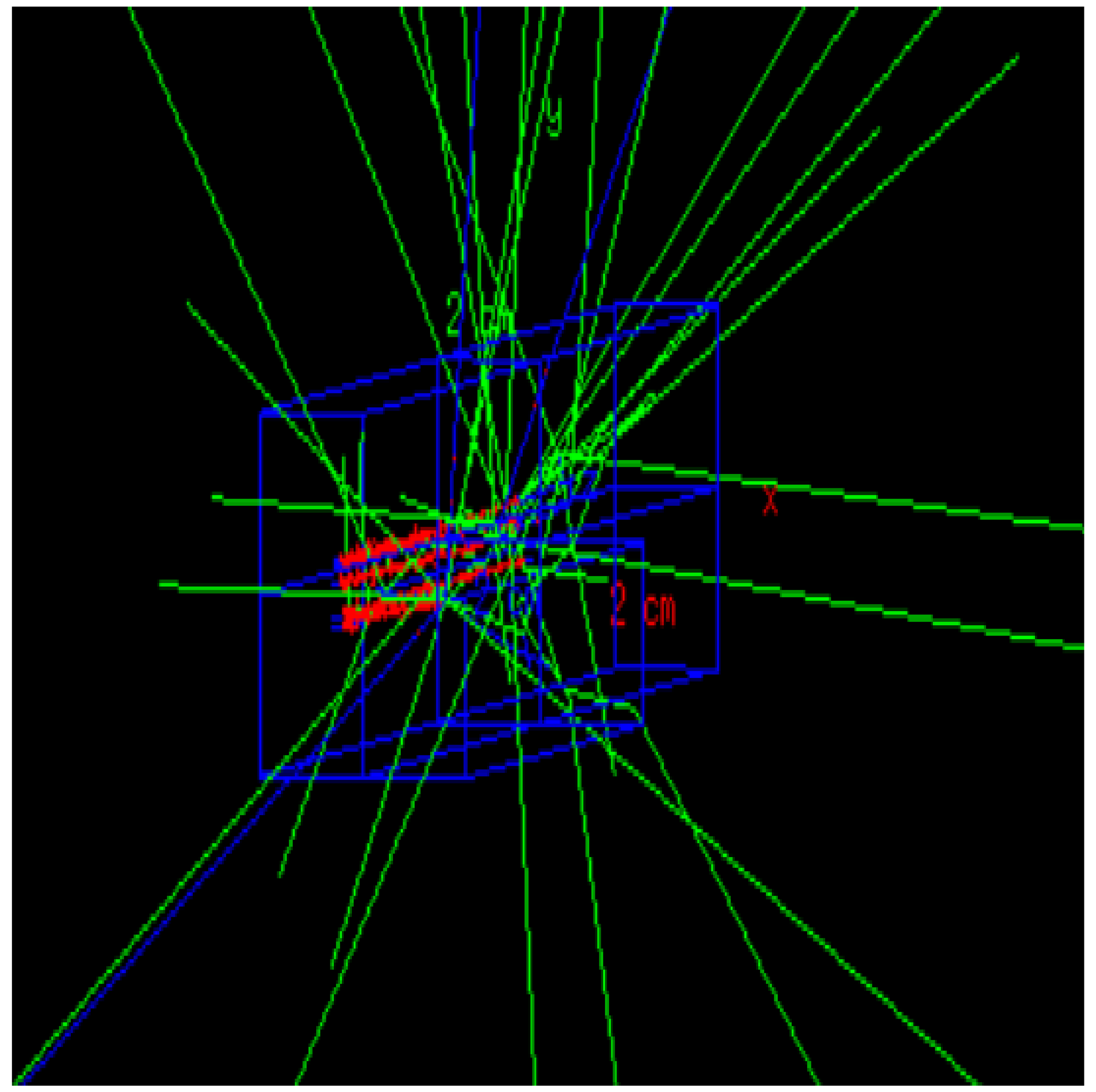
Proton and carbon-ion minibeams were simulated using Monte Carlo software (TOPAS v3.3_beta1) at energies of 115 MeV and 217 MeV/u, respectively. The minibeam arrays were configured as 0.3-mm planar parallel minibeams with 1-mm center-to-center spacing in a 5x5- mm² rectangular array, each using 500,000 histories. Irradiations were simulated in both a water phantom and a computed tomographic (CT) image of a brain tumor patient. Peak to valley ratios (PVR) were recorded as a function of beam depth to determine the depths of tissue to which the distinct spatial pattern of minibeams could be preserved.



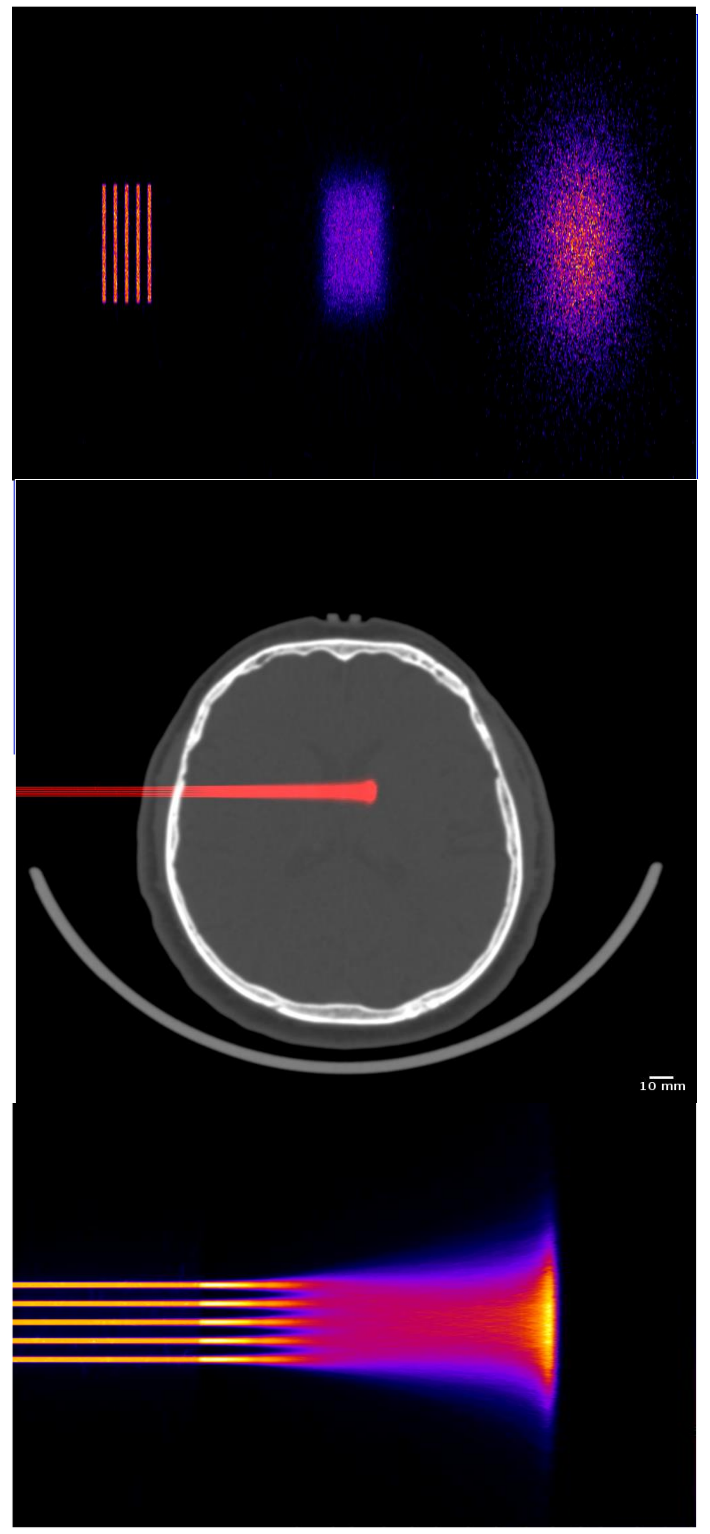


RESULTS

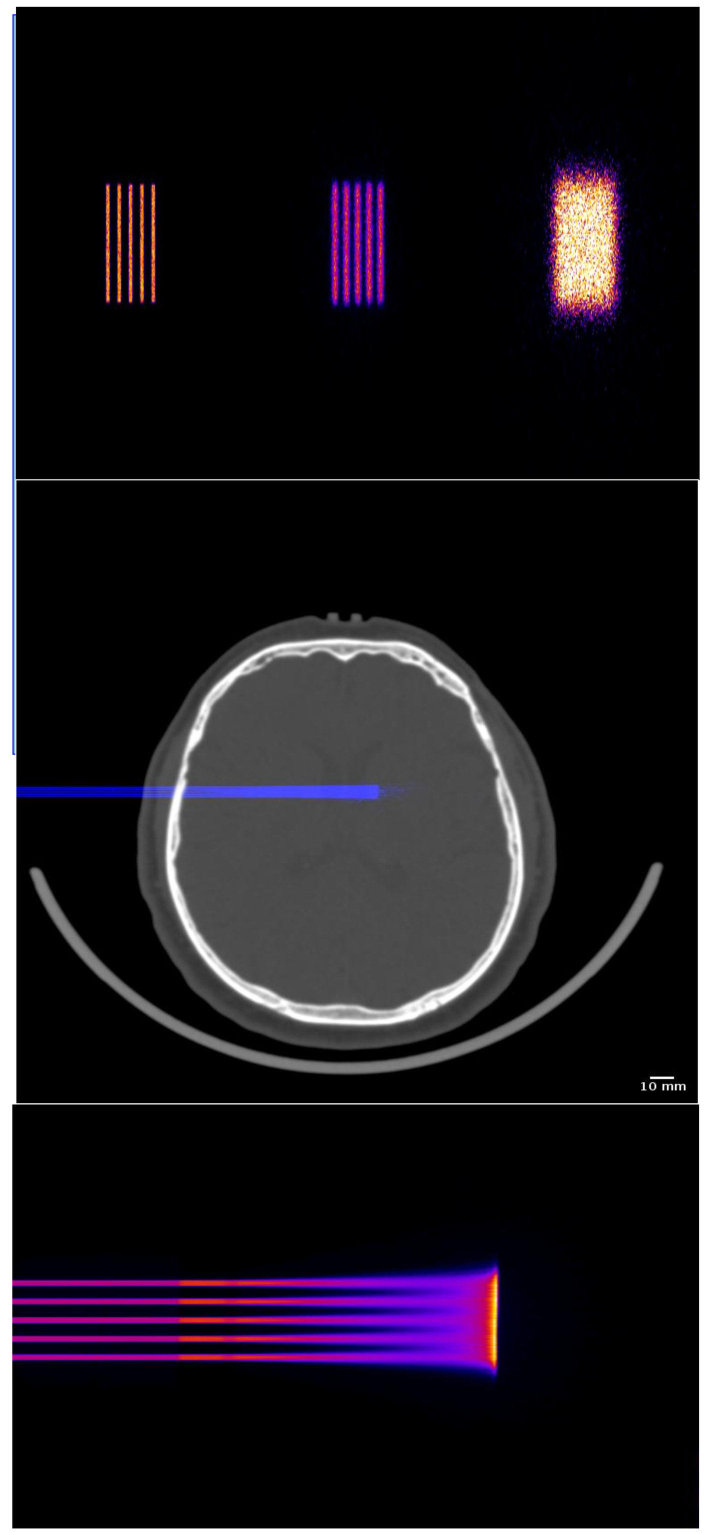
For the brain tumor patient, the simulated proton minibeams exhibited PVRs of 115.14 ± 16.69, 6.89 ± 0.32, 1.08 ± 0.06, 1.09 ± 0.20 at depths of 0, 2, 4, and 6 cm. Simulated carbon-ion minibeams had PVRs of 109.27 ± 7.83, 63.88 ± 4.30, 24.13 ± 1.48, 3.28 ± 0.07, respectively. The dose distributions revealed a minibeam merge depth of approximately 4 cm for the protons, compared to 9 cm for carbon ions.



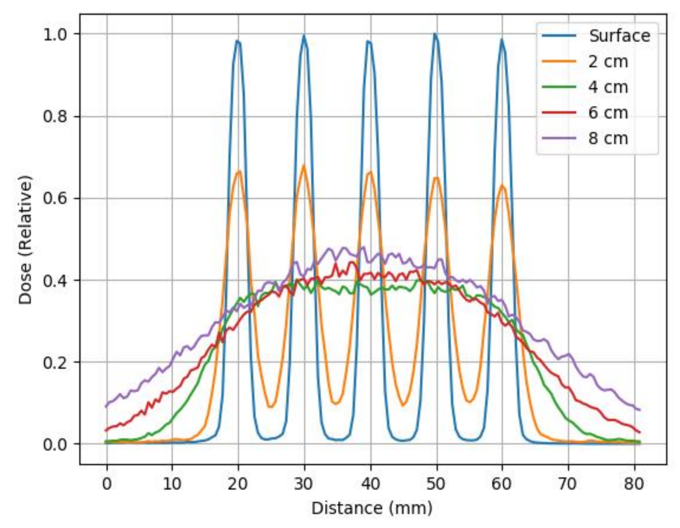
Tool for Particle Simulation (TOPAS) carbon ion minibeam simulation visualization within a simulated water phantom



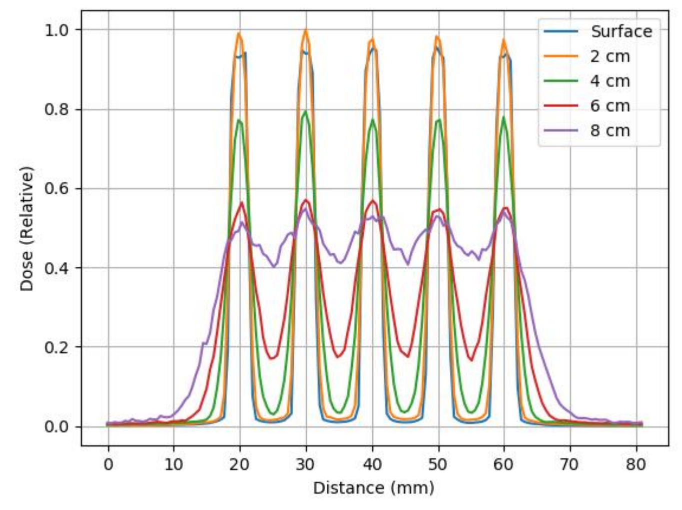
Beam's Eye view (BEV) of proton minibeam at surface, 5cm and 10cm depths (top). Axial view of proton minibeam in head CT (center). Lateral view of proton minibeam (botton)



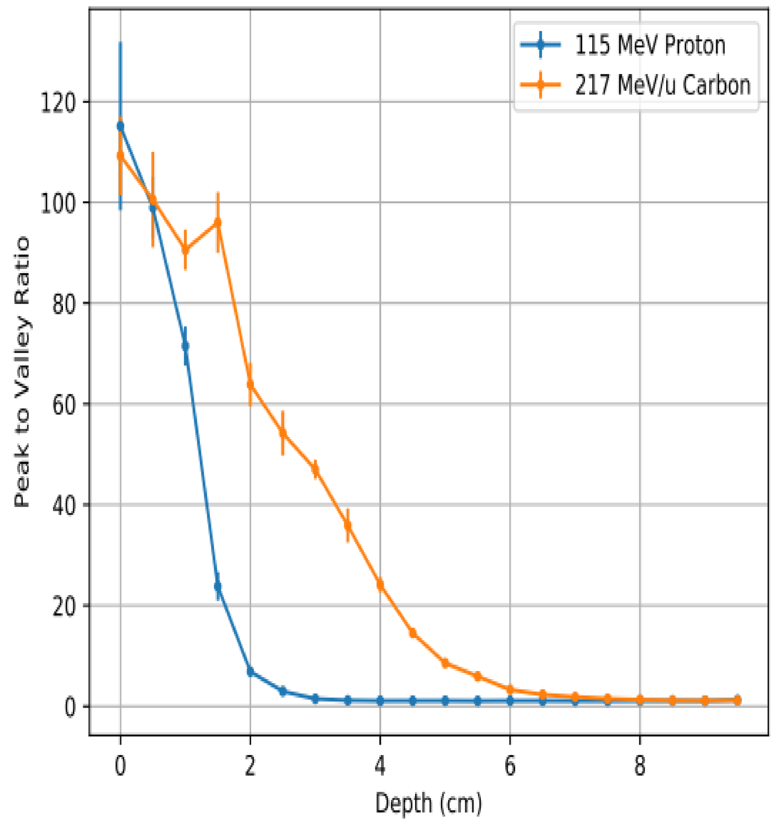
Beam's Eye view (BEV) of carbon ion minibeam at surface, 5cm and 10cm depths (top). Axial view of carbon ion minibeam in head CT (center). Lateral view of carbon ion minibeam (bottom)



Lateral beam profile of proton minibeam at various depths



Lateral beam profile of carbon ion minibeam at various depths



Peak to value ratios (PVRs) comparison between measured proton and carbon ion minibeams

Beam Depth	Carbon Ion PVR	Proton PVR
Surface	109.27 ± 7.83	115.14 ± 16.69
0.5 cm	100.54 ± 9.46	98.95 ± 6.13
1.0 cm	90.58 ± 4.01	71.49 ± 3.87
1.5 cm	96.00 ± 6.03	23.82 ± 2.84
2.0 cm	63.88 ± 4.30	6.89 ± 0.32
2.5 cm	54.21 ± 4.41	2.98 ± 0.07
3.0 cm	47.01 ± 1.90	1.48 ± 0.03
3.5 cm	35.88 ± 3.37	1.17 ± 0.05
4.0 cm	24.13 ± 1.48	1.08 ± 0.06
4.5 cm	14.52 ± 0.42	1.10 ± 0.03
5.0 cm	8.57 ± 0.36	1.10 ± 0.24
5.5 cm	5.95 ± 0.28	1.06 ± 0.12
6.0 cm	3.28 ± 0.07	1.09 ± 0.20
6.5 cm	2.33 ± 0.03	1.09 ± 0.25
7.0 cm	1.86 ± 0.04	1.08 ± 0.28
7.5 cm	1.50 ± 0.03	1.07 ± 0.17
8.0 cm	1.30 ± 0.03	1.10 ± 0.18
8.5 cm	1.15 ± 0.03	1.12 ± 0.18
9.0 cm	1.11 ± 0.04	1.09 ± 0.21
9.5 cm	1.18 ± 0.26	1.24 ± 0.22

Peak to value ratios (PVRs) comparison between measured proton and carbon ion minibeams

CONCLUSIONS

Our work demonstrates an early step in the development of a Monte Carlo based research treatment planning system for proton and carbon-ion minibeam therapy. The deeper merge depth and relatively higher PVRs at depth for carbon-ion minibeams, compared with protons, may prove to be favorable for deeper brain tumors. Future studies will focus on inverse planning tools needed for minibeam therapy with particle beams

REFERENCES

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ACKNOWLEDGEMENTS

This work was done with the help of the faculty of Vanderbilt University Medical Center and the Department of Radiation Oncology.

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