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Analytical pencil beam dose and dose-rate engine development for FLASH therapy studies of heavy ion and very high energy electron beams

Background: With the growing interest of ultra-high dose rate therapy (FLASH-RT) different ionizing particle beams have been considered. With most of the experimental results acquired with electron or photon beams, knowledge on heavier ion use remains sparse.
Our previous work has developed a model for FLASH effect dose threshold estimation. Our results have suggested that, FLASH-RT could be more feasible with lighter ions such as lithium, helium and protons, as well as other low linear energy transfer (LET) particles –such as very high energy electrons (VHEE).
As our previous work has focused only single field irradiation modelling, multi-field treatment plan studies are of high clinical relevance, as well as characterization of dose rate parameters for technological delivery considerations is needed. Thus, necessity for a dose and dose-rate engine for the investigated particles is clearly indicated.
Aims: Primarily, to create an analytical pencil beam dose and dose-rate calculation engine for heavy ion and very high energy electron beams. Secondarily, to investigate and compare different analytical characterization approaches for different dosimetric parameters.
Methods: Monte Carlo simulations were performed in Geant4 environment to create an "experimental beam dataset"for protons, helium-3, helium-4, lithium-6, lithium-7 and carbon ions, as well as electrons for clinically relevant energies, as well as transmission-level energies. Analytical characterization was then performed on the acquired dataset of the pristine pencil beams. For integrated depth dose, different normalization options were investigated for efficient calculations. For lateral dose profile, various fitting functions were investigated and quality of fit was compared.
Physical implementation for a treatment planning system was then investigated, while focusing also on the different dose-rate definitions for FLASH-RT.
Conclusions: Depth normalization to dose maximum and practical range for ion and electron beams, respectively, proved to be most efficient integrated depth dose parametrization options. As for lateral dose profile - a sum of either three gaussian or two gaussian and one logistic function proved to be best approximations for ions, while a sum of double logistic and gaussian function –for VHEE.
The developed engine is sufficient and will be crucial for further comparison studies on ion FLASH-RT delivery methods.

Type of contribution

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