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The importance of the Monte Carlo physics settings for simulations in proton therapy

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Introduction: The Christie NHS Foundation Trust began treating patients using proton therapy in Dec. 2018. As part of the current patient specific quality assurance, each proton field is delivered to a SolidWater (SW) phantom (1 hour for preparation/analysis per patient plus 2 hours of beam time per plan). Monte Carlo (MC) based independent dose calculations have been proposed to reduce these measurements, however, when implementing a multi-purpose Monte-Carlo code such as Geant4, the underlying physics settings have to be chosen from a wide range of possible options. We aim to characterize their influence on clinical dose calculations when taking the whole MC beam-modelling process into account.
Material and Methods: A GATE 8.1 (Geant4 10.3.3) based MC system was set-up for clinical dose calculations as follows: 1) Choose underlying Geant 4 settings, 2) define initial beam optics, 3) adjust energy and energy spread to reproduce proton integral depth dose curves, 4) model beam modifying devices (pre-absorber, 2/3/5 cm Lexan plates to treat superficial tumours). This process was repeated using two pre-built MC physics lists, which differ in the modelling of electro-magnetic interactions, namely QGSP_BIC (EM Opt 0) and QGSP_BIC_EMZ (EM Opt 4). Example simulation results showing spot sizes in air with and without a pre-absorber positioned 46 cm upstream of iso-center are presented in comparison to commissioning measurements. Finally, for one clinical plan (paediatric patient, sarcoma of the neck, 5cm pre-absorber) the influence of different physics settings is shown in the patient CT, and dose distributions simulated in a SW phantom are compared to patient specific quality assurance measurements (two sets of repeated measurements, analysed with 2%/2mm gamma analysis).
Results: Without pre-absorber, beam sizes (sigma) in air are marginally affected by the choice of physics settings (agreement between QGSP_BIC/QGSP_BIC_EMZ simulated spot sizes within 0.1mm, red lines in Figure 1a). Differences in simulated scattering are however relevant when a pre-absorber is inserted into the beam (green/blue/black lines in figure 1a, differences of up to 1 mm for a 5 cm Lexan pre-absorber), with QGSP_BIC_EMZ showing closer agreement to measurements than QGSP_BIC (0.24mm vs 0.72mm difference). The influence of this scattering difference is demonstrated for a clinical case in figure 1b and 1c. Agreement to patient specific quality assurance measurements is higher for QGSP_BIC_EMZ when compared to QGSP_BIC (100% vs. 98.2%at 1.3 cm depth, 99.5% vs. 99.0% at 4.3 cm depth (treatment room 1) and 94.8% vs 92.7% at 1.3 cm depth, 97.9% vs 97.7% at 4.3 cm depth (repeat measurements in treatment room 2). Calculation times are higher (factor of 1.6/1.4 in the CT/SW) for QGSP_BIC_EMZ.
Conclusion: First results indicate that in Geant4 10.3.3, QGSP_BIC_EMZ reproduces measurements more accurately when compared to QGSP_BIC for treatments with pre-absorber, which comes at the cost of increased calculation time. As such, MC simulations are a promising tool to reduce the amount of physical measurements for proton therapy, but it is crucial to carefully choose the underlying settings, as for example differences in electro-magnetic models included in pre-built Geant4 physics lists affect the scattering of clinical proton beams and lead to differences in simulated doses. This work forms the first part of a multi-institutional study which aims to establish recommendations for MC settings for proton therapy.

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