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Dosimetric investigations and software tools for robust radiotherapy with heavy charged particles

In radiation therapy of tumors, the advantage in precision afforded by the use of scanned beams of protons and carbon ions may be severely reduced by uncertainties between planned and delivered treatment, like setup errors, introducing particle range variations, and organ motion, causing interplay effects. This dissertation presents novel computational tools and dosimetric investigations, aiming at quantifying and counteracting these phenomena.

First of all two research-enabling developments for particle therapy are presented: a programmable distributed treatment plan evaluation program and a time-resolved RBE-aware dose computation method. Along with their design and software implementation, this dissertation presents a demonstration of the former in evaluating large amounts of dose distributions and the full commissioning of the latter, using phantom and patient data.

With the help of these two programs, original indication-specific dosimetric robustness studies are conducted, using a systematic approach and clinically realistic assumptions, and presented in this dissertation. In the skull base region the effects of setup errors are comprehensively investigated for proton and carbon ion treatments, assessing the influence of plan modulation, particle species and beam setup. Instead, for therapy of prostate tumors with carbon ions, this dissertation investigates interplay effects caused by irregular target motion, recorded through implanted radiofrequency markers, and assesses potential countermeasures at planning and delivery time. Additionally, the effects of interfraction motion are investigated, along with the feasibility of target-based repositioning for scanned beams.

Finally, based on the collected indication-specific data, this dissertation proposes new potential clinical countermeasures. A beam angle optimization software is developed and commissioned against extensive skull-base dose computations and an offline adaptive therapy platform, based on the software developed at the beginning of this dissertation, is discussed using the example of prostate cancer therapy.