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Detection of patient anatomical changes during carbon-ion radiotherapy using secondary ion tracking

Introduction: Carbon-ion radiation therapy offers several advantages to treat deep-seated tumors compared to other radiation therapy with photons or protons. The focused depth dose deposition of carbon ions allows to cover with high doses the full tumor volume while minimizing the dose deposited in surrounding healthy tissues. However, this also leads to a higher sensitivity to anatomical changes during the treatment delivery. This can then lead to an overdosage in the healthy region or underdosage in the tumor region and impair the treatment outcome. It is, thus, of great importance to monitor these anatomical changes during and between patient irradiations.

Aim: In our research we develop and investigate a non-invasive carbon-ion treatment monitoring method based on secondary-ion detection. Secondary ions are nuclear fragments from the interactions of the therapeutic carbon ions with the patient nuclei and can emerge from the treated patient as a by-product of the treatment. Our research focuses on exploiting measured secondary ion tracks around the patient for a non-invasive monitoring of the radiation field in the patient and the anatomical changes influencing it. In this contribution, we present the capability of the method to detect and localize a 2-mm-thick air cavity, which might appear within patients during their treatment.

Methods: A typical clinical carbon-ion irradiation of a head tumor was performed on a head model (PMMA cylinder) at the Heidelberg Ion-Beam Therapy Centre (HIT), Germany. The emerging nuclear fragments were measured by a mini-tracker composed of a two small 1.4 x 1.4 cm² pixelated 300-µm-thick silicon semiconductor detectors Timepix3 (AdvapPIX TPX3), developed at CERN and commercialized by ADVACAM s.r.o. (Prague). They offered data-driven, dead-time free, and simultaneous per-pixel information of fragment's ToA, deposited energy and impact position. Measured secondary ion tracks were analyzed and their origin distribution along the beam axis was compared for different internal geometries of the head model (with or without 2-mm-thick air cavity). The precision of the localization of this cavity along the beam axis was studied for different positions of the mini-tracker (at 10°, 20°, 30°, 40°, 50°) and different position of the cavity.

Results: The measured fragments carry information about geometrical changes in the head model (cf Figure.1). In particular, the presence of the 2-mm-thick air cavity can be detected, and even located. In this contribution, we will present in detail how the performance of the method changes with changing the mini-tracker position.

Conclusion: Overall, this work shows that the developed carbon-ion beam monitoring method based on secondary-ion detection with small Timepix3 detectors placed around an irradiated head model allows the detection of even minor anatomical changes within a patient head model.

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