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Quantitative helium-beam radiograph of a head and neck model and comparison to X-ray CT projections

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Introduction: Cancer treatment with ion-beams is a highly promising radiotherapeutic technique. Compared to the conventionally used photon irradiation, ion beams offer an advantage of concentrating the radiation dose to the tumor and sparing the surrounding healthy tissue. However, in order to use the full potential of ions, an accurate knowledge about the depth at which the ions stop in the tissue is crucial. With ion beam radiography the stopping position could potentially be verified on a daily basis before each irradiation. In this way, possible errors can be detected and thus uncertainties of the dose deposition in the patient minimized. This contribution presents the potential of such method. A quantitative helium-beam radiograph (αRad) of an anthropomorphic head phantom is compared to the standard method.

Materials and Methods: Experiments were conducted at the Heidelberg Ion-beam therapy center (HIT) using helium-ion beams with energies of up to 197.01 MeV/u. A dedicated detection system was built in-house employing six Timepix detectors. The detectors, which utilize the Timepix chip developed at CERN, were purchased from ADVACAM s.r.o., Prague, Czech Republic. They have a sensitive silicon layer of 300μm, a pixel pitch of 55μm and can detect single ions with an efficiency of nearly 100%.
Two detectors each are used as front and rear trackers to measure the position and direction of ions entering and exiting the imaged object. With this information, the most likely path of each single ion can later be estimated using the Cubic Spline algorithm to improve the spatial resolution.
The remaining two detectors are used to measure the energy deposition of each single ion and to identify the corresponding information on the trackers via a coincidence window of 200ns. The energy deposition can then be connected to the water-equivalent-thickness (WET) of the object via recently established calibration curves.
In this way, a quantitative helium-beam radiograph of an anthropomorphic phantom (CIRS 731-HN) was acquired. To assess its accuracy concerning WET-prediction, it was compared to the potential gold standard of WET prediction, namely dual-energy X-ray CT (DECT). As this method is currently not yet used in many facilities, also the clinical standard, single-energy X-ray CT (SECT), was compared to the DECT. In this way, the performance of the presented imager can be put into perspective with the clinically used system.

Results: A 48x24 mm^2 region of the projection of a single-energy X-ray CT and a helium-beam radiograph were compared to the corresponding region of a dual-energy X-ray CT. The WET prediction of both helium-beam radiograph and SECT deviates from the one of DECT by (0.971 ± 0.016) % and (0.650 ± 0.011) %, respectively. The deviation was calculated in terms of mean absolute percentage difference.

Conclusion: The helium-beam radiograph of the anthropomorphic head phantom performs similarly well as the projection of the SECT, which is commonly used for ion range prediction in clinics. Therefore, we conclude that helium-beam radiography can compete with the SECT concerning WET accuracy. The presented new imaging modality based on very light and handy detectors is a promising tool to verify the range of ions in radiotherapy treatments on a daily basis, which could lead to less damage of healthy tissue during an ion radiotherapy treatment.

Primary author: METZNER, Margareta (German Cancer Research Centre)

Co-authors: Mr KEHREIN, Florian (German Cancer Research Centre); Ms KNOBLOCH, Catherine (German Cancer Research Centre); Mr RAZA, Mohsin (German Cancer Research Centre); Dr ACKERMANN, Benjamin (Heidelberg Ion-Beam Therapy Center); Dr BRONS, Stephan (Heidelberg Ion-Beam Therapy Center); Mr MATOUŠ, Michal (ADVACAM s.r.o); JAEKEL, Oliver (German Cancer Research Centre DKFZ); MARTISIKOVA, Maria (German Cancer Research Center); GEHRKE, Tim (Heidelberg University Hospital / German Cancer Research Center)

Presenter: METZNER, Margareta (German Cancer Research Centre)

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