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Helium-beam radiography (αRAD) in ion-beam therapy

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Ion-beam therapy has the great potential to improve cancer treatments compared to the standard radiotherapy based on photons. This is due to the fact that ion beams can provide dose distributions that are strongly focused on the tumor volume.
However, in clinical practice this potential is often not fully exploited, because the highly-focused dose distribution has an increased sensitive to uncertainties. Uncertainties during the treatment delivery are often related to anatomical changes (like tumor regression or cavity fillings), the procedure of patient positioning or the determination of the tissues'composition, which is currently based on X-ray CT imaging and is essential for calculating where the ion beams will stop.

In this context, we consider ion-beam imaging a very promising novel imaging modality, since it could address all the named sources of uncertainties at the same time.
Over the last years we developed in our group a novel and very compact detection system for ion-beam radiography that is exclusively built from six thin silicon pixel detectors (thickness < 0.5 mm) using the Timepix technology for detector readout. As imaging radiation, helium ion beams with an initial energy that is high enough to traverse the object to be imaged were chosen, since they were shown to improve the radiographs' spatial resolution while preserving the dose efficiency at an equal noise level compared to protons.

In this contribution, the latest results of our quantitative method for helium-beam radiography that was used to image complex objects that mimic the human anatomy will be presented.
In the context of the first important application, namely the verification of the determination of the tissues' composition, deviations of the integrated stopping power along the beam direction (referred to as water-equivalent thickness, WET) were compared to the current gold standard of stopping-power determination based on X-ray dual-energy CT. The deviations were found to be below 1 %, which represents a distinctive improvement compared to X-ray single-energy CT that are expected to have uncertainties between 2.3 –2.6 %. These results of the comparison between helium-beam radiography and a projection of dual-energy CT as gold standard are shown in figure 1.
In context of a second application, the feasibility of patient positioning using small (36 mm x 36 mm), low-dose (down to 23 µGy) helium-beam radiographs was investigated. The results show the helium-beam radiographs of suitable anatomical regions including bones enable patient positioning with respect to 5 degrees of freedom (2 translations & 3 rotations) with submillimeter/subdegree accuracy.

Given these promising results, next steps towards an envisaged clinical application are outlined.

Figure 1: Comparison of images showing a part of an anthropomorphic head phantom that were obtained by the novel approach of helium-beam radiography or by dual-energy CT.

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