High-resolution particle tracker for in-vivo FLASH radiotherapy monitoring

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Background

Precise spatial dose delivery to the tumor, resulting in the sparing of surrounding healthy tissue, is a key parameter for successful radiotherapeutic treatment. During treatment, and especially between individual fractions, tissue shifts, and various deformations can occur, which may ultimately lead to the irradiation of healthy tissue within the patient body. To prevent this, it is necessary to monitor the beam online. This approach applies both to FLASH therapy and conventional radiotherapy using charged particle beams. For the purposes of carbon ion therapy, we have developed a special monitoring unit.

Methods

The novel high-resolution particle tracking detector system consists of 28 hybrid semiconductor Timepix3 pixel detectors organized into seven units (Figure 1a). Each unit consists of two layers (telescope) of two Timepix3 chips with single monolithic silicon sensor (Figure 1a). All units are synchronized with nanosecond precision. Clinical test are being finalized in DFKZ Heidelberg.

The detection system (Figure 1b) tracks charged nuclear fragments produced by interactions of the carbon ions with nuclei of the patient's body (Figure 1c). The imaged tracks allow for the reconstruction of fragments'origins, enabling comparisons between different treatment fractions. This comparison can reveal, interfractional changes in the patient's morphology or positioning.

Results

This system is effectively utilized for beam control in carbon ion therapy. By precisely identifying particle tracks with < 55 µm resolution can accurately calculate and determine the interaction location with high accuracy. Tests of a similar approach were conducted under FLASH therapy conditions, where we measured secondary radiation. We demonstrated that the detectors provide data from which, for example, the time structure of the beam can be derived. The same principle and methods can be applied in conditions of FLASH therapy.

Conclusions

This work presents the detector design and its performance testing, demonstrates the feasibility and explores the potential application of this concept for FLASH therapy.

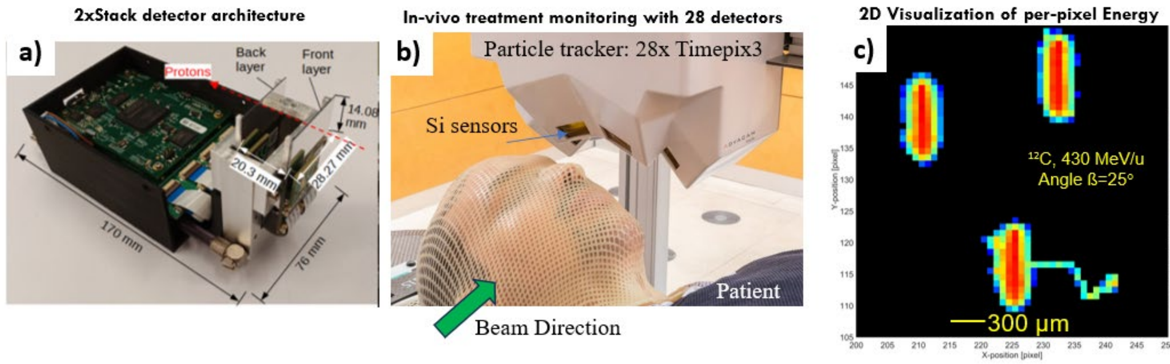

Fig. 1. a) Detection module with two synchronized Timepix3 detectors. b) Particle tracker for carbon ion therapy at the Heidelberg Ion Beam Therapy Center (HIT). c) Visualization of energy deposition by carbon particles in a Timepix3 chip.

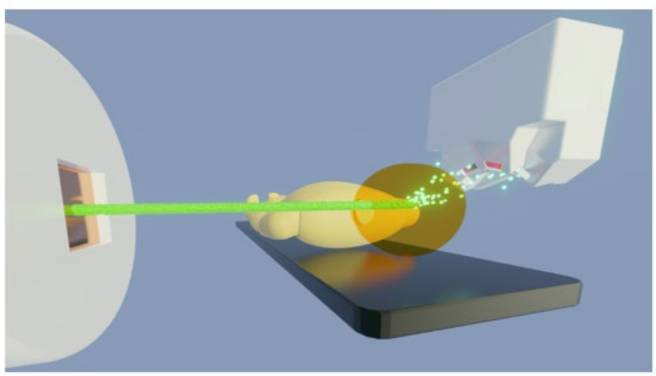

Fig.2. Illustration of carbon beam radiotherapy and its monitoring by tracking of the secondary particles generated by collisions of primary carbon ions with patient's body