The use of computed tomography images in Monte Carlo treatment planning

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Monte Carlo (MC) dose calculations cannot accurately assess the dose delivered to the patient during radiotherapy unless the patient anatomy is well known. This thesis focuses on the conversion of patient computed tomography (CT) images into MC geometry files.

Metal streaking artifacts and their effect on MC dose calculations are first studied. A correction algorithm is applied to artifact-corrupted images and dose errors due to density and tissue mis-assignment are quantified in a phantom and a patient study. The correction algorithm and MC dose calculations for various treatment beams are also investigated using phantoms with real hip prostheses. As a result of this study, we suggest that a metal artifact correction algorithm should be a part of any MC treatment planning. By means of MC simulations, scatter is proven to be a major cause of metal artifacts.

The use of dual-energy CT (DECT) for a novel tissue segmentation scheme is thoroughly investigated. First, MC simulations are used to determine the optimal beam filtration for an accurate DECT material extraction. DECT is then tested on a CT scanner with a phantom and a good agreement in the extraction of two material properties, the relative electron density ρ_e and the effective atomic number Z is found. Compared to the conventional tissue segmentation based on ρ_e-differences, the novel tissue segmentation scheme uses differences in both ρ_e and Z. The phantom study demonstrates that the novel method based on ρ_e and Z information works well and makes MC dose calculations more accurate.

This thesis demonstrates that DECT suppresses streaking artifacts from brachytherapy seeds. Brachytherapy MC dose calculations using single-energy CT images with artifacts and DECT images with suppressed artifacts are performed and the effect of artifact reduction is investigated. The patient and canine DECT studies also show that image noise and ob ject motion are very important factors in DECT. A solution for reduction of motion in DECT is proposed.

In conclusion, this thesis strengthens the link between CT and MC dose calculations by means of artifact reduction and DECT tissue segmentation.

Key words: computed tomography, Monte Carlo, dose calculations, treatment planning, tissue segmentation

The following publications are included in the thesis:

1. M. Bazalova, L. Beaulieu, S. Palefsky, and F. Verhaegen. Correction of CT artifacts and its influence on Monte Carlo dose calculations. *Med. Phys.* **34**:2119–2132, 2007.
2. M. Bazalova, C. Coolens, F. Cury, P. Childs, L. Beaulieu and F. Verhaegen. MonteCarlo dose calculations for phantoms with hip prostheses. *J. Phys.: Conf. Ser.* **102**: 012001, 2008
3. M. Bazalova and F. Verhaegen. Monte Carlo simulation of a computed tomography x-ray tube. *Phys. Med. Biol.* **52**: 5945–5955, 2007.
4. M. Bazalova, J.F. Carrier, L. Beaulieu, and F. Verhaegen. Tissue segmentation in Monte Carlo treatment planning: A simulation study using dual-energy CT images. *Radioth. Oncol.* **86**: 93–98, 2008.
5. M. Bazalova, J.-F. Carrier, L. Beaulieu and F. Verhaegen. Dual-energy CT-based material extraction for tissue segmentation in Monte Carlo dose calculations. *Phys. Med. Biol.* **53**: 2439–2456, 2008.