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Dual energy CT imaging for preclinical and clinical radiotherapy

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Valorisation addendum

In this thesis, the use of preclinical and clinical dual energy CT (DECT) imaging is investigated in the context of tissue segmentation for radiation dose calculations in the field of radiotherapy. It is shown that DECT imaging is a useful tool for analyzing tissues and that DECT tissue segmentation can increase the accuracy of radiation dose calculations. This chapter discusses the clinical relevance of these findings and contains an implementation overview.

Clinical relevance

In the Netherlands, more than 100 thousand patients are diagnosed with cancer each year. [1] About 32% of these patients receive radiotherapy as (a part of) the primary treatment. [2] Like any other treatment, radiotherapy can cause side effects. General radiotherapy side effects are local skin problems, fatigue and secondary cancer development. In addition to these general side effects, irradiation of specific treatment sites can cause a number of other side effects. [3] Irradiation of the head and/or neck can cause a dry mouth, mouth and gum sores, difficulty swallowing, stiffness in the jaw, nausea, hair loss, lymphedema and tooth decay. Side effects of irradiating the chest are difficulty swallowing, shortness of breath, breast or nipple soreness, shoulder stiffness, pneumonitis and fibrosis. Irradiation of the stomach and/or abdomen can cause nausea, vomiting and diarrhea. Side effects of irradiating the pelvis are diarrhea, rectal bleeding, incontinence, bladder irritation, sexual problems and infertility. It is important to reduce these side effects to improve the quality of life after radiotherapy. A more precise irradiation can reduce radiotherapy side effects by sparing the healthy tissues surrounding the tumor. Improving the accuracy of radiation dose calculations is a crucial step in this process.

The patients that would benefit most from DECT tissue segmentation are the brachytherapy and proton therapy patients. Patients that are treated with megavoltage photon beams would benefit only slightly from DECT tissue segmentation due to the fact that the difference in energy deposition for tissues in megavoltage beams is negligible. Patients also benefit indirectly from preclinical DECT tissue segmentation since more precise preclinical irradiations can improve the quality of preclinical studies.

Implementation overview

As discussed in this thesis, both preclinical and clinical radiotherapy can benefit from DECT tissue segmentation. Unfortunately, the current (pre)clinical treatment planning systems are not (yet) able to handle DECT images. A number of steps are required to use DECT images for tissue segmentation in the (pre)clinical radiotherapy workflow. Each step requires thorough testing and periodical quality assurance.

Step 1: Image registration of the low and high energy CT images

This step is only relevant for the dual-spiral DECT modality in which motion between the two acquisitions could cause a misregistration of the low and high energy CT images. The open source software Elastix/Transformix was used in this thesis to perform the image registration. [4]

Step 2: Convert low and high energy CT numbers to Z_{eff} and ρ_e

In this thesis, an in-house developed MATLAB toolbox that applies the Landry et al and Saito methods was used to calculate Z_{eff} and ρ_e, respectively. [5,6] These methods require a separate calibration scan of a phantom with known elemental compositions and densities. The phantom should be scanned using the same (pre)clinical imaging protocols and should have the same size as the patient or specimen.

Preferably, steps 1 and 2 would be modules that are integrated into either the (CB) CT scanner software or the (pre)clinical treatment planning system.

Step 3: Choose reference materials and perform tissue segmentation

The tissue segmentation is performed by calculating the distances between a voxel value and a number of reference tissues (i.e. materials) and subsequently assigning the elemental composition of the closest reference tissue to that voxel. In the case of DECT tissue segmentation, this distance is the Mahalanobis distance in the (ρ_e,Z_{eff}) space. An in-house developed MATLAB toolbox was used in this thesis to perform the DECT tissue segmentation. Alternatively, it is possible to extract elemental tissue compositions from DECT images using the Hünemohr et al method. [7] However, this method introduces a large amount of noise and is in practice only suitable for calculating means and standard deviations for larger regions, such as an organ.

Step 4: Perform dose calculations and optimize treatment plan

The dose calculation engine should be able to handle voxels with different elemental compositions. The Monte Carlo method is intrinsically capable of doing this. However, most superposition-convolution methods are not (or have limited capabilities). The radiotherapy treatment plan optimization requires no specific changes.

Preferably, steps 3 and 4 would be modules that are integrated into the (pre) clinical treatment planning system.

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