Abstract

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Split-filter dual-energy CT: investigation of tumor visibility, spectral separation, and dose allocation

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Split-filter dual-energy computed tomography (DECT) has recently been implemented for clinical use as an added feature to the Siemens SOMATOM Definition Edge CT scanner. This split-filter technique is referred to as TwinBeam (Siemens Healthcare, Forchheim, Germany). TwinBeam is a novel modality performed with an x-ray source operated at 120 kVp and a removable split-filter made of adjacent 0.05 mm of gold and 0.6 mm of tin. This dissertation explores the use of TwinBeam for imaging pancreas and liver tumors for radiation therapy applications. This dissertation also compares the new split-filter system to other DECT modalities based on spectral separation and dose allocation.

Accurate tumor delineation is crucial for stereotactic body radiation therapy. Unfortunately, tumor delineation using conventional single-energy CT (SECT) images can be a challenge for pancreatic adenocarcinomas and liver tumors where contrast between the tumor and surrounding healthy tissue is low. The first part of this work investigates the utility of TwinBeam to improve pancreas and liver tumor visibility as quantified by contrast and contrast-to-noise-ratio (CNR) for radiation therapy applications. The visibility of pancreatic adenocarcinomas was found to substantially increase with TwinBeam virtual monoenergetic images (VMIs), while the increase in visibility of liver tumors was not universal but was observed for certain patients. The investigation of other dual-energy images, including relative electron density and effective atomic number images, were also explored for tumor delineation. The difference between tumor and healthy tissue based on these images varied by tumor location but still provided additional information to complement VMIs and aid in tumor delineation.

The accuracy of TwinBeam iodine-enhanced images was investigated and used to quantify the iodine concentration within pancreas and liver tumors and surrounding healthy tissue during bi-phasic imaging for radiation therapy simulation. The accuracy was found to be dependent on patient size; therefore, a methodology to determine the iodine concentration within 3D contours from patient datasets was established. First order

texture analysis was also performed using TwinBeam VMIs and analyzed as a function of reconstruction energy. Mean CT number and standard deviation increased with decreasing energy for virtual monoenergetic images (VMIs), while skewness and kurtosis were seen to be stable and did not change as a function of reconstructed energy.

A subjective contouring study with split-filter DECT images was performed to investigate the current implementation of TwinBeam for delineating pancreas and liver tumors for radiation therapy applications. Three contouring sessions were conducted several days apart. Four clinicians were asked to contour the pancreas or liver gross target volume (GTV) on one of three different TwinBeam DECT images (VMI, iodine-enhanced, or virtual SECT image). Tumor conspicuity, tumor edge sharpness, contouring confidence, and image quality were also scored on a five-point scale. The GTVs were compared using Jaccard coefficient (JC), Dice similarity coefficient (DSC), Hausdorff distance (HD), and overall volume. Tumor edge sharpness score negatively correlated with HD for both the pancreas and liver cases. The intra-clinician and inter-clinician variability were analyzed across the different image types. For some pancreas and liver cases, the TwinBeam VMIs decreased the variability of the GTVs compared to the virtual SECT image.

Monte Carlo models of split-filter DECT with peak tube voltages of 120 kVp and 140 kVp were developed based on measurement of half value layer and beam profile from the Siemens SOMATOM Definition Edge scanner. These two models were used to characterize split-filter DECT based on spectral separation and dose allocation and to investigate the potential benefits of increased tube voltage. Overall, the spectral separation increased with peak tube voltage, and dose allocation was unchanged with increased tube voltage for larger phantom sizes. The impact of the spectral differences caused by the split-filter on CT dosimetry was also investigated; the energy dependence across the beam was found to vary with ionization chambers used for CT dosimetry.