Assessing Photon Treatment Planning Using Relative Electron Density Map with Dual-Energy CT

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ABSTRACT

To evaluate the feasibility of integrating dual-energy computed tomography (DECT) into the radiation oncology workflow for photon therapy, with the goal of reducing reliance on separate non-contrast and contrast-enhanced scans while maintaining accurate dose calculation and high-quality target delineation.

Pseudo–monoenergetic images were generated from both non-contrast and contrast-enhanced datasets across a range of energy levels. Relative electron density (RED) maps were derived from DECT and used for dose recalculation. Dosimetric differences between plans calculated on planning CT and RED maps were assessed without re-optimization.

RED maps derived from DECT are largely insensitive to the presence of contrast agents, allowing accurate dose calculation without the need for separate non-contrast scans. These findings support the feasibility of a streamlined DECT-based workflow in radiation oncology, providing multiple images from one contrast-enhanced scan fulfilling both contouring and planning purposes, with reduced imaging dose and simplified clinical processes.

INTRODUCTION

Compared to non-contrast CT scans, contrast-enhanced images have better image contrast for target and OAR delineation purposes. Since no contrast agent is present during patient treatments, the high CT numbers in the CT images obtained from SECT can misrepresent the material information, like RED, resulting in less optimal treatment plans. Therefore, both CT scans with and without contrast agent are necessary, which exposes patients to doubled imaging dose and extended time for image acquisition. With dual-energy CT (DECT), the RED map can be derived from low- and high-voltage images.

Our study compared the dose forward calculated on the RED maps to the original plan on the pseudo mono-energetic images in TPS. The results showed similar target coverages and OAR sparing. Multiple sets of pseudo mono-energetic images can be derived from the DECT scans, among which our physicians preferred the mid to high keV images for contouring purposes.

METHODS AND MATERIALS

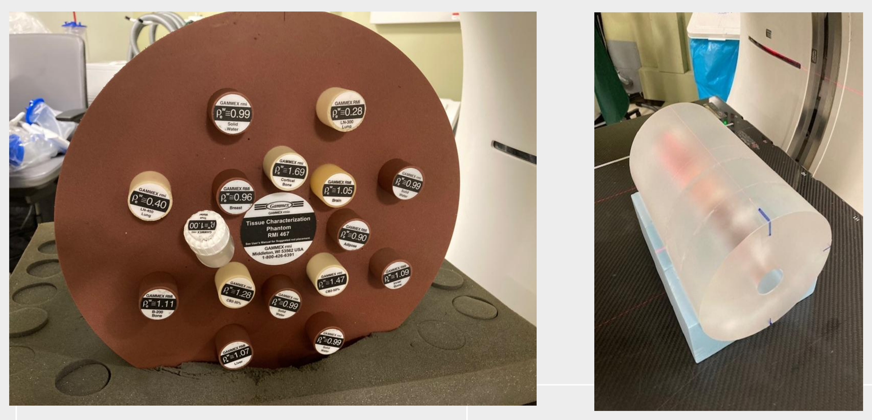
RED was derived from 90/Sn150kVp DECT obtained with a dual-source CT system and dose-neutral scan protocol compared with SECT. DECT capabilities were first evaluated in a tissue-mimicking phantom covering the clinically relevant RED range, using contrast-enhanced and non-contrast scans.

The clinical treatment plan was optimized on the pseudo mono-energetic images from the non-contrast DECT scan and forward calculated on the RED maps from both non-contrast and contrast-enhanced DECT scans. Five sets of pseudo mono-energetic images were derived from the contrast-enhanced DECT scans, among which physician review and selection of preferred scan was made for contouring purposes.

Image quality was evaluated with signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNSR), which defined as below:

$$SNR = \frac{HU_{median}(target)}{\sigma(HU)_{brain-PTV}} \quad (1)$$

$$CNR = \frac{HU_{median}(target) - HU_{median}(brain - PTV)}{\sigma(HU)_{brain-PTV}} \quad (2)$$

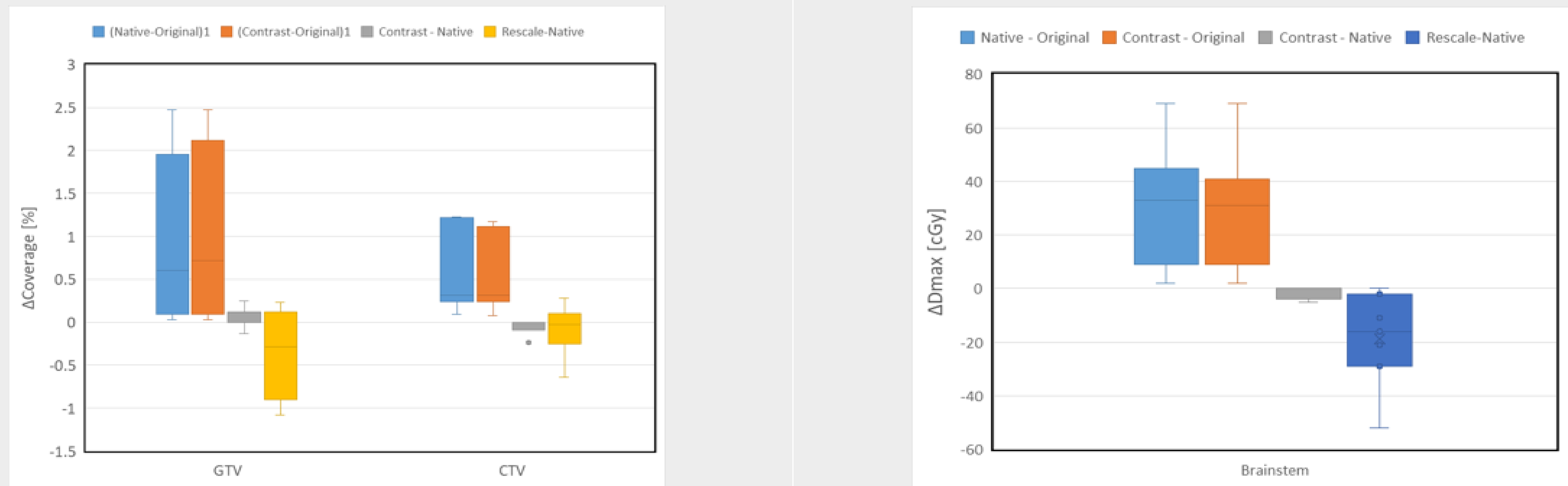


(a) (b)

Figure 1. The Gammex surrogates for DECT scan acquisition: (a) the Gammex phantom; (b) in-house made acrylic phantom.

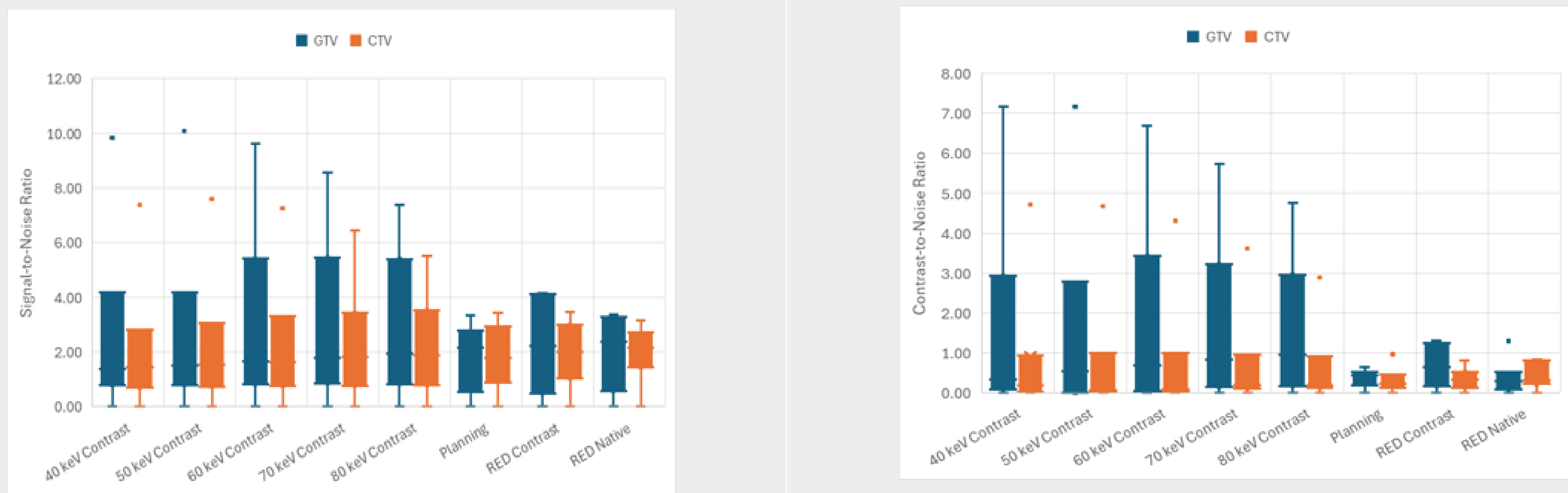
RESULTS

Good agreement was observed in the dose calculated on the RED maps of the patient scans compared to that of the original planning images. The mean change in target volume coverages is <2% in GTV, <1% in CTV, and mean change is <40 cGy in maximum dose to brainstem. Moderate to high keV images (60 and 70 keV) were chosen for contouring, which provided better signal-to-noise and contrast-to-noise ratios.



(a) (b)

Figure 2. The plan comparison between the original plan and the forward calculated on RED maps from both the non-contrast and contrast-enhanced DECT scans. The changes in the target coverage (GTV and CTV) are shown in (a) and the changes in maximum dose to the brainstem in (b).



(a) (b)

Figure 3. The signal-to-noise ratio (SNR) shown in (a) and contrast-to-noise ratio (CNR) shown in (b) are calculated on different sets of images derived from the DECT scans. The targets (GTV/CTV) are the signals and the brain minus PTV are the background.

DISCUSSION

The native CT images of the patients are acquired and reconstructed as the 3D volumetric model based on which the treatment plans are created and optimized for the treatments. The CT images acquired at the DECT can generate pseudo mono-energetic images which are imported to the TPS for planning purposes.
In contrast to the single image set available at the SECT scanner, multiple pseudo-energetic image sets can be reconstructed from one DECT scan.

In our study, we noticed that the RED maps derived from the DECT scans are less sensitive to the visual impact of the contrast agent compared to other image series from DECT and SECT. This was observed between the RED maps from the native and contrast-enhanced scans. And its influence on the dose deposition is insignificant and negligible in the TPS as shown in our planning studies.

CONCLUSIONS

Contrast-enhanced DECT scans can provide RED maps close to the ground truth derived from non-contrast DECT scans. Our studies showed that the dose forward-calculated on the RED maps from the DECT scan agreed well with the planning images. RED maps derived from DECT are minimally affected by the presence of contrast agents, enabling accurate dose calculation without requiring separate non-contrast acquisitions. In addition, the image sets derived from the contrast-enhanced DECT scans provide flexibility in optimizing image quality for contouring via the pseudo-monoenergetic keV selection.

Overall, DECT has the potential to replace the conventional dual-scan approach with a single acquisition, thereby reducing imaging dose, minimizing registration uncertainties, and streamlining the clinical workflow.

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