Simultaneous image reconstruction and material decomposition using multi-energy cone beam CT on a preclinical irradiation

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JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

Accurate treatment planning in radiotherapy usually requires structural and materials composition of the subject. In preclinical studies, modern small animal irradiation platforms are equipped with cone beam CT (CBCT) to provide 3D images for image-guided irradiation. In this work, we implemented a simultaneous image reconstruction and material decomposition algorithm on multi-energy (ME) CBCT from multiple scans on a preclinical CBCT platform to derive voxel density and material composition images for dose calculation and other advanced applications.

METHOD

- Multiple scans of X-ray CBCT projection images were acquired with 50, 60 and 70 kVp on a Precision Smart platform. The flat panel detector has the pixel pitch of 0.2 mm and matrix size of 1024 ×1024. The system has the SAD=30.49 cm and SDD=62 cm.
- Phantoms: a microCT calibration phantom and a cadaver mouse
- The simultaneous image reconstruction and material decomposition algorithm solved an optimization problem to determine x-ray attenuation coefficients in each kVp, electron density relative to water (rED), and elemental composition (EC). The objective function contained a tight-frame regularization term for image quality, a data fidelity term to ensure consistency between the attenuation coefficients and the projection images, and a self-consistency term to ensure agreement between attenuation coefficients, and rED and EC. The EC was further subject to the constraint of a sparse representation of the material's ECs in a dictionary. The optimization problem was solved by an alternating-direction minimization scheme.

$$\min_{x,\rho,\alpha} \frac{1}{2}\sum_i \|P_i x_i - b_i\|_2^2 + \lambda\|Wx\|_1 + \frac{\beta}{2}\|x - \rho\cdot(\alpha\Omega K + K_3)\|_F^2, \; s.t. \; \|\alpha_i\|_0 < s, \alpha_{i,j} \geq 0, \sum_j (\alpha\Omega)_{i,j} = 1.$$

RESULTS

- Projections images and sinograms of the microCT calibration phantom and the mouse are shown in Fig. 1.
- The reconstructed x-ray images and decomposition images of the microCT calibration phantom is presented in Fig. 2.
- In the microCT calibration phantom, the mean relative error of rED and EC were 2.19% and 4.40% comparing to the ground truth values, respectively.
- More specific, the average decomposition errors of H, O, Ca elements were 5.31%, 6.61%, and 1.30%, respectively.
- Quantitatively, compared to the ground truth values of the microCT calibration phantom, the mean decomposition error for each inset material is plotted in Fig. 3.
- The algorithm is able to provide rED and EC images for the cadaver mouse case. The decomposition results are shown in Fig. 4.

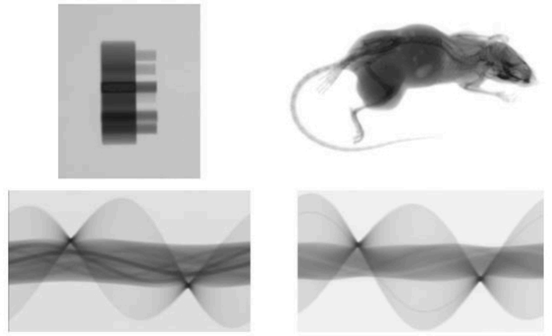

Fig. 1. The projection image and the sinogram of the microCT calibration phantom (left) and a cadaver mouse (right) acquired at 50 kVp.

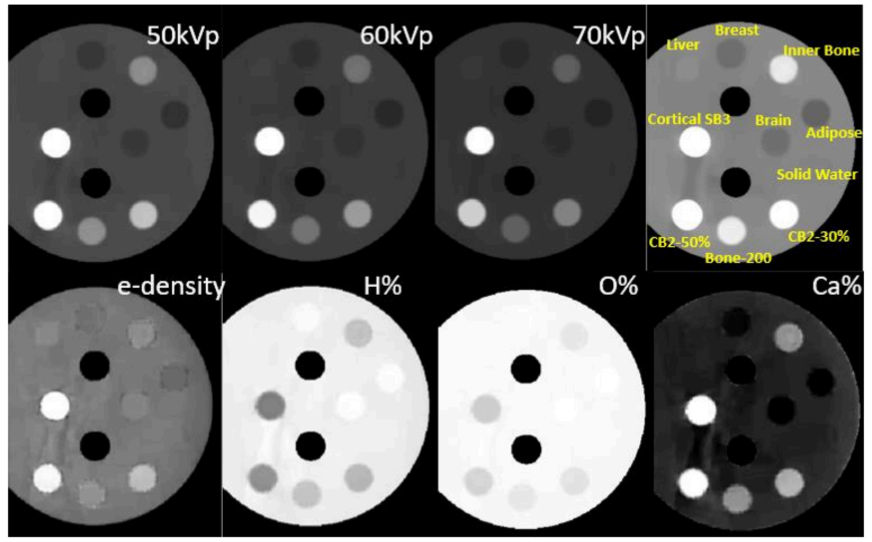

Fig. 2. Reconstruction (top) and decomposition images (bottom) of the microCT calibration phantom. The results serve as the library for materials in the preclinical applications.

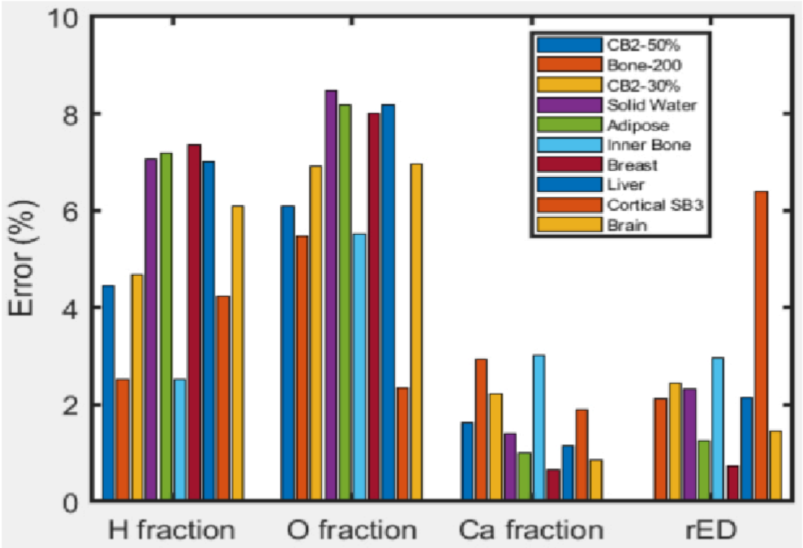

Fig. 3 Mean decomposition error for each insert in the microCT calibration phantom

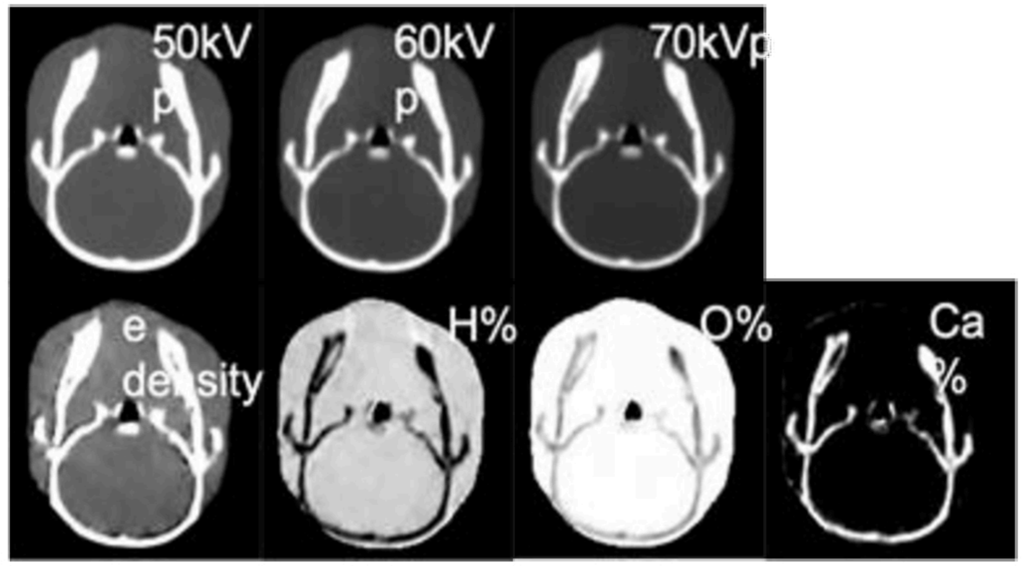

Fig.4 Reconstructed mouse images at different kVps and the materials decomposition map of electron density, hydrogen, oxygen and calcium.

CONCLUSIONS

- The implemented simultaneous image reconstruction and material decomposition algorithm on MECBCT is able to provide structure, materials composition and electron density relative to water with satisfactory accuracy on the preclinical imaging system.
- These information can be used for dose calculation and other applications in pre-clinical radiation experiments.

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ACKNOWLEDGEMENTS

This work is supported in part by grants from the National Institutes of Health (R37CA214639) and from the Core Facility Award (RP180770) from the Cancer Prevention Research Institute of Texas.

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