Dual-contrast Imaging of Gadolinium and Iodine using K-edge Imaging in PCCT

Martin V. Rybertt[1,2], Katie E. Villaseñor[1,2], Leening P. Liu[1], Pooyan Sahbaee[3], Harold I. Litt[1]
Manoj Mathew[1], David P. Cormode[1], Ali H. Dhanaliwala[1], Peter B. Noël[1]

[1]Department of Radiology, University of Pennsylvania, Philadelphia, PA, USA
[2]Department of Bioengineering, University of Pennsylvania, Philadelphia, PA, USA
[3]Siemens Healthineers, Malvern, PA, USA

Hypothesis: Photon-counting CT (PCCT) enables advanced spectral decomposition techniques such as K-edge imaging. This technique is named after the K-edge effect, a sharp increase in the attenuation profile of a high-Z material at a unique energy level. By leveraging K-edge imaging, PCCT enables dual-contrast imaging, wherein two contrast agents are administered concurrently to image multiple phases—such as the arterial and portal venous phases of the liver—during a single acquisition. This study demonstrates the feasibility of K-edge imaging with a clinical PCCT system.

Methods: To evaluate K-edge imaging of I and Gd, we prepared solutions that contained either I or Gd (pure solutions) and solutions where both materials were mixed (mixed solutions). Concentrations of pure solutions were 1, 2.5, 5, and 10 mg/mL for each material, while mixed solutions were prepared in ratios of 1:2.5, 2.5:1, 2.5:2.5, 2.5:5, 5:2.5, and 5:5 mg/mL of I to Gd. Solutions were scanned within a thoracic phantom using a PCCT scanner (NAEOTOM Alpha, Siemens Healthineers) at a tube voltage of 140 kVp, bin thresholds of 20, 55, 72, 90 keV, and dose levels of 1, 2, 4, and 8 mGy. Material decomposition was performed through a least squares estimation using expected values from a calibration as ground truth. Material-specific images were reconstructed for water, I, and Gd. Performance was assessed through a Bland-Altman analysis and contrast-to-noise ratio was measured to evaluate image quality.

Results: K-edge imaging of I and Gd exhibited accurate decomposition and quantification of I and Gd. Material-specific images showed adequate separation of I from Gd on mixes. Bland-Altman analysis shows similar accuracy between pure and mixed solutions, with bias of 0.74±0.47 and -0.08±0.2 mg/mL in pure solutions of I and Gd at 8 mGy, while bias in mixed solutions was 0.43±0.21 and -0.74±0.23 mg/mL. Pure solutions demonstrated higher image quality in comparison to mixed solutions.

Conclusions: We demonstrate feasibility of K-edge imaging of iodine and gadolinium on a clinically-approved PCCT system. Material-specific images show precise quantification of I and Gd as well as successful separation of I and Gd in mixed solutions, a key performance metric for potential dual-contrast imaging applications.

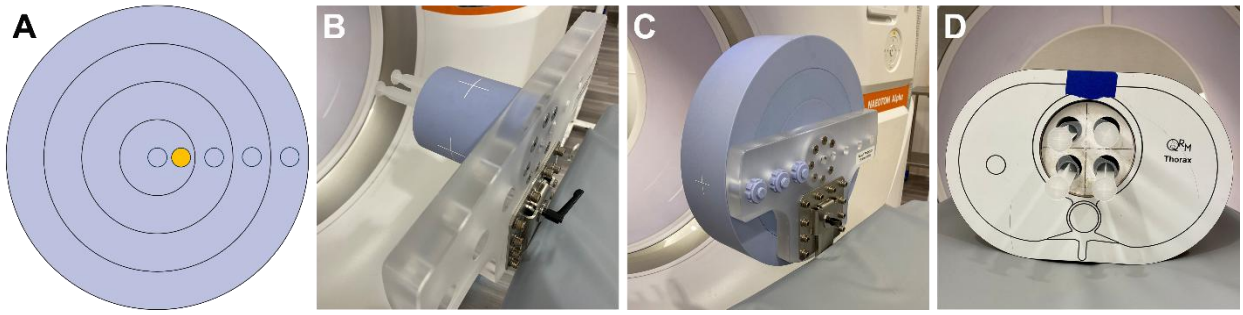

Figure 1. Calibration and experimental setup. A syringe filled with the calibration material (water, I, or Gd) was placed within the calibration phantom, all remaining holes were filled with water-mimicking inserts (A, B). Additional 10 cm extension rings (C) were added after completion of each set of calibration scans on a dual-source photon-counting CT. Syringes filled with contrast agent solutions were placed within a thoracic phantom (D) and scanned for evaluation of multi-material decomposition.

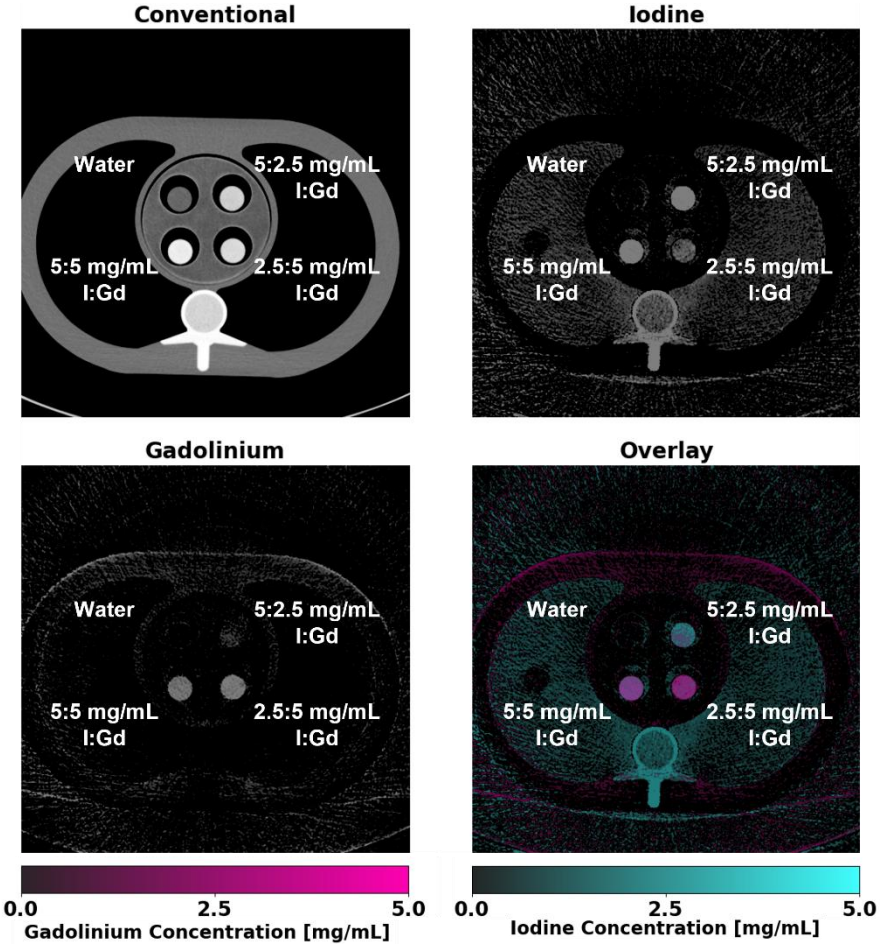

Figure 2. The figure displays four reconstructed axial images of a phantom containing varying concentrations of iodine (I) and gadolinium (Gd) mixtures: Conventional (top left), Iodine map (top right), Gadolinium map (bottom left), and Overlay (bottom right). The conventional image displays a standard grayscale CT attenuation image (WL/WW: 200/600 HU), illustrating the inability to separate the two contrast agents. The Iodine and Gadolinium maps (WL/WW: 2.5/5 mg/mL) illustrate successful material separation using K-edge imaging, represented by color intensity scales (cyan for iodine, magenta for gadolinium). The Overlay image highlights spatial distribution of both contrast agents, enabling enhanced visualization of co-localized and distinct regions of each contrast agent.