Enhanced K-Edge CT Using Dual-Filter Spectral Separation for High-Sensitivity Imaging of Bismuth

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2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

ABSTRACT

Purpose: Photon-counting CT (PCCT) k-edge imaging sensitivity for high-Z contrast agents is limited by **spectral overlap** between energy bins, reducing CNR for targeted pharmaceuticals at low concentrations. We present **enhanced k-edge CT (EKCT)**, a dual-filter method to boost bismuth sensitivity.

Methods: EKCT uses two 110 kVp spectra with heavy filtration: **low-energy** (0.89 mm Bi + 1 mm Cu) below the bismuth k-edge (90.5 keV), and **high-energy** (6 mm Cu) above it. CNR was compared between conventional single-spectrum k-edge CT (KCT) and EKCT for bismuth vs. iodine on a benchtop PCCT.

Results: EKCT reached **89–91% spectral purity** (vs. 72–75% for KCT), reducing spectral overlap to **<11%**. Bismuth EKCT achieved a contrast to noise ratio of **12.4 (188 HU)** for 0.1 mg/ml Bismuth, a **17-fold improvement** over iodine in energy integrating CT and 1.9 times higher signal than KCT.

Conclusion: EKCT combined with bismuth contrast enables high-sensitivity detection of low-concentration high-Z contrast agents through physical spectral separation.

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INTRODUCTION

Conventional CT contrast sensitivity is limited to roughly **~1%** bismuth by volume, while many high-Z targeted therapeutics accumulate at concentrations of **≤0.1%** or lower, below the detection floor of standard CT.

This work extends our high-Z imaging capability with an optimized dual-filter benchtop implementation, benchmarking EKCT directly against conventional **iodine** contrast and validating contrast specificity on a marine snail shell.

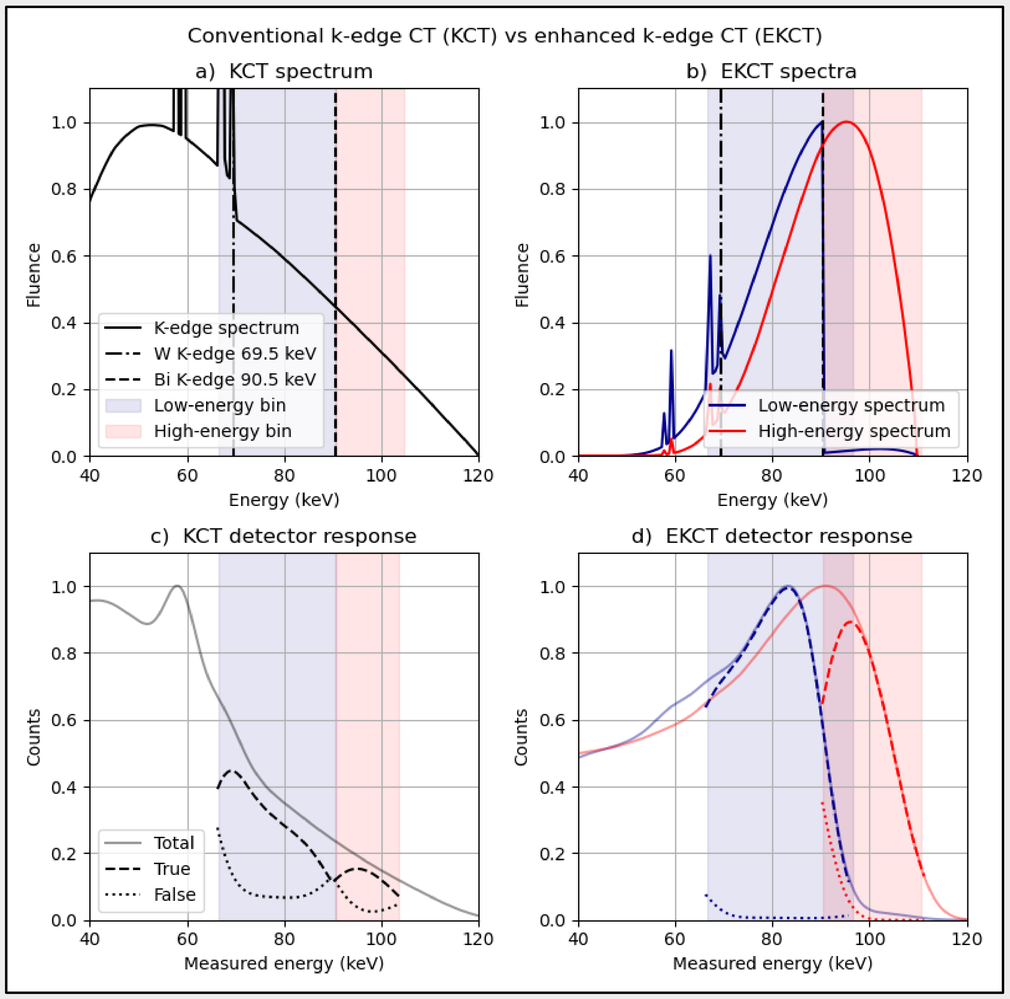

Figure 1. Spectral optimization & detector response: KCT vs. EKCT.

MATERIALS AND METHODS

EKCT was performed on a benchtop CZT photon-counting detector with programmable energy bins. Two 110 kVp spectra were used: **low-energy** (0.89 mm Bi + 1 mm Cu) below the bismuth k-edge (90.5 keV), and **high-energy** (6 mm Cu), optimized for above-k-edge detection (Figure 1).

CNR was measured for **0.1% bismuth and iodine** solutions vs. water, using energy-integrated (EICT), single-spectrum (KCT), and EKCT reconstructions, and validated by imaging a bismuth-filled marine snail shell (Figure 2).

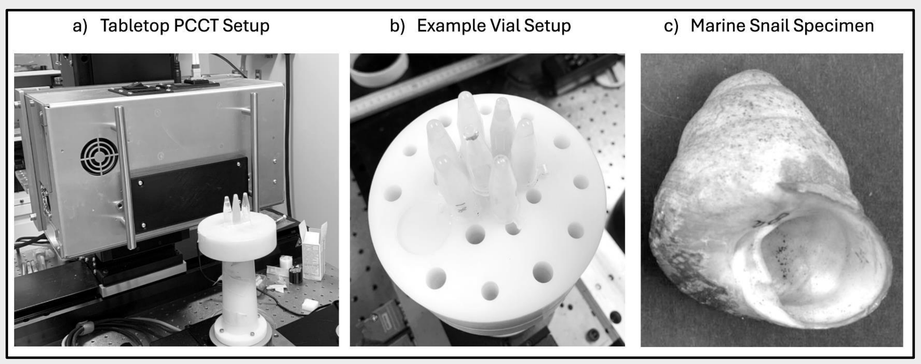

Figure 2. Benchtop PCCT setup, vials, and snail specimen.

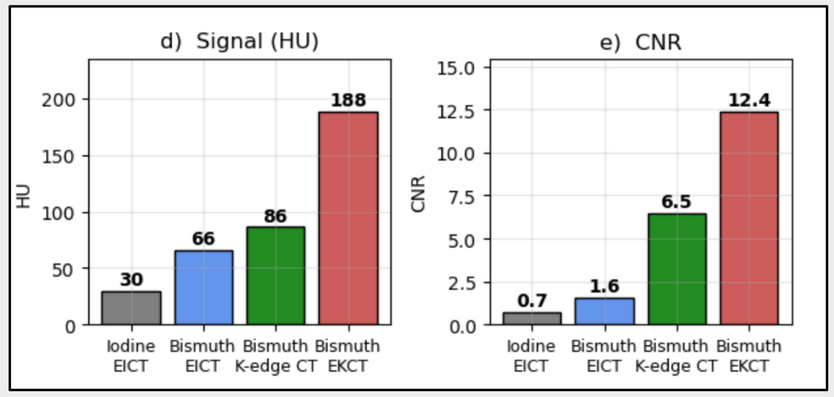

Figure 3. Signal and CNR in 0.1% (1 mg/ml) solution measured in vials imaged on benchtop photon counting CT.

RESULTS

EKCT increased spectral purity to **89–91%**, vs. 72–75% for KCT, reducing spectral overlap between bins from 25–28% to **<11%** (Figure 1).

Bismuth EKCT achieved **CNR = 12.4 (188 HU)** on the benchtop PCCT, a **17-fold improvement** over iodine EICT (0.71, 30 HU) and **119% higher** signal than bismuth KCT (6.5, 86 HU) (Figure 3). Material differentiation was preserved throughout: bismuth produced a positive k-edge signal while iodine produced a negative signal.

EKCT also localized the bismuth signal in the snail shell more precisely than KCT (Figure 4).

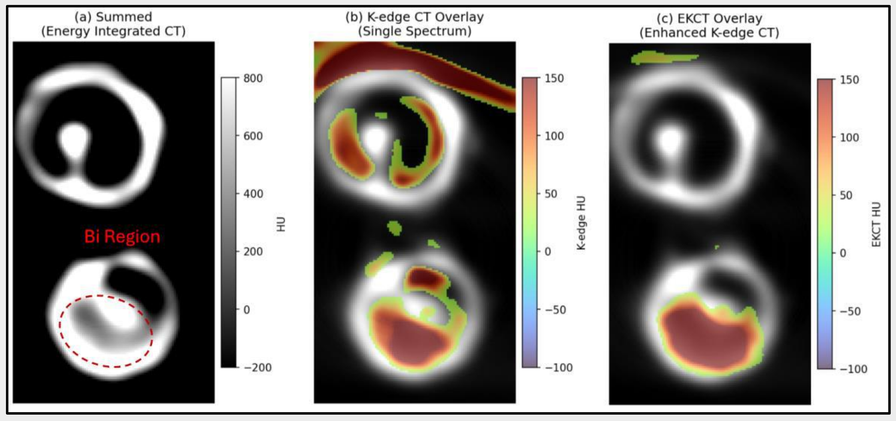

Figure 4. Snail-shell overlay: EKCT vs. KCT bismuth localization. Some artifacts persist due to variation in pixel response.

DISCUSSION

Physical spectral separation, obtained by filtering each acquisition (Bi below k-edge, Cu above), suppresses cross-bin contamination that limits conventional KCT, driving EKCT's sensitivity gain.

This **17-fold CNR gain** over iodine positions EKCT as a strong candidate for imaging **bismuth-based targeted nanoparticles** (e.g., AGuIX-Bi) at physiological tumor concentrations (~0.1 mg/mL), which are otherwise difficult to visualize with conventional contrast agents.

Detector non-uniformity remains a limitation, visible as artifacts in Figure 4; bin-specific calibration is planned as future work to further improve EKCT image quality.

CONCLUSION

EKCT combined with bismuth contrast achieves **17-fold higher CNR** than conventional iodine imaging through physical spectral separation, enabling improved detection of low-concentration high-Z contrast agents and a step toward clinical translation of targeted bismuth therapies.