CT Number Accuracy of Virtual Monoenergetic Images in Photon-Counting CT: Implications for Iodine, Iron, and Fat Quantification

Xinhua Li, Ph.D, Yifang Zhou, Ph.D
Department of Imaging, Cedars-Sinai Medical Center

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

Purpose

Photon-counting CT (PCCT) virtual monoenergetic imaging (VMI) is increasingly used for quantitative imaging and biomarker development. However, despite the theoretical expectation that monoenergetic reconstructions should produce stable Hounsfield unit (HU) measurements across acquisition conditions, VMI CT numbers are influenced by X-ray attenuation, subject size, beam hardening, scatter, and detector-related effects (charge sharing, pulse pileup, K-escape, threshold effects, energy misregistration). When VMI can or cannot be interpreted as physical monoenergetic attenuation remain poorly understood. We aim to evaluate PCCT VMI CT number accuracy against ground-truth liver imaging data covering a wide range of iodine, fat, and iron concentrations, VMI energies, phantom sizes, and acquisition conditions.

Methods and Materials

Anthropomorphic liver phantoms (CIRS) representing medium-sized (25×32.5 cm²) and large (31×39 cm²) abdomens contained unenhanced and iodine-enhanced parenchyma (0.68 and 1.89 mg/cm³ iodine), and multiple iodine, fat, and iron oxide (Fe_3O_4) inserts with clinically relevant shapes, volumes, and concentrations. The phantoms were scanned on a Siemens NAEOTOM Alpha using clinical abdomen protocol [120 kV and140 kV; $CTDI_{vol}$ 8.51/12.8 mGy (medium/large phantom)].VMIs were generated using projection domain multi-material modeling with a water/iodine basis. CT numbers were measured from 40–190 keV in 1-keV increments using syngo.via (VB80F). Mean values from three repeated scans were compared with CIRS specifications at 50, 60, 80, 100, and 150 keV.

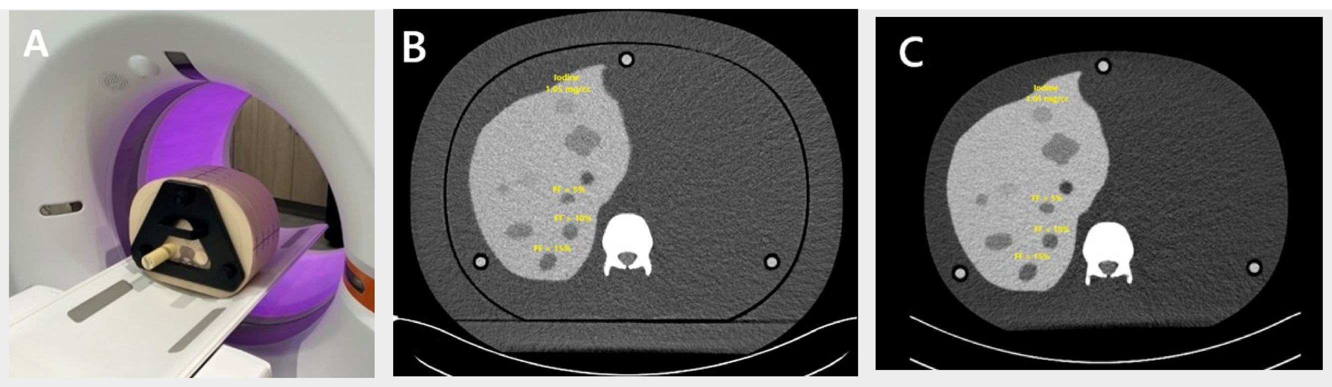

Figure 1. Large liver phantom setup (A), as well as CT images of the large (B) and medium-sized phantoms (C). FF denotes fat volume fraction.

Results

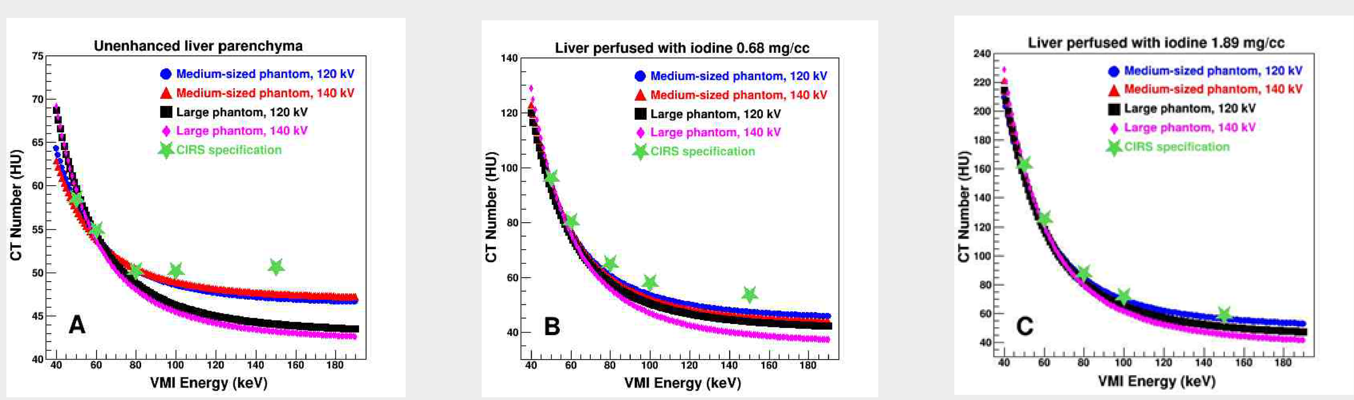

Figure 2. Comparison of CT numbers of liver parenchyma with unenhanced (A) and perfused with iodine at concentrations of 0.68 mg/cm³ (B) and 1.89 mg/cm³ (C) versus CIRS specifications.

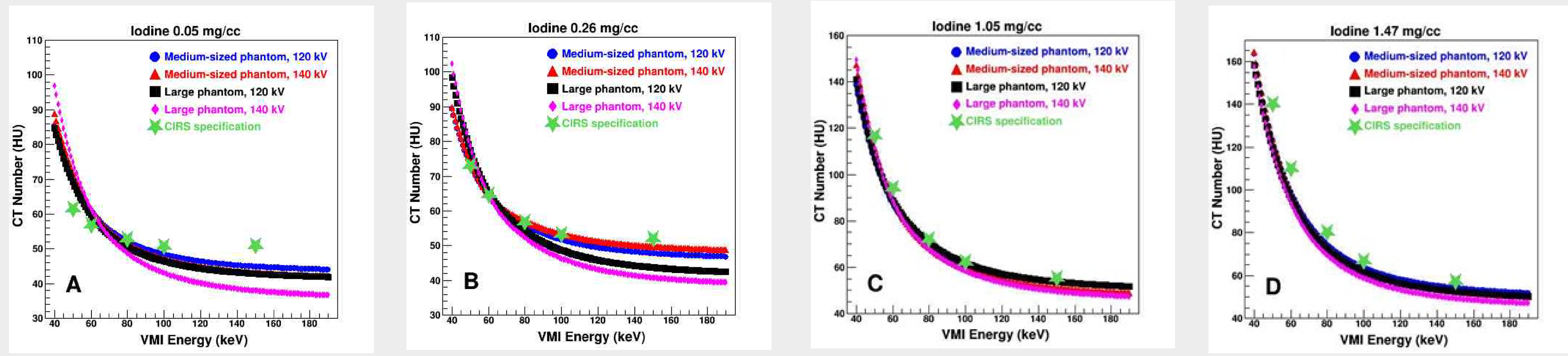

Figure 3. Comparison of CT numbers of liver–iodine inserts with iodine concentrations of 0.05 mg/cm³ (A), 0.26 mg/cm³ (B), 1.05 mg/cm³ (C), and 1.47 mg/cm³ (D) versus CIRS specifications.

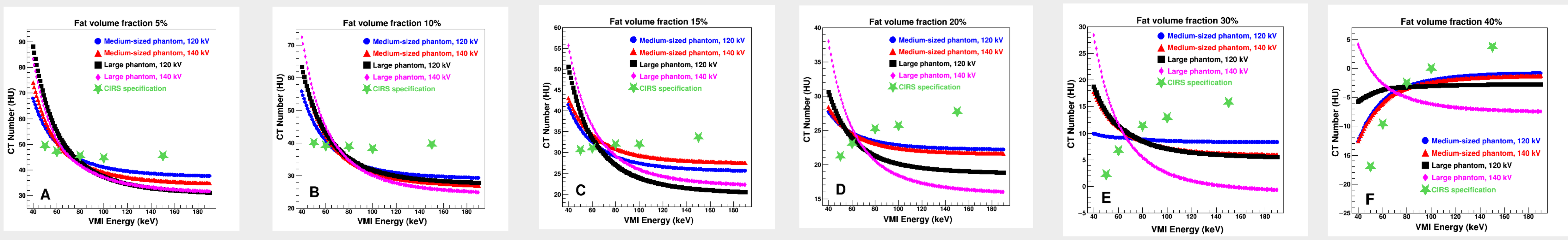

Figure 4. Comparison of CT numbers of liver–fat inserts with fat volume fractions of 5% (A), 10% (B), 15% (C), 20% (D), 30% (E), and 40% (F) versus CIRS specifications.

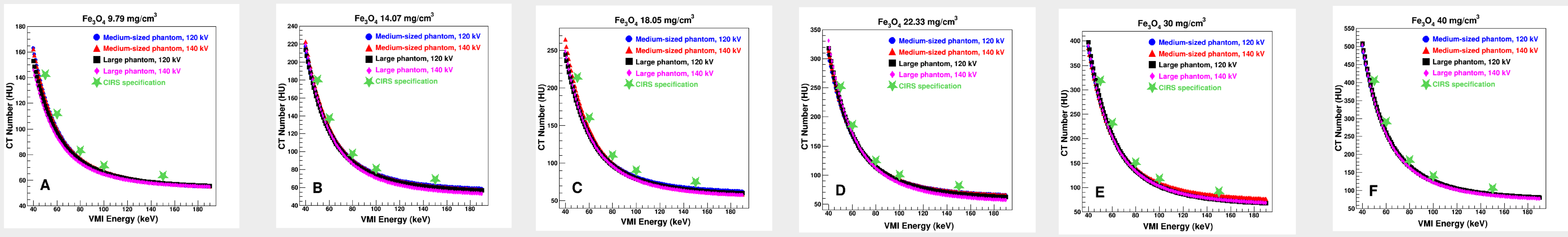

Figure 5. Comparison of CT numbers of liver–Fe_3O_4 inserts with iron concentrations of 9.79 mg/cm³ (A), 14.07 mg/cm³ (B), 18.05 mg/cm³ (C), 22.33 mg/cm³ (D), 30 mg/cm³ (E), and 40 mg/cm³ (F) versus CIRS specifications.

Across three liver phases (Fig. 2), VMI CT numbers generally agreed with CIRS specifications, with root-mean-square errors (RMSEs) of 1.7–8.2 HU and relative RMSEs of 3.4%–14.1%. Similarly, for four iodine inserts (Fig. 3), RMSEs were 1.6–13.0 HU, with relative RMSEs of 3.1%–14.2%.

For six fat volume fractions (5%-40%) (Fig. 4), VMI CT numbers did not consistently match CIRS specifications (RMSE = 3.8–10.4 HU). Relative RMSEs were 13.3%-26.4%, excluding 30%-40% fat inserts, with unstable relative errors due to reference CT numbers close to zero.

For six Fe_3O_4 inserts (iron concentrations 9.79-40 mg/cm³) (Fig. 5), VMI CT numbers were systematically lower than CIRS specifications (RMSE = 10.7–30.0 HU; relative RMSEs = 8.7%-14.4%). CT number–keV relationship remained highly consistent across 120/140 kV and phantoms.

Discussion

A central finding was the strong material dependence of VMI CT number accuracy.

(1) For liver parenchyma and liver–iodine inserts, VMI CT numbers closely tracked narrow-beam monoenergetic reference values, with only small deviations across kV and phantom size.
(2) Liver-fat inserts exhibited substantial CT number variation with kV and phantom size, and high relative RMSEs, even after excluding inserts with reference CT numbers near zero.
(3) Liver–Fe_3O_4 insets showed consistent CT number underestimation across VMI energies and iron concentrations, while remaining highly reproducible across 120/140 kV and phantom sizes.

Conclusion

In PCCT, VMI CT number accuracy depends on how completely a material is represented in water–iodine decomposition basis. Our results confirm that liver– iodine CT numbers can serve as reliable quantitative biomarkers. However, materials that are partially represented show substantial variation with kV and subject size, or systematic underestimation. Notably, high reproducibility does not guarantee quantitative accuracy. *[Reference: Report of AAPM Task Group 291. Med Phys. 2020;47(7).]*