Liver Fat Quantification in Medium and Large Phantoms: Photon Counting CT Vs Dual-Energy CT Virtual Monoenergetic Imaging

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Purpose

To evaluate the relationship between fat volume fraction (FF) and Hounsfield units (HU) in unenhanced fatty lesions and to identify virtual monochromatic imaging (VMI) settings that minimize FF quantification errors, by comparing photon counting CT (PCCT) with dual-energy CT (DECT) across different subject sizes.

Methods and Materials

Six fatty lesions (FF 5%–40%) were embedded in an anthropomorphic liver within a medium abdomen–pelvis phantom (25×32.5 cm²) and a large phantom (31×39 cm²) created by adding an airtight soft-tissue–equivalent layer (CIRS). Phantom scans on Siemens NAEOTOM Alpha used an abdomen–pelvis protocol (120/140 kV; $CTDI_{vol}$ 8.51 mGy [medium] and 12.8 mGy [large]; QR40f; QIR 3; slice thickness 1 mm). Spectral images were analyzed across VMI energies (40–190 keV). DECT comparisons included fast kV switching (FKVS, 80/140 kV) on GE Revolution CT using 14 mGy [medium] and 21 mGy [large]) and dual-source (DS) CT on Siemens Force (80/Sn 150 kV, 100/Sn 150 kV) using 14.5 mGy [medium], generating VMI images from 40–140 keV. Comparisons also included single energy (SE) scans. HU values from 3 repeated scans underwent linear regression between HU and known FF,

$$FF = a \times CT\,(HU) + b\,. \quad (1)$$

Quantification accuracy was assessed using root-mean-square error (RMSE) of predicted vs true FF.

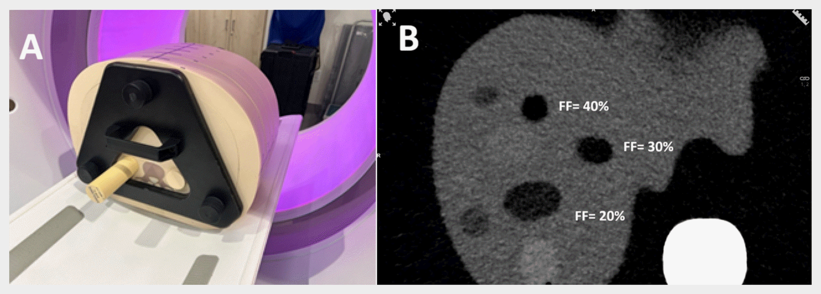

Figure 1. Large phantom setup on a Siemens NAEOTOM Alpha (A), and CT image of medium-sized phantom (B) showing three fat inserts.

Results

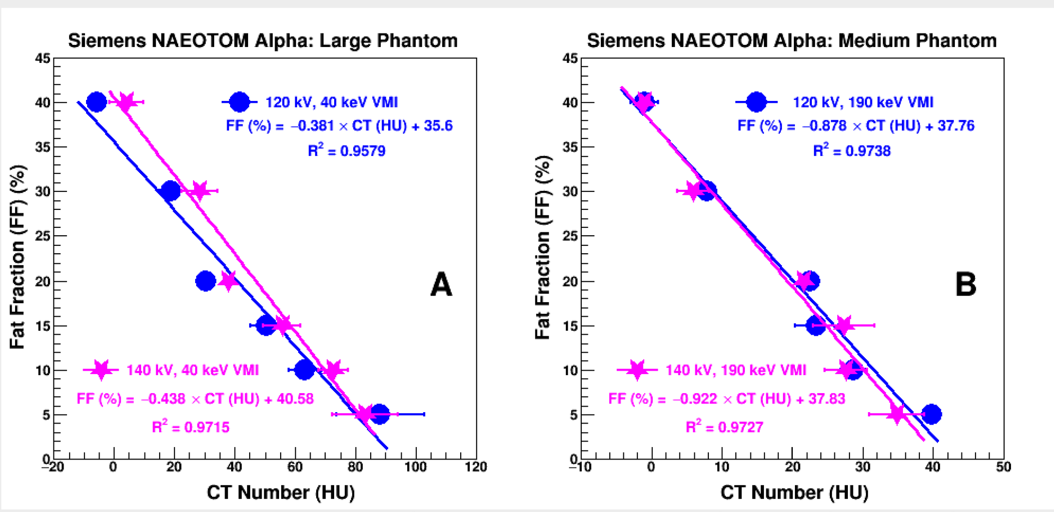

Figure 2. Siemens NAEOTOM Alpha: FF–CT number relationships at the VMI energy corresponding to the poorest goodness of fit. Two phantoms (A,B) are shown with linear regression parameters. Error bars show standard deviations of repeat scans.

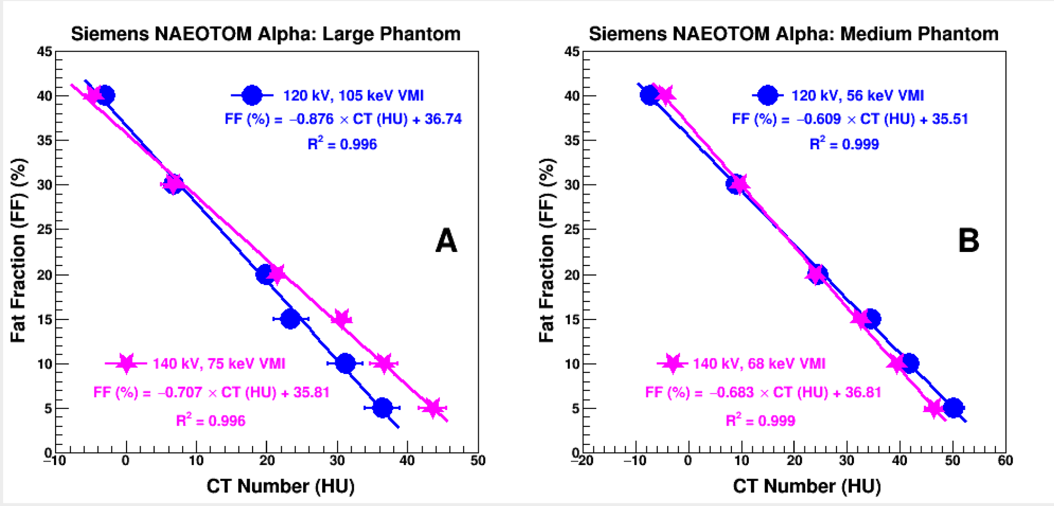

Figure 3. Siemens NAEOTOM Alpha: FF–CT number relationships at the VMI energy corresponding to the best goodness of fit. Two phantoms (A,B) are shown with linear regression parameters.

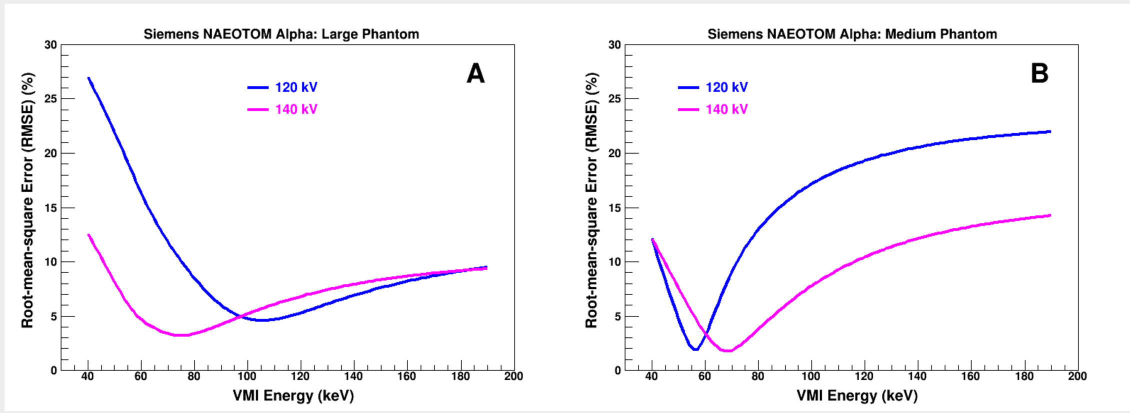

Figure 4. Siemens NAEOTOM Alpha: Relative RMSEs of FF estimates derived from linear regression (Eq. 1) across VMI energies. Results are shown for two phantoms (A, B).

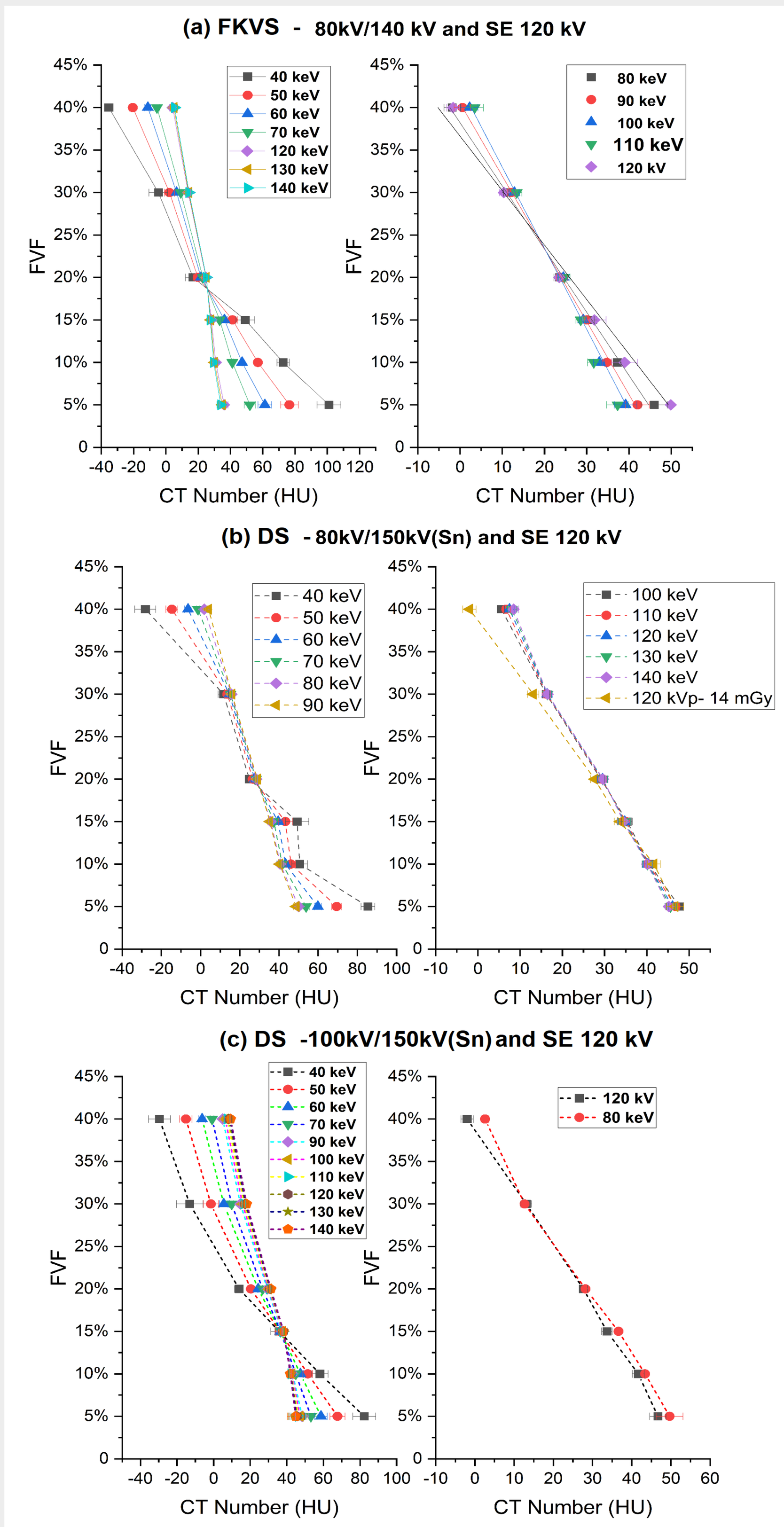

Fig. 5 Energy-integrating detector CT: FF–HU for medium phantom (14.5 mGy).
(a) FKVS: RMSE = 10.5%–34.5% (left), 4.8%–9.1% (right).
(b) 80/Sn 150 kV: RMSE = 10.3%–37.0% (left), 2.4%–9.5% (right).
(c) 100/Sn 150 kV: RMSE = 15.9%–36.8% (left), 9.5%–10.2% (right).

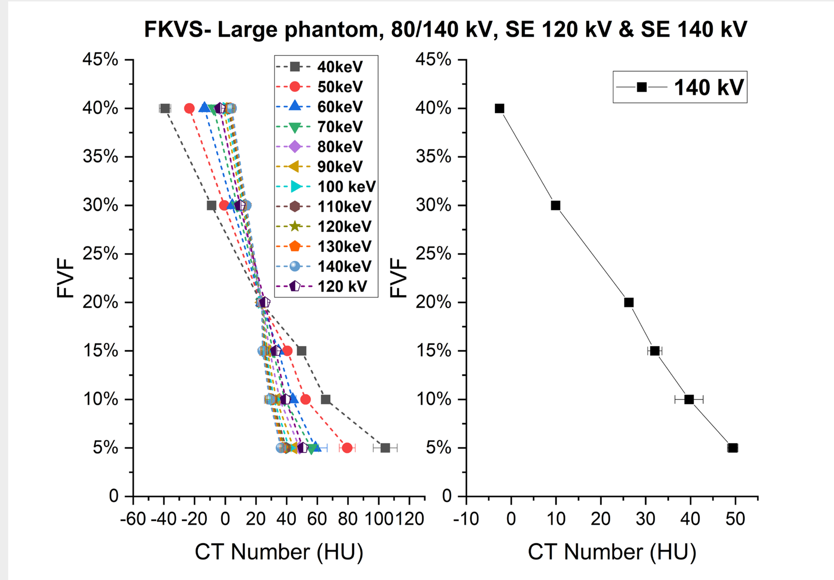

Figure 6. GE Revolution CT: FF–HU for large phantom (21 mGy). RMSE = 14.9%-46% (left) and 9.2% (right).

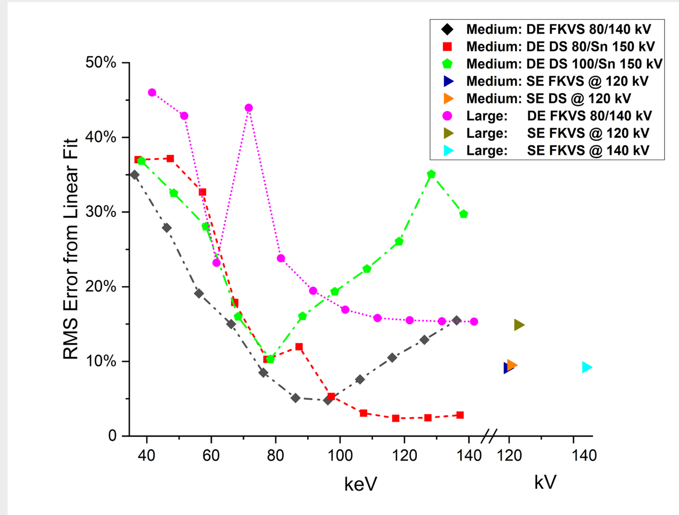

Figure 7. Energy-integrating detector CT: RMS errors for both phantoms from predicted FF values through least-square linear fits (Eq. 1).

Optimal VMI energy and minimum rRMSE

- PCCT (large, 120 kV): 105 keV/4.6%
- PCCT (medium, 120 kV): 56 keV/1.9%
- PCCT (large, 140 kV): 75 keV/3.2%
- PCCT (medium, 140 kV): 68 keV/1.8%
- FKSV (large): 140 keV/15.3%
- FKSV (medium): 100 keV/4.8%
- Dual-source CT (medium, 80/Sn 150 kV): 120 keV/2.4%

Discussion

- FF–HU relationship is technology, size-dependent
- DECT: no single VMI setting achieved robust (<5% error) FF quantification across 2 phantoms
- PCCT: enables accurate FF quantification
  RMS error <2% (medium phantom)
  RMS error <5% (large phantom)
  Achieved at 39% lower dose than DECT
- PCCT (140 kV): promises for robust FF quantification across phantom sizes using a single ~70 keV VMI

Reference: Zhou Y, Li X. Liver fat volume fraction assessment in medium and large anthropomorphic phantoms – dual energy virtual monochromatic imaging versus single-energy CT. Med Phys. 2025;52(9):e18105. doi: 10.1002/mp.18105.