Monoenergetic Energy Selection for Fat–Liver Differentiation in Photon-Counting CT

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Introduction

Photon-counting CT (PCCT) records individual X-ray photons and sorts them into energy bins, enabling simultaneous multi-energy acquisition and routine reconstruction of virtual monoenergetic images (VMIs) from 40–190 keV in a single scan[1,2]. Differentiating fat from liver on the basis of Hounsfield units (HU) underlies several quantitative CT tasks, most notably the detection and grading of hepatic steatosis, where adipose and hepatic parenchyma must be separated reliably[3,4].

Low-keV VMIs maximize the fat–liver HU difference and soft-tissue contrast, while higher-keV VMIs reduce beam-hardening and noise. However, VMI HU accuracy depends on patient size: attenuation, beam-hardening, and scatter all scale with object size, so the same tissue can report different HU in a small versus large patient[2,5]. For a fat–liver task this size dependence can shift both tissues and the separation between them, motivating an energy choice that preserves separability while minimizing size-related HU bias.

Purpose

To quantify energy- and size-dependent HU shifts in PCCT monoenergetic imaging and their impact on fat–liver separability, and to identify VMI energies that preserve separation while minimizing patient-size–dependent HU bias for fat-related workflows.

Materials & Method

Scanner & phantom: A multi-energy phantom with soft-tissue insert modules was scanned on a Siemens NAEOTOM Alpha PCCT.

Sizes: Two habitus configurations, 20 cm (small) and 40 cm (large), to bracket clinical patient size.

VMIs: VMIs reconstructed from 40–190 keV with fixed iterative reconstruction strength and constant reconstruction parameters.

Materials: Soft-tissue surrogates — adipose, liver, breast, brain, blood, lung surrogates, and background.

Analysis: Mean HU measured with consistent ROIs in adipose, liver, and background. Fat–liver separability = $HU_{Liver} - HU_{Adipose}$; size dependence $\Delta HU_{size} = HU_{40cm} - HU_{20cm}$ versus energy.

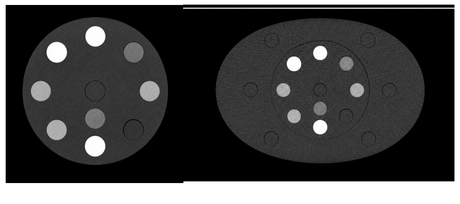

Figure 1. CT images of the multi-energy phantom with soft-tissue inserts in the 20 cm and 40 cm configurations.

Results

Fat–liver separability (ΔHU = HU_Liver − HU_Adipose) was largest at low keV and decreased with increasing energy; size-related HU bias was greatest at low keV and reversed sign at high keV.

Low keV (40 keV): adipose was −150.1 HU (20 cm) vs −122.5 HU (40 cm) and liver 71.0 vs 80.5 HU, giving ΔHU of 221.1 vs 203.0 HU. Size bias was positive: +27.7 HU (adipose), +9.5 HU (liver), +14.7 HU (background).

High keV (190 keV): adipose was −37.9 HU vs −48.2 HU and liver 63.5 vs 54.0 HU, giving ΔHU of 101.4 vs 102.2 HU with a sign reversal in size bias (adipose −10.3 HU; liver −9.5 HU).

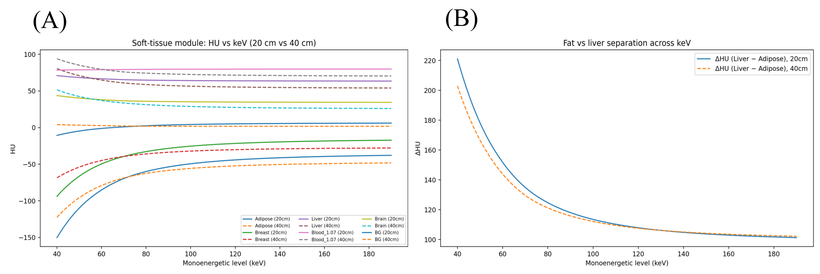

Figure 2. (A) Soft-tissue HU vs keV for 20 cm and 40 cm phantoms (adipose, liver, breast, brain, blood, background).
(B) Fat–liver separation, ΔHU (Liver − Adipose) vs keV for 20 cm and 40 cm phantoms; largest at low keV, declining with energy.

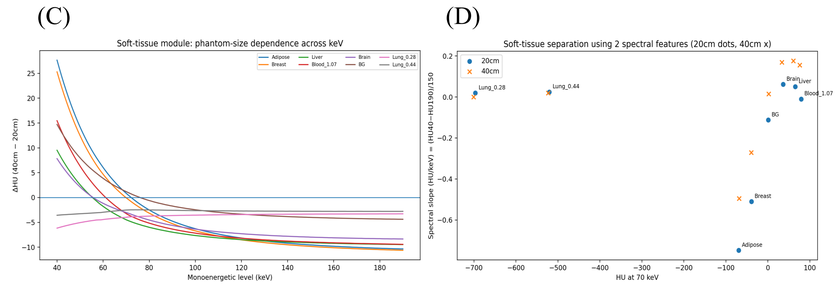

Figure 3 : (C) . Size dependence ΔHU (40−20 cm) across keV for soft tissues. Bias is largest at low keV and approaches/crosses zero near 60–80 keV, reversing sign at high keV.
(D) 2-feature separation: spectral slope vs HU at 70 keV (20 cm dots, 40 cm ×); tissue clusters remain well separated across size.

Results (cont.)

Mid keV (70 keV): ΔHU was 134.9 vs 129.6 HU (20 vs 40 cm) with markedly reduced size sensitivity (≤~5 HU for adipose, liver, and background), giving a favorable balance of separability and size robustness.

Overall, fat–liver separability fell from ~221 HU at 40 keV to ~101 HU at 190 keV, while size bias was largest at 40 keV (up to +27.7 HU for adipose) and reversed to negative by 190 keV, confirming an energy-dependent tradeoff between contrast and size robustness.

Table 1. Adipose, liver, and fat–liver separation (HU) at 40 vs 190 keV, shown as 20 cm / 40 cm.

Metric (20/40 cm)	40 keV	190 keV
Adipose HU	−150 / −123	−38 / −48
Liver HU	71 / 81	64 / 54
ΔHU (Liver−Adipose)	221 / 203	101 / 102
Size bias, adipose	+27.7	−10.3
Size bias, liver	+9.5	−9.5

Conclusion

Fat–liver separability decreases with increasing keV, while size-related HU bias is greatest at low keV and can reverse sign at high keV.

Mid-range energies (~70 keV) maintain substantial fat–liver separability while minimizing size bias (≤~5 HU), offering a robust operating point.

These findings support robust energy selection and QC expectations for fat-related workflows such as hepatic steatosis assessment, where patient size can otherwise shift quantitative HU.

References

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