Energy-dependent reproducibility of radiomic features across virtual monoenergetic dual-energy CT images: a phantom study

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PURPOSE / OBJECTIVES

Background:
Virtual monoenergetic images (VMIs) reconstructed from dual-energy CT (DECT) allow for optimized tissue contrast and reduced artifact over conventional single-energy CT scans. While DECT holds immense promise for high-dimensional radiomic profiling, the quantitative stability of these imaging biomarkers across varying energy levels (keV) remains a significant barrier to clinical translation.

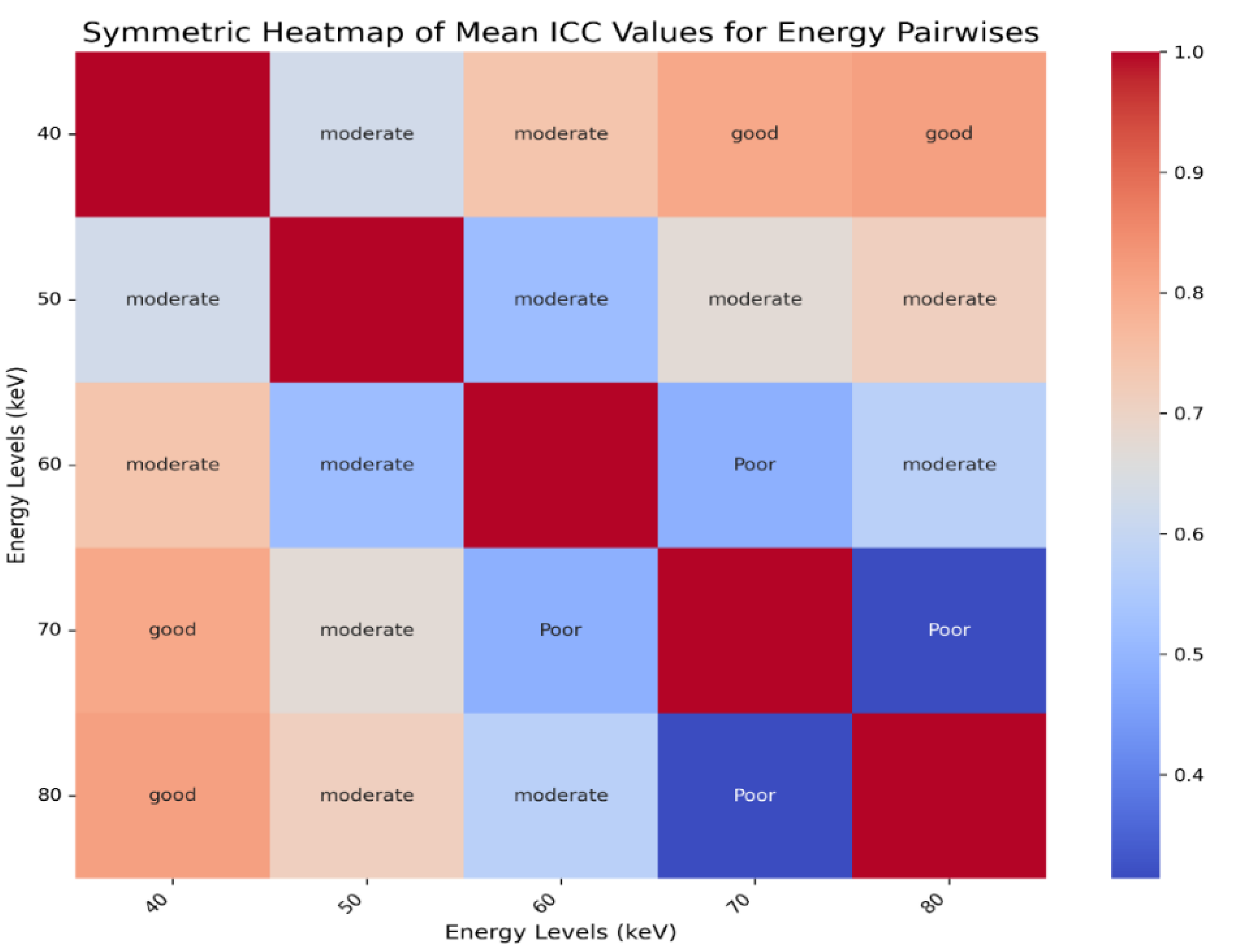
Study Objectives:
Quantify Stability: Evaluate the reproducibility of IBSI-compliant radiomic features across a clinical spectrum of VMIs (40-140 keV).
Identify Robust Biomarkers: Categorize specific feature classes (e.g., shape, first-order, texture matrices) into stability tiers based on their sensitivity to keV shifts.
Establish Harmonization Guidelines: Provide a baseline benchmark for feature selection and harmonization strategies in multi-energy CT imaging protocols.

MATERIALS AND METHODS

We utilized a GE Revolution CT with Gemstone Spectral Imaging (GSI) Xtream Suite (General Electric Healthcare, Waukesha, WI, USA) equipped with fast kV-switching technology between 80 and 140 kVp. We conducted reproducibility quantification measurements using a phantom with six cylindrical inserts (CIRS Model 062M, CIRS Inc.), representing tissues such as water (1.0 g/cc density), lung (0.507), adipose (0.960), breast (0.990), muscle (1.060), and liver (1.070). Radiomic features were extracted and regions of interest delineated using Java-based LIFEx software, focusing on cylindrical ROIs measuring 2.5 cm in length and 1.8 cm in diameter for each insert. A total of 106 features were analyzed, employing the intraclass correlation coefficient (ICC) to evaluate feature reproducibility, categorized into three grades: Grade A (> 80%), Grade B (50%-80%), and Grade C (< 50%).

Figures

Figure: Symmetric heatmap illustrating the mean Intraclass Correlation Coefficient (ICC) across energy level comparisons. The grading categories are as follows: Grade A (Good) – ICC > 80%, Grade B (Moderate) – ICC between 50% and 80%, and Grade C (Poor) – ICC < 50%



RESULTS

The mean intraclass correlation coefficient (ICC) for the water insert between 40 and 80 KeV was highest at 0.82 (SD = 0.25, 95% CI: 0.77–0.86). Among feature categories, intensity features (n=23) showed the highest agreement, with an ICC of 0.91 (SD = 0.38). For these features, the number of Grade A classifications ranged from 74% to 96% across energy levels from 40 to 80 KeV. Conversely, NGTDM features (n = 5) had the lowest ICC at 0.342 (SD = 0.17), with NGTDM_Contrast displaying the poorest agreement at an ICC of 0.067 (SD = 0.019).

TABLES

Table: Mean Intraclass Correlation Coefficient (ICC) of radiomic features between energy levels.

Energy Pairwise (KeV)	Mean ICC	Standard Deviation	Confidence Intervals 95%	Lower bound	Upper Bound
40 vs 50	0.63	0.36	0.07	0.56	0.69
40 vs 60	0.74	0.30	0.06	0.69	0.80
40 vs 70	0.80	0.26	0.05	0.75	0.85
40 vs 80	0.82*	0.25	0.05	0.77	0.86
50 vs 60	0.52	0.36	0.07	0.45	0.58
50 vs 70	0.67	0.32	0.06	0.61	0.73
50 vs 80	0.71	0.30	0.06	0.65	0.77
60v s7 0	0.49	0.35	0.07	0.42	0.55
60 vs 80	0.58	0.34	0.06	0.51	0.64
70 vs 80	0.31	0.34	0.07	0.25	0.38

IMPACTS

Reproducibility challenges in virtual monoenergetic DECT radiomics:
Virtual monoenergetic images produced by DECT have shown significant utility in improving diagnostic precision. However, reproducibility of radiomic features, essential for robust clinical decision-making, remains underexplored.

Supports robustness of quantitative imaging biomarkers:
By quantitatively evaluating energy-dependent reproducibility of radiomic features, this work provides essential evidence for the stability and reliability of radiomic biomarkers, which is critical for their use in longitudinal analyses and multi-center studies.

REFERENCES

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