An Analytical Physics-Guided Standardization Approach for Radiomics Analysis in CT

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Introduction: While numerous studies have demonstrated the clinical potential of radiomics, the inherent dependency of radiomic features on specific acquisition and reconstruction protocols impede translation due to robustness and reproducibility concerns. Whereas current batch-based and deep learning standardization methods seek to find transformations to minimize feature variability, we propose a novel framework that directly accounts the different spatial resolution and noise properties in imaging data. Consequently, the method offers a generalizable and interpretable treatment to standardize radiomics data. to systematically and transparently standardize radiomic measurements to a common baseline.

Methods: In brief, the effect of blur is standardized through analytically removing and applying the measured MTF properties via an image domain deblur-reblur operation. The effect of noise can then be removed in the radiomics domain through deconvolving a noise distribution drawn from the NPS. Following this procedure, radiomic features from any starting to reference imaging condition may be standardized.

Evaluation Method: To evaluate, we first acquired MTF and NPS measurements of eight different reconstruction kernels at five different dose levels via a calibration phantom. We then scanned an anthropomorphic lung phantom under the same imaging conditions. We performed the standardization procedure for all pairs of starting and reference kernel, at every dose level, and with 40 disjoint ROIs for a total of 12,800 ($8 \times 8 \times 5 \times 40$) test cases. The standardized histogram and GLCM radiomic features (RFs) (following *pyradiomic* definitions) were compared to the RFs from the starting kernel by computing the average absolute percentage difference, y, where the reference RFs were set as the baseline.

Results: For every starting kernel, reference kernel, and dose level imaging condition, the average absolute percentage difference of the standardized was less than or equal to the starting radiomic features. We observed that it was generally more difficult for radiomic features to standardize from a smoother to sharper kernel and that the standardization performed similarly at all dose levels: $y_{stan,low\ dose} = 6.2 \pm 2.4$, $y_{start,low\ dose} = 33.7 \pm 31.0$ and $y_{stan,high\ dose} = 4.7 \pm 3.8$, $y_{start,high\ dose} = 20.8 \pm 16.4$, where numbers correspond to the mean and standard deviation of y measurements across all starting and reference kernel pairs.

Discussion and Conclusions: Radiomics have precise mathematical definitions and as an imaging's system's spatial resolution and noise properties can be readily characterized, we offer a clear and explainable standardization procedure to not only incorporate multi-protocol, multi-source medical image and radiomic feature data, but also potentially enhance radiomic model generalizability and performance.

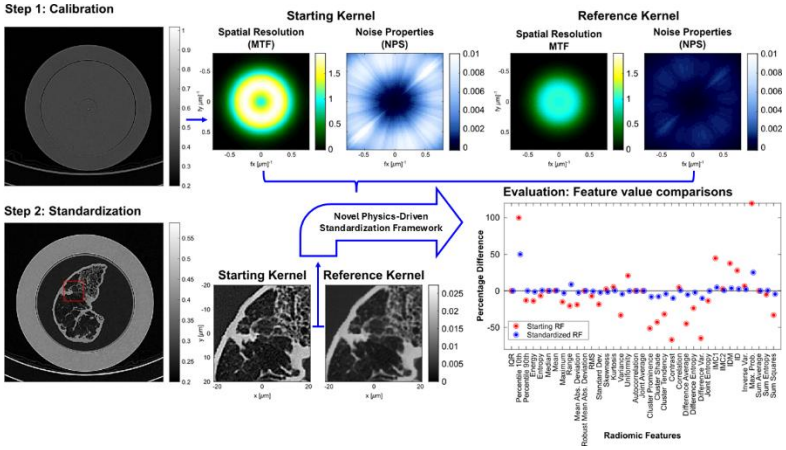

Figure 1: Diagram of the standardization procedure. The MTF and NPS, are acquired for both the starting and reference kernel. From the lung phantom, the standardization steps are applied (image domain deblur-reblur & radiomics domain deconvolution) to then estimate the radiomics under the reference kernel. Noticeably, the percentage difference of the starting radiomic features (red) are more variable than the standardized ones (blue).

References [Gang J Gang et al. 2021 Phys. Med. Biol. 66 074004].