Assessing the robustness of radiomics feature measurements using the noise equivalent count rate, and the future role of Total Body PET

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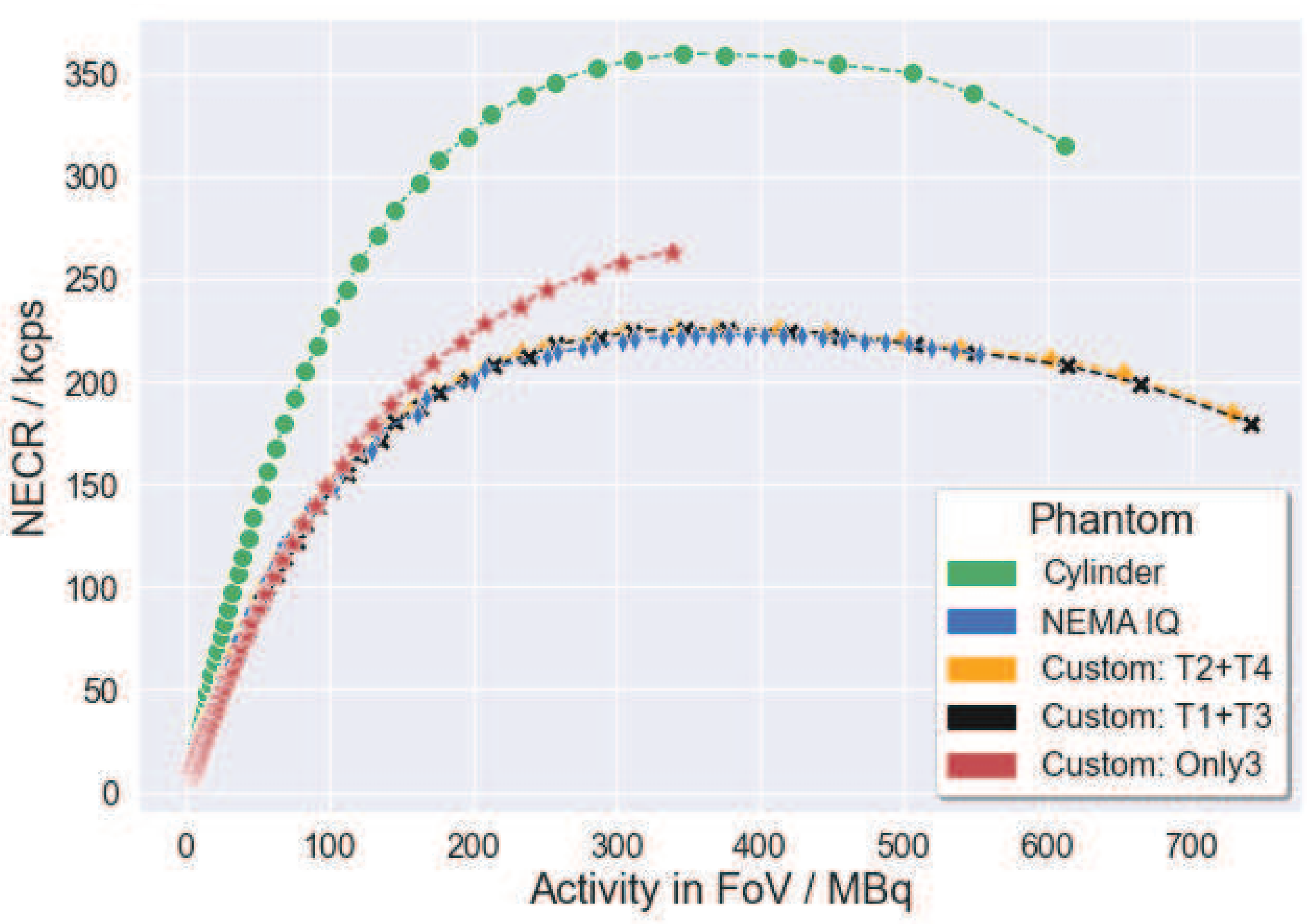
Introduction

Radiomics is a branch of medical image analysis concerned with the extraction of 'feature' metrics from a region of interest, which could then be used for artificial intelligence-aided diagnosis and treatment planning. Heterogeneity features, for example, can be excellent predictors of the degree of hypoxia, or the success of a course of radiotherapy. Currently there is a lack of understanding around the reproducibility and uncertainty of these features in quantitative PET (positron emission tomography). This project explores using the noise equivalent count rate (NECR) to estimate the effect of data noise on texture features, aided by the use of 3D-printed anthropomorphic phantoms, and shows where Total Body PET can improve the current outcomes .

The Noise-Equivalent Count Rate (NECR)



If T, R and S represent true, random and scattered count rates and Δt the scan duration:

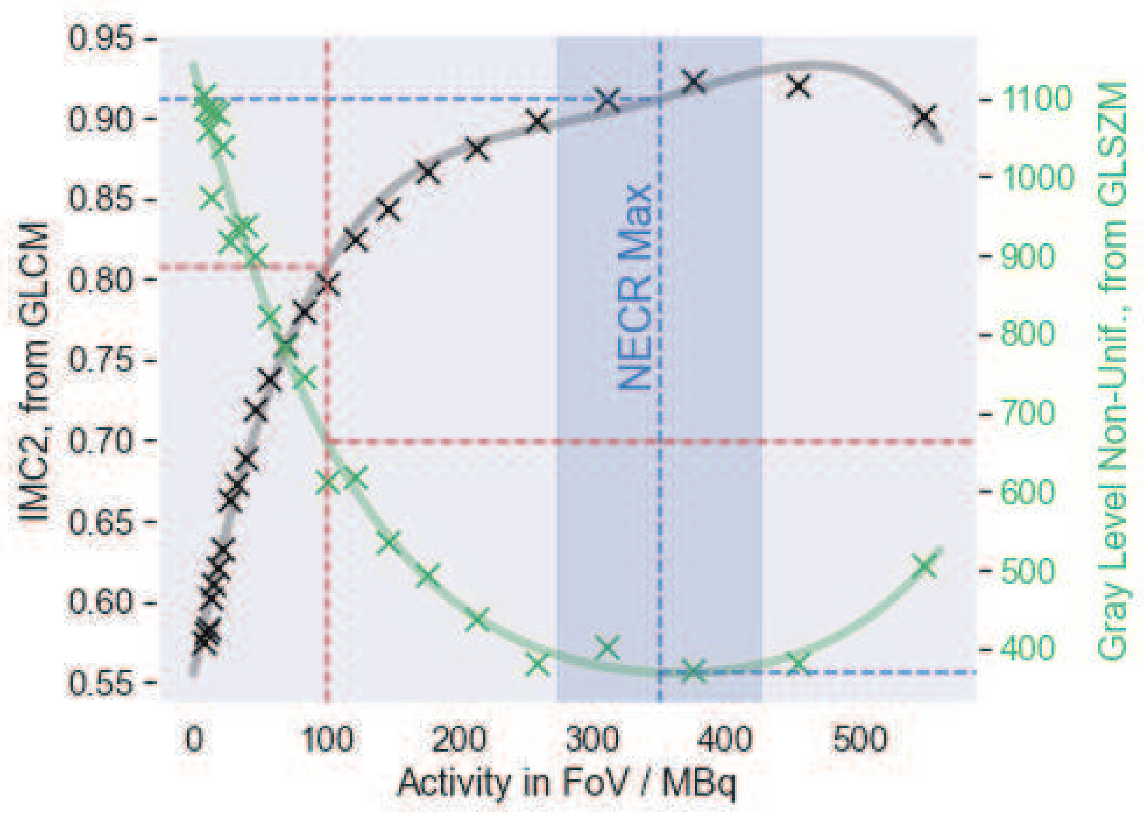
$$\text{NECR} = \frac{T^2}{T + S + x \cdot R}; \quad (1)$$

$$\text{SNR}^2_{\text{data}} = \text{NECR} \times \Delta t. \quad (2)$$

The NECR, a proxy for signal-noise ratio of the count data, is an object- and scanner-dependent performance metric with a characteristic variation with activity [1].

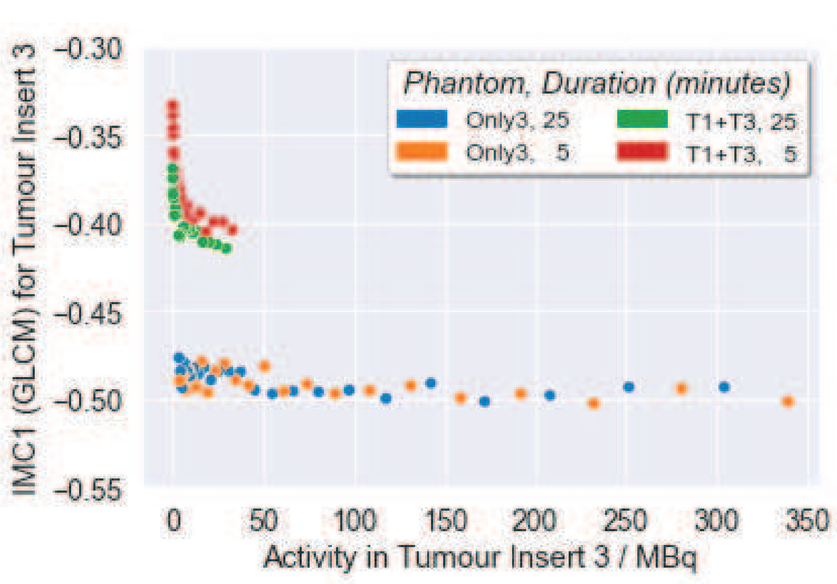
Correction Factors for Heterogeneity Features

- A 20 cm cylinder phantom was filled with ^{18}F and left to decay over 12 hours; 24x 5 minute & 24x 25 minute scans were taken on a Siemens Biograph mCT.
- This was repeated for the NEMA phantom with standard sphere inserts and 3 arrangements of 4 3D-printed tumour-like inserts.
- Of the 75 texture matrix features, 32 were observed to correlate well with NECR ($|\text{PMCC}| \geq 0.9$). Correction factors from $100\ \text{MBq} \rightarrow \text{NECR}_{\text{max}}$ were calculated.
- The feature-NECR $|\text{PMCC}|$s reduce significantly when considering the 5 minute frame dataset; only 7 texture features surpassed the $|\text{PMCC}| \geq 0.9$ threshold, with the $|\text{PMCC}|$ for the ten features listed falling by an average of (11.5 ± 6.6) %.
- $|\text{PMCC}|$s for the ten listed features also fall when considering 25 minute scan data from VOIs of the phantom inserts; falling (53.4 ± 9.3) % for the largest insert and (64 ± 22) % for the smallest.



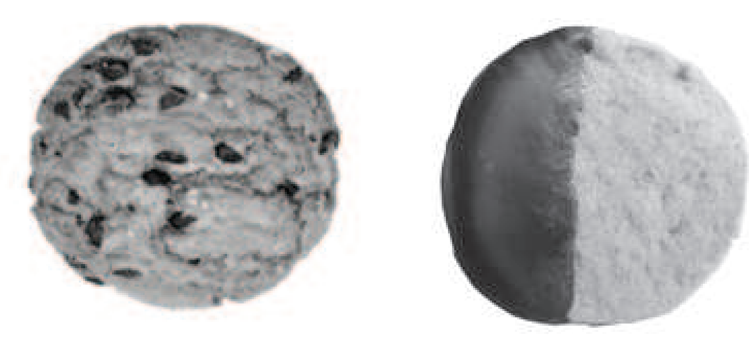
Feature	$\lvert\text{PMCC}\rvert$	Compensation Factor, 100 MBq $\rightarrow$ A(NECR_{max})
IMC2 (GLCM)	0.996	1.129 ± 0.020
Correlation (GLCM)	0.994	1.177 ± 0.037
Gray Level Non Unif. (GLSZM)	0.991	0.640 ± 0.019
IMC1 (GLCM)	0.985	1.697 ± 0.071
Dependence Entropy (GLDM)	0.984	1.048 ± 0.009
MCC (GLCM)	0.982	1.213 ± 0.034
Small Dependence Emphasis (GLDM)	0.964	0.686 ± 0.015
Zone Percentage (GLSZM)	0.964	0.598 ± 0.022
Run Length Non Uniformity (GLRLM)	0.963	0.956 ± 0.002
Inverse Variance (GLCM)	0.963	1.213 ± 0.017

Tumour-Specific 'NECR'



It is clear that metrics are more robust when we know more about specific 'regional' noise, shown by comparing to same tumour insert with cold background. Can we develop a metric that can tell us how much noise originates from a specific region of the scan? Initial efforts assume R is dependent on the LOR-map, which can be approximated by dividing by the fraction of solid angle subtended by the ROI; other assumptions include S dependence on μ-map, and T proportional to activity concentration in ROI.

Heterogeneity & Radiomics



In the event that two images, as above, share identical means and standard deviations of their pixel values, more convoluted features are required to distinguish them numerically. Radiomics software packages include the use of:

- **GLCM**, the gray level connectivity matrix;
- **GLDM**, the gray level dependence matrix;
- **GLRLM**, the gray level run length matrix;
- **GLSZM**, the gray level size zone matrix;
- **NGTDM**, the neighbourhood gray tone difference matrix; [2].

features extracted from these 'texture' matrices are understandably complex and their behaviour in response to noise difficult to predict.

TBP Advantages

$$\text{SNR}_{\text{image}} \propto \sqrt{\eta \times \Delta t} \quad (3)$$

where η is the effective scanner sensitivity [3]. Using the information for the uEXPLORER [4]:

$$\Omega^{\text{mCT}} \approx 0.99\pi; \quad \Omega^{\text{TBP}} \approx 3.71\pi \quad (4)$$

For a phantom like the NEMA IQ,

$$\eta^{\text{TBP}} \approx 4 \times \eta^{\text{mCT}} \quad (5)$$

The geometric sensitivity advantage is comparable to the Δt boost required to generate 'good' $|\text{PMCC}|$ between NECR and texture features for the cylinder data. TBP can be seen as utilising the longer frame duration data for the better modelling of noise for texture features - particularly useful in patient scans.

References

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