Establishing reproducibility of radiomic heterogeneity metrics using GATE simulations and 3D-printed phantoms

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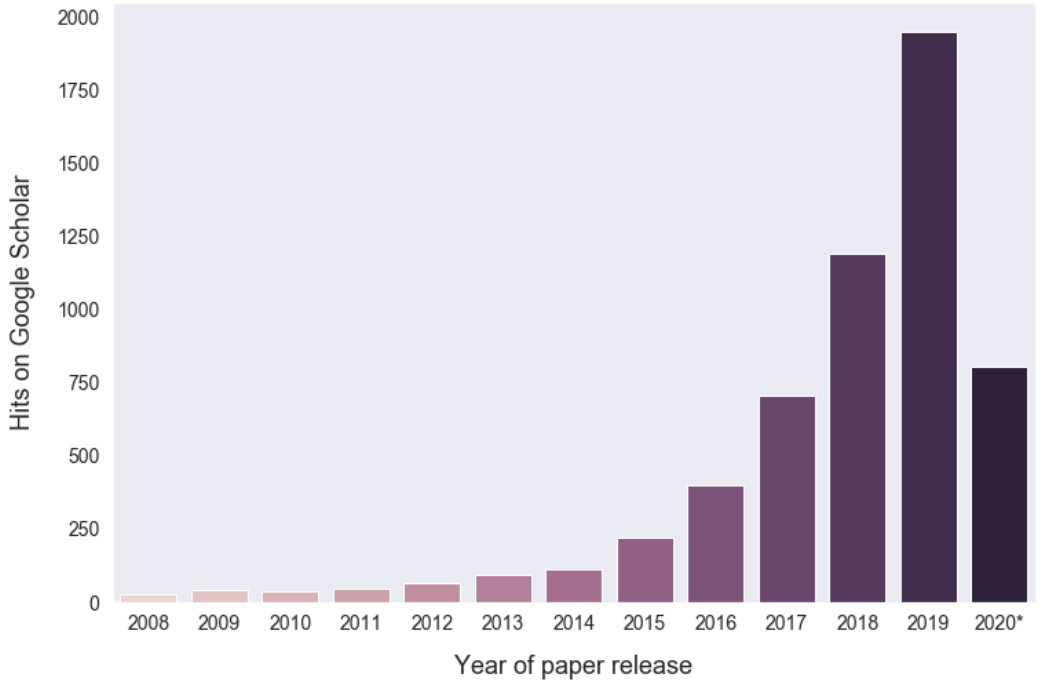
Quantitative PET

- Voxels (3D pixel) of reconstructed images give values of activity concentration
- Quantitative features of this distribution can give clinical information
- The study of medical image metrics is known as **radiomics**
- One of the fastest-growing fields in modern medicine

Hits on Google Scholar *for article titles containing "PET" & "radiomics"*



Radiomics

- New AI-based softwares for patient use based on radiomics analysis
- Worldwide increase in number & value of hospital partnerships for these companies (see Imagia EVIDENS [1], QUIBIM [2], etc)
- Largely used for improving precision radiotherapy, treatment prognosis

[1] *Imagia Partners with Top US and Canadian Hospitals to Facilitate AI Accelerated Healthcare Discoveries:* https://www.businesswire.com/news/home/20191217005309/en/
[2] *QUIBIM Precision image analysis platform spreads to the Pacific:* https://www.healthcareitnews.com/news/quibim-precision-image-analysis-platform-spreads-pacific

Radiomics Challenges

- Radiomics software packages rarely offer uncertainties on metrics
- Two factors:
  - Inherent PET uncertainty (scatter, random, attenuation, partial volume effects…)
  - Complexity of radiomic metrics

Metric Complexity

- PET metrics divided into categories: **uptake, shape & heterogeneity**
- **Uptake** measures activity concentration (kBq/ml), or contextualised by normalisation (to injected value, standardised uptake value or SUV)
- **Shape** metrics describe an ROI/tumour's volume & surface area, sphericity, elongation, flatness, etc.
- Values of shape metrics dependent on algorithms used to interpolate curvature of ROI

Metric Complexity - Heterogeneity

- Issues surrounding definition of heterogeneity
- First order metrics (e.g. mean, standard deviation, etc.) influenced by image noise
- Higher-order metrics calculated from derived texture matrices
  - *Size-zone matrix, connectivity matrix, run-length matrix, dependence matrix…*
- Example: using size-zone matrix to calculate *small area emphasis*

Two heterogeneous objects with identical mean and standard deviation. Small area emphasis higher in left object over right. This information can be used to classify the object.

Project Motivation

- Common issue across field is the **lack of standardisation** in
  - reconstruction protocols
  - radiomic extraction algorithms
- Difficult to establish **reliability** and **reproducibility** of radiomic metrics
- Especially important to critically evaluate these as implementation into clinical software edges closer

Project Aim

- Establish reproducibility in radiomic **heterogeneity** metrics
- Compare graphs of noise-equivalent count rate (**NECR**) vs. activity and heterogeneity vs. activity
- $NECR = \frac{T^2}{T+S+xR}$
- T, S, R are true, scattered & random coincidences
- $1 \leq x \leq 2$ dependent on method of random calculation
- Test dependence of heterogeneity metric on image noise

$$\% \text{ Integral Uniformity} = 100 \times \frac{\max - \min}{\max + \min}$$

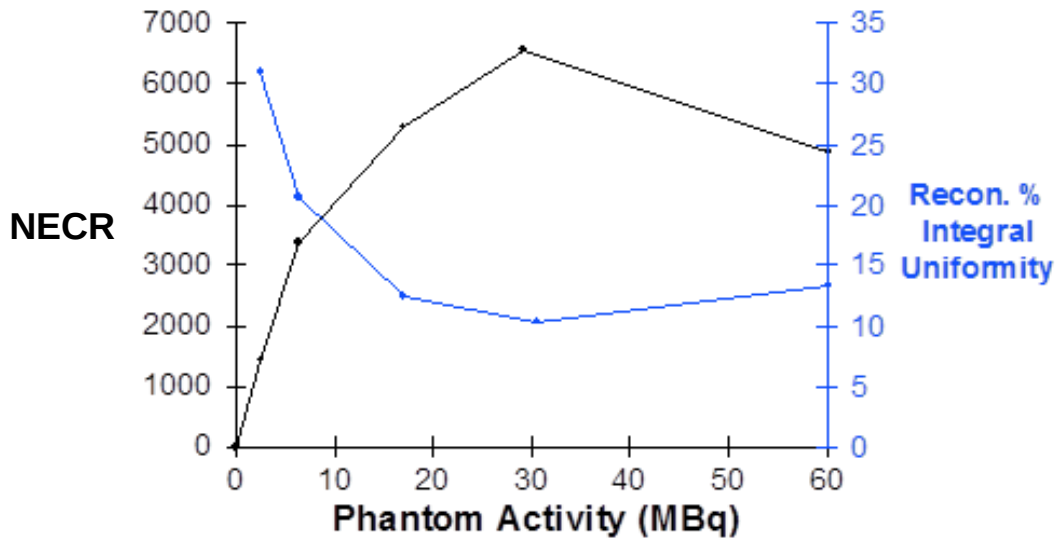
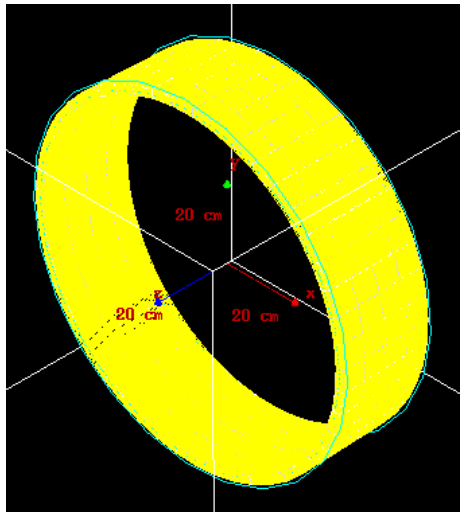


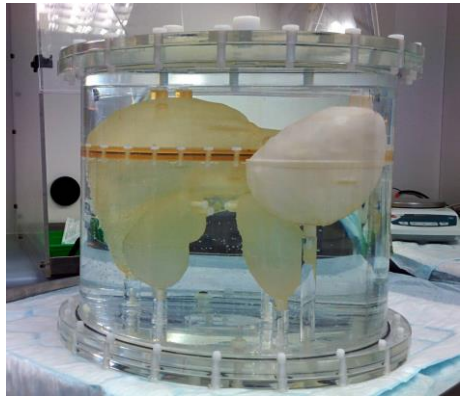
Figure courtesy of P. Julyan et al., The Christie NHS Foundation Trust

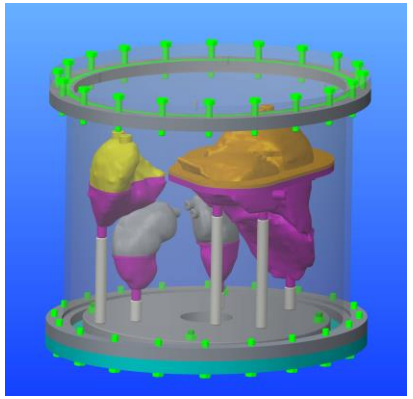
Project Methods

- Establish ground truth with use of Monte Carlo simulation & validation with 3D-printed phantoms
  - GATE software built on Geant4 for medical imaging MC simulation
  - 3D-printed tumour lesions from patient data, ideally unorthodox shape and heterogeneity
- Initial pilot study: 20 cm x 20 cm cylinder phantom



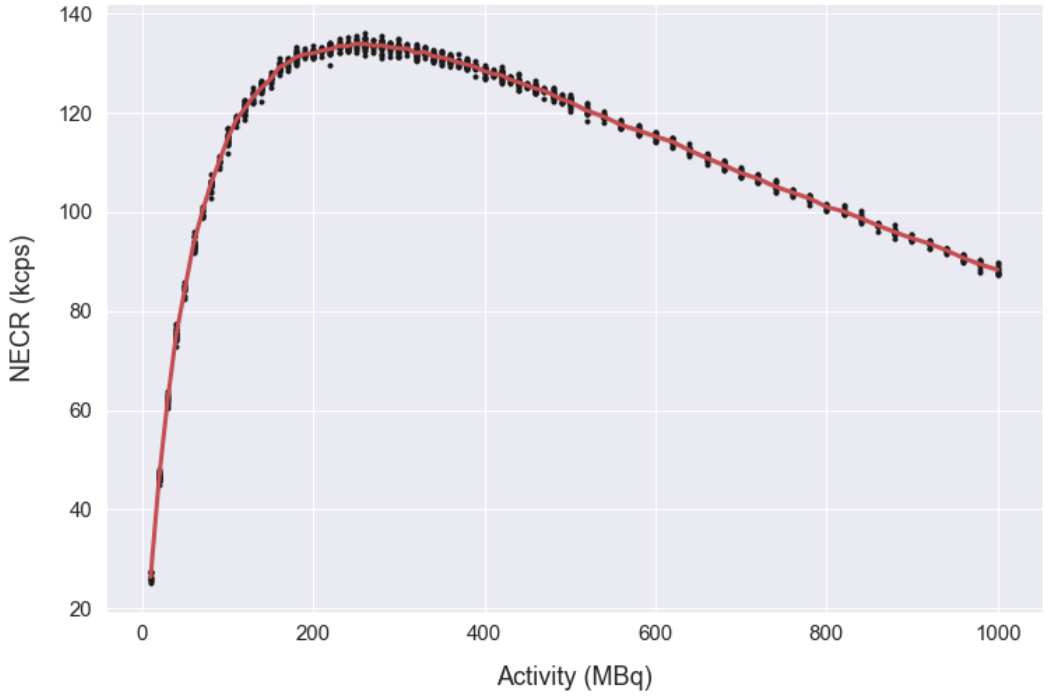
Left, simulation of Siemens Biograph mCT using GATE; Below, 3D-printed organs from patient data from previous group work





Initial Results

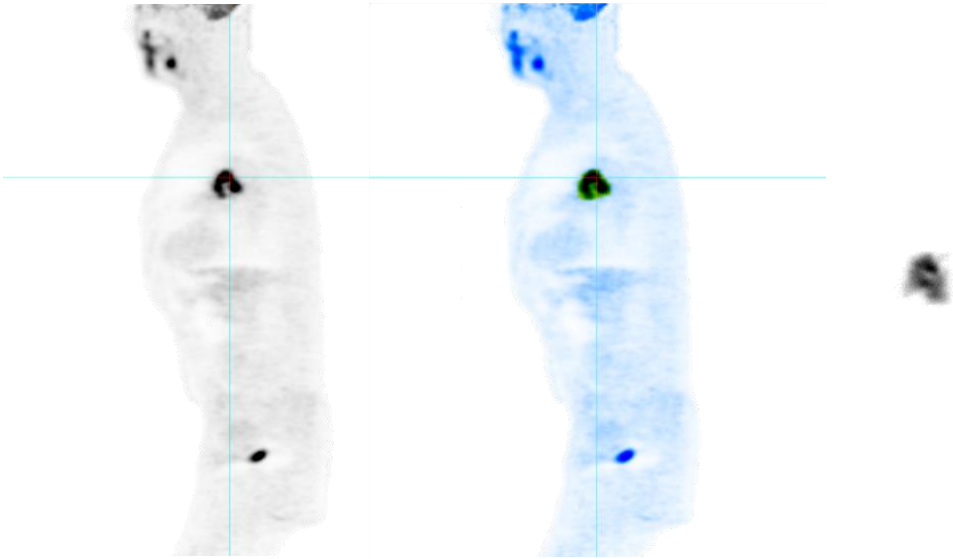
- COVID-19 lockdown so far curtailed efforts for taking data on scanner
- Simulations of cylinder show expected characteristic shape
- Image reconstruction required for the simulated data.
- At the minute, no simple go-between for mCT geometry due to *virtual crystal* arrangement



Initial simulation results for NECR vs activity

Initial Results

- COVID-19 lockdown so far curtailed efforts for taking data on scanner
- Simulations of cylinder show expected characteristic shape
- Creation of bespoke tumour phantoms underway



Above : segmenting NSCLC for phantom creation

Right : oesophagael tumour CAD model

Conclusions

- Radiomics-based clinical software showing exciting future possibilities
- Work should be done to ensure reliability and reproducibility of extracted image metrics
- This project on comparing NECR/activity curves against heterogeneity metric/activity curves showing initial promise but is only in nascent phase

Conclusions

- Google Drive link to data:

  https://drive.google.com/drive/folders/1WB-Z3l7MkUuWtqNkyBKjcUAuItuHZDwt?usp=sharing

QUESTIONS

Thank you for listening.

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