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Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

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Istituto Nazionale di Fisica Nucleare

Study of the robustness of radiomic features and of its potential impact on AI-based CAD systems

next_AIM workshop on XAI techniques for medical data analysis

16 - 18 October 2024, Bari, Italy.

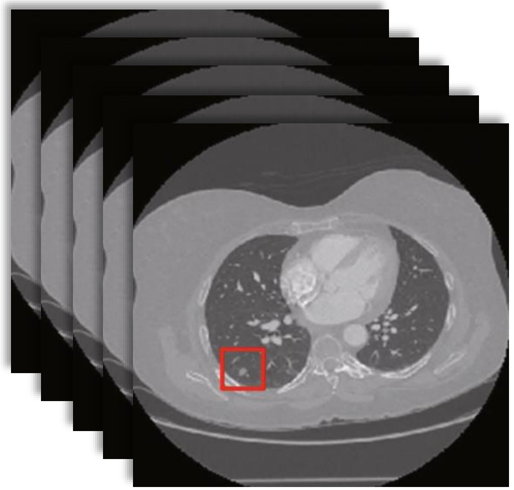
Maria Irene Tenerani

(HEAL ITALIA, Department of physics, University of Pisa)

Lung cancer is the leading cause of cancer death worldwide and one of the most aggressive tumors.

Lung nodules are the early radiological signs.

Chest CT is the best imaging modality to detect them.



5-year survival of **10–15%** → 10-years survival of **75%** if diagnosed at first stage

The National Lung Screening Trial (NLST) usefulness of a **screening program** on the at-risk population using CT:

- relative **reduction in mortality rate** in the LDCT group compared with the X-ray group by **20%***;
- High **radiation dose and** high **false positives rate.**

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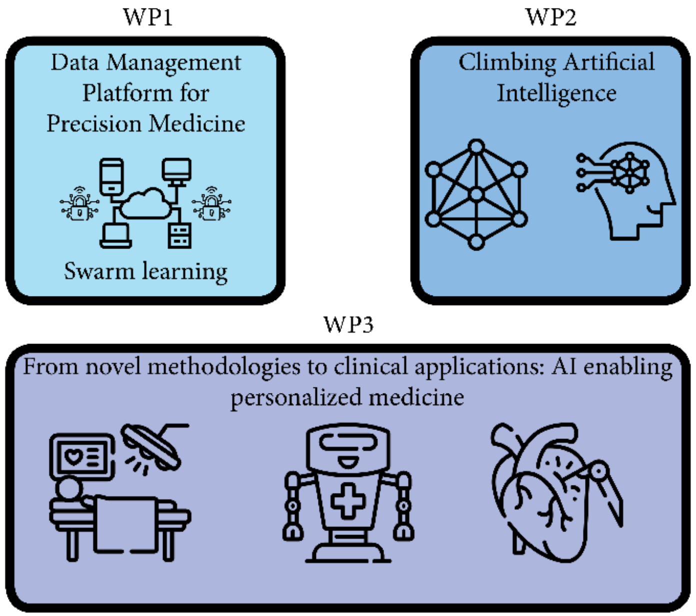
SPOKE 2

Intelligent Health

WP3 - TASK 3.3



OBJECTIVE

Optimization and validation of a low-dose chest CT protocol for lung nodules detection.

Reducing the radiation dose without degrading the imaging properties.

Image analysis and classification systems based on **DL** and **radiomics**.

- **IR algorithms** to reduce the dose while preserving **image quality**
- **Image denoising**
- **CAD** to retrieve low contrast details
- **Radiomics** and **DL** for **nodules segmentation** and **classification**.

The CAD must be robust so the significant features on which it is built must also be robust.

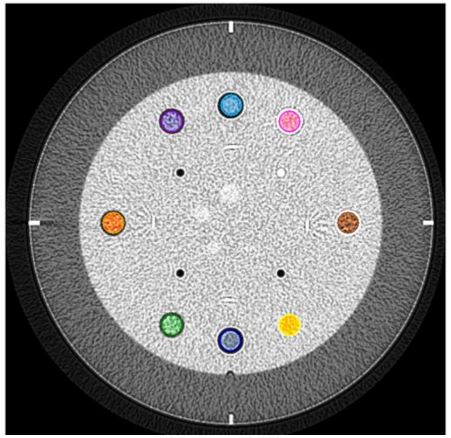
Multicentric datasets are fundamental for creating reliable models that can adapt to changes in the dataset.

Standardized procedures for data harmonization do not exist yet.

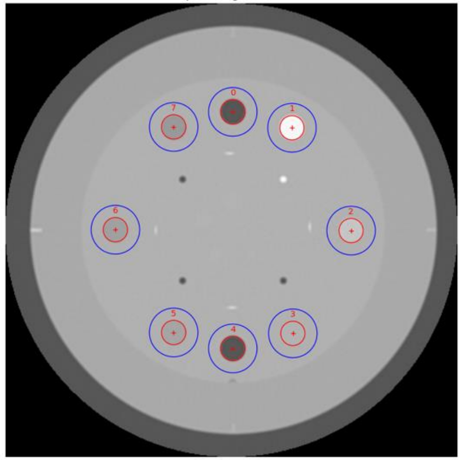
Feature robustness and data harmonization are key requirements for the explainability and generalizability of radiomics-based clinical prediction models.

In this study repeatability and robustness of radiomics features extracted from CT images of phantoms are investigated using an a priori image harmonization strategy based on image quality matching to increase the robustness of radiomic features and perform multi-centric studies with low-dose acquisition protocols.

Image quality evaluation



Catphan Image with ROIs



Detectability index with Non-prewhitening matched filter with eye filter (NPWE) model observer

signal to be detected *Spatial resolution*

$$d'^2_{NPWE} = \frac{\left[\int\int |W(u,v)|^2 \, TTF^2(u,v) E^2(u,v) du dv\right]^2}{\int\int |W(u,v)|^2 \, TTF^2(u,v) NPS(u,v) E^4(u,v) du dv}$$

noise characteristics

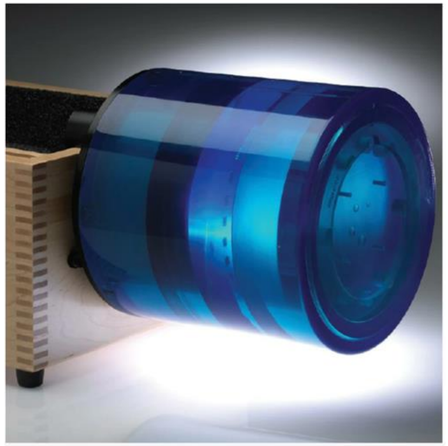
$$E(\rho) = \left| \eta \rho^{1.5} \cdot e^{-0.98 \cdot \rho^{0.68}} \right|^2$$

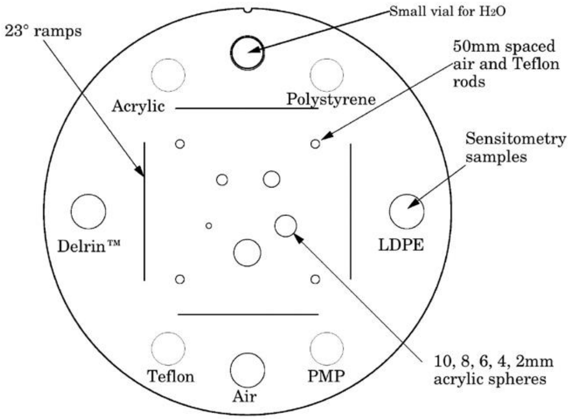
*Eye filter**

Evaluated with **imQuest software** (Duke University, Durham) and script written in house and currently under development.

Solomon, Justin, Joshua Wilson, and Ehsan Samei. "Characteristic image quality of a third generation dual-source MDCT scanner: noise, resolution, and detectability." Medical physics 42.8 (2015): 4941-4953.

Catphan phantom CT acquisitions





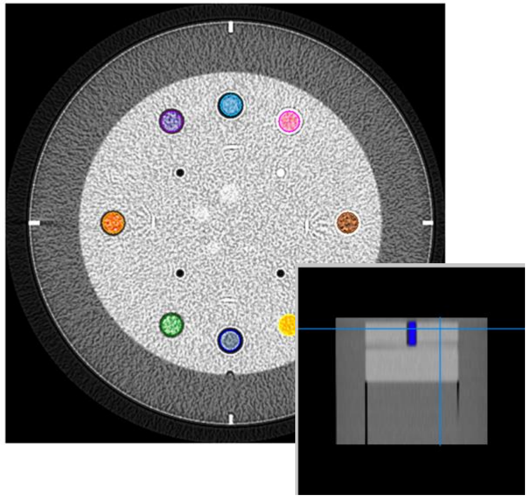
96 CT scans:

- Institutional clinical CT protocols
- 2 CT systems
- 4 dose levels
- 4 reconstruction methods
- 3 repetitions

	Revolution GE	Aquilon Toshiba
$CTDI_{vol}$ [mGy] (Tube current [mA])		
High	13.52 (160)	16.50 (300)
Standard	6.76 (80)	8.30 (150)
Reduced	4.06 (50)	5.00 (90)
Low	2.03 (25)	2.49 (45)
Data acquisition		
Tube potential (kVp)	120	120
Pitch	0.984	0.938
Image Reconstruction		
Display field of view (mm)	210	219
Pixel Spacing (mm)	0.406	0.427
Slice thickness (mm)	1.25	1.00
Kernel	LUNG	FC56
Reconstruction algorithm	FBP, ASIR	FBP, AIDR 3D
Iterative level	0%, 10%, 40%, 70%	0%, mild, standard, strong

Preparatory radiomics study with Catphan

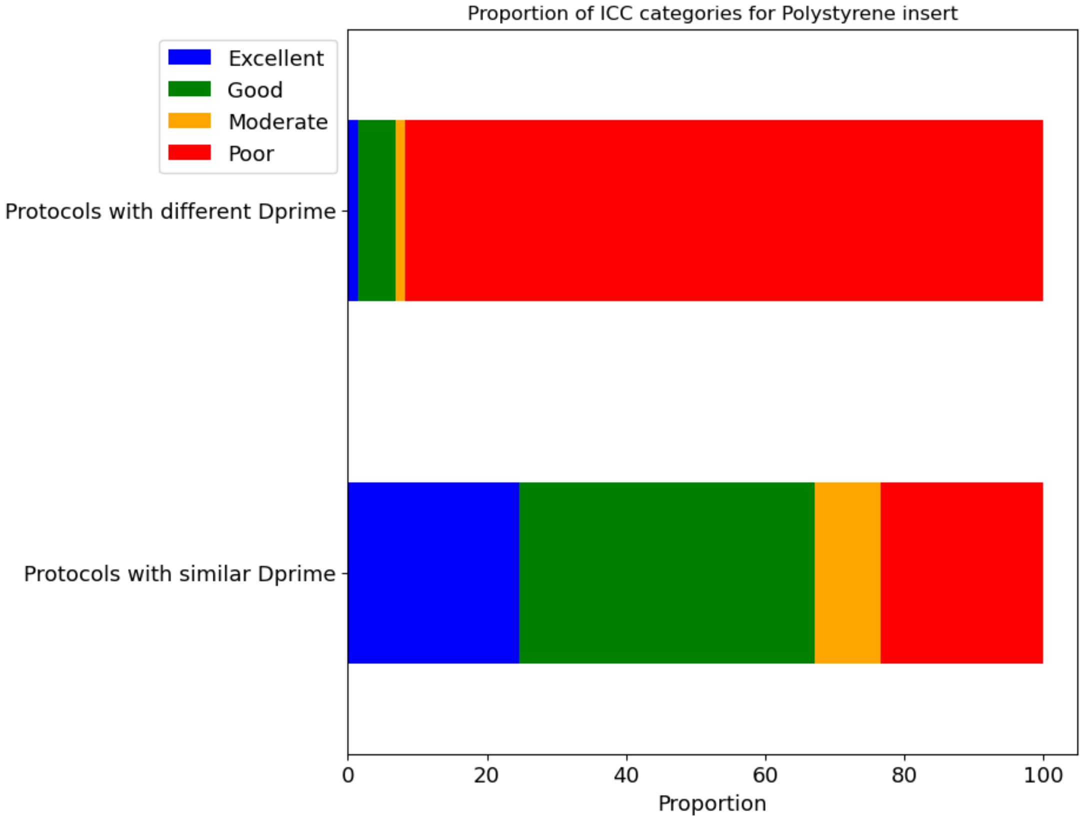
- **86** radiomic features extracted with Pyradiomics from each ROI in each CT series:
  - → **first-order statistics features;**
  - → **second-order statistics features.**
- BW=25 HU.
- Features extracted from original images, without applying any filters.



Intraclass Correlation Coefficient:

$$ICC = \frac{MS_R - MS_E}{MS_R + \frac{1}{n}(MS_C - MS_E)}$$

Excellent: ICC $\geq$ 0.9
Good: 0.75 $\leq$ ICC $<$ 0.9
Moderate : 0.5 $\leq$ ICC $<$ 0.75
Poor: ICC $<$ 0.5



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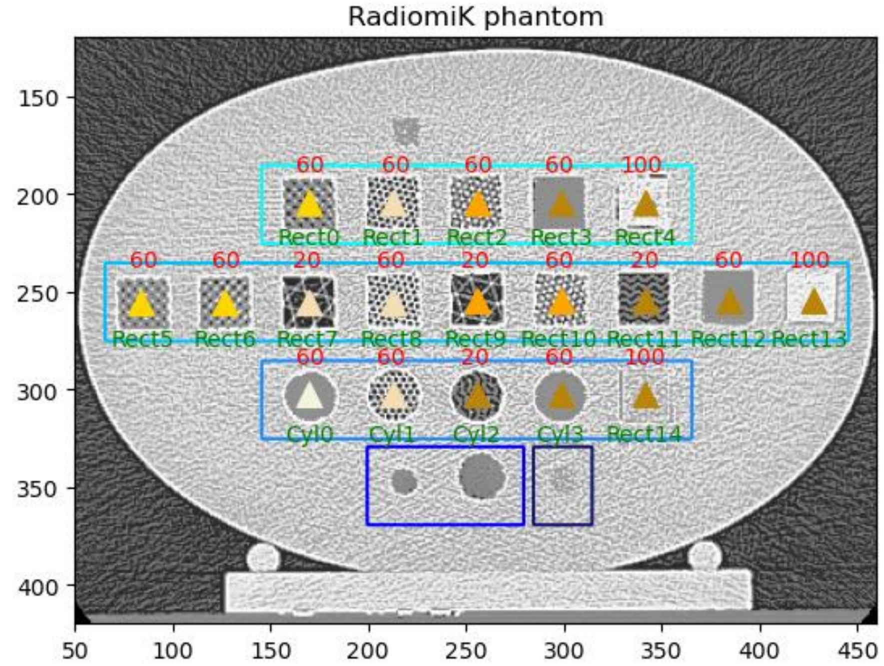
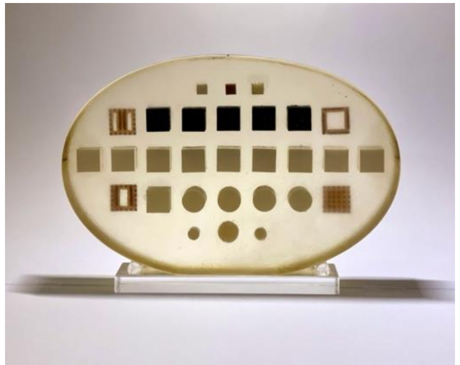
Preliminary radiomics study with RadiomiK phantom

Custom phantom designed to **test repeatability** and **reproducibility** of **CT radiomic features**.

- **25 inserts** (~15mm) with different materials, textures, shapes and sizes:
    - 6 inserts with homogeneous materials;
    - **19 inserts** with different textures:
        - 3 materials, 3 filling percentages, 2 shapes and 5 textures.

**Pallotta et al. PO-1536: RadiomiK: a phantom to test repeatability and reproducibility of CT-derived Radiomic Features.*





Acquisition Protocols and features extraction

- **Two CT scanners**: Revolution Evo 64 Slice (GE Healthcare) and Aquilon CX 128 Slice CT (Toshiba).
- **10 acquisition protocols** and **3 repetitions** for a total of **30 CT scans**.
- **3 dose levels** and **4 Iterative reconstruction blending levels** (ASIR and AIDR3D).
- **Sharp reconstruction kernel**.

Features extraction with **Pyradiomics**:

- **Bin Width:** 25 HU and 50HU.
- **86 features**: first and second order.
- **Original images**.

RadiomiK Protocol	Scanner	$CTDI_{vol}$ [mGy]	Iterative level
1	GE	7	FBP
2	GE	7	ASIR 10%
3	GE	7	ASIR 70%
4	Toshiba	2	AIDR3D MILD
5	Toshiba	2	AIDR3D STD
6	Toshiba	2	AIDR3D STRONG
7	Toshiba	4	FBP
8	Toshiba	4	AIDR3D MILD
9	Toshiba	4	AIDR3D STD
10	Toshiba	4	AIDR3D STRONG

Table 3.4: Set of acquisition/reconstruction parameters corresponding to the protocols used to obtain the RadiomiK CT images.

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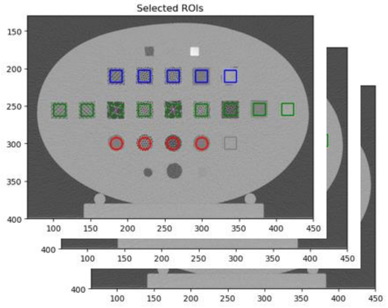
Repeatability

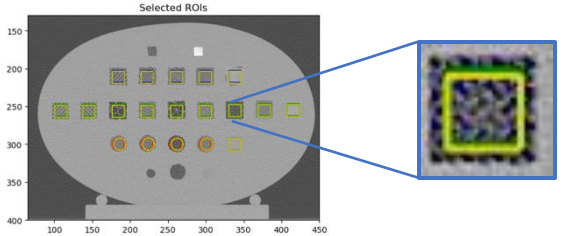
Closeness of agreement between measured features values obtained by means of replicate measurements.

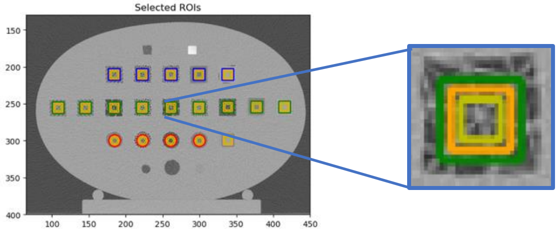
Coeff. of Variation

$$CV = \frac{\sigma}{\mu}$$

- **Test-Retest**: 3 repetitions
- **ROI (Region of Interest) Positioning**: 10 ROI positions
- **ROI volume**: 3 ROI volumes







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Robustness

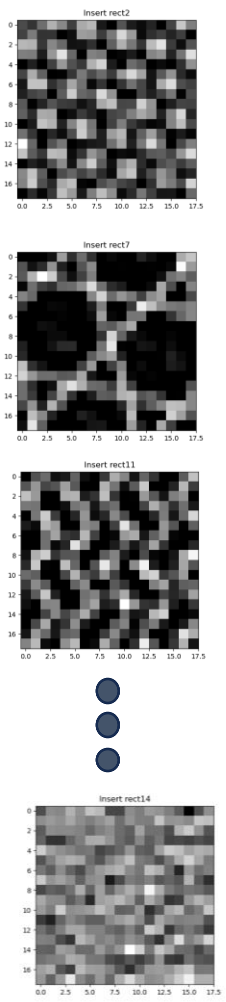
Invariance of feature values in the acquisition of the same subject across different settings.

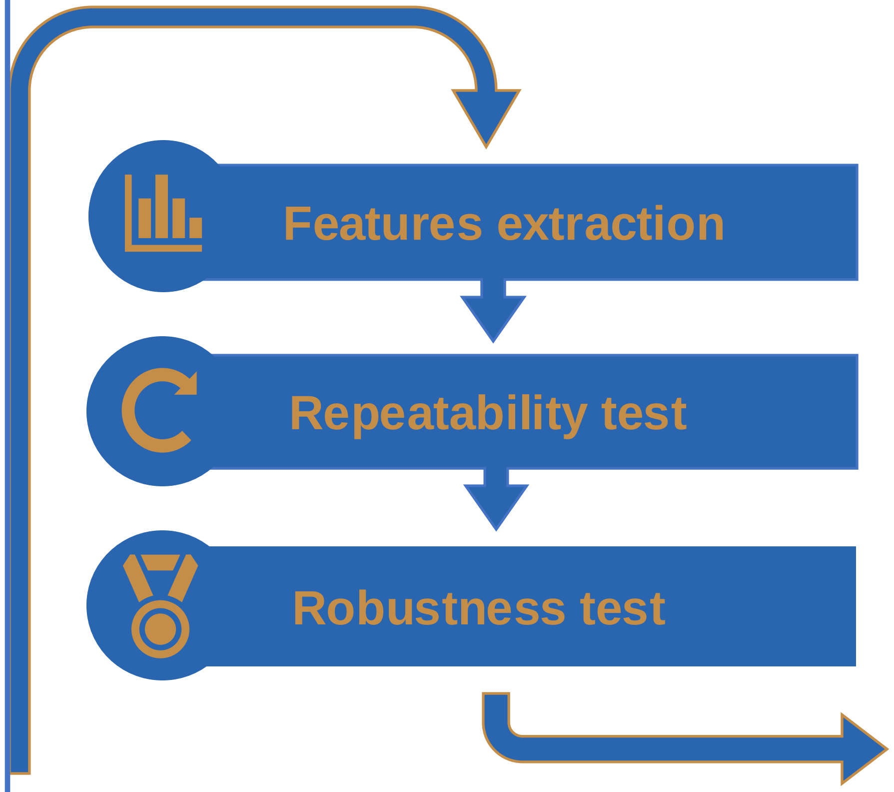
Non-repeatable features discarded from the robustness analysis

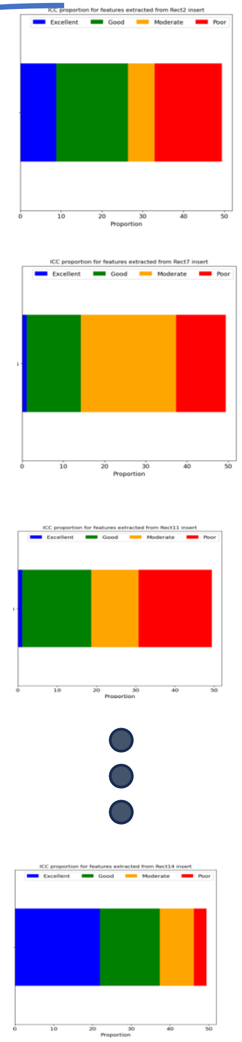
Intraclass correlation coeff.

$$ICC = \frac{MS_R - MS_E}{MS_R + \frac{1}{n}(MS_c - MS_E)}$$

Excellent: ICC $\geq$ 0.9
Good: 0.75 $\leq$ ICC $<$ 0.9
Moderate : 0.5 $\leq$ ICC $<$ 0.75
Poor: ICC $<$ 0.5







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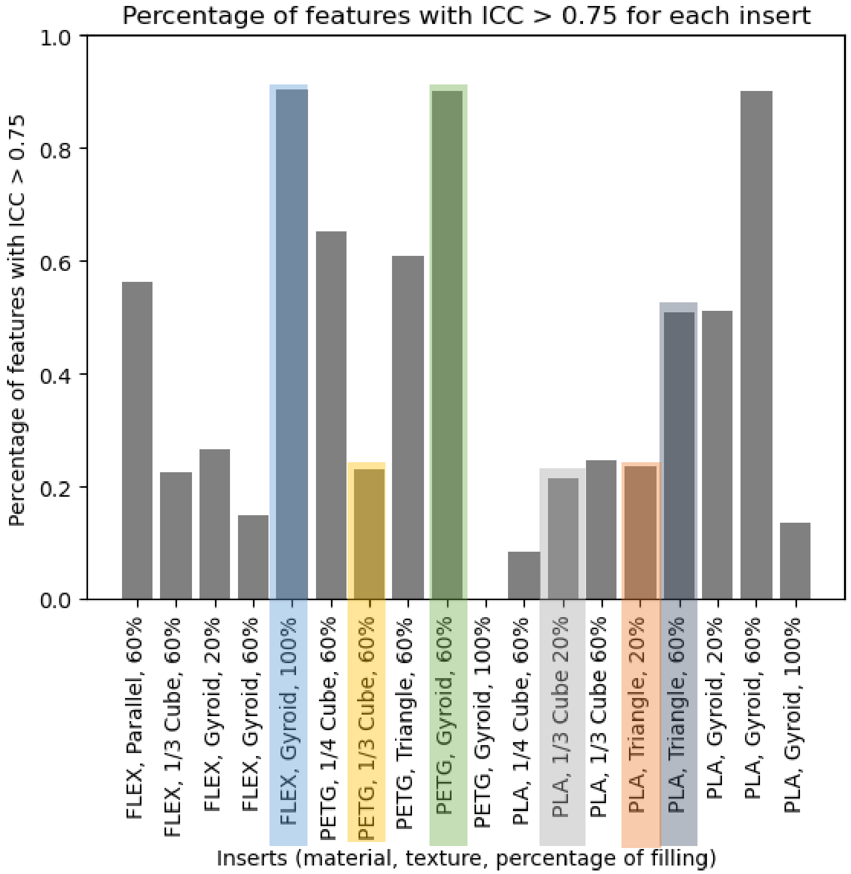
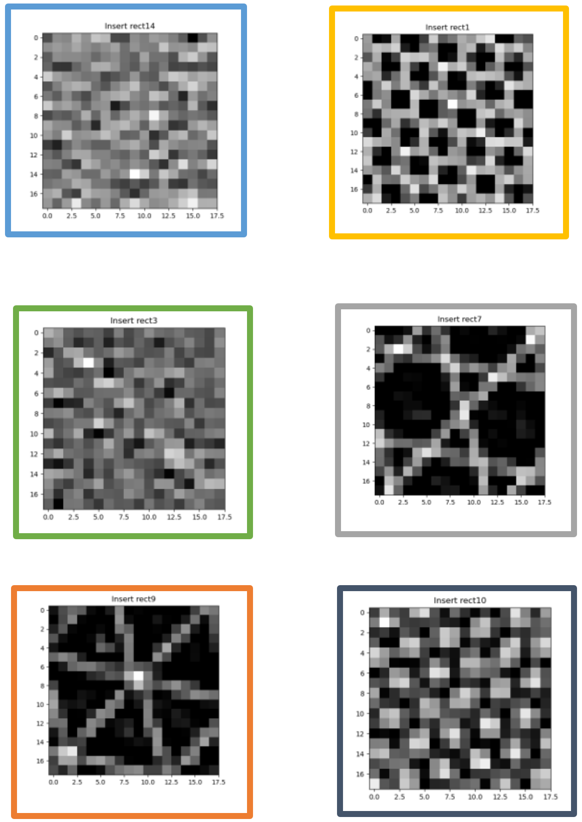
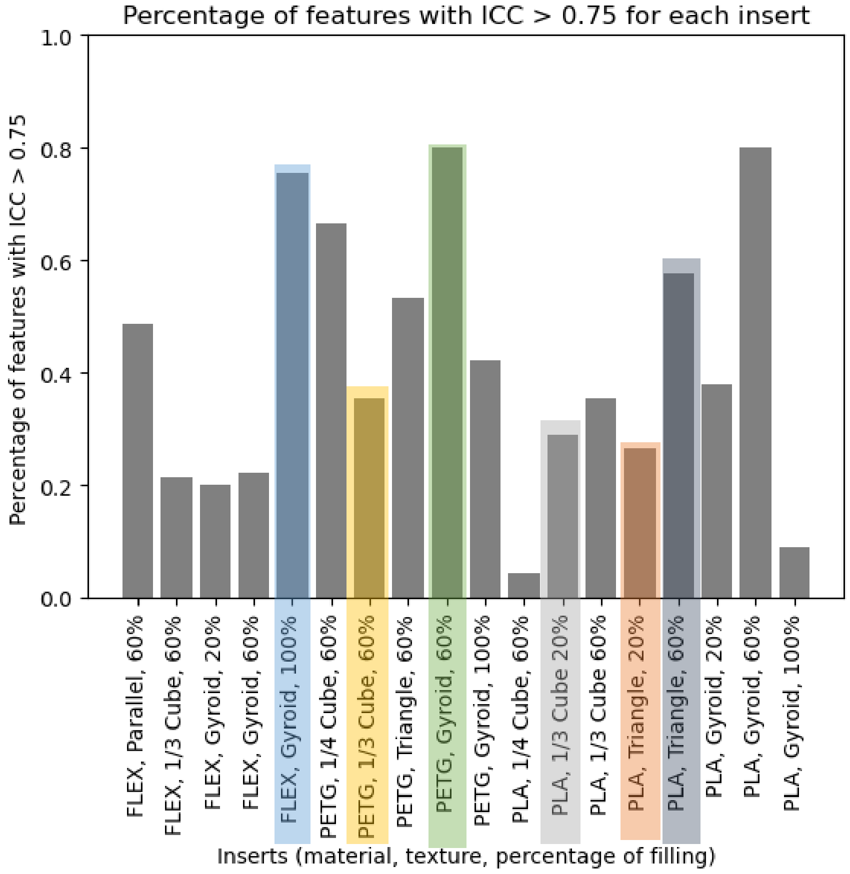
Results

$$\%P = \frac{N^{\circ}_{\text{reap feat}}(ICC > 0.75)}{N^{\circ}_{\text{reap feat}}}$$



BW 25 HU





BW 50 HU

Conclusions and Future developments

Radiation dose reduction:

- high **IR algorithms** blending level to design **ultra-low dose acquisition protocols**;
- **image denoising** using AI.

Ai models to support radiologist:

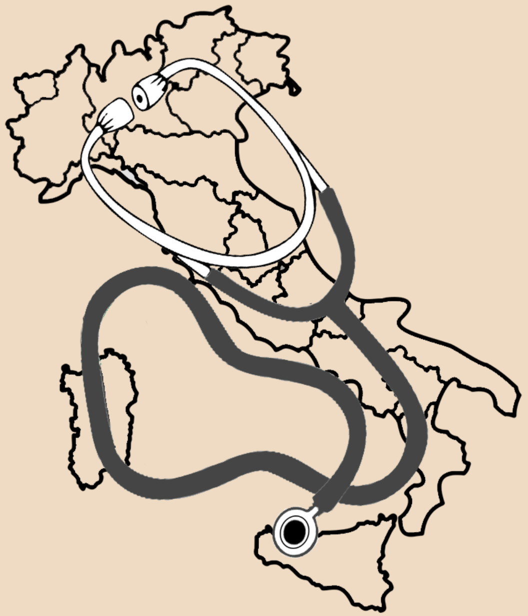
- **multi-centric studies** with harmonization strategy based on image quality matching and standardized process for image acquisition and features extraction;
- **XAI** on segmentation of Lung nodules using Grad-CAM.

Expand this study to **more clinical facilities** using a **data sharing platform*.**

*Scapicchio, Camilla, et al. "Integration and Optimization of XNAT-Based Platforms for the Management of Heterogeneous and Multicenter Data in Biomedical Research."

Further investigate how radiomics could be integrated with **AI-based CAD systems** (hybrid models).

Thank you for the attention



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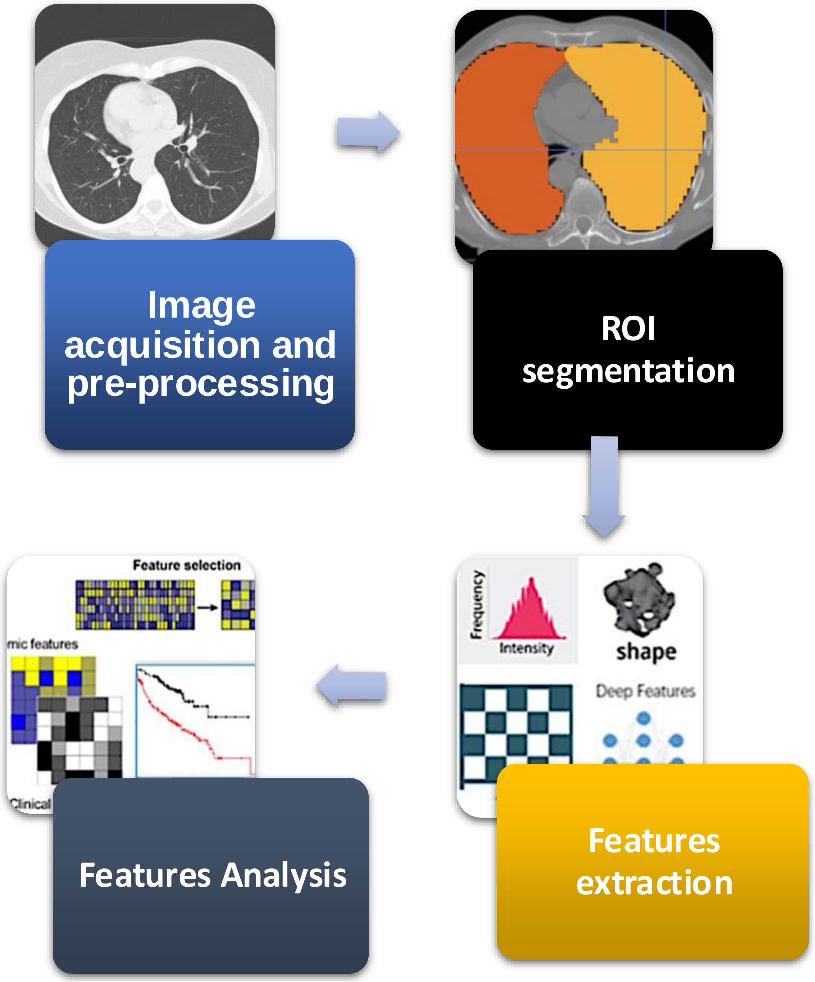
Radiomics in CT imaging

Predictive models combining **AI** with **radiomic features**.

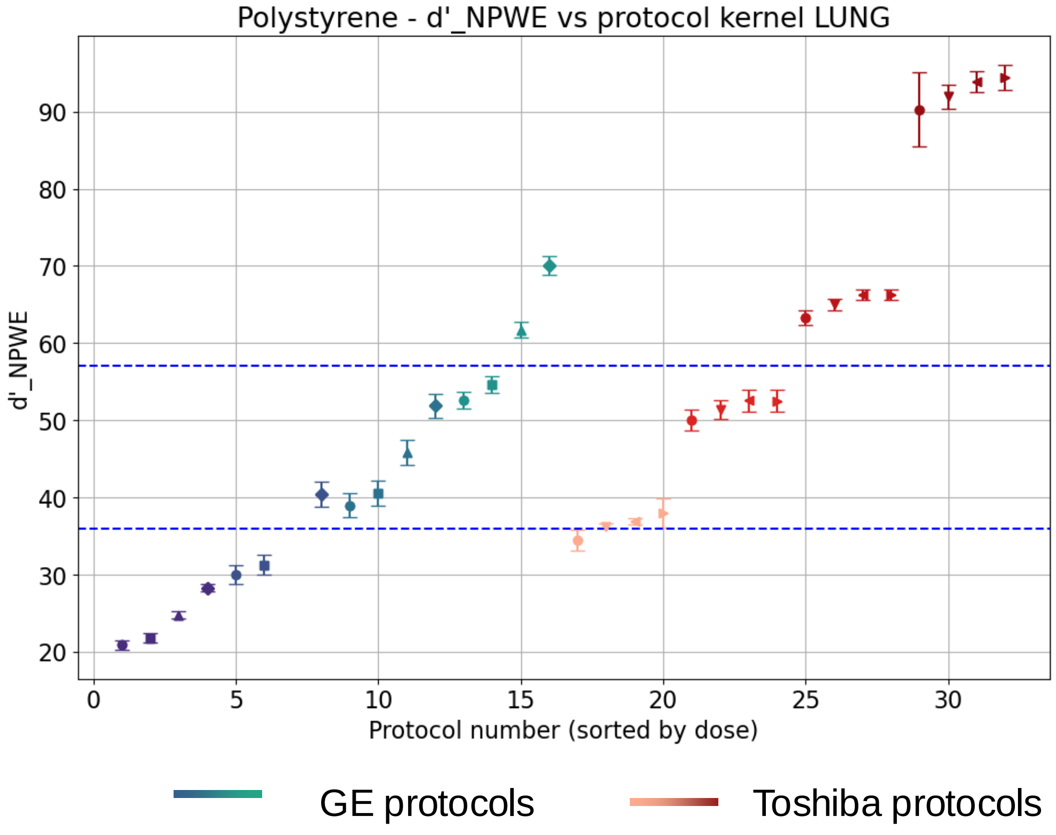
Instability of the features with respect to the **acquisition parameters**.

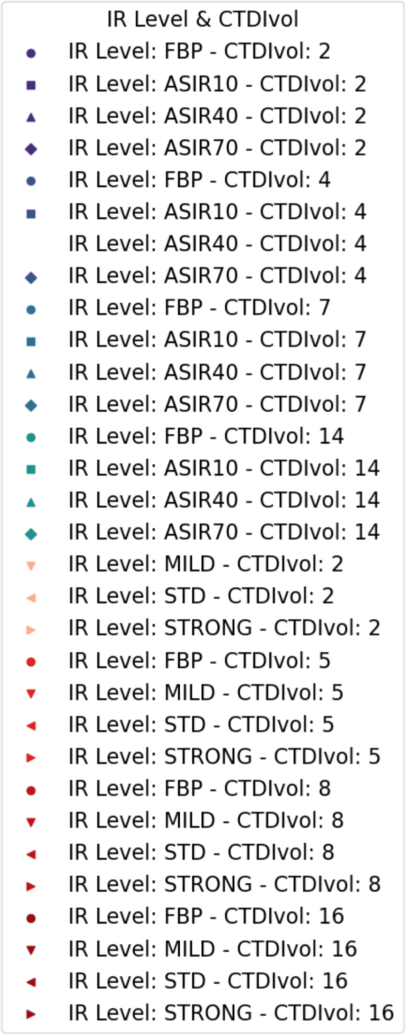
Evaluation of **repeatability** and **robustness** acquiring **CT scans** of a commercial phantom and a custom phantom using different acquisition protocols with an **a-priori harmonization strategy based on image quality matching***.

**Scapicchio, Camilla, et al. "Investigation of a potential upstream harmonization based on image appearance matching to improve radiomics features robustness: a phantom study." Biomedical Physics & Engineering Express 10.4 (2024): 045006.*



Protocol	Scanner	$CTDI_{vol}$	Iterative level
8	GE	4	ASIR 70%
9	GE	7	ASIR 0%
10	GE	7	ASIR 10%
11	GE	7	ASIR 40%
12	GE	7	ASIR 70%
13	GE	14	ASIR 0%
14	GE	14	ASIR 10%
18	Toshiba	2	AIDR 3D MILD
19	Toshiba	2	AIDR 3D STANDARD
20	Toshiba	2	AIDR 3D STRONG
21	Toshiba	5	FBP
22	Toshiba	5	AIDR 3D MILD
23	Toshiba	5	AIDR 3D STANDARD
24	Toshiba	5	AIDR 3D STRONG





- Identification of the 14 **equivalent protocols** providing similar image quality.
- **Potential harmonization strategy** based **on image quality matching** to improve radiomics features robustness.