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MEDICAL IMAGING METROLOGY

Perspectives from the AAPM Working Group on the Physics of Quantitative Imaging

AAPM-WGPQI

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Disclosures

- The presenter has no relevant financial relationships to disclose
- No conflicts of interest related to this presentation

AAPM and Medical Imaging Metrology

- 9700+ members, 21 regional chapters
- Medical physicists, imaging and therapy scientists, industry and federal representatives

Imaging and data

Standardization
Harmonization

Procedures and guidelines

Quality assurance
Quality control

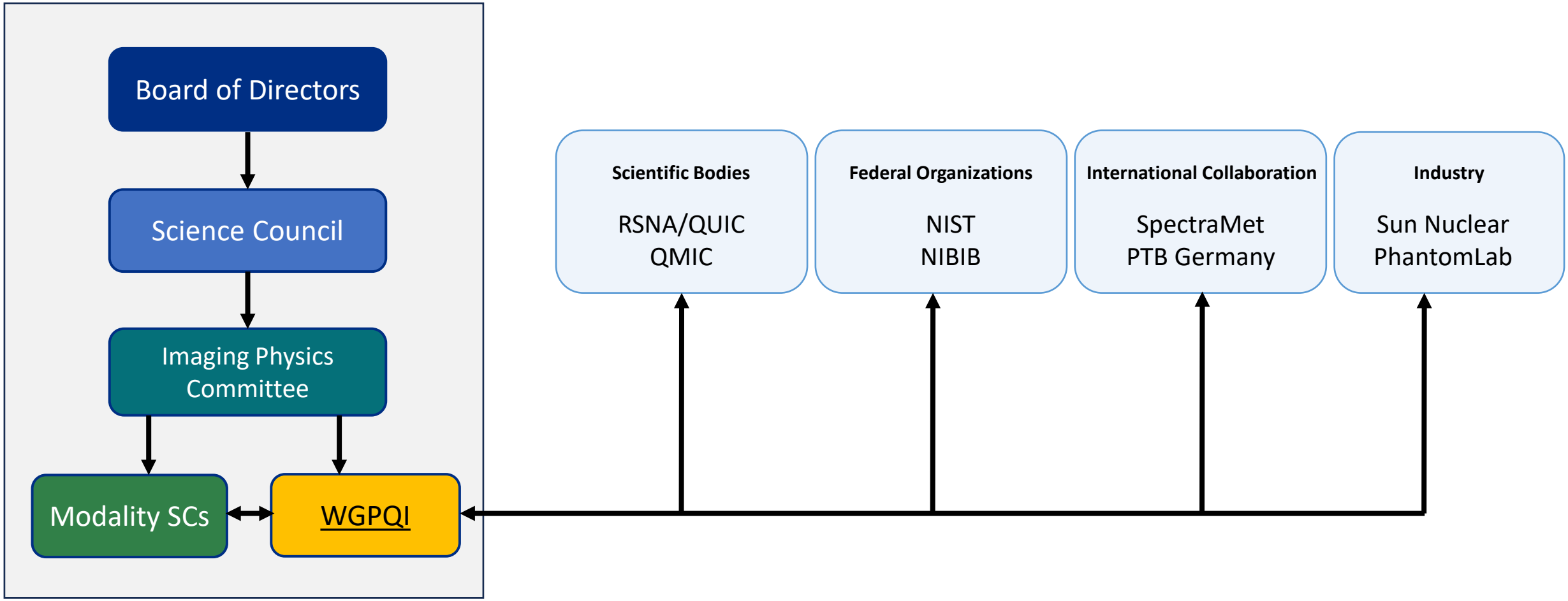
Phantoms

Design, development, validation

Metrology TGs/WGs

TG 162, TG 120, TG 299, TG 480, DICOMC, **WGPQI**

AAPM Working Group on the Physics of Quantitative Imaging



Physics-related challenges in quantitative imaging



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Quantitative CT

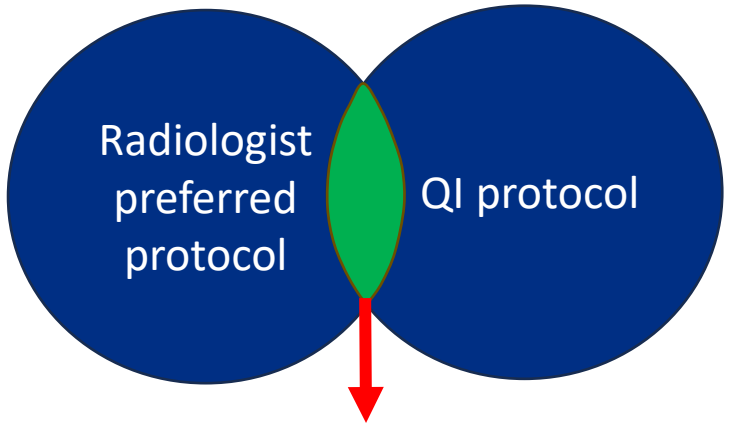
Goal: To obtain one or more measurements to aid clinical diagnosis, disease monitoring, and/or intervention

- Morphology (shape, size, texture, area/volume)
- Composition (radiodensity, mass density, volume fraction)
- Fluid flow (FFR, perfusion, 4D flow)
- Physiologic motion (4DCT, joint kinematics)

Challenges

- QI scanner agnostic? **There is no "one-size-fit-all" QI methodology**
- Newer CT technologies and technical features (e.g., energy-integrating CT versus photon-counting CT)

Image quality driven
Offers flexibility
Individual/site preferences
Focuses on clinical indication



Measurement driven
Offers standardization
Supports reproducibility
Focuses on precision

Balanced approach:
Better outcomes for patients

Quantitative MRI

Does it matter? Clinical question/need that is currently not adequately met by other methods, including qualitative MRI.

Does it work? In qMR, the bottleneck is often reproducibility

- Metrology guidelines need to be practical and achievable in clinical setting
- Practical QMR phantoms for use in clinical settings

Does it have clinical (non-radiologist) champions? For example, quantitative liver MRI has benefited enormously from the efforts of hepatologists to get liver qMR methods used clinically and in clinical trials.

Courtesy: Diego Hernando, Dariya Malyarenko, Trevor Andrews

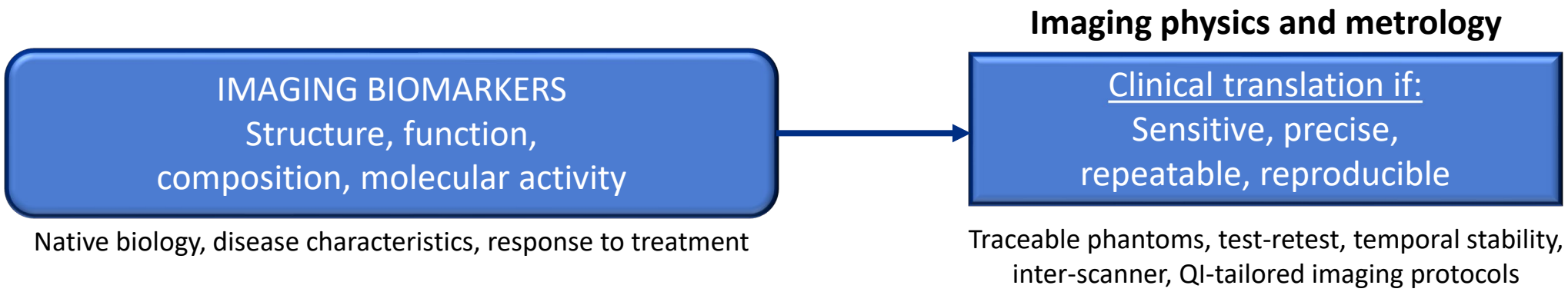
Sources of variability in QI

Patient (body habitus/BMI, heart rate)

Operator (patient positioning, protocol selection)

Scanner (hardware, calibration, drift, acquisition parameters)

Software (reconstruction, post-processing, analytical tools, version control)



WGPQI

- Harness the expertise of AAPM members – **physics of diagnostic imaging**
  - Image acquisition and reconstruction
  - Post processing and computer-aided analysis
  - Data science and analytics
- **Physics-driven** methods to estimate the quantitative magnitude of biomarkers
  - WGPQI will **not** include the discovery or translation of imaging biomarkers themselves
- Expected outcome – **Quantitative Physics Imaging Document (QPID)**
  - Modality-specific, task-specific **guidance document**
  - Describes measurands and imaging parameters to support quantitative claims
  - Metrological performance – precision, bias, repeatability, reproducibility

WGPQI team

Computed tomography



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NIBIB



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Ted Lynch
Sun Nuclear, Mirion



Richard Mallozzi
Phantom Laboratory

WGPQI current activities

Quantitative spectral CT inter-scanner reproducibility using photon-counting CT

Phantom study to assess attenuation and/or iodine concentration of known materials and to evaluate agreement (or variability) of these measurements under extremely harmonized conditions across sites and scanners.

TG465: Development and validation of dynamic CT for musculoskeletal imaging

(WGPQI co-parent with AAPM CT sub-committee)

Development and optimization of dynamic musculoskeletal imaging protocols for specific joints and assessing precision, bias, repeatability and reproducibility of key measurands using the established protocols.

TG480: Quality assurance and optimization of MRI-based R2* mapping

(WGPQI co-parent with AAPM WG on Quantitative MR)

Describe QA and QC procedures for MRI-based R2* mapping with a focus on liver iron quantification, including a description of known failure modes and artifacts.

Quantitative spectral CT inter-scanner reproducibility using photon-counting CT

Liu LP, Rybertt MV, Noel PB, Ren L, Duan X, Rajendran K, Zhang D, Kim GH, McNitt-Gray MF



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QPID – Spectral CT

Purpose

Assess agreement (or variability) in photon-counting CT (PCCT) measurements (attenuation and iodine concentration) under extremely harmonized conditions across sites and scanners

Four participating sites with clinical PCCT installations

- University of Pennsylvania
- University of California Los Angeles
- Mayo Clinic Rochester
- University of Texas Southwestern Medical Center









QPID – Spectral CT

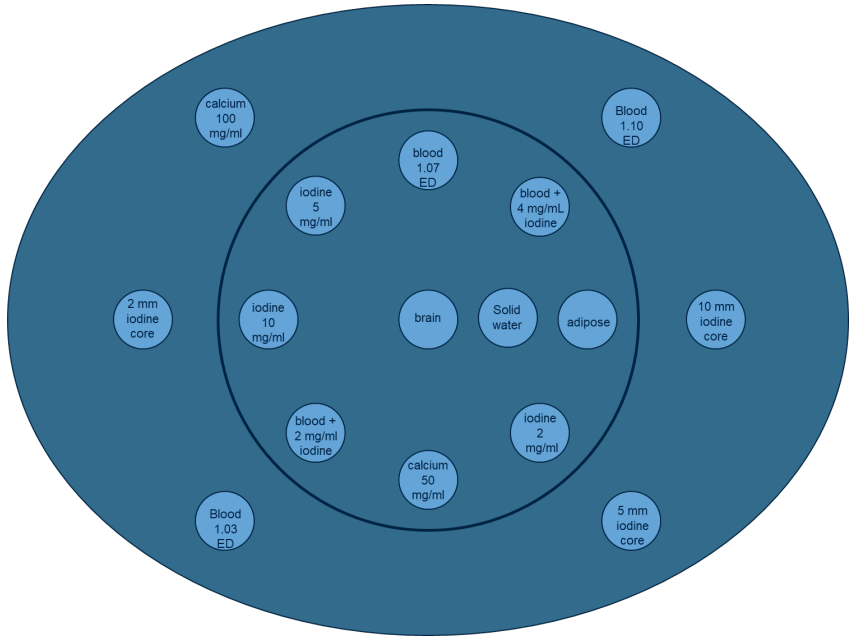
Inserts: solid water, adipose, blood 70, blood + 2 mg/mL iodine, blood + 4 mg/mL iodine 2 mg/mL, iodine 5 mg/mL, iodine 10 mg/mL

GENERAL SCAN	
Patient Type	Adult
Organ Characteristic	Abdomen
Target Region	Abdomen
Scan Mode	RoutineSpiralAdultAbdomenQuantumplus
Decision Trees	
Acquisition [mm]	144 x 0.40
Scan Direction	Head to Feet
Table Direction	In

DOSE	
CARE Dose4D & CARE keV	Off
kV	140
Eff. mAs	87
CTDIvol [mGy]	(32 cm) 10.0
SSDE [mGy]	(34.6 cm) 10.4
DLP	~134
Dose Notification CTDIvol [mGy]	0
[mGy*cm]	0
Shaped Filter	Standard
mA average	348/348

CONFIG	
Memo	
Check&GO	Coverage
Check&GO Image Type	MPR
Check&GO Orientation	Coronal
Scan Start	START key
Scan Ref. Lines	Off

TIMING	
Pitch	1
Rot. Time [s[	0.25
Exam Time [s]	2.08
Patient Instruction	None
Absolute Start Delay	2.0 | 2



Multi-energy CT phantom (MECT, Gammex/Mirion)

Scanner: NAEOTOM Alpha (Siemens Healthineers)

Liu et al.

Standard test object, matched scan protocol

QPID – Spectral CT

GENERAL RECON	
Slice Thickness [mm]	2
Increment [mm]	2
No. of Images	~48
Comment 1	
Comment 2	

IMAGE IMPRESSION	
Window@120kV	Mediastinum
FAST Window	Off
Kernel	Qr48
QIR	On
QIR Strength	2
iBHC	On
iBHC material	Quantum
iMAR	Off

RECON BOX	
Image Orientation	Axial
Image Order	Head to Feet
FAST Planning	Thorax-Lung
FAST Planning Width	Wide
Matrix Size	512
Matrix	Square
Width [mm]	450
Height [mm]	450
Center X [mm]	0
Center Y [mm]	0
Mirroring	None
HD FoV	Off

RECON&GO				
Spectral Recon	Monoenergetic Plus	Iodine	VNC	None
Auto keV	Off	Off	Off	Off
Energy [keV]	40-190 (10 keV intervals)	None	None	None
Inline Results	None	None	None	SPP
Multi Recons	None	None	None	None
Fix Axial	On	On	On	On

GENERAL RECON				
Slice Thickness [mm]	2	2	2	2
Increment [mm]	2	2	2	1
No. of Images	~48	~48	~48	~96
Comment 1				
Comment 2				

Matched image reconstruction and image types

QPID – Spectral CT

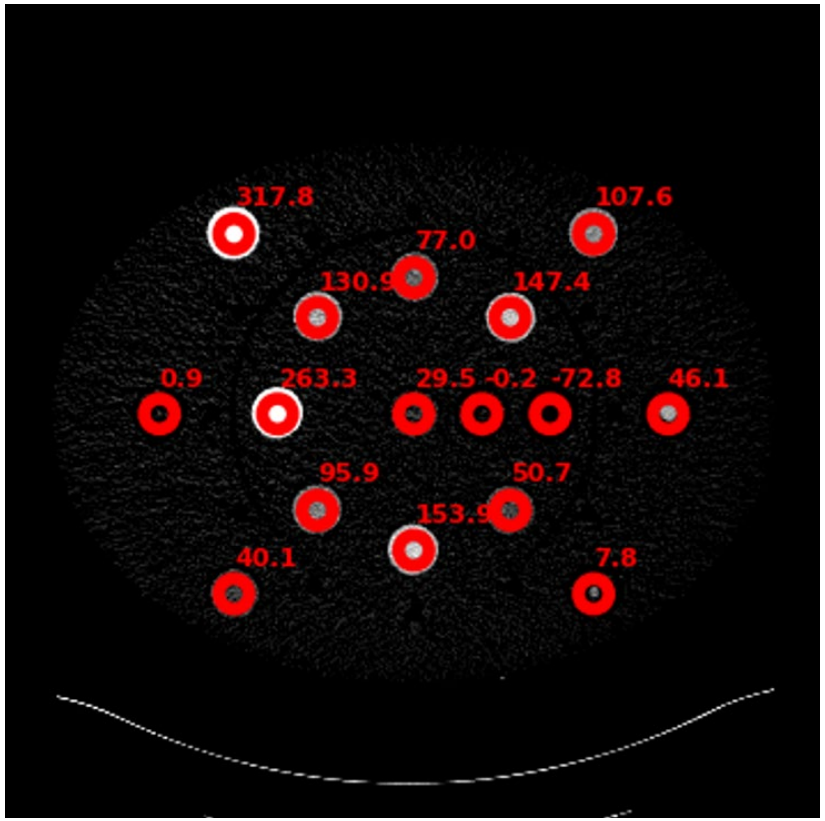
Standardized measurements (ROI size, location)

Standardized image analysis

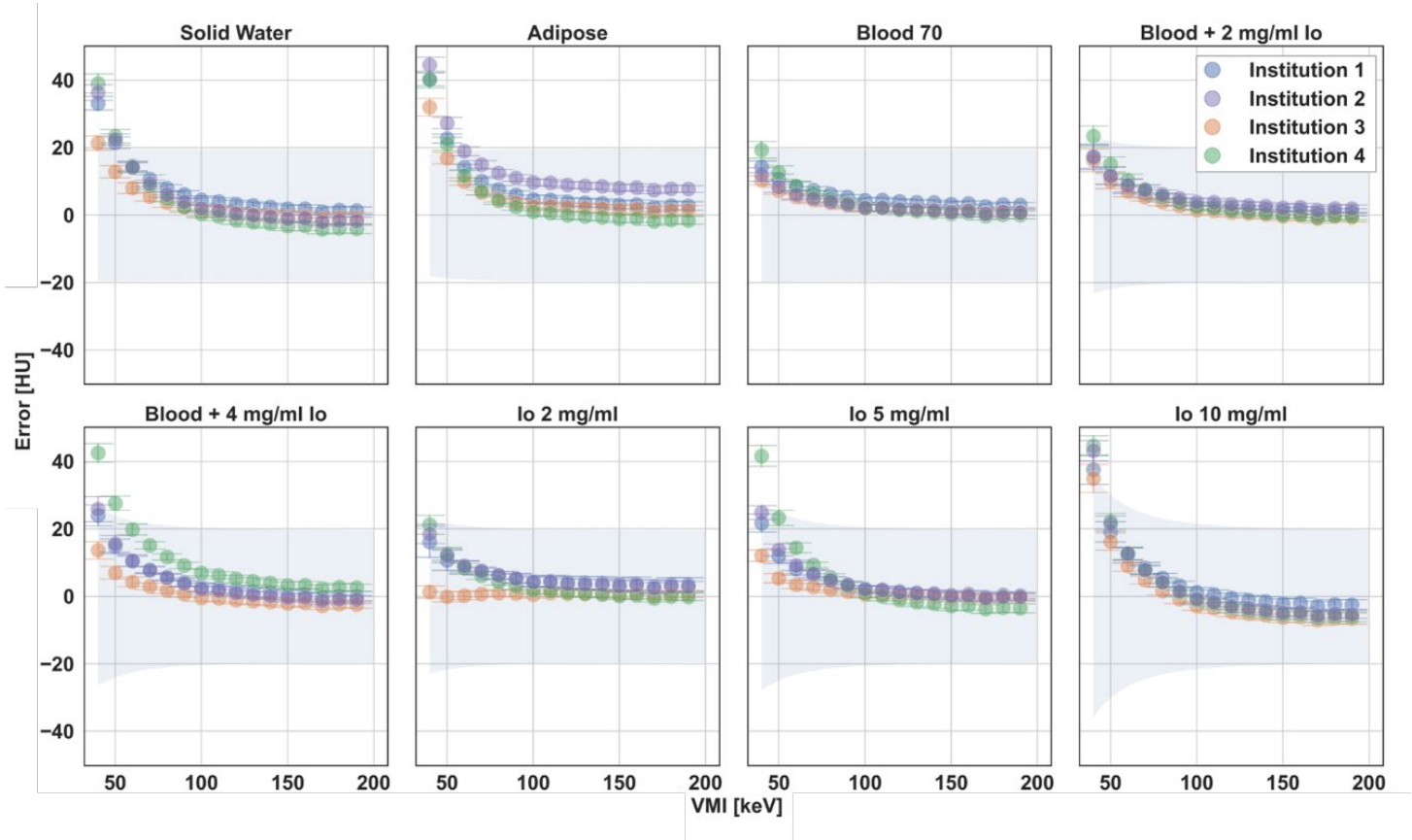
- Average error (for each insert across sites)
- Standard deviation of the error (for each insert across sites)
- Average noise (for each insert across sites)
- Standard deviation of the average errors between sites for test condition (inter-scanner standard deviation)

Standardized statistical analysis

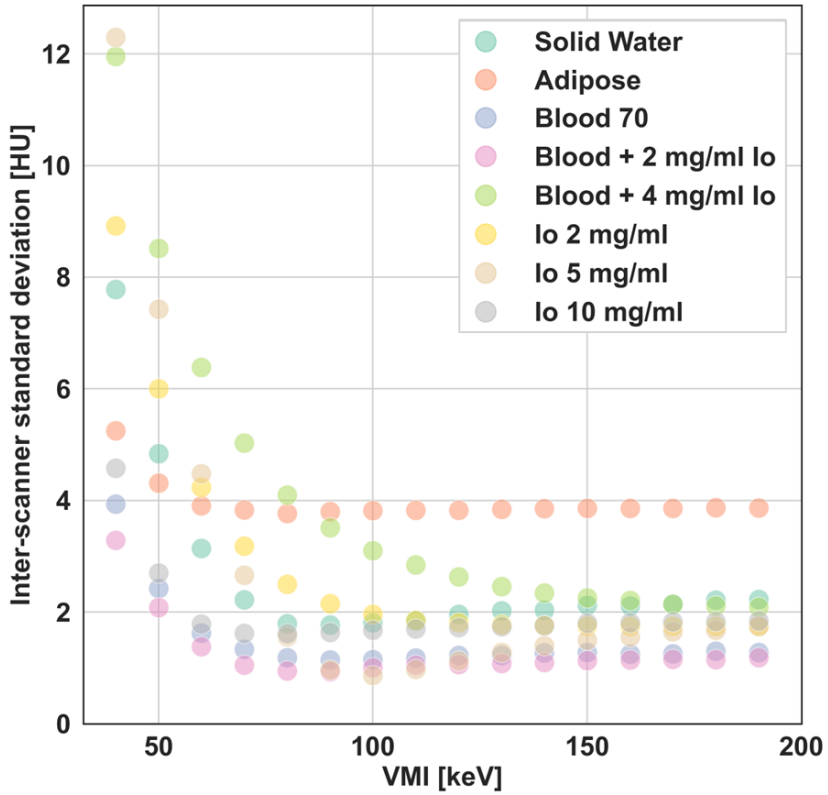
- Mean relative error
- SD of relative error
- Repeatability coefficient (RC)
- Within-case coefficient of variance (wCV)
- Reproducibility coefficient (RDC)
- Reproducibility interval (RI) - relative error of the measured vs. expected attenuation



QPID – Spectral CT



Error of various phantom inserts at a tube voltage of 140 kV and a $CTDI_{vol}$ of 10 mGy. Blue shaded regions correspond to the expected range of values, based on the phantom manufacturers' specifications of the material compositions.



Inter-scanner standard deviation for different inserts.

WGPQI/QPID dissemination

1. **RSNA Annual Meeting 2026**: Liu et al. Inter-institutional Repeatability and Reproducibility of Quantitative Spectral Results with Clinical Photon-counting CT. Accepted for Poster presented at RSNA 2026, Chicago, IL
2. **AAPM Annual Meeting 2026**: Liu et al. Inter-Institutional Quantification of Spectral Results with First-Generation Clinical Photon-Counting CT. In 2026 Joint AAPM| COMP Annual Meeting & Exhibition 2026 Jul 19, Vancouver BC, Canada
3. **SPIE Medical Imaging 2026**: Liu et al. "Evaluating inter-institutional reproducibility of quantitative spectral results with clinical photon-counting CT: initial results using the same scanner, protocol, and phantom", Proc. SPIE 13924, Medical Imaging 2026: Physics of Medical Imaging, 139241T, 2 Apr 2026, Vancouver BC, Canada
4. **RSNA Annual Meeting 2025**: Liu et al. Inter-institutional Consistency of Quantitative Spectral Results with Clinical Photon-counting CT, presented at RSNA 2025, Chicago, IL

Symposium/courses

1. Rajendran K, Boss M, Kim GH, McNitt-Gray MF, Physics of Quantitative CT and MRI, RSNA 2025 Chicago, IL
2. Liu LP, Hernando D, Fowlkes JB, Rajendran K, Physics of Quantitative CT, MRI and Ultrasound, AAPM 2026, Vancouver BC, Canada

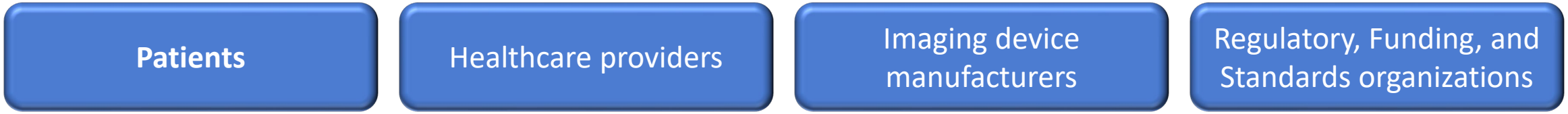
Outlook – medical imaging metrology



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Quantitative Imaging Metrology

- Contemporary medicine benefits from "**metrologically sound"** quantitative imaging



- Medical physics has a central role in QI and biomarker development, validation, and clinical deployment
  - Measurand(s) and imaging conditions, scanner parameters
  - Benchmarks: Precision, Bias, Repeatability and Reproducibility
  - Standardization, harmonization, and traceable phantoms
  - Clinical QC/QA procedures

QPID from AAPM WGPQI

Outlook



Fully finished floor that looks unfinished

Standards: Backward compatibility vs. future facing

Consensus: Collaborative decision making

Reward: Incentives for “best practices”

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AAPM HQ

AAPM Science Council

Spectral CT reproducibility

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Grace Kim, PhD

Peter Noel, PhD

Martin Rybertt, PhD

Liqiang Ren, PhD

Xinhui Duan, PhD

Di Zhang, PhD

NIST and NIBIB

Stephen Russek, PhD

Martin Tornai, PhD