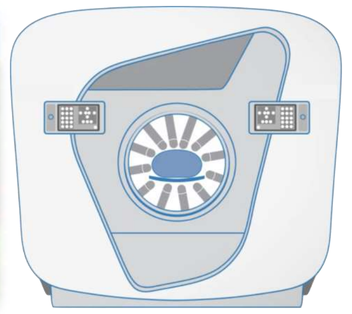
SOCIETY OF NUCLEAR MEDICINE AND MOLECULAR IMAGING
SOUTHWESTERN CHAPTER

# LATEST DEVELOPMENTS IN CZT SPECT IMAGING

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BRIGHAM HEALTH
BRIGHAM AND WOMEN'S HOSPITAL

HARVARD MEDICAL SCHOOL TEACHING HOSPITAL

Mass General Brigham

# DISCLOSURE

I have no relevant financial interests to disclose

# LEARNING OBJECTIVES

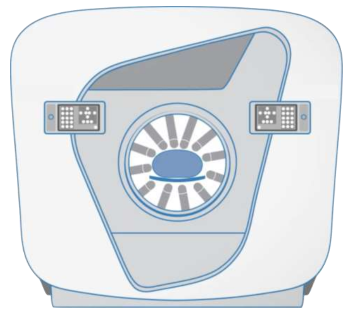
## At the end of this presentation, you will be able to,

A) **Recognize** the **specificity** of **CZT-based SPECT systems**

B) **Identify** the **advantages** of **CZT detector technology** for imaging

C) **Categorize** the **clinical applications** of **CZT-based SPECT** and **SPECT/CT systems**





# OUTLINE

I. CZT DETECTORS FOR SPECT
II. CARDIAC DEDICATED CZT SPECT
III. FULL-RING CZT SPECT/CT
IV. CLINICAL APPLICATIONS AND ADDED VALUE
V. ABSOLUTE QUANTITATION CALIBRATION
VI. IMPACT OF THE CALIBRATION ACCURACY ON QUANTITATION

# CZT DETECTORS

**C**admium **Z**inc **T**elluride (**CZT**)

## Characteristics

- Semiconductor at room temperature
- **Direct Conversion** of the $\gamma$-ray energy into an electronic signal
- **Higher Density** than conventional NaI(Tl): **5.8** Vs **3.7** g/cm$^3$. However, due to cost considerations, CZT detectors are thinner (**5 to 7.3 mm**) than conventional (**9.5 mm**).
  **Stopping Power is very similar** (~95% for $^{99m}$Tc) [1,2].

[1] Wells, *et al.* J. Nucl. Cardiol. 2020
[2] Slomka, *et al.* J. Nucl. Med., 2019

# CZT DETECTORS

**C**admium **Z**inc **T**elluride (**CZT**)

## Characteristics

- *Semi-Conductor*
- *Direct Conversion of the γ-ray energy into an electronic signal*
- *Stopping Power is very similar to NaI(Tl)*

## Performance compared to conventional NaI(Tl)+PMT detector

- Better **Energy Resolution**: **5-6%** Vs **9-10%** for $^{99m}$Tc [1-3]

→ Improves *scatter discrimination* with narrower energy window

[1] Wells, *et al.* J. Nucl. Cardiol. 2020
[2] Slomka, *et al.* J. Nucl. Med., 2019
[3] Hutton, *et al.* Clin. Transl. Imaging, 2018

# CZT DETECTORS

**C**admium **Z**inc **T**elluride (**CZT**)

## Characteristics

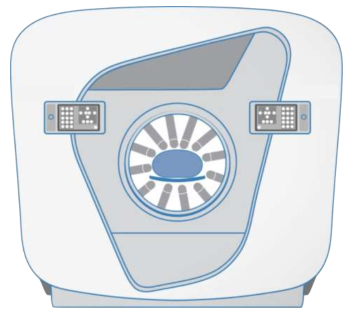
- *Semi-Conductor*
- *Direct Conversion of the γ-ray energy into an electronic signal*
- *Stopping Power is very similar to NaI(Tl)*

## Performance compared to conventional NaI(Tl)+PMT detector

- Better Energy Resolution
- Improved **Detector Spatial Resolution** (= pixel size **~2.46 mm**, typically) Vs **~3.8 mm** for $^{99m}$Tc [1]

[1] Hutton, *et al.* Clin. Transl. Imaging, 2018





# CZT DETECTORS

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## Characteristics

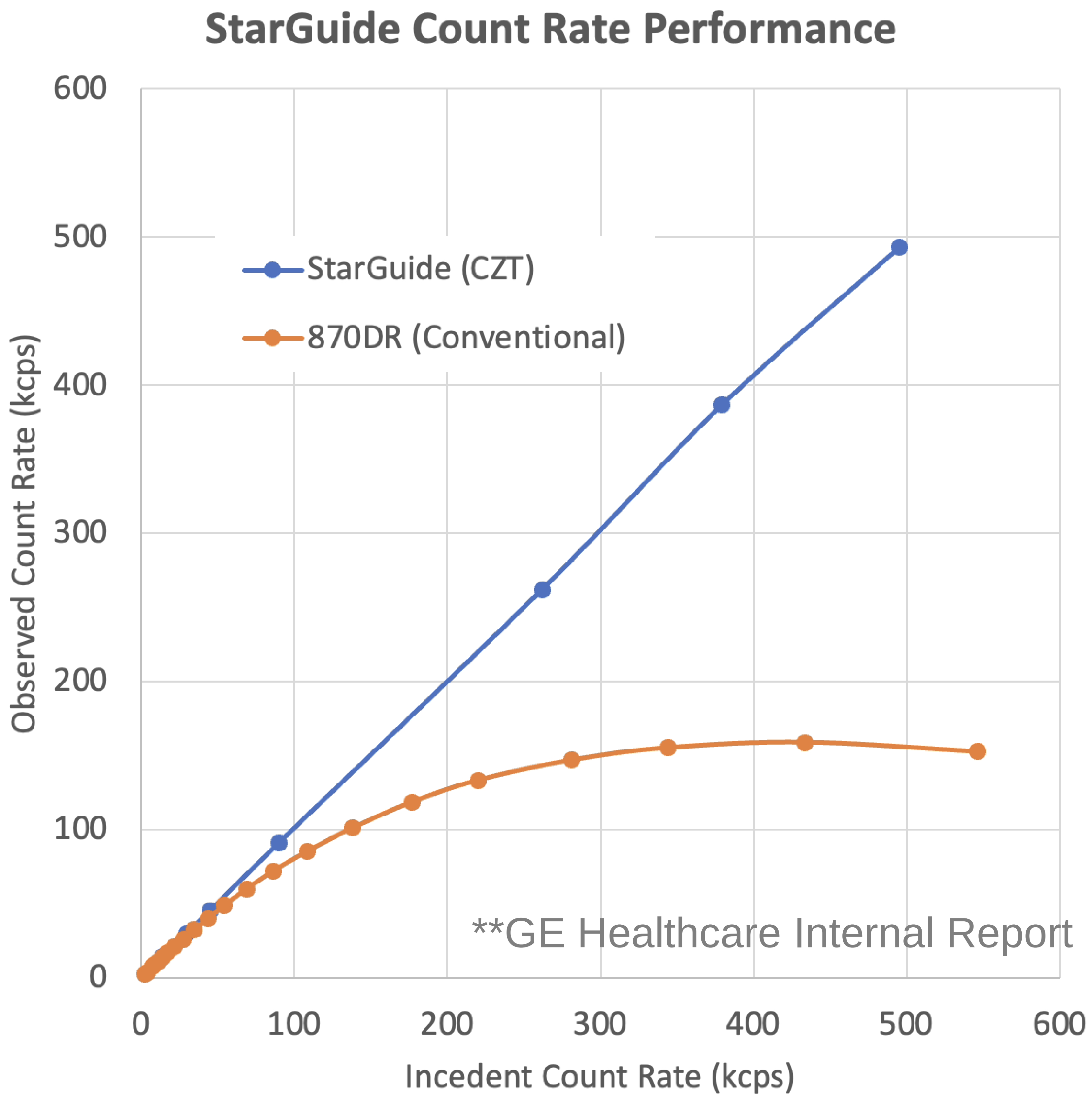
- *Semi-Conductor*
- *Direct Conversion of the $\gamma$-ray energy into an electronic signal*
- *Stopping Power is very similar to NaI(Tl)*

## Performance compared to conventional NaI(Tl)+PMT detector

- Better Energy Resolution
- Improved Detector Spatial Resolution
- **High Count-Rate Capability**

→ **No dead time** or detector saturation in the **clinical range**
< 1% count rate loss Vs 20% loss ≥ 250 kcps [1]

[1] GE Healthcare. NM870 SPECT/CT specification sheet



# CZT DETECTORS

**C**admium **Z**inc **T**elluride (**CZT**)

## Characteristics

- *Semi-Conductor*
- *Direct Conversion of the γ-ray energy into an electronic signal*
- *Stopping Power is very similar to NaI(Tl)*

## Performance compared to conventional NaI(Tl)+PMT detector

- Better **Energy Resolution**
- Improved **Detector Spatial Resolution**
- Enhanced **Count-Rate Capability**
- **Higher Cost**
- **Compact Detector** facilitates more **efficient SPECT System Design**


Adapted from Peterson and Furenlid. *Phys. Med. Biol.*, 2011

SNMMI

# CARDIAC CZT SPECT



## MYOSPECT® (GENERAL ELECTRIC HEALTHCARE)

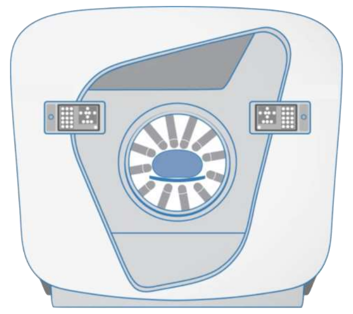
- 19 or 9 (*MyoSPECT ES*) CZT-based detectors
- Multi-Pinhole Collimation
- Each detector focuses on the cardiac region

*Courtesy of GE Healthcare*

## D-SPECT® (SPECTRUM DYNAMICS MEDICAL)

- 9 (*Cardio*) or 6 (*Vista*) CZT-based detectors
- Focusing Parallel-Hole Collimation
- Each detector focuses on the cardiac region


*Courtesy of Spectrum Dynamics Medical*



# FULL-RING CZT SPECT/CT

## NOVEL SYSTEM DESIGNS

- 360-degree acquisition
- Closer patient contouring compared to conventional systems
- Adaptive Imaging for a broad range of clinical studies

### STARGUIDE® (GENERAL ELECTRIC)

- 12 CZT-based detectors
  7.25 mm thick; Up to 270 keV
- Swiveling Parallel-Hole Collimation
- Optical Scan Guided

### VERITON-CT® (SPECTRUM DYNAMICS)

- 12 CZT-based detectors
  *200 Series*: 6.0 mm thick; Up to 200 keV
  *400 Series*: 7.3 mm thick; Up to 400 keV
- Swiveling Parallel-Hole Collimation
- Detectors can focus on a VOI Region

First US Install!

# FULL-RING CZT SPECT/CT

## VERITON-CT®

### SPECT
- 12 CZT Swiveling Detectors
- 360-degree Acquisition
- Adaptive Imaging
- Parallel-Hole Collimators

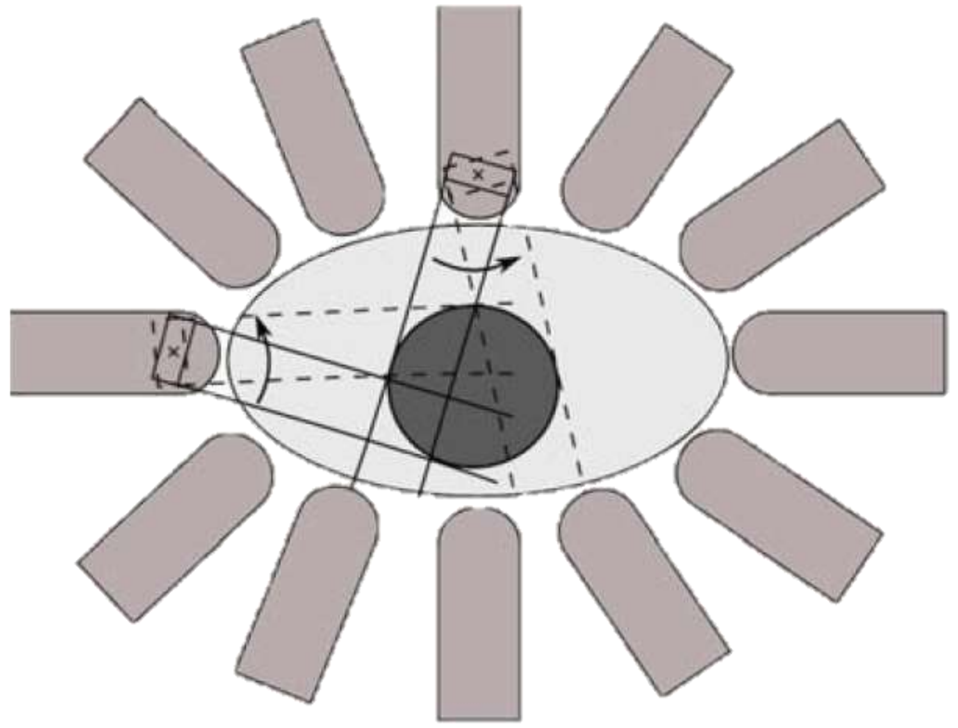
### CT
- 16, 64, 128 slices (*0.625 mm*)
- Low-dose CT for SPECT AC
- Diagnostic AC

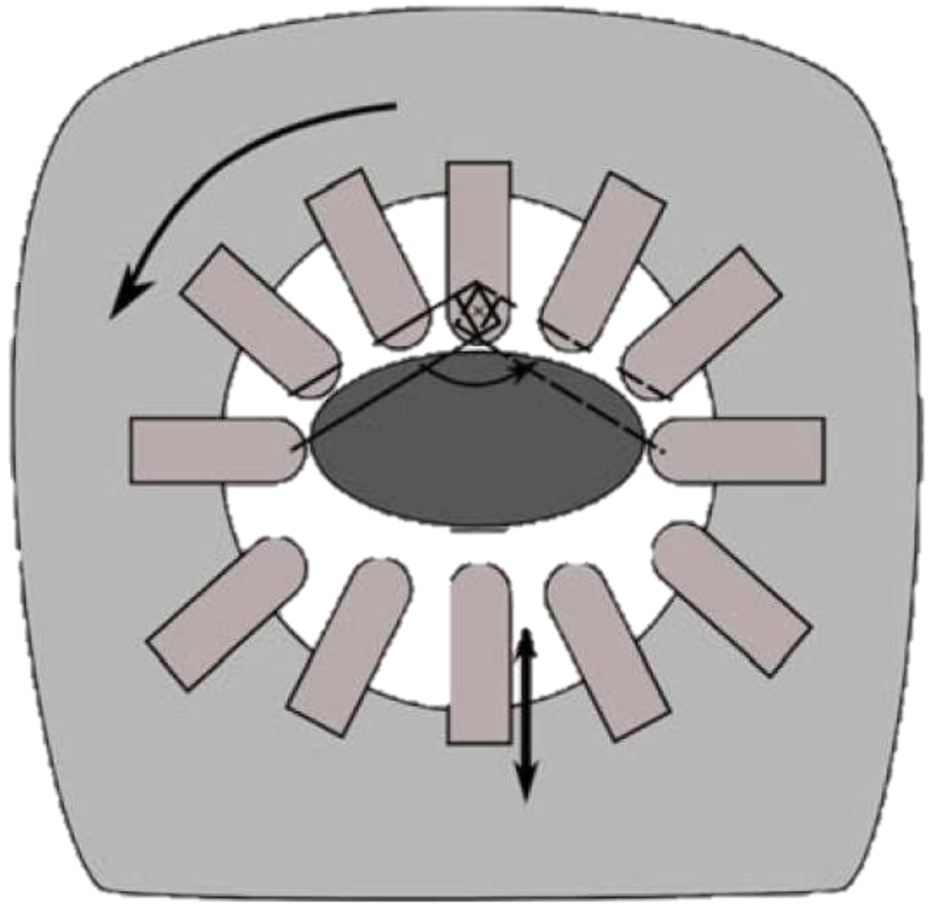

**Broad Range of Clinical Applications**

Focused Scan

3D Dynamic Scan

Whole-Body Scan

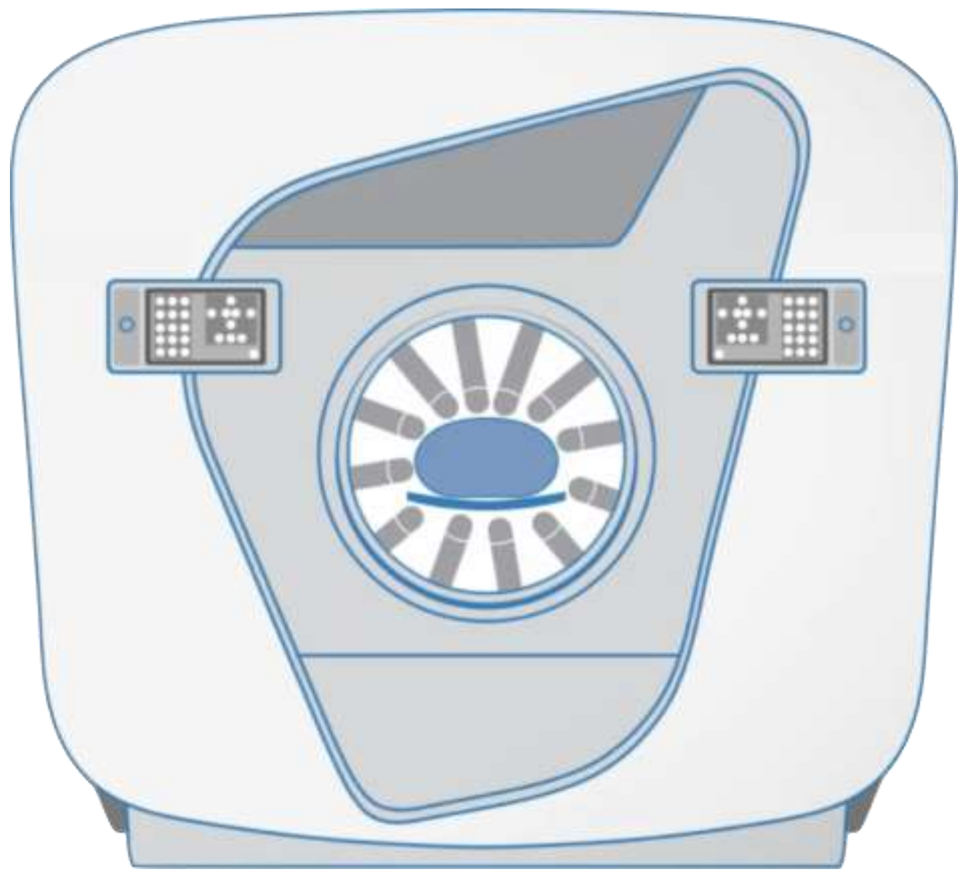




# FULL-RING CZT SPECT/CT

## 1 detector column

# FULL-RING CZT SPECT/CT

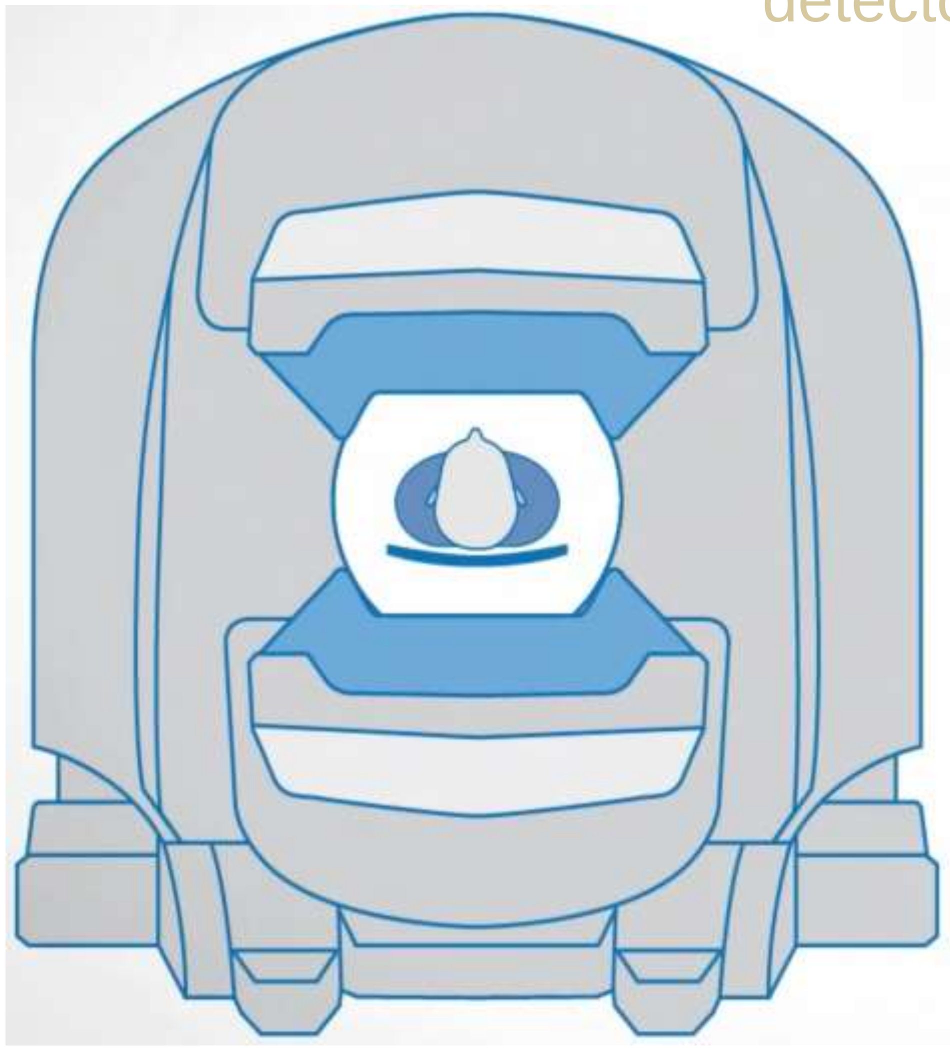


## Improved Imaging Performance

High Sensitivity and Improved Spatial Resolution compared to Conventional Systems

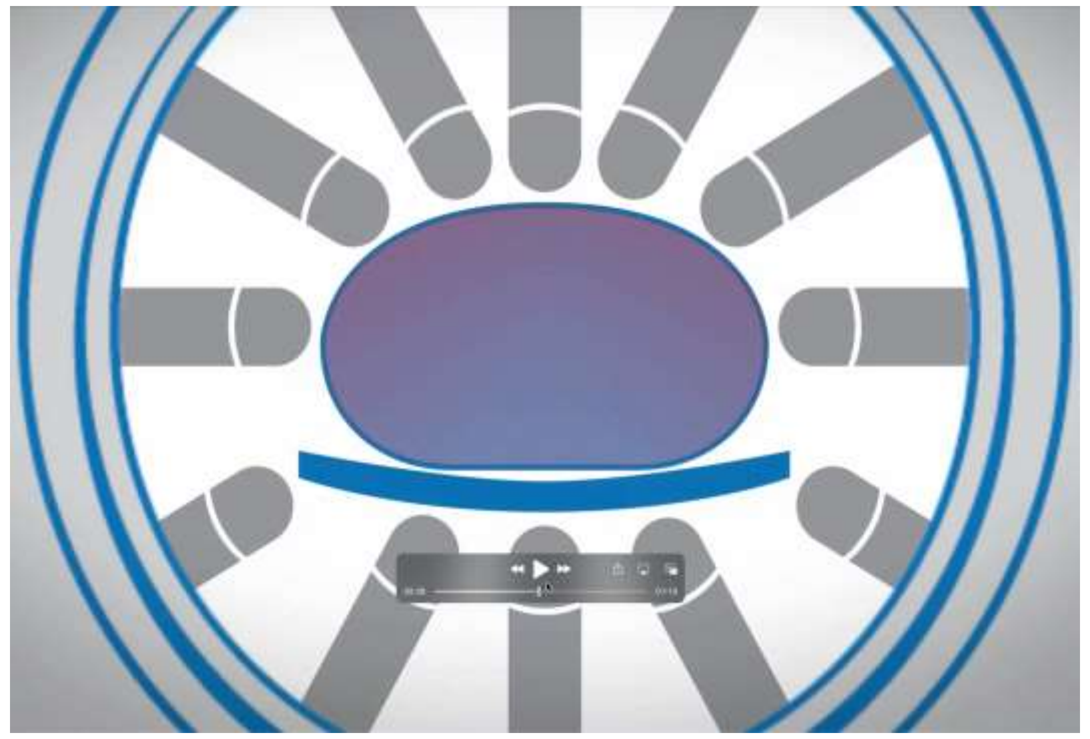
**Conventional Dual-Head**

Unused detector area

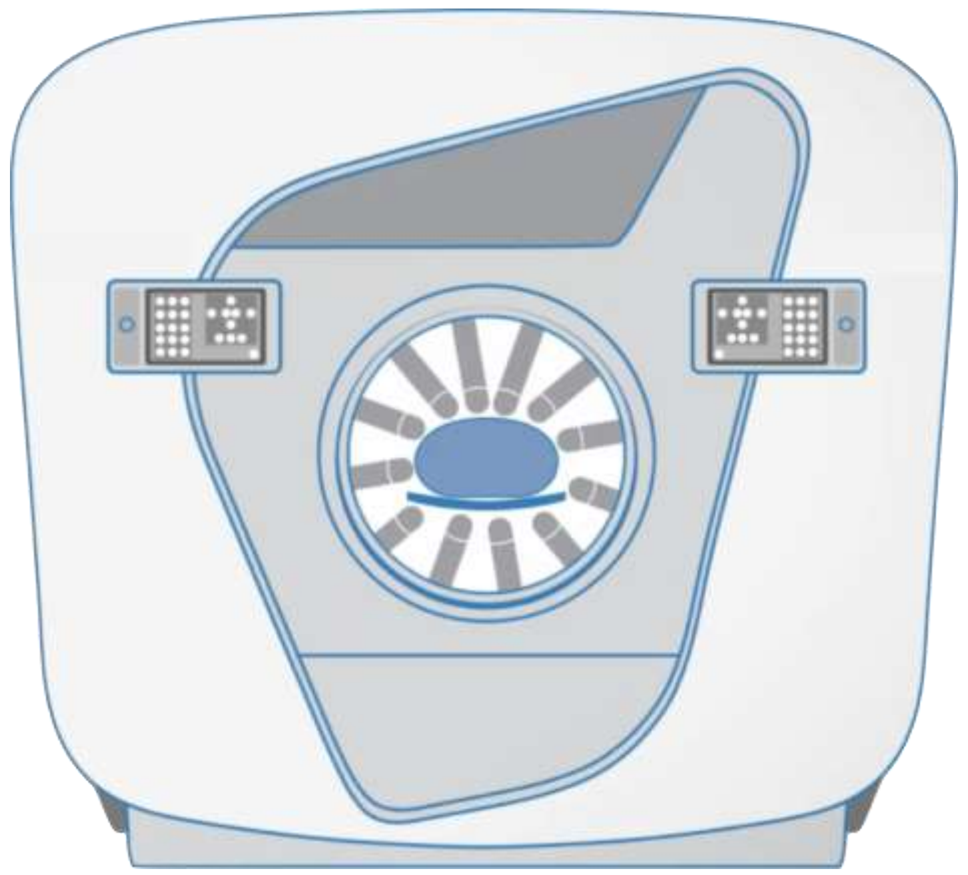


**Full-ring CZT**


**Detector Swiveling**



Better Sensitivity and Spatial Resolution because of 360-deg Geometry, Closer-Contouring, and Detector Swiveling/Adaptive Imaging



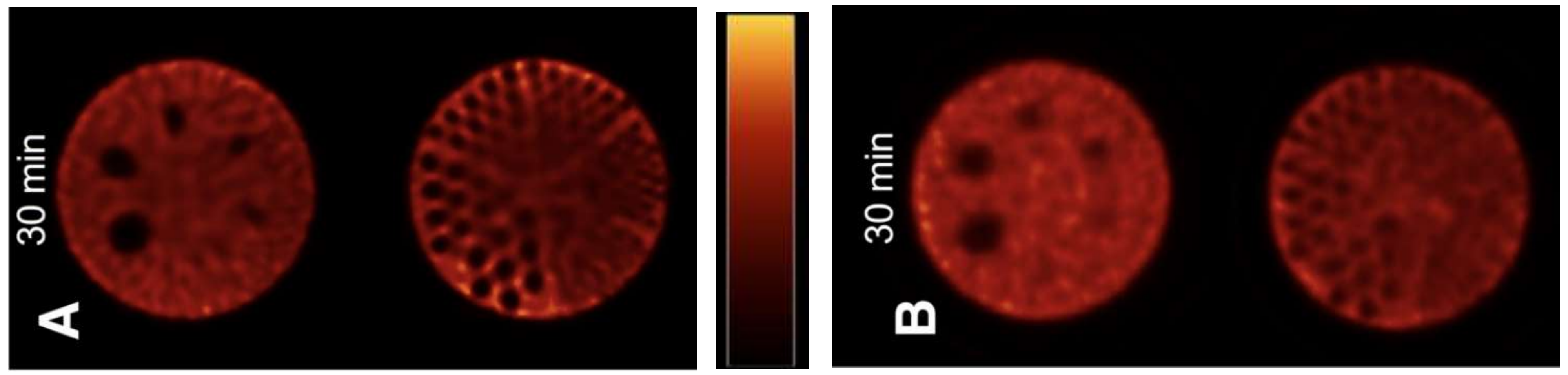
## Improved Imaging Performance

High Sensitivity and Improved Spatial Resolution compared to Conventional Systems

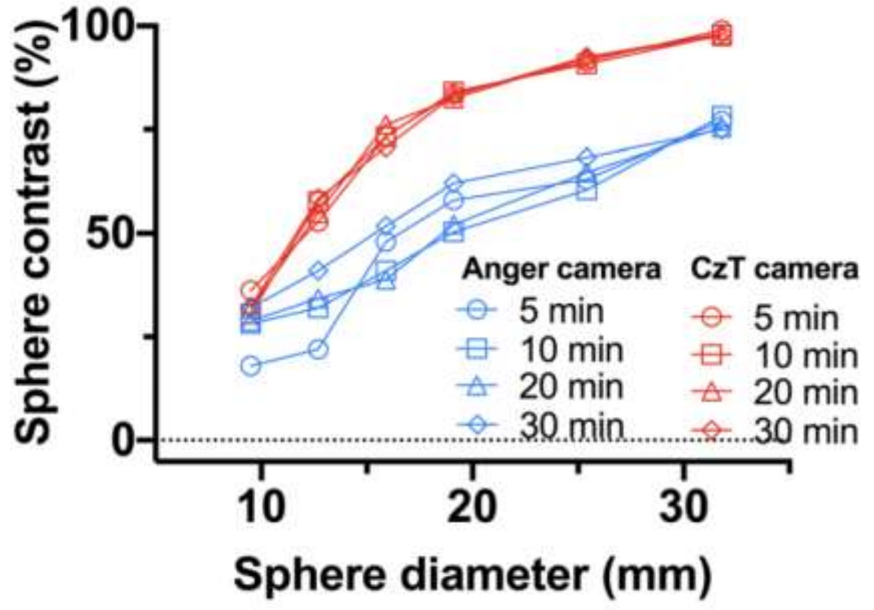
### Sensitivity for a $^{99m}$Tc point source in head phantom (cps/MBq)

| | |
|---|---|
| Conventional dual-head LEHR | 57.0 |
| Full-Ring CZT (Non-Focus Mode) | 73.4 (+22%) |
| Full-Ring CZT (Focus Mode) | 342.4 (+500%) |

### Tomographic Spatial Resolution

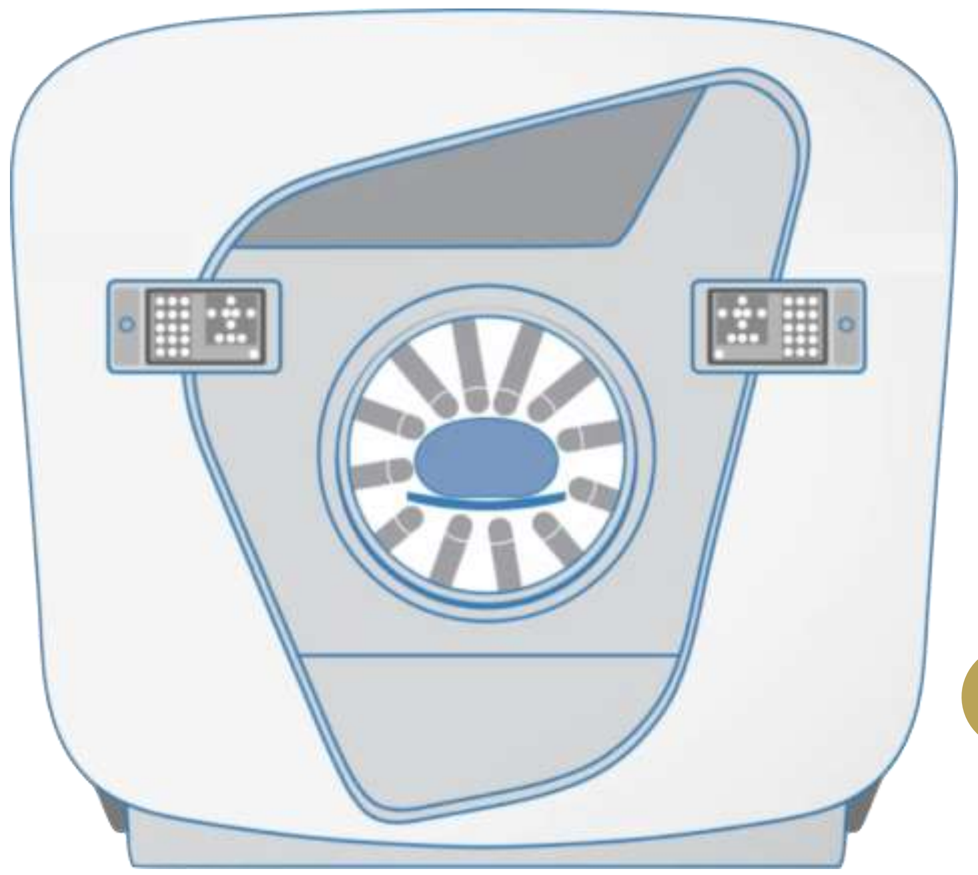



Full-Ring CZT    Conventional




*Adapted from Desmonts, et al. EJNMMI physics. 2020*

# FULL-RING CZT SPECT/CT



**Improved Imaging Performance**
- High Sensitivity and Improved Spatial Resolution compared to Conventional Systems

**Adaptive Imaging**
- Novel Detector Arrangement
- Versatility in Application
- Optimum Performance

**Quantitation**
- CT-based Attenuation Correction
- Scatter Correction
- Sophisticated Reconstruction Algorithm Built-into the software

**3D Dynamic Imaging**
- 360° Acquisition with no Gantry Rotation
- High Sensitivity
- High Count Rate Capability

# FULL-RING CZT SPECT/CT

**3D Dynamic Imaging**

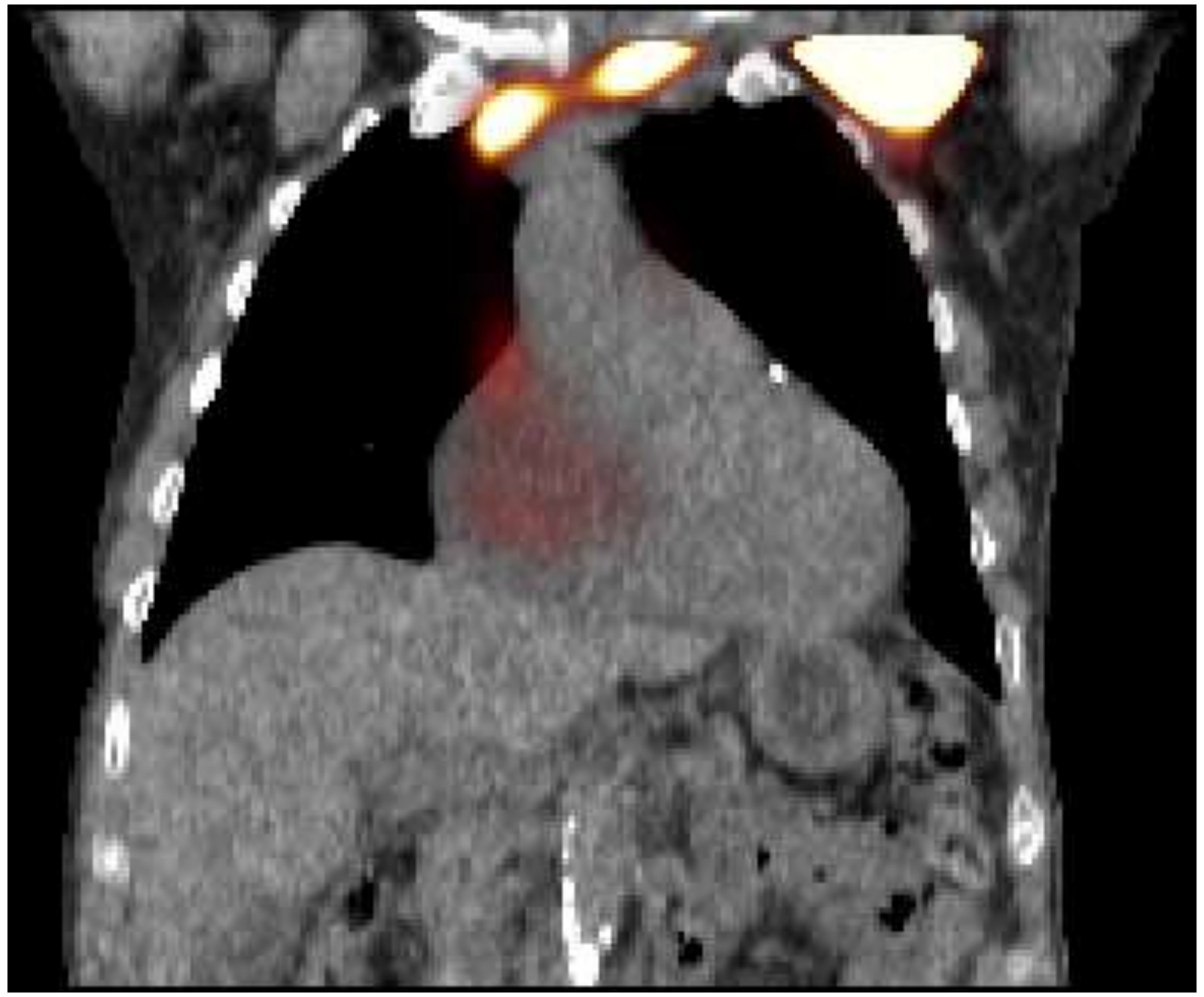
- 360° acquisition with no gantry rotation
- 3 - 10 sec frame rate
- High Count-Rate capability

**ATTR-Cardiac Amyloidosis**
**3D Dynamic Imaging**

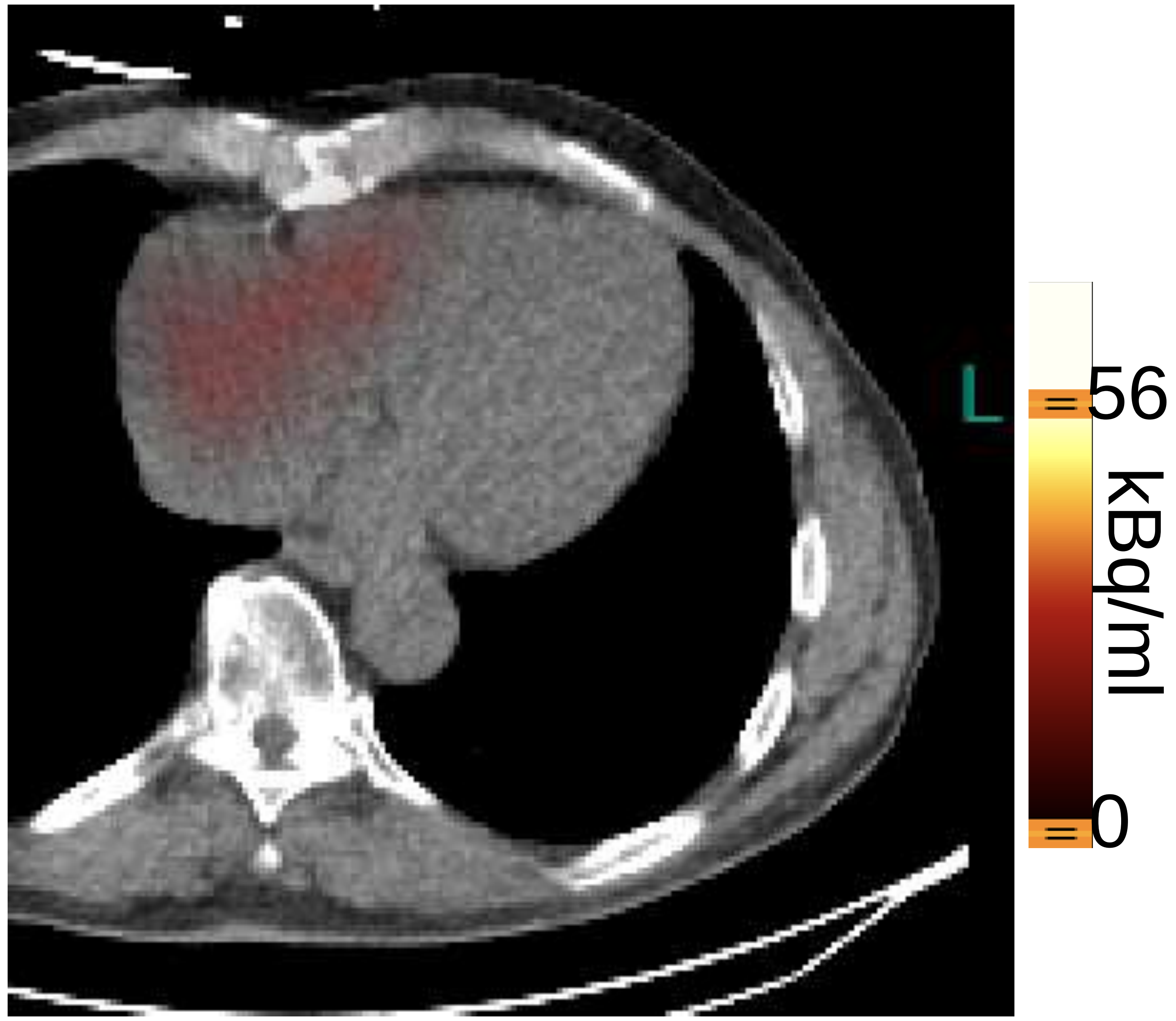
- 20 min dynamic scan
- 138 frames of 8.7 sec
- 20.3 mCi ($^{99m}$Tc-PYP)

- 71y Male
- BMI of 26.3
- Disease Grade 3

Coronal View



Transaxial View



# APPLICATION TO CARDIAC IMAGING

## Full-Ring CZT SPECT/CT has major advantages for MPI,

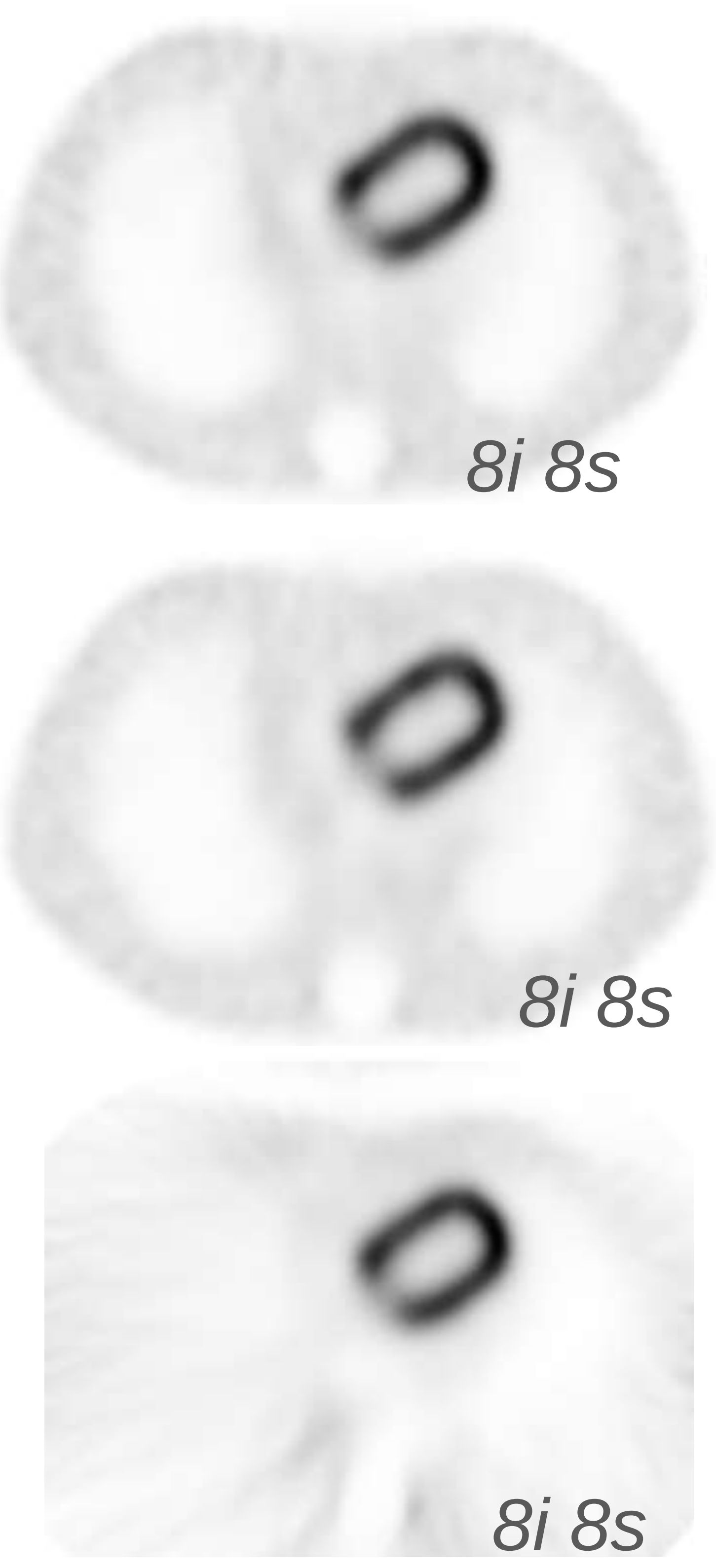
**High sensitivity** and **spatial resolution** can **improve** qualitatively and quantitatively **MPI images** compared to conventional SPECT/CT

Full-Ring CZT

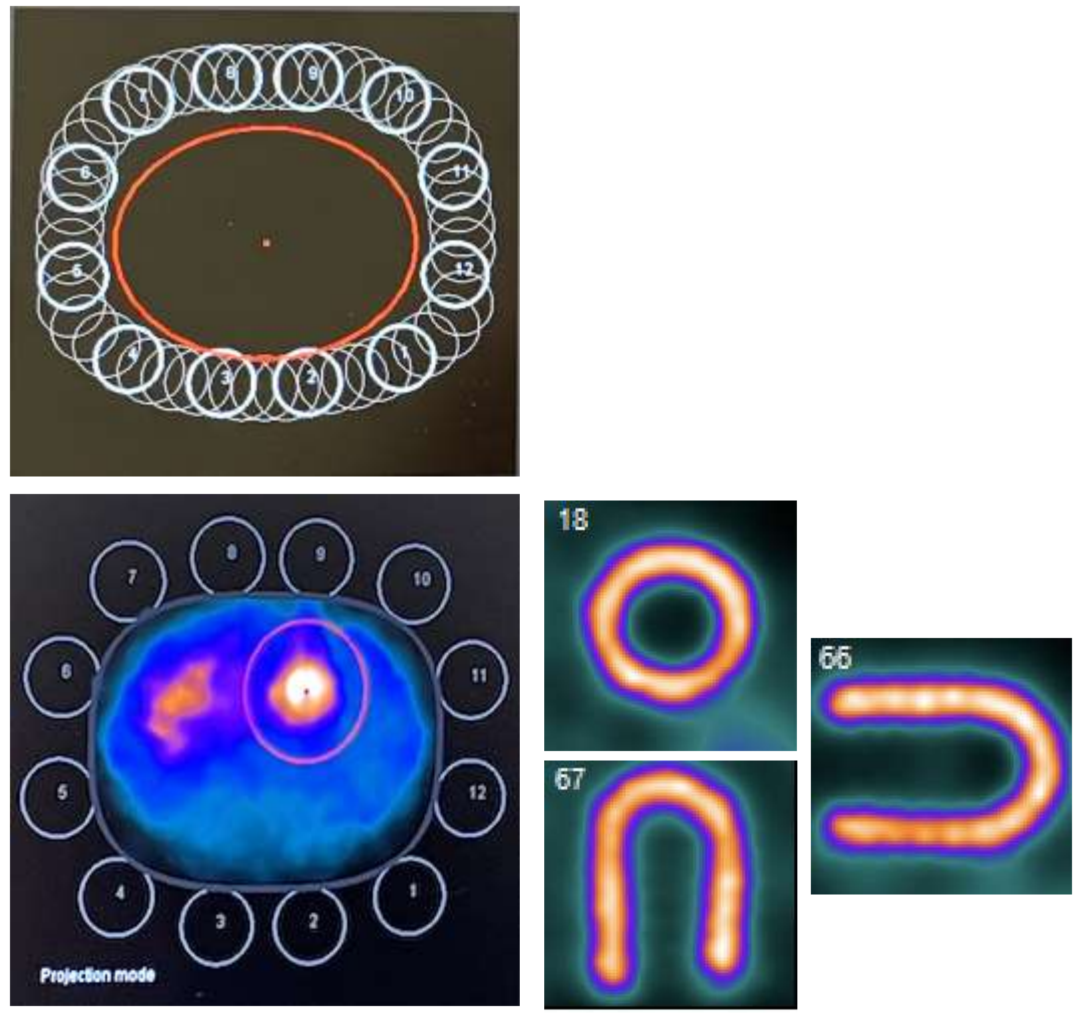
Non Focus

Focus Phantom Contour

Focus Cardiac Region

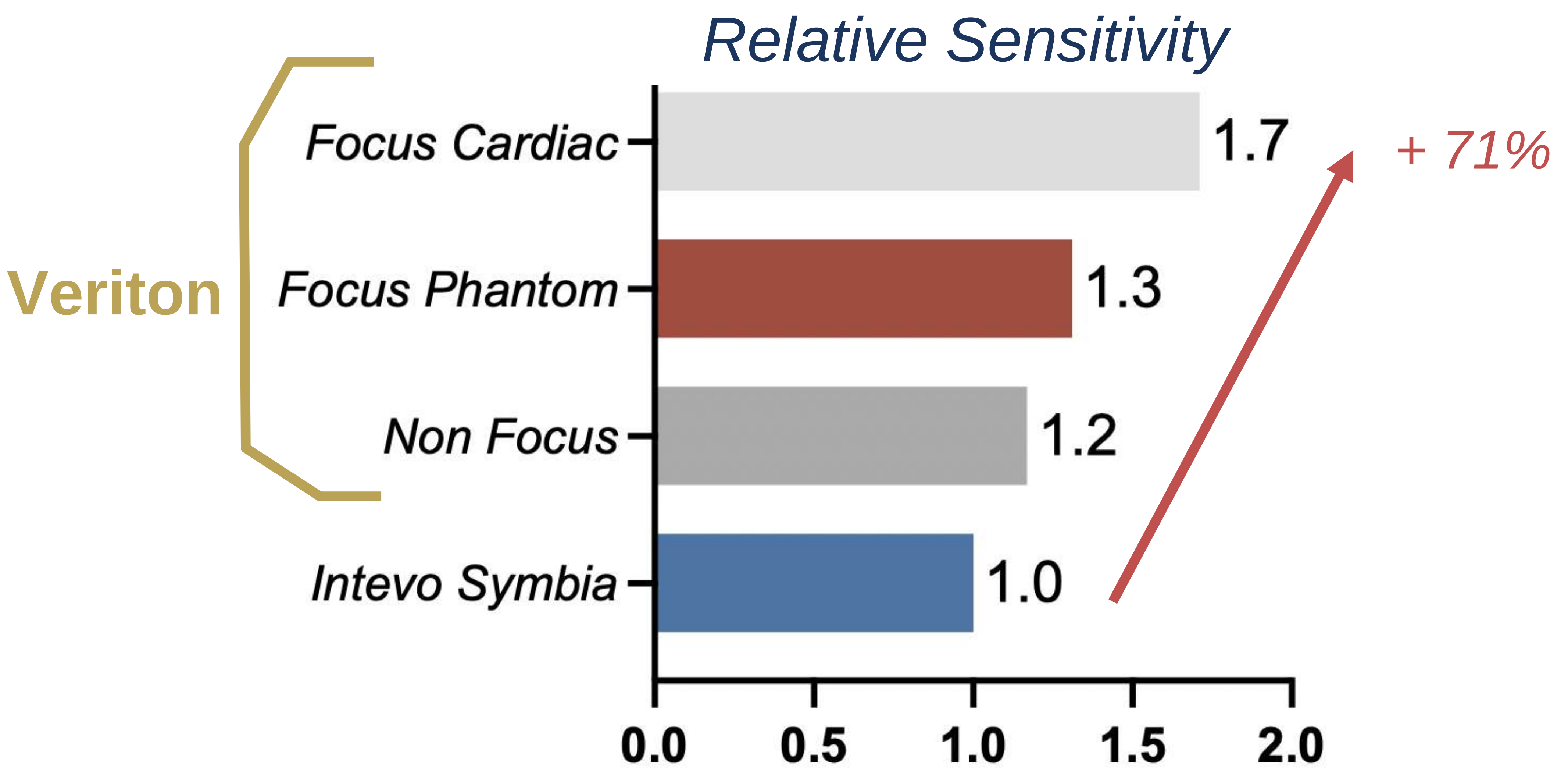



Detector Layout



Conventional

Equal Imaging Time

## Full-ring CZT SPECT/CT has multiple advantages for MPI,

- **High sensitivity** and **spatial resolution** that can enhance qualitatively and quantitatively MPI images compared to conventional SPECT/CT and cardiac CZT SPECT
- Enables accurate **A**ttenuation **C**orrection (**AC**) that can improve **accuracy** and **imaging time** (*stress-only imaging*) compared to cardiac CZT SPECT [1-3]
- Can offer **M**yocardial **B**lood **F**low (**MBF**) and **M**yocardial **F**low **R**eserve (**MFR**) quantitation, thanks to 3D dynamic imaging capability
- Provides a **diagnostic CT** for **coronary calcium** scoring and **CT angiography** studies [4]

[1] Gowd, *et al.* J. Nucl. Cardiol. 2014
[2] Huang, *et al.* J. Nucl. Med. 2016
[3] Hendel, *et al.* J. Nucl. Med. 2002
[4] Slomka, *et al.* J. Nucl. Med. 2019

## AI-Based Attenuation Correction

- **Attenuation** can cause artefacts

- Dual bed positions (upright/supine) helps resolving such artefacts, thus reducing the need for rest imaging [1]

- **AI-based Attenuation Correction** has emerged as a powerful tool for low-dose stress-only MPI with single bed position [2-6]

- TruCorr® is commercially available for D-SPECT [7,8]

Upright

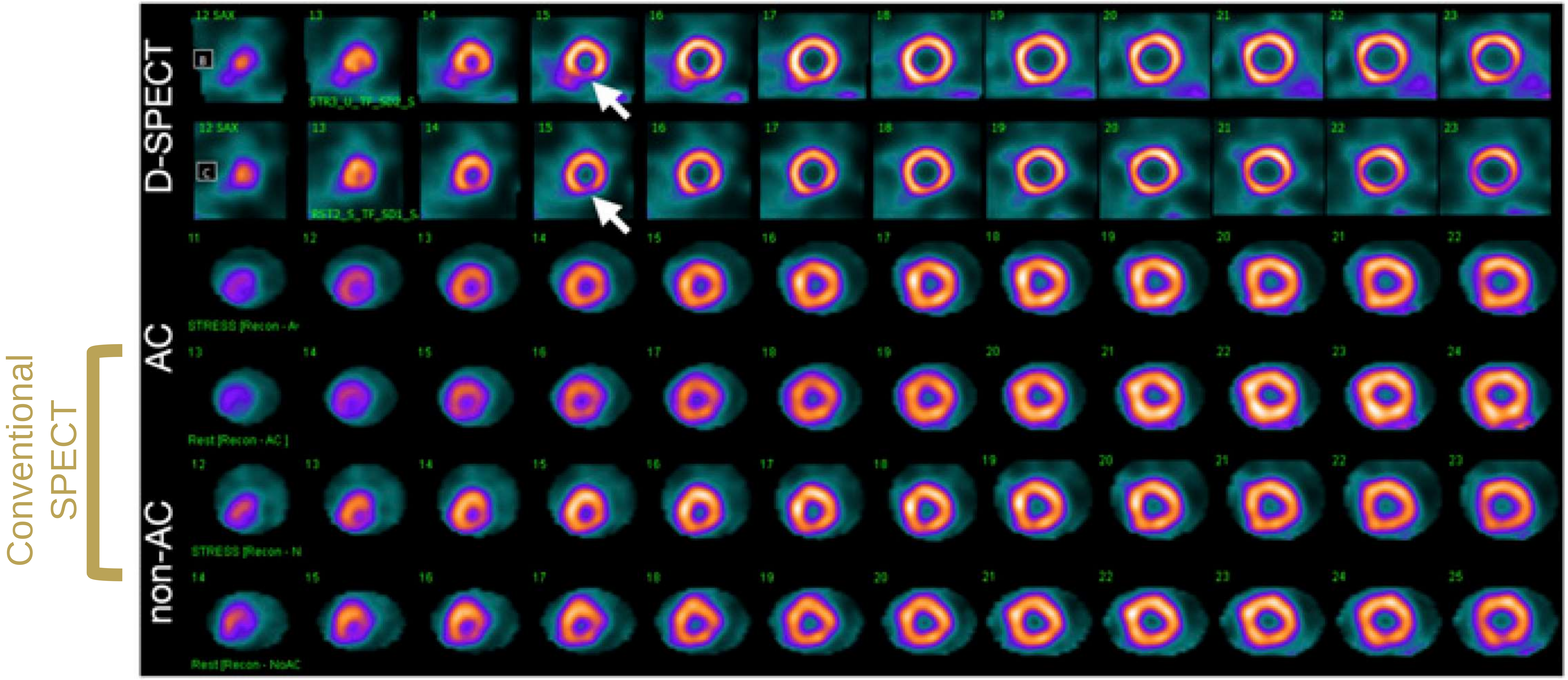
Supine

[1] Nishiyama, et al. Circ. J., 2014
[2] Yang, *et al.* J. Nucl. Med., 2021
[3] Chen, *et al.* J. Nucl. Cardiol., 2022
[4] Shi, *et al.* Eur. J. Nucl. Med. Mol. Imaging, 2020
[5] Liu, *et al.* J. Nucl. Cardiol., 2021
[6] Shanbhaq, *et al.* J. Nucl. Med., 2022
[7] Sanchez, *et al.* Eur. J. Nucl. Med. Mol. Imaging, 2022
[8] Ochoa, *et al.* Eur. J. Nucl. Med. Mol. Imaging, 2022

# MPI WITH CARDIAC CZT SPECT

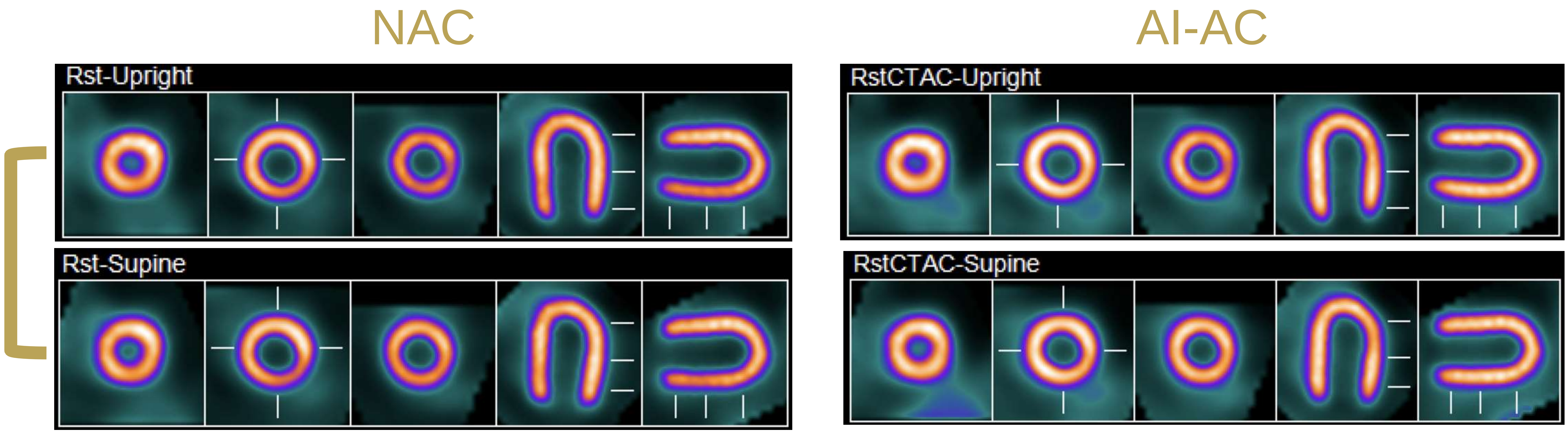
**Cardiac CZT SPECT (*DSPECT*) provides,**

**High Performance** Cardiac Imaging with **Enhanced Image Quality**
Up to **8 times Sensitivity Increases** compared to Conventional Systems




Johnson RD et al. J Nucl Med Technol 2020; 48:297-303

## **Slightly better performance** of TruCorr® (***AI-based AC***) in Supine position




**Torso Phantom Study**
(**$^{99m}$Tc-Sestamibi**)

- ❑ **Stress** equivalent study
- ❑ Activity ratios - Myo:BP:Liver:Bkg 10.9:1.4:3.0:1.0
- ❑ Equal scan time: *5 min 30 sec*

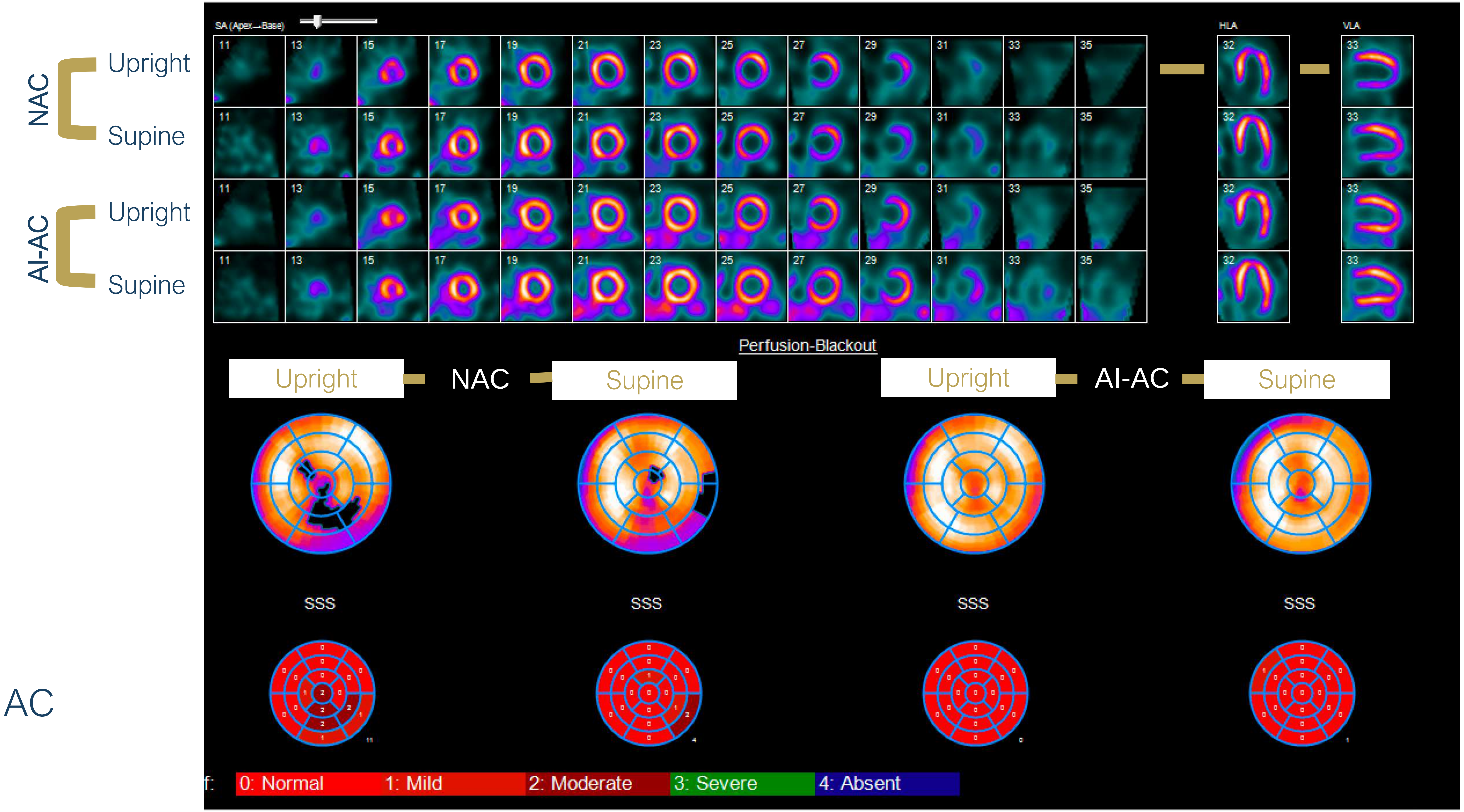
# MPI WITH CARDIAC CZT SPECT

## SPECT Acquisition ($^{99m}$Tc-Sestamibi)

- **Stress** study
- Dose: *6 mCi*
- Scan time: *6 min*

- 45y Male
- BMI of 35.6

- w/ and w/o AI-based AC
- Supine and Upright



# MPI WITH CARDIAC CZT SPECT

## Torso Phantom Study
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- **Stress** equivalent study
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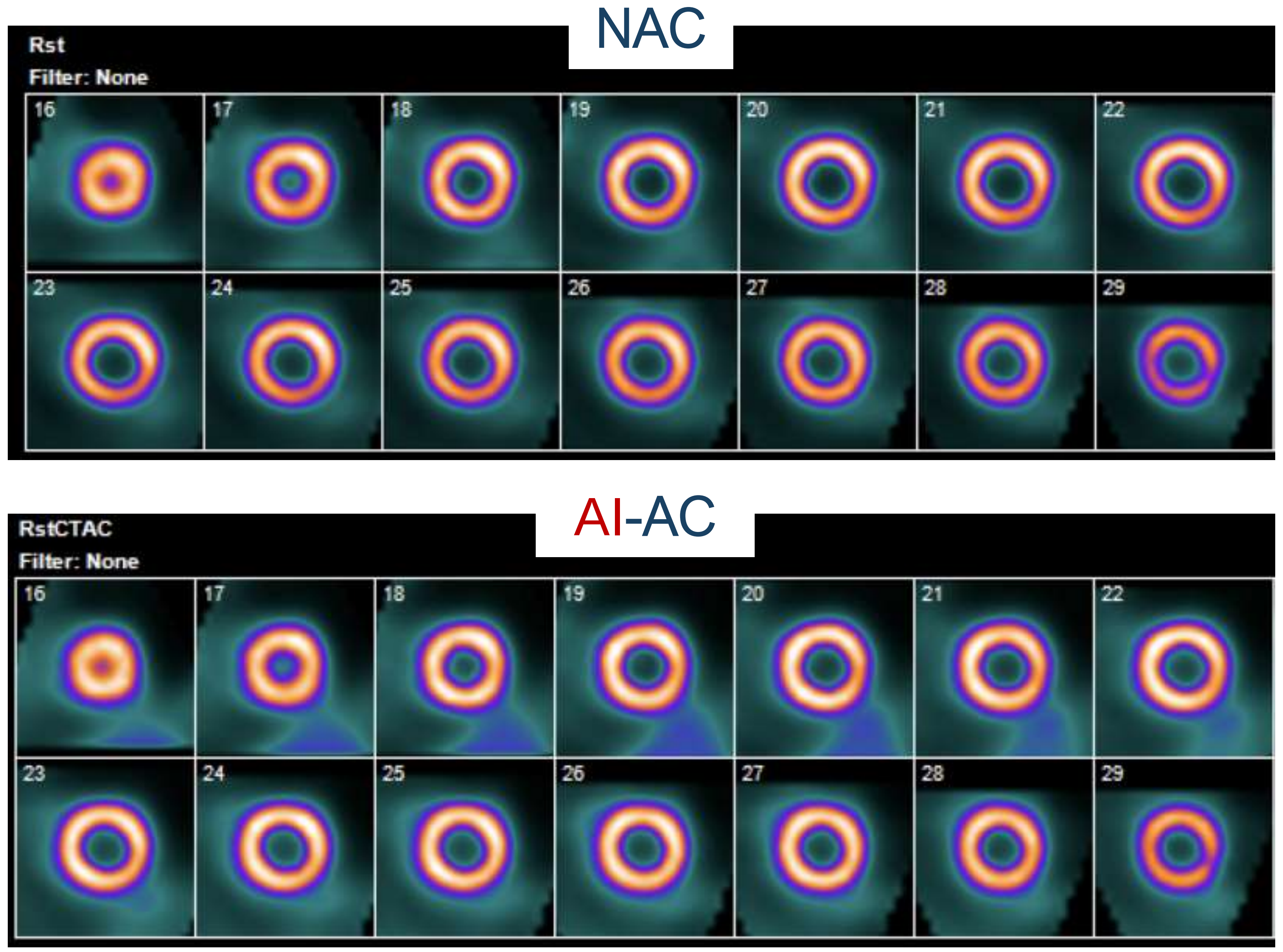
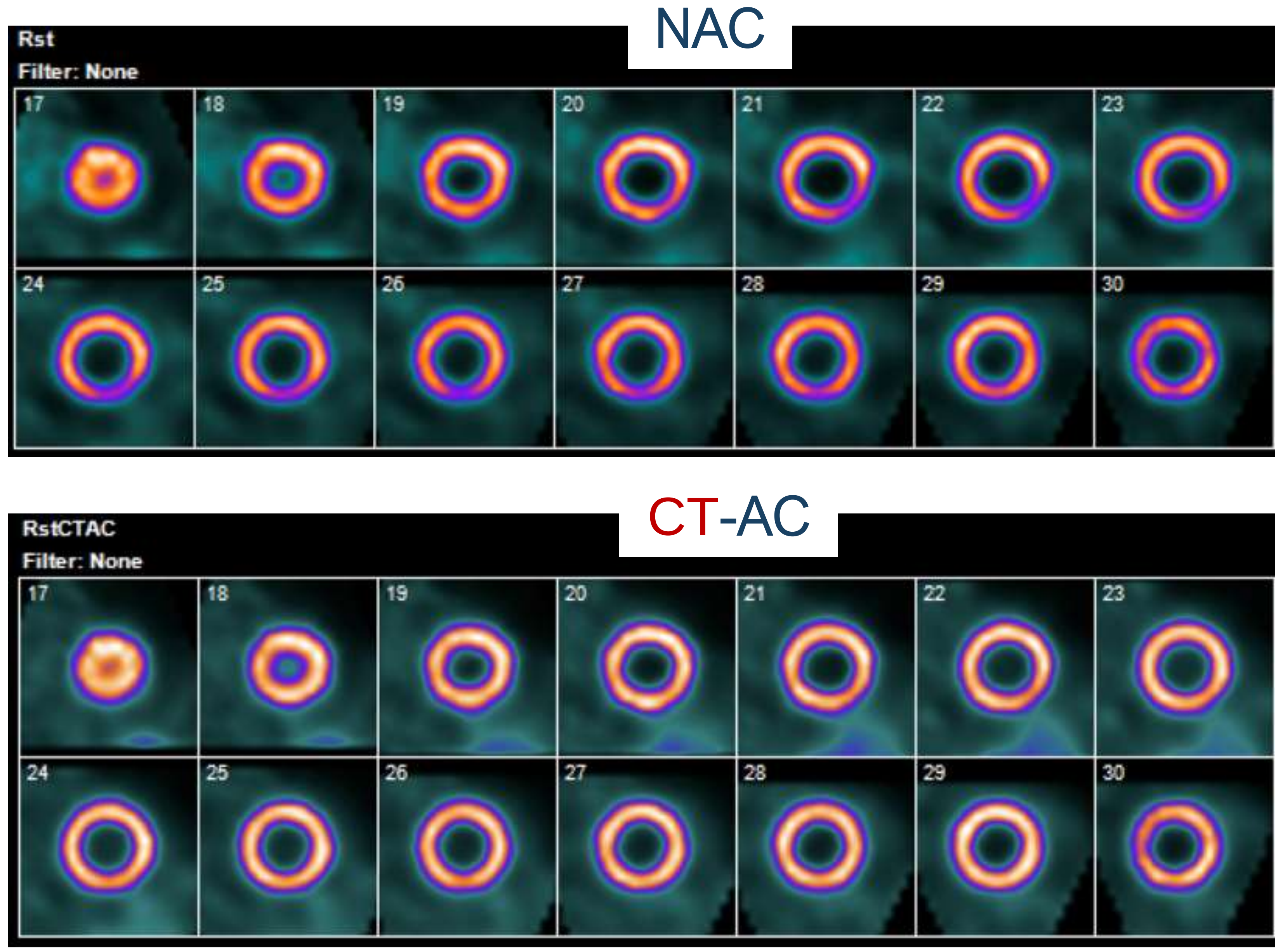
- Equal Scan time: *5 min 30 sec*
- w/ and w/o AI-based AC
- Supine and Upright

**Cardiac CZT**
*DSPECT*

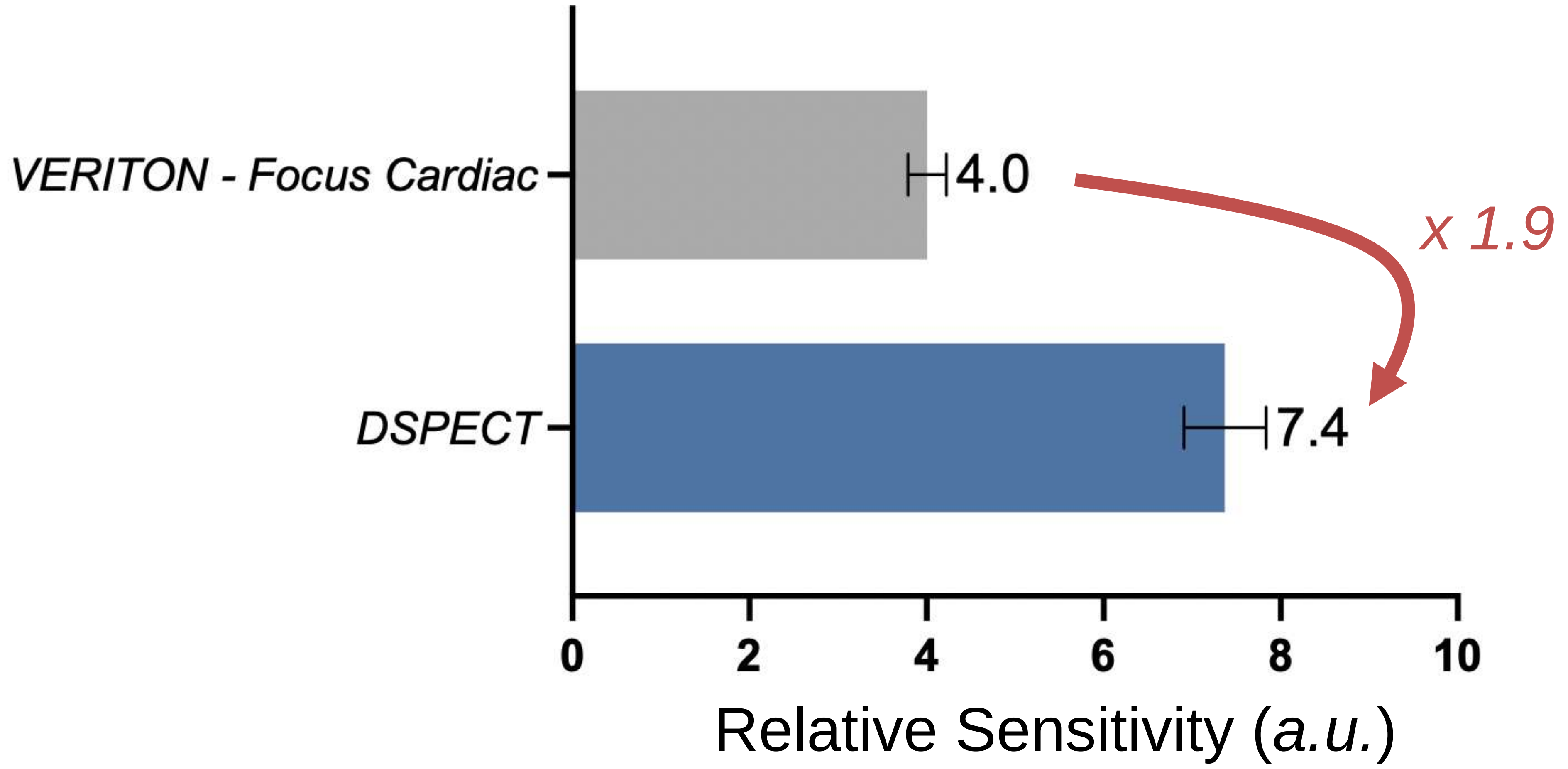



**Full-ring CZT**
*Veriton*




AI-AC TruCorr® works well with phantoms

Full-ring CZT leads to better spatial resolution at the expense of lower sensitivity



# MPI WITH CARDIAC CZT SPECT

## SPECT Acquisition ($^{99m}$Tc-Sestamibi)

- **Rest** study
- Dose: *10 mCi*

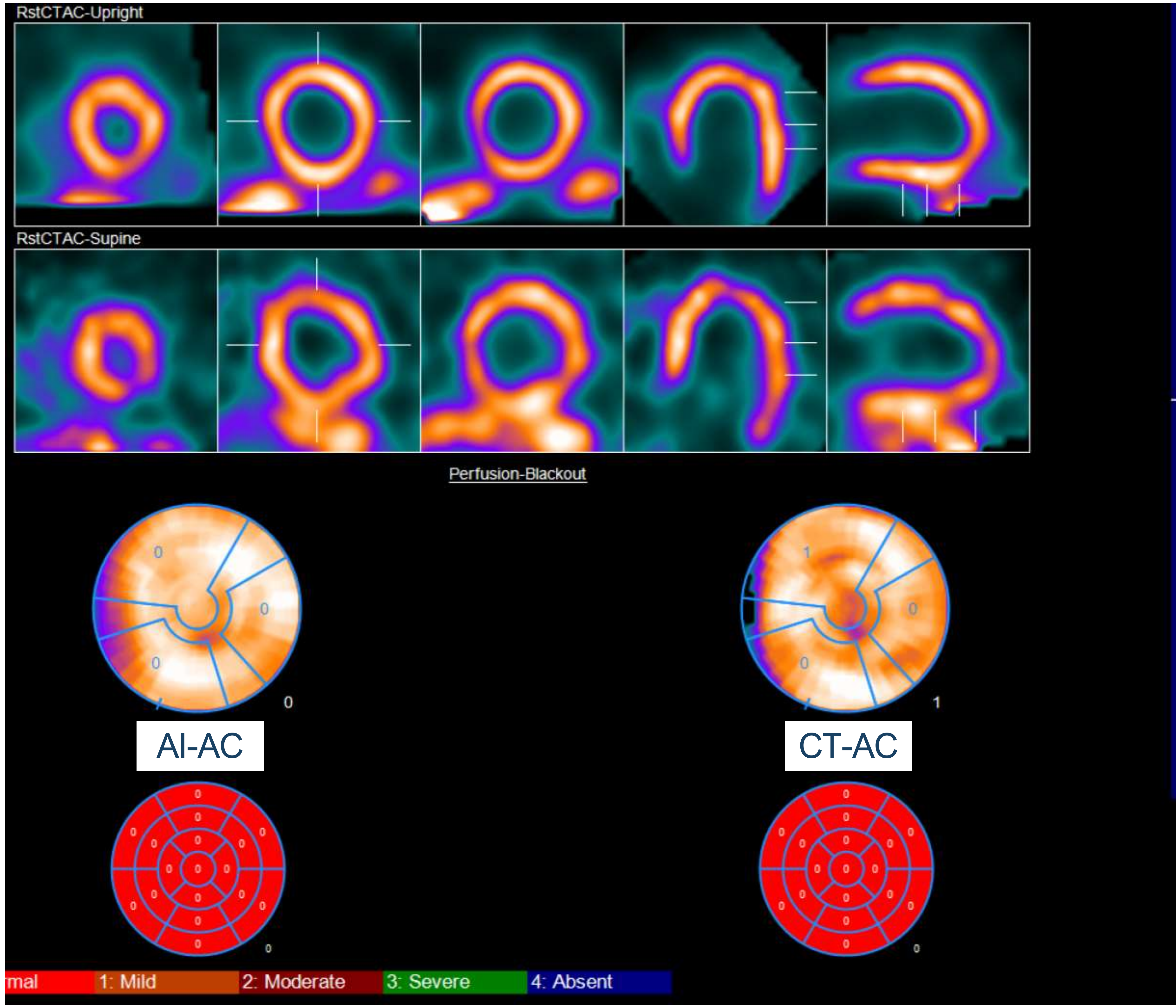
- 68y Female
- BMI of 25.3

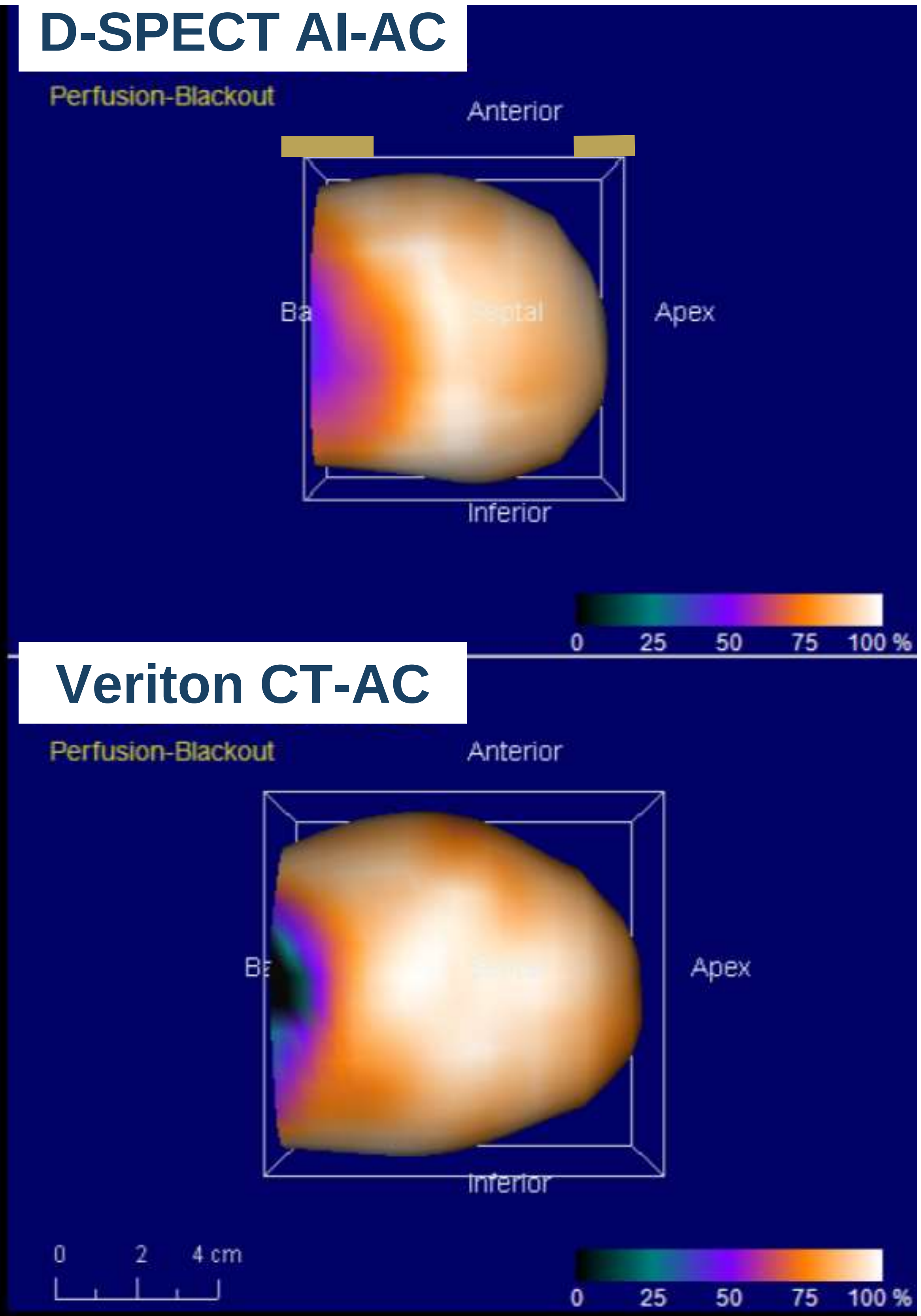
- Veriton CT-AC
  Supine
  *4 min* / 3.8 Mcts

- DSPECT AI-AC (*90 min delay*)
  Upright
  *6 min* / 3.4 Mcts

DSPECT AI-AC

Veriton CT-AC



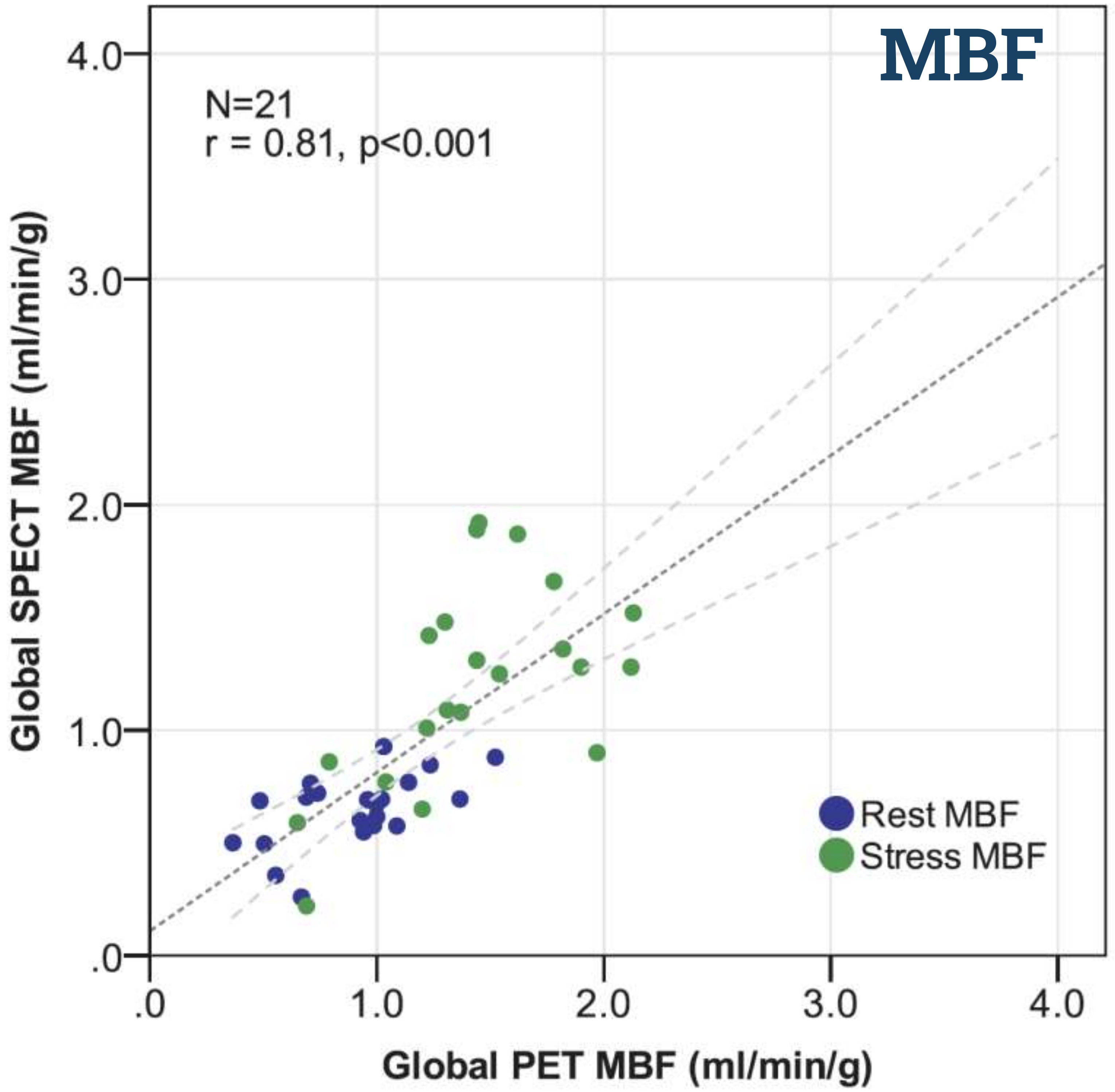
# MPI WITH CARDIAC CZT SPECT

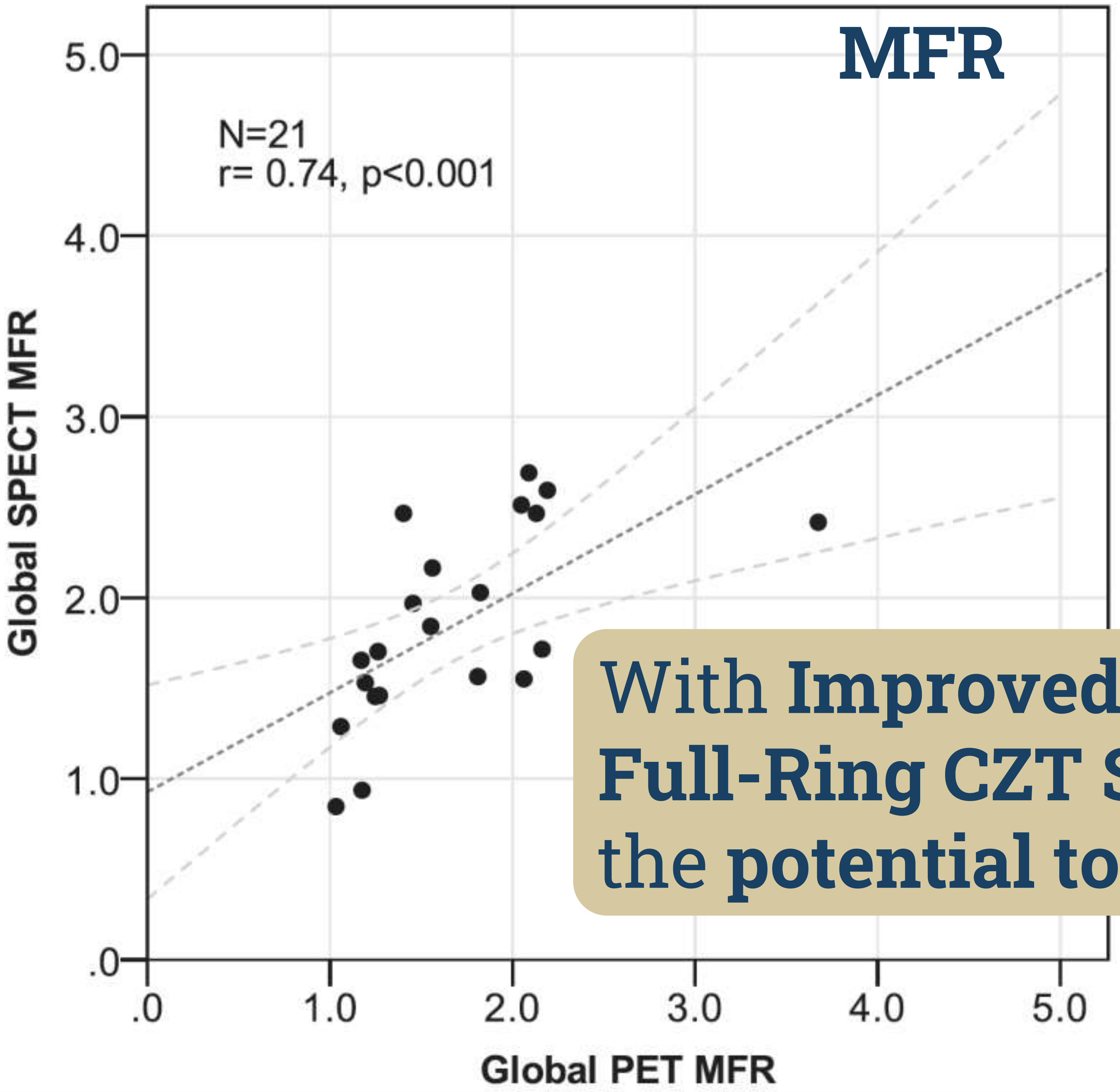
**Promising MBF/MFR assessment via SPECT Imaging with Cardiac CZT systems [1-4],**

- In several single center human studies in which PET was used as reference

[2] Wells. J. Nucl. Med. 2017
[3] Otaki. J. Nucl. Cardiol. 2021
[4] Agostini. Eur. J. Nucl. Med. Mol. Imaging, 2018

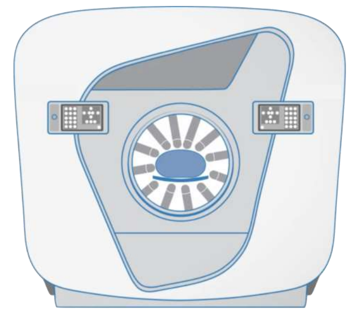
[1] Adapted from De Souza, et al. Circulation: Cardiovascular Imaging, 2022




With **Improved 3D Dynamic Imaging Capability, Full-Ring CZT SPECT/CT** has the **potential to enhance further MBF/MFR quantitation.**



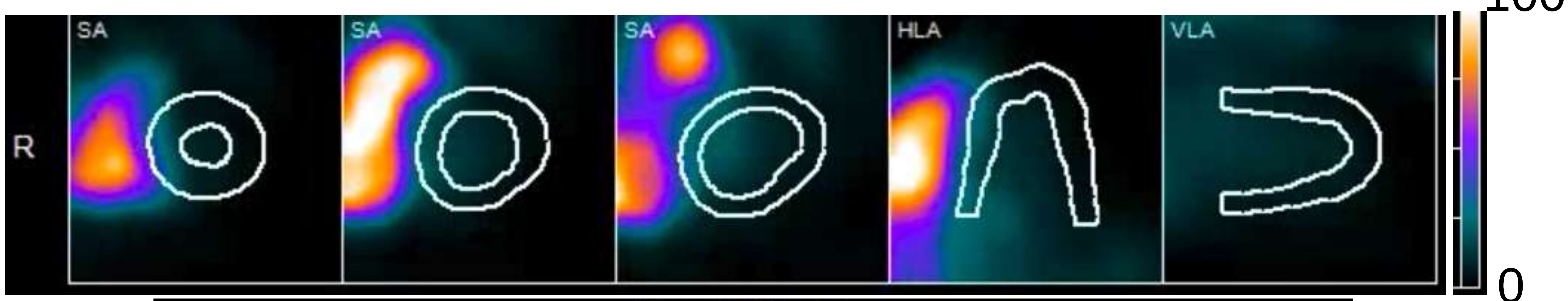


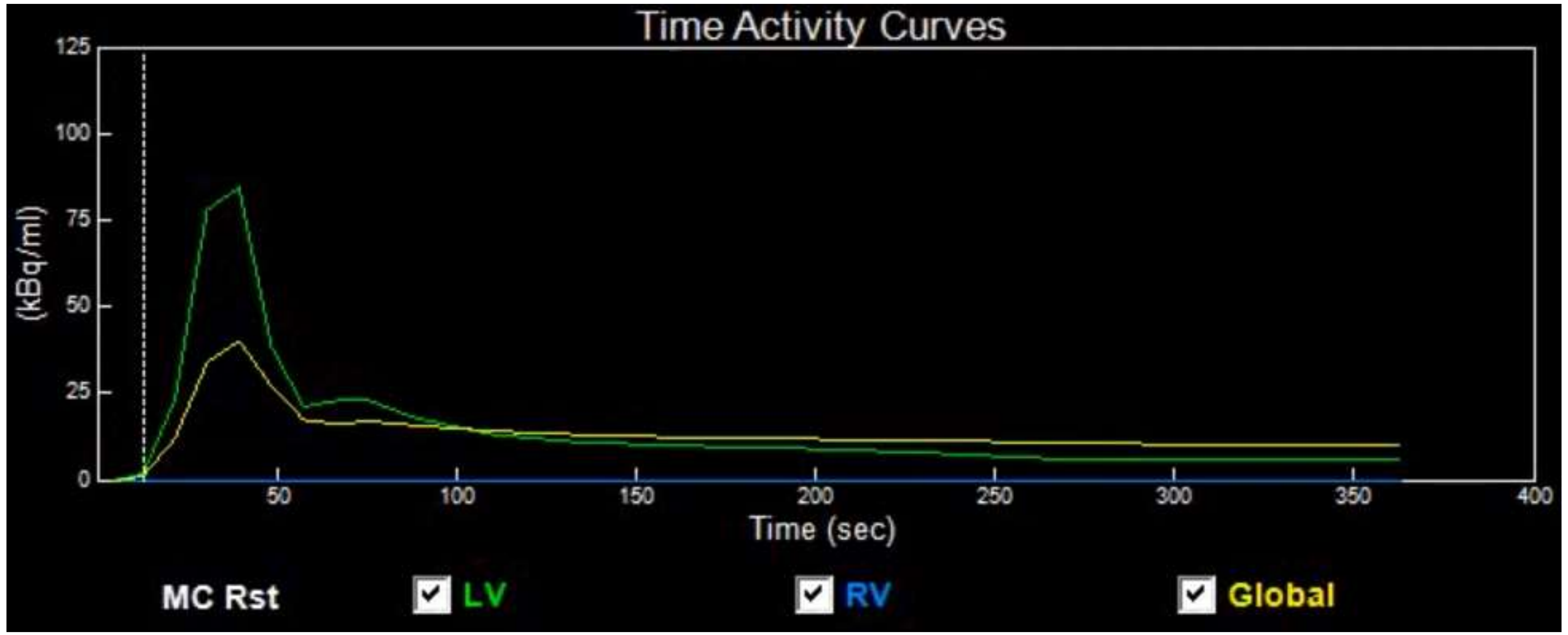
# MPI WITH FULL-RING CZT SPECT

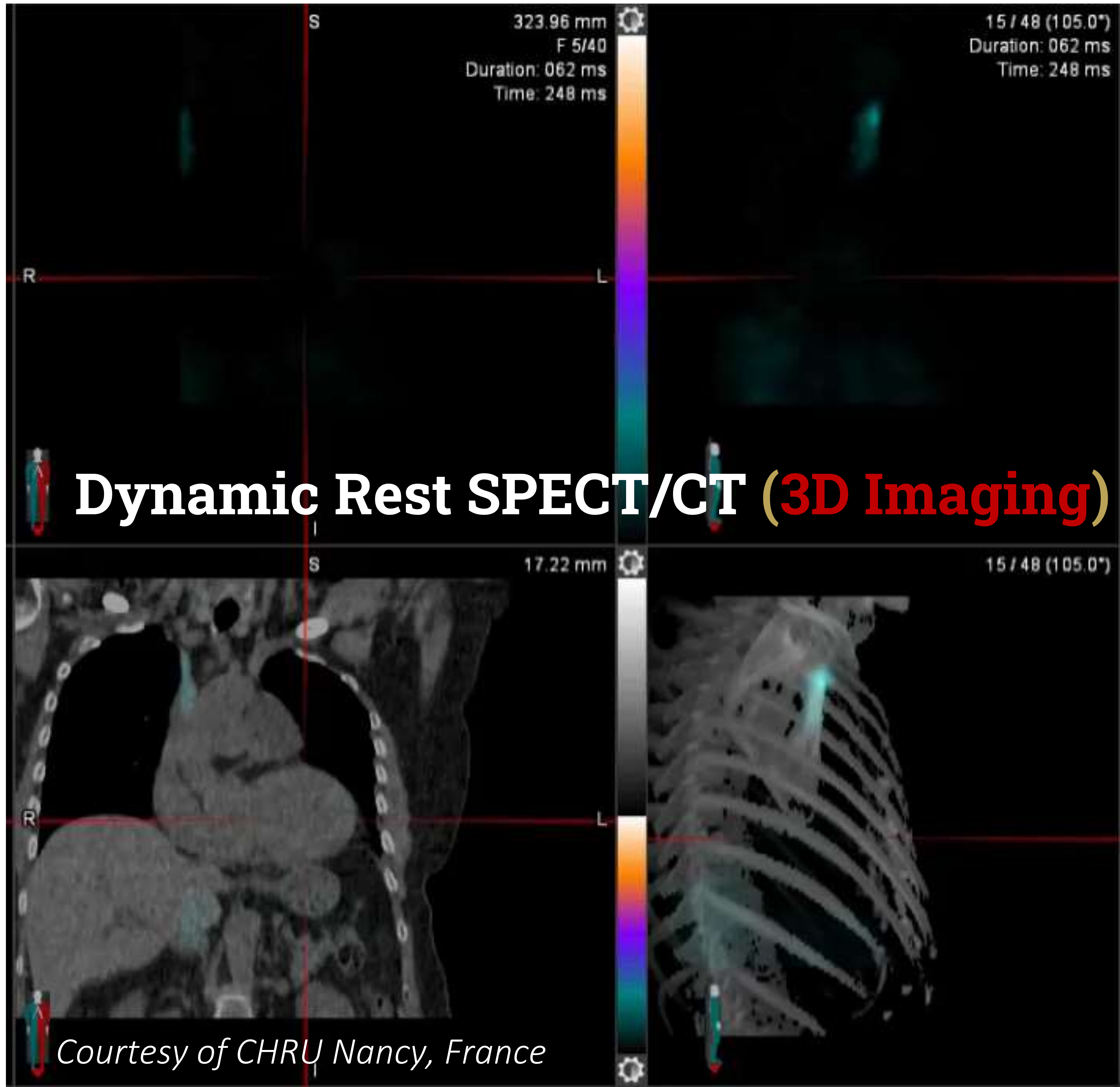
## Full-Ring CZT SPECT/CT has major advantages for MPI,

> Offers **M**yocardial **B**lood **F**low (**MBF**) and **M**yocardial **F**low **R**eserve (**MFR**) quantitation, thanks to **3D dynamic imaging** capability. CT-AC provides higher accuracy compared to cardiac CZT SPECT

**6-min 3D Dynamic SPECT/CT Acquisition ($^{99m}$Tc-Sestamibi)**



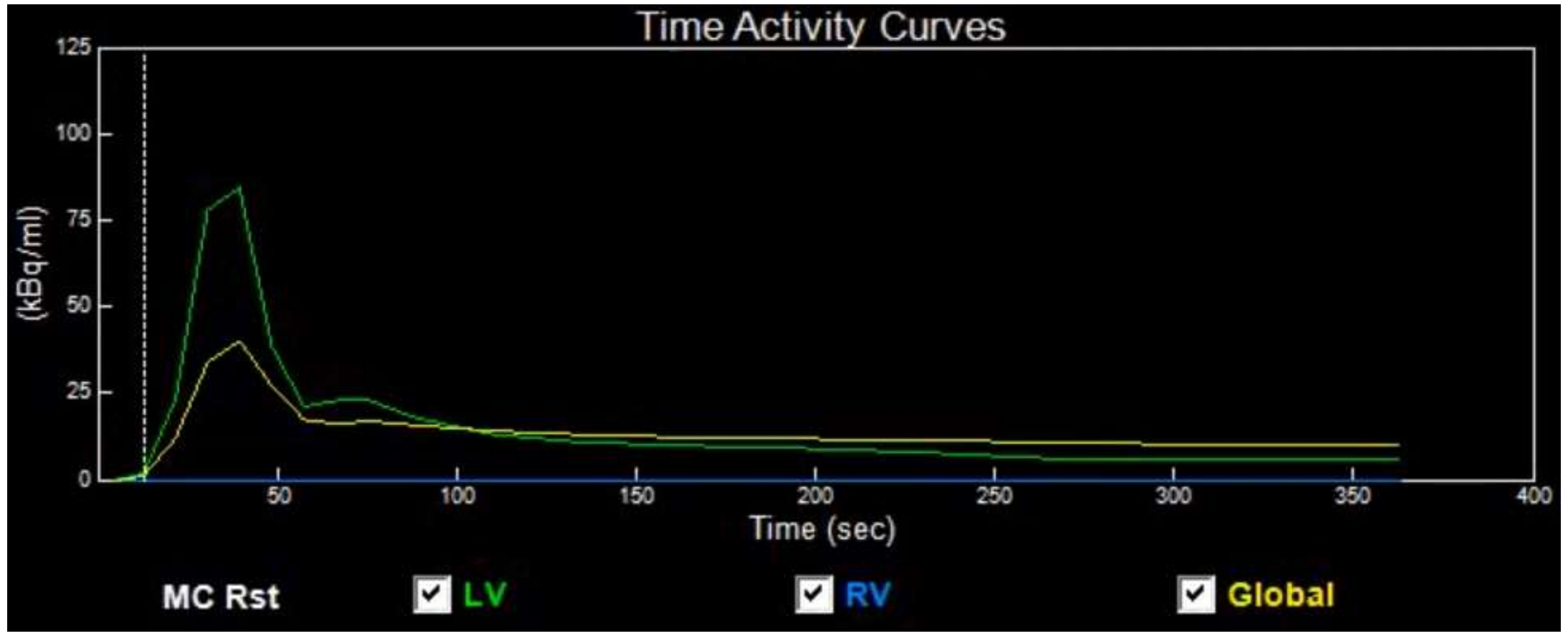



## 6-min 3D Dynamic SPECT/CT Acquisition ($^{99m}$Tc-Sestamibi)

- **Rest** study
- Bolus Injection (20 mCi)
- 67y Male
- BMI of 30.7

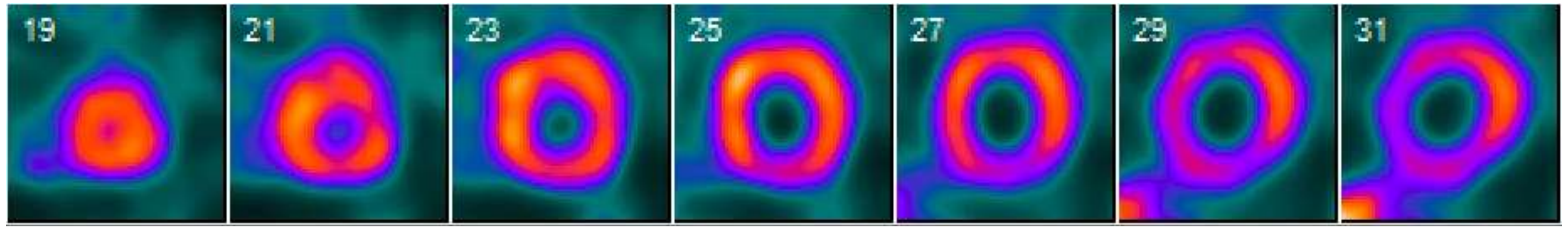
- **Framing:** 9x8 sec, 1x16 sec, 2x24 sec, 7x32 sec




Net Retention Model

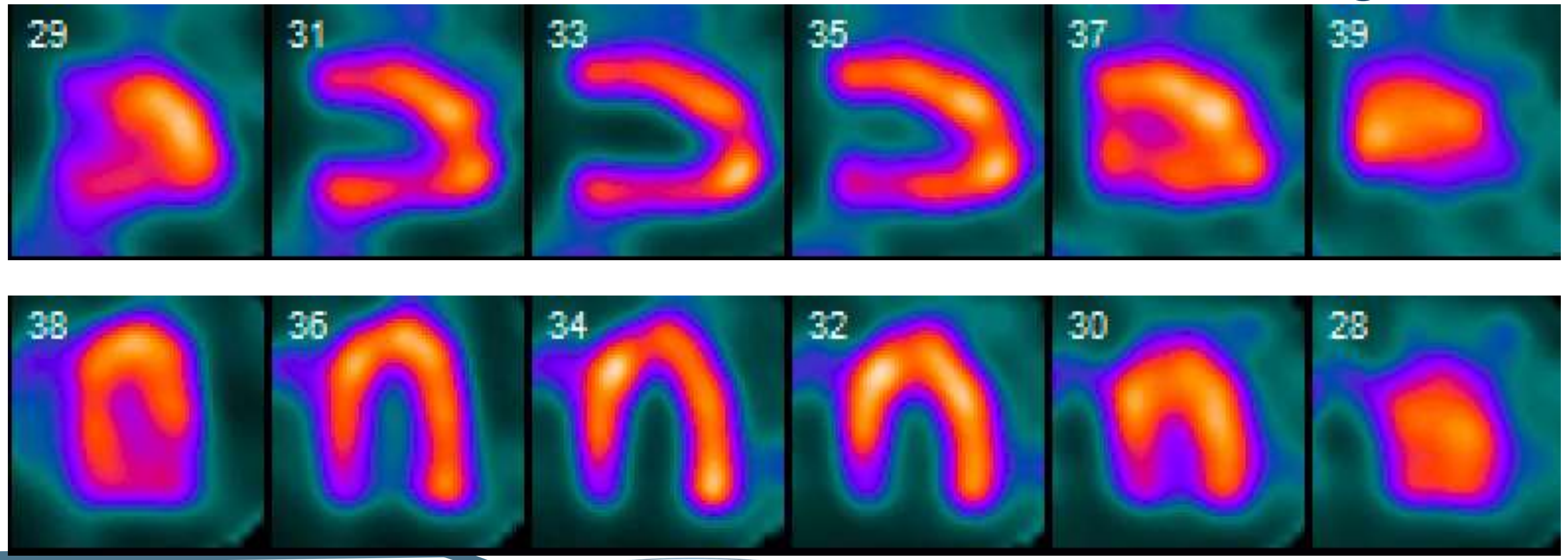
**MBF (ml/min/g)** ~ 0.62

## 9-min Gated SPECT/CT Acquisition

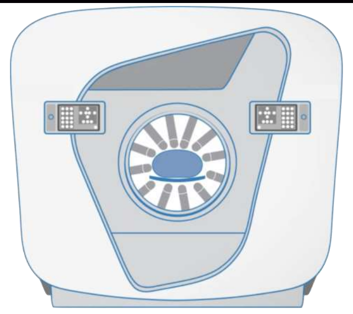



Short Axis

Horizontal Long Axis

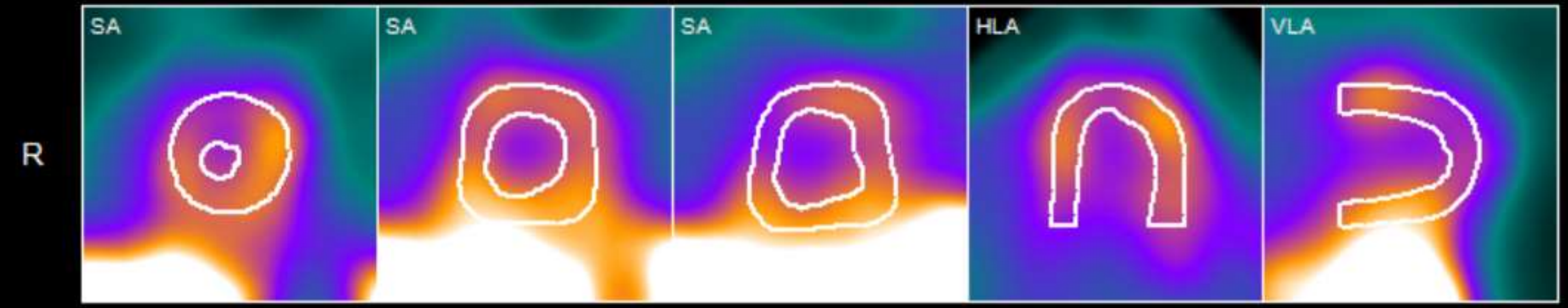


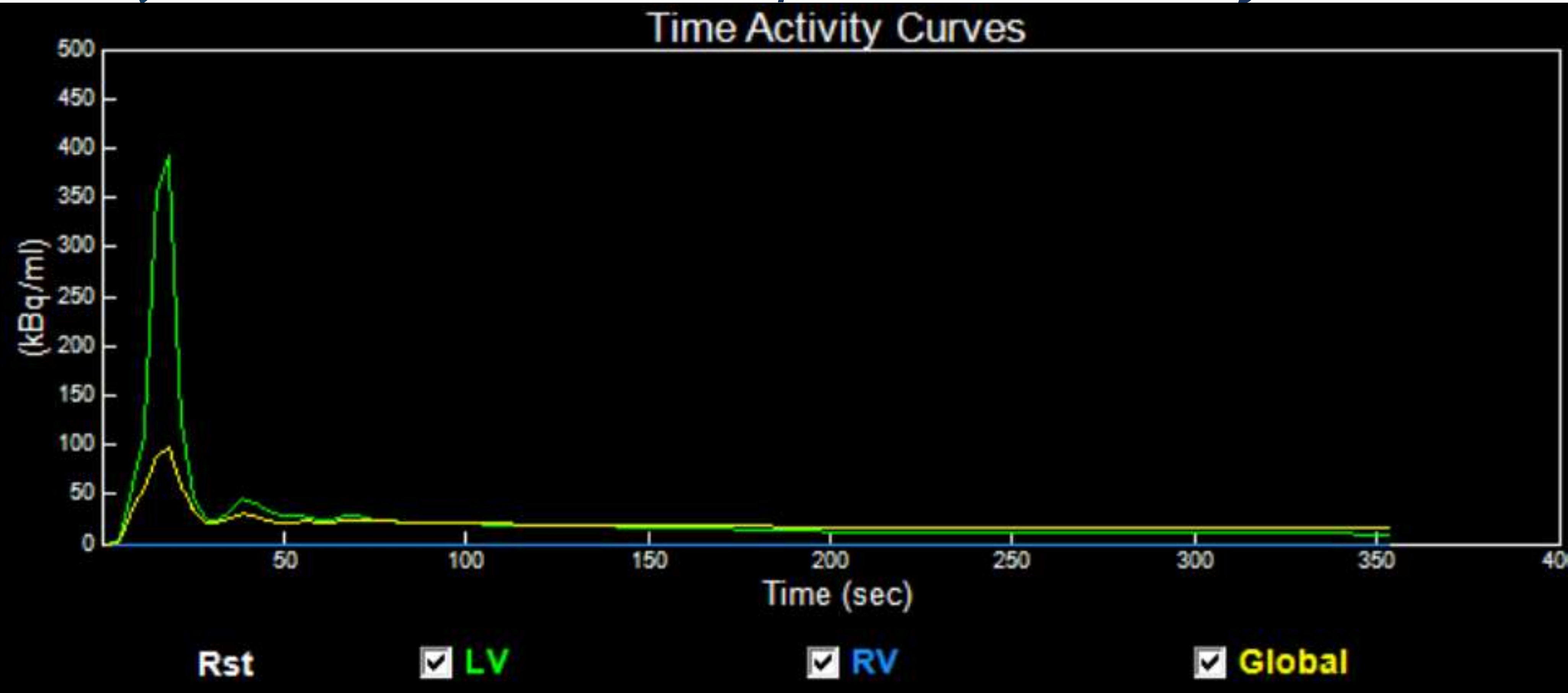

Vertical Long Axis



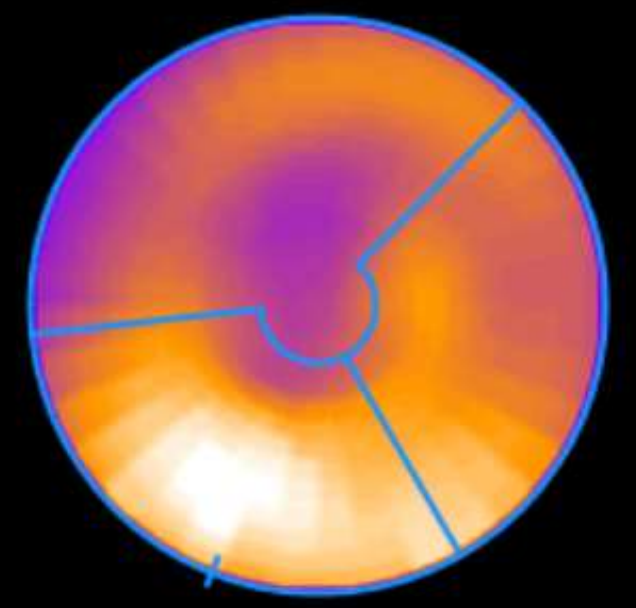
# MPI WITH FULL-RING CZT SPECT

## 6-min 3D Dynamic SPECT/CT Acquisition ($^{99m}$Tc-Sestamibi) – *Another Example Rest-Only*

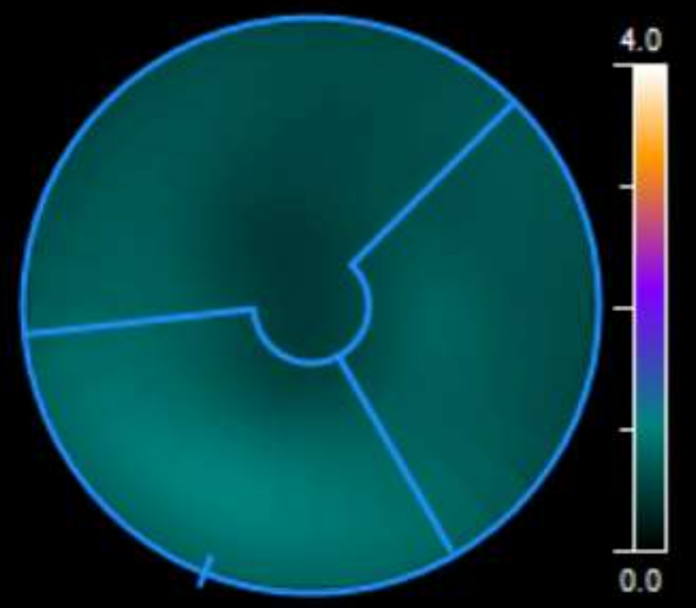



Perfusion-Normalized
RST1_DYN_2i16s-MBF_BP1_TA



Flow
RST1_DYN_2i16s-MBF_BP1_TA



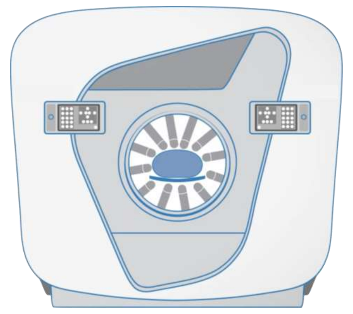

Flow (ml/min/g)


Algorithm (Rst): VERITON MIBI ROI NetRet Leppo AC
Algorithm (–): --

Global Results

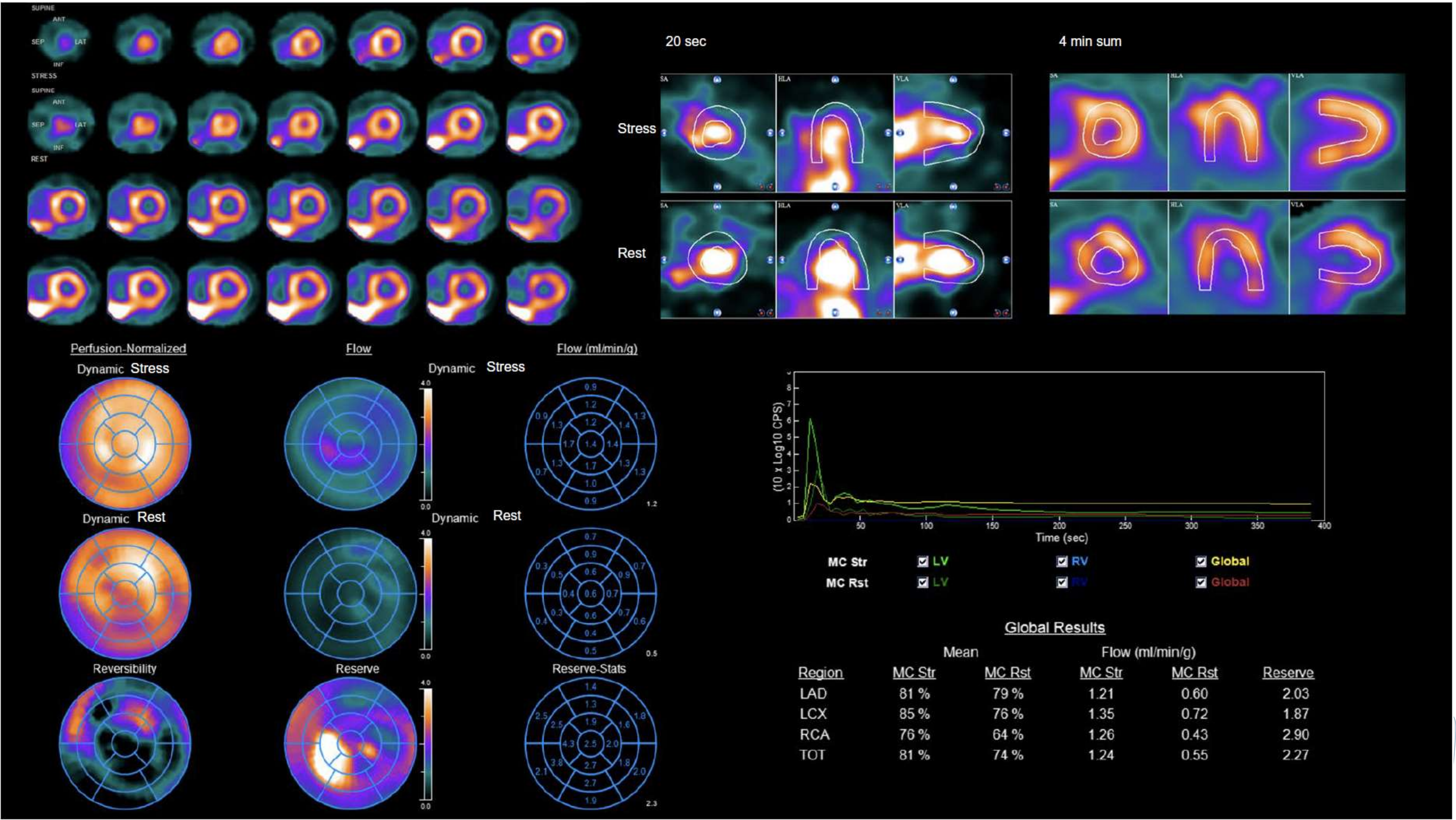
| | Mean | | Flow (ml/min/g) | | |
|---|---|---|---|---|---|
| Region | Rst | – | Rst | – | Ratio |
| LAD | 70% | – | 0.61 | – | – |
| LCX | 78% | – | 0.69 | – | – |
| RCA | 86% | – | 0.81 | – | – |
| TOT | 77% | – | 0.68 | – | – |





# MPI WITH FULL-RING CZT SPECT

## 7-min 3D Dynamic SPECT/CT Acquisition ($^{99m}$Tc-Sestamibi) – GE Starguide





Bailly, *et al.* (2023). Dynamic cardiac SPECT with flow measurement using 3D-ring CZT: when SPECT is inspired by PET. *EJNMMI*, *50*(6), 1837-1839.

**Cardiac Amyloidosis** is a form of **progressive heart failure** (*protein misfolding disorder*)

**Scintigraphy and SPECT/CT with Bone Avid Tracers ($^{99m}$Tc PYP/DPD),**

- **>91% sensitive**, **87% specific** for **cardiac ATTR** [1]
- **Standard of Care for Diagnosis** [2]
- **Potential Roles**
  - **Prognosis**
  - **Early diagnostic**
  - Assessment of **disease progression**
  - Assessment of **treatment response**

[1] Gillmore JD, et al. *Circulation* 2016.
[2] Dorbala, et al. *Circulation: Cardiovascular Imaging*, *2021*.

# ATTR-CARDIAC AMYLOIDOSIS IMAGING

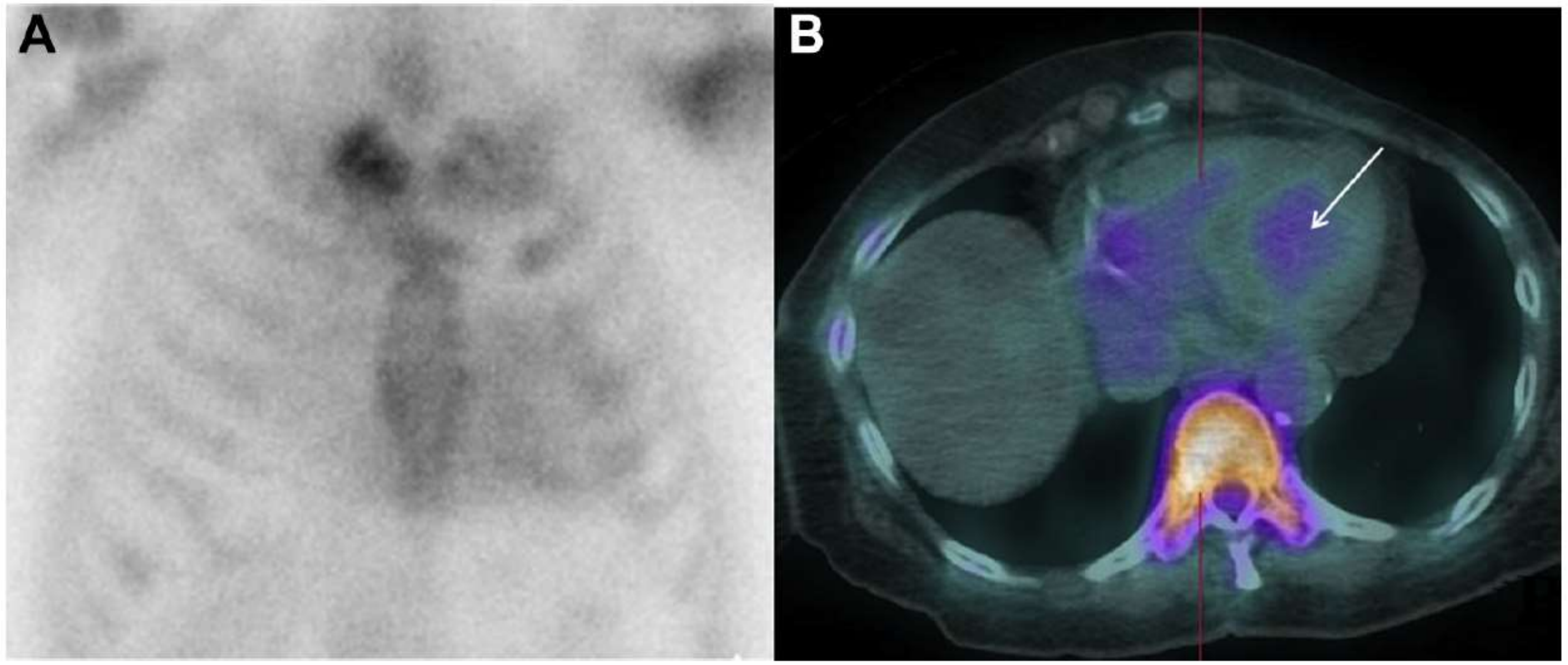
**SPECT is recommended over scintigraphy [1,2],**

- Delineate blood pool from myocardial activity

**SPECT/CT is superior to SPECT [1,2]**

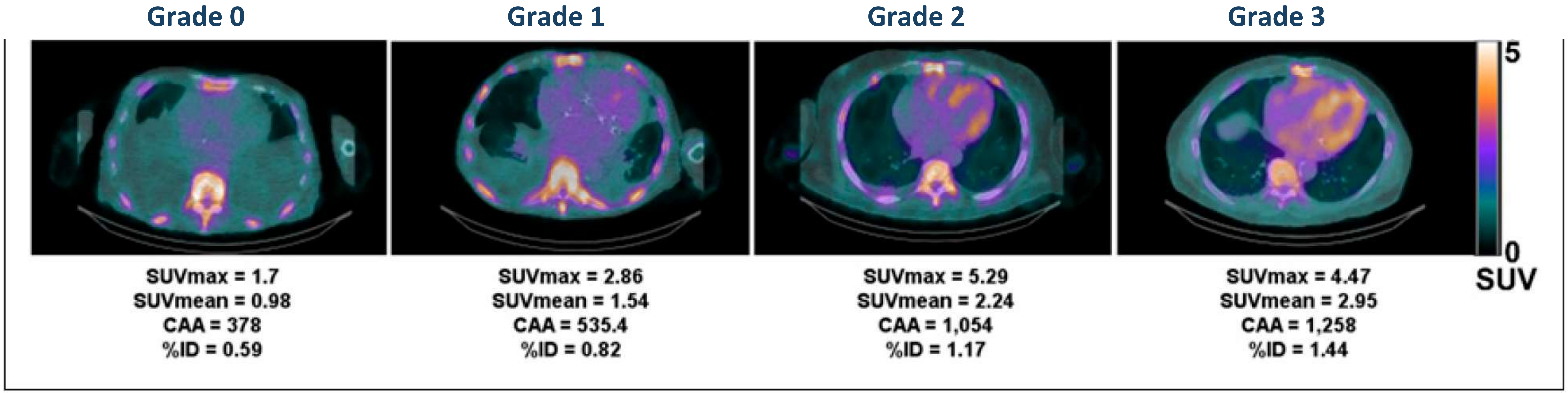
- Attenuation and Scatter Correction
- Improved Quantitation
- Anatomic localization – particularly valuable for low-uptake scans and blood pool delineation

[1] Dorbala, et al. *Circulation: Cardiovascular Imaging*, *2021*.




Adapted from [2] Hanna, et al. *Journal of the American College of Cardiology*, *2020*.

**Quantitative Full-Ring CZT SPECT/CT** offers **the potential for early detection, risk stratification, and monitoring of response to therapy** in **cardiac amyloidosis patients**




Adapted from Dorbala, et al. *Journal of Nuclear Medicine, 2021*

# ATTR-CARDIAC AMYLOIDOSIS IMAGING

## 3D Dynamic Imaging enables,

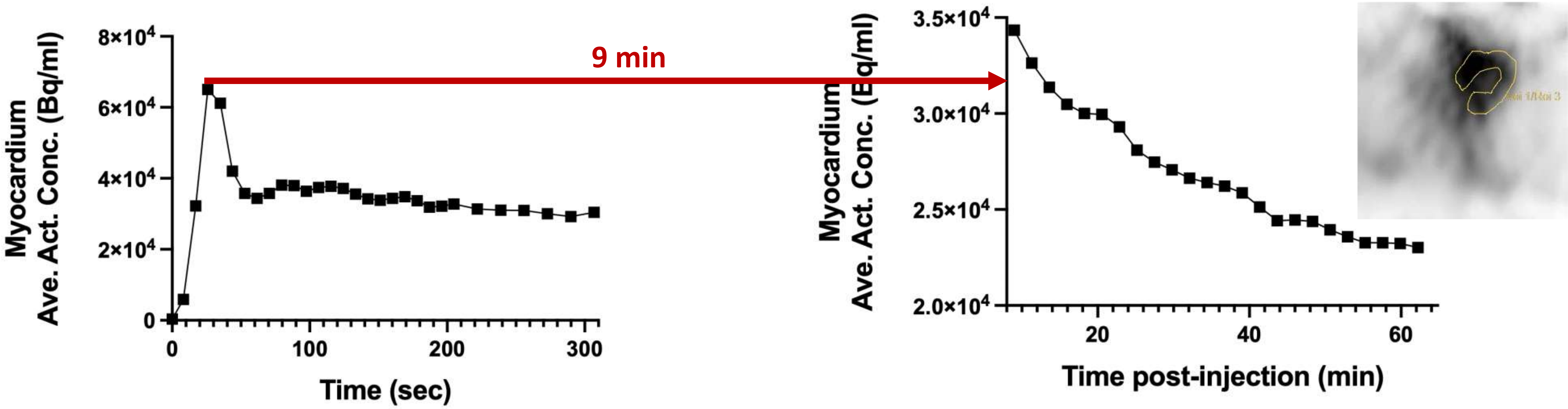
- Segmentation of blood pool region from early frames to improve quantitation
- Determination of PYP/DPD myocardium uptake over time to reduce uptake time

### Dynamic SPECT/CT

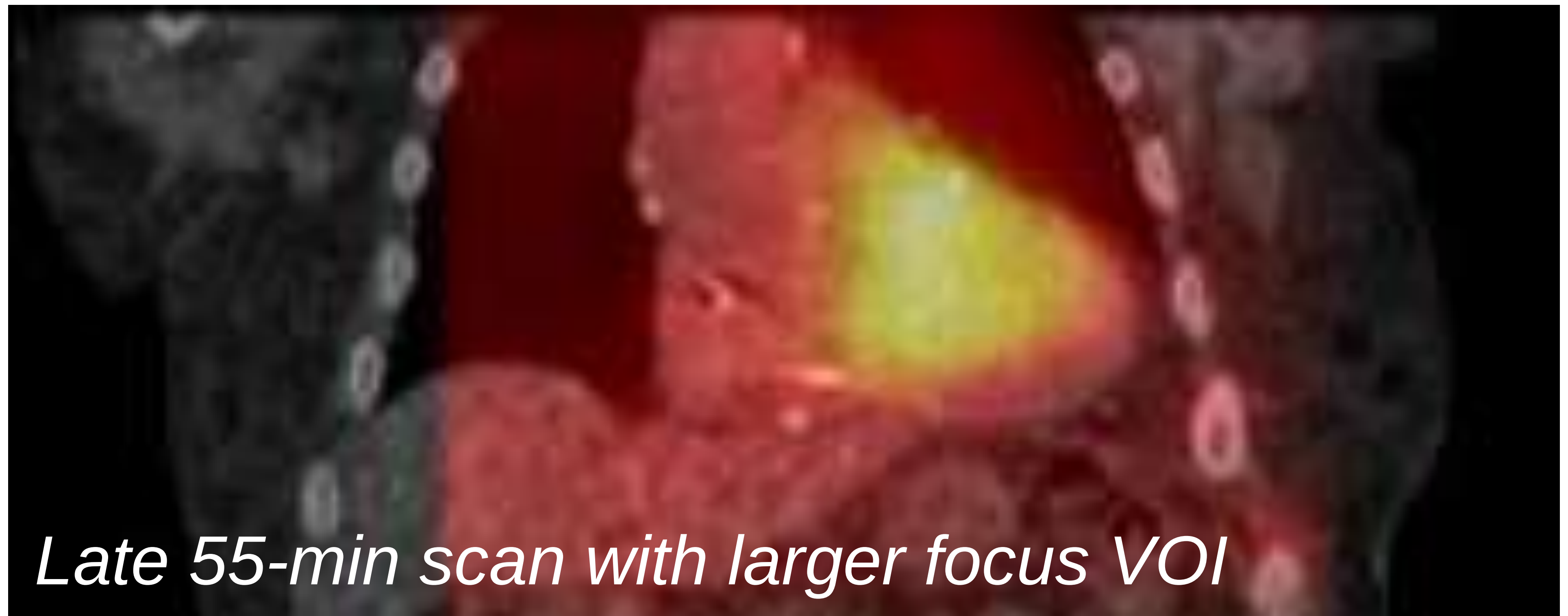
20 mCi ($^{99m}$Tc-PYP)
82y Male
Positive Case
BMI: 24.7

**Early Imaging**

**Late Imaging –** *9 min post injection*




*Early 5-min scan focus on the heart*



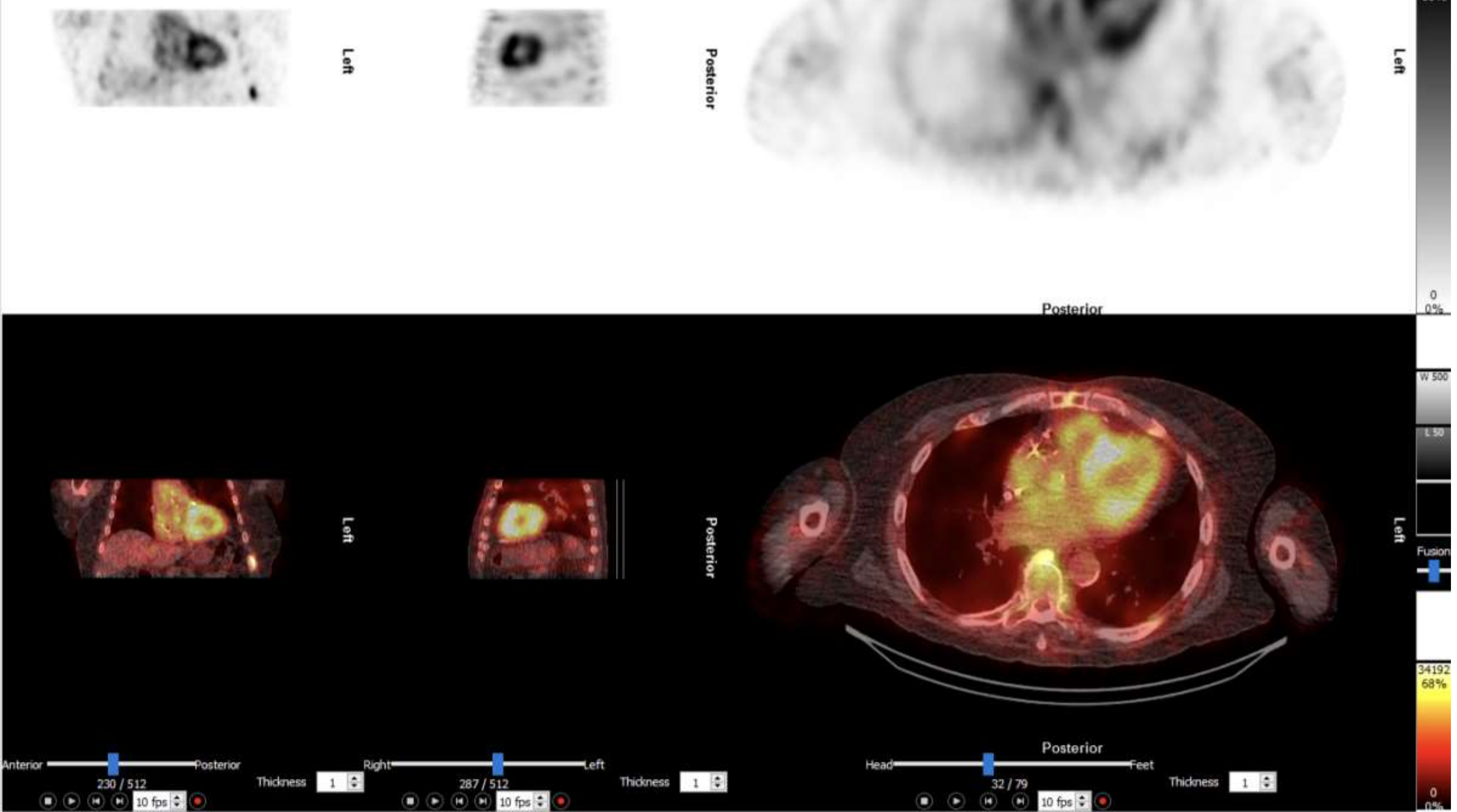
*Late 55-min scan with larger focus VOI*

## 3D Dynamic Imaging enables,

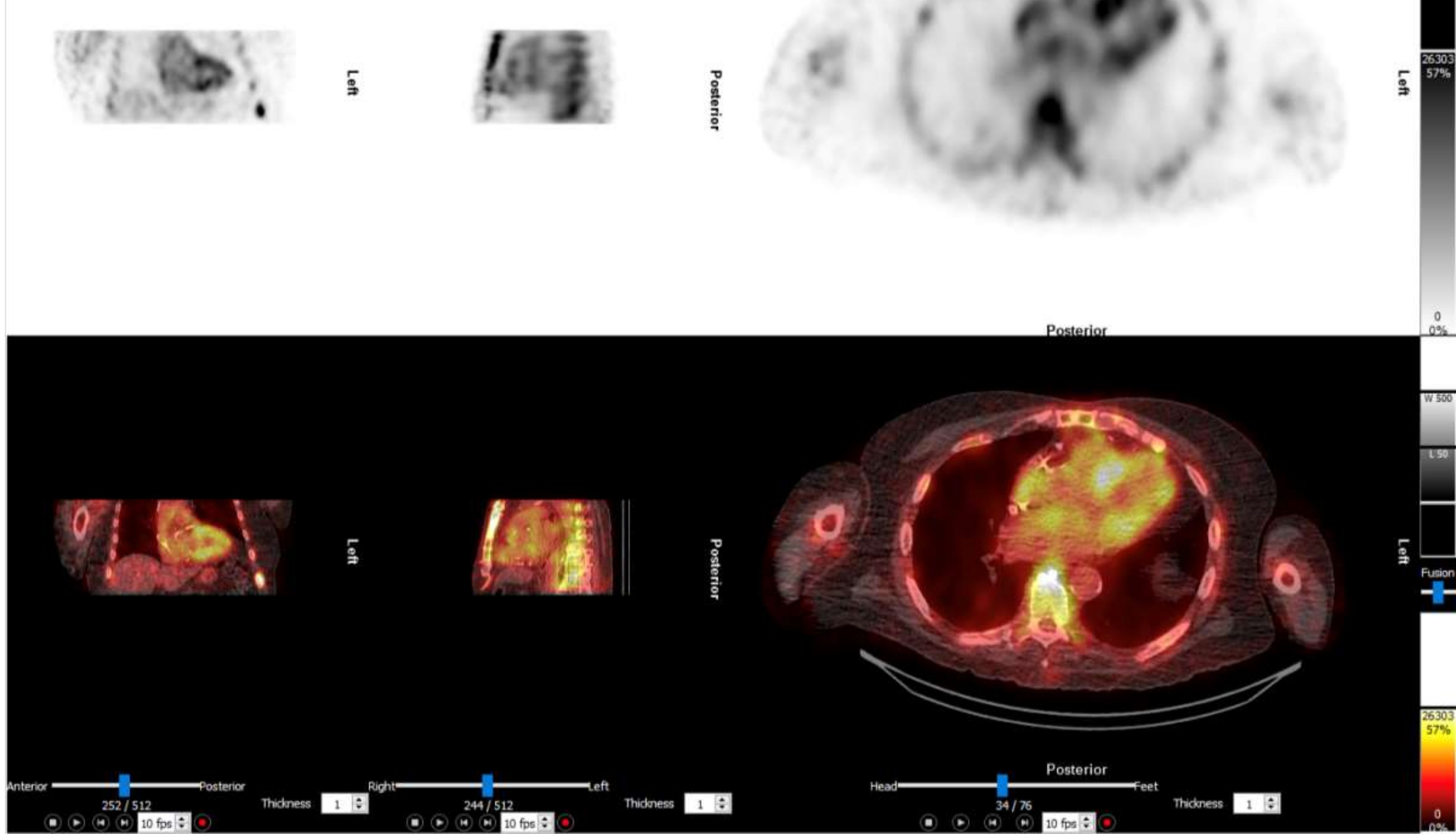
- Segmentation of blood pool region from early frames to improve quantitation
- Determination of PYP/DPD myocardium uptake over time to reduce uptake time

**Cardiac Uptake** already seen **early on**
**Uptake time** can very likely be **shortened**, resulting in **improved Clinical Care**

**70 min** post-injection
**Higher Myocardial Uptake** than the clinical scan




**145 min** post-injection
**Clinical scan**

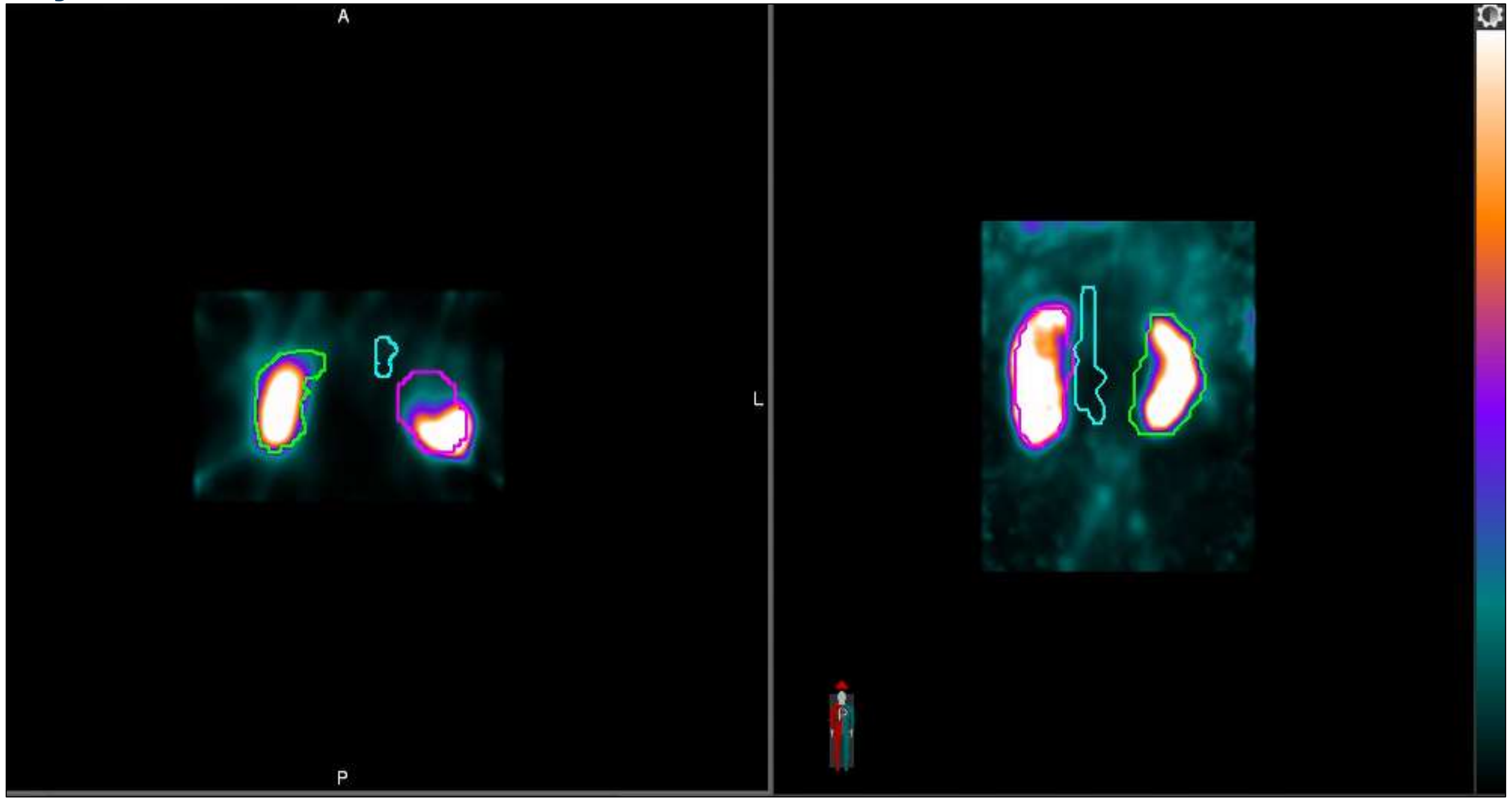


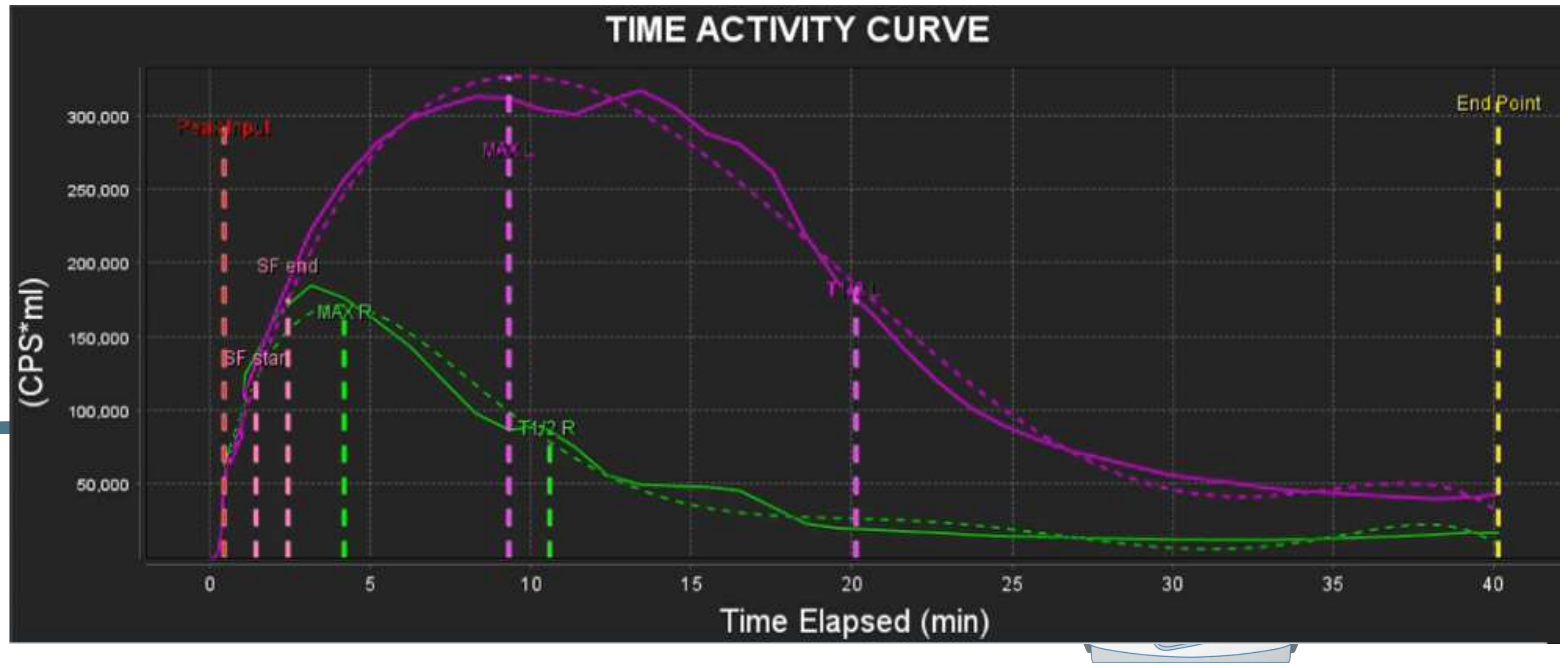
# 3D DYNAMIC RENAL IMAGING

## Full-ring CZT SPECT/CT offers

- **High sensitivity** and **improved spatial resolution** that can enhance image quality and quantitation while reducing the acquisition time and/or injected dose
- CT-based anatomic information that can be used for ROI definition and to aid localization [1-3]
- Enhanced **3D dynamic capability**

**Dynamic SPECT/CT** — 40 min total scan time




- 84y Male; BMI: 24
- $^{99m}$Tc-MAG-3: 10 mCi

Images courtesy of Royal United Hospitals Bath NHS Foundation Trust, Bath, UK

[1] Jacene, *et al.* Open Med Imaging 2008.
[2] Arun, *et al.* Nucl. Med. Commun. 2013.
[3] Eldredge, *et al.* Obesity Surgery. 2020.

# 3D DYNAMIC **BRAIN** PERFUSION IMAGING

## Dynamic SPECT/CT Acquisition ($^{99m}$Tc-ECD)

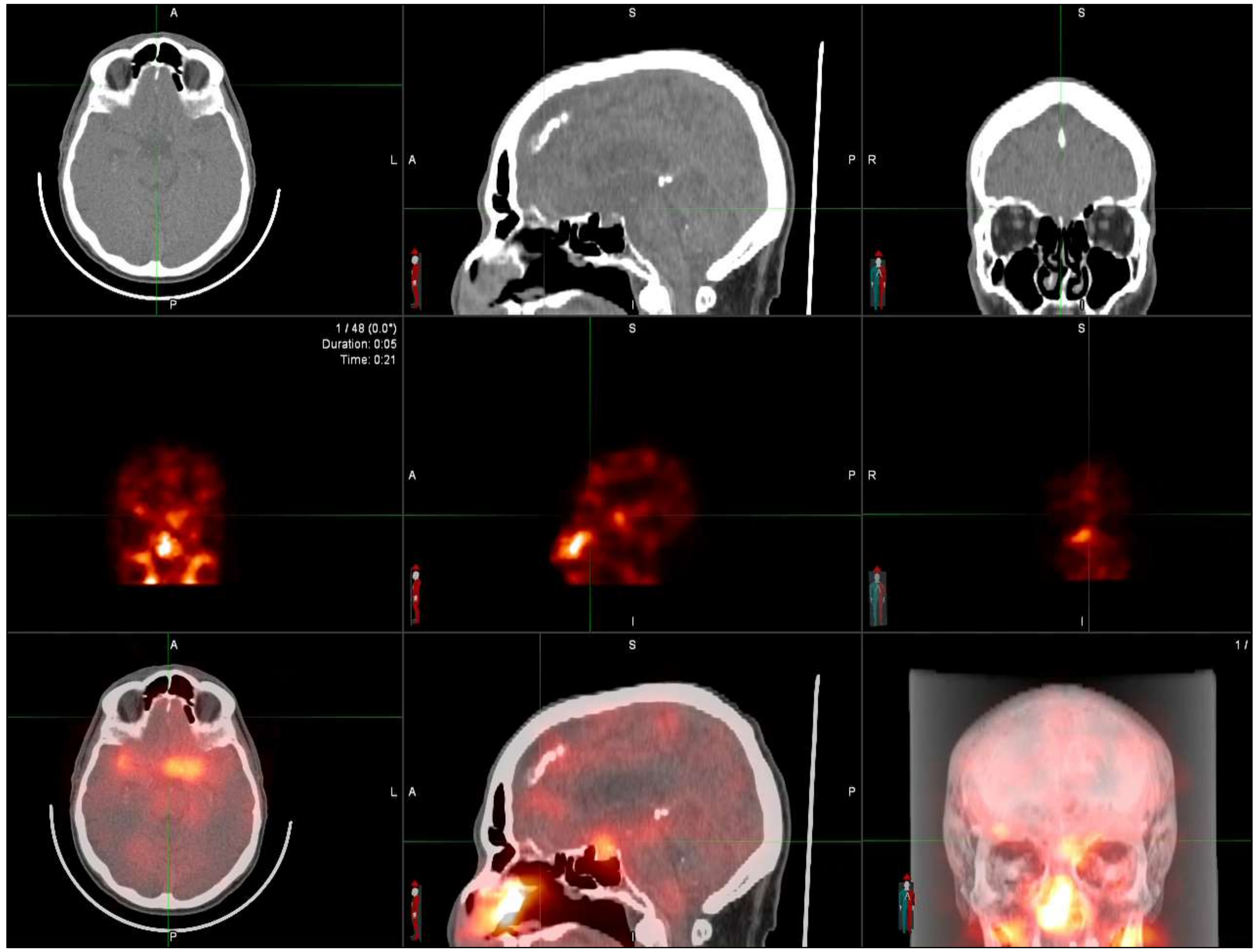
- 79y Male
- BMI: 21
- Dose: *17.9 mCi*

**Dynamic** SPECT/CT 5 sec/frame – 15 min

CT

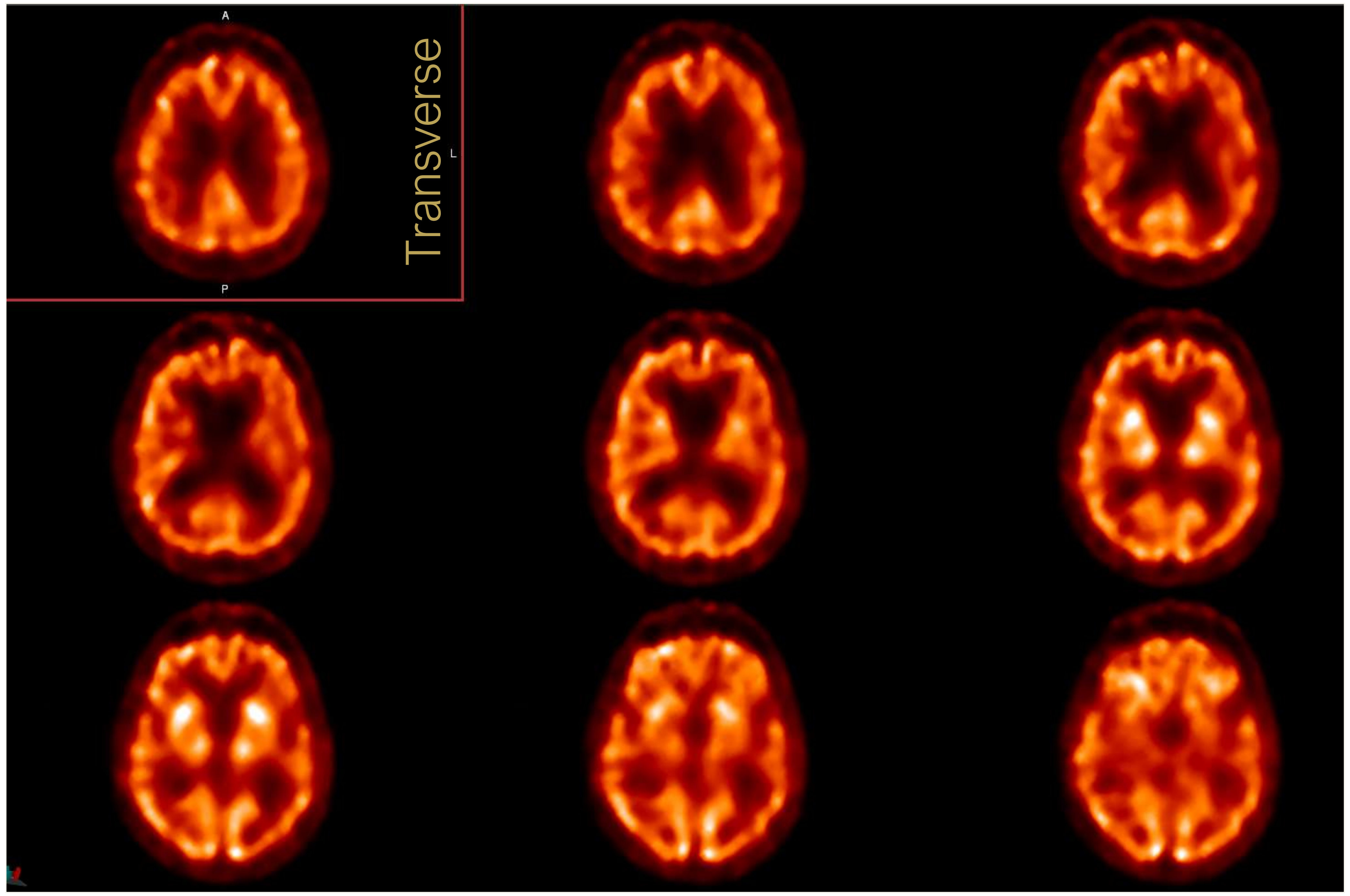
SPECT

Fused




Transverse Sagittal Coronal

Delayed **Static** SPECT/CT – 15 min




Images Courtesy of Centre Hospitalier Régional Universitaire (CHRU) de Nancy, Nancy, France

# 3D DYNAMIC BRAIN PERFUSION IMAGING

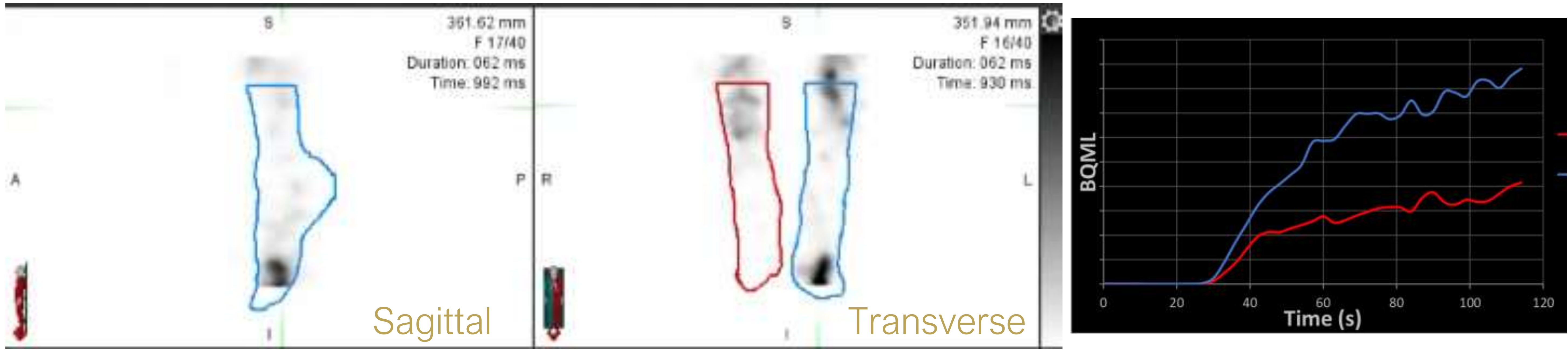
## Full-ring CZT SPECT/CT

- Can offer **CT-based anatomic information** that can be used for ROI definition compared to **SPECT-only** and **planar**
- Provides **3D dynamic capability** that can enhance **multi-phase bone imaging** compared to **conventional SPECT/CT** (*limited to 2D Dyn Imaging*)

**Three Phase Bone SPECT/CT**

- 45y Male
- BMI: 26.6
- $^{99m}$Tc-HMDP 12.1 mCi

**Dynamic SPECT/CT** 2 min (40 frames of 3 sec)




**Flow phase (I)** | **BP phase (II)** | **Delayed phase (III)**

Dynamic SPECT/CT 2 min | Static SPECT/CT 5 min | Static SPECT/CT 5 min

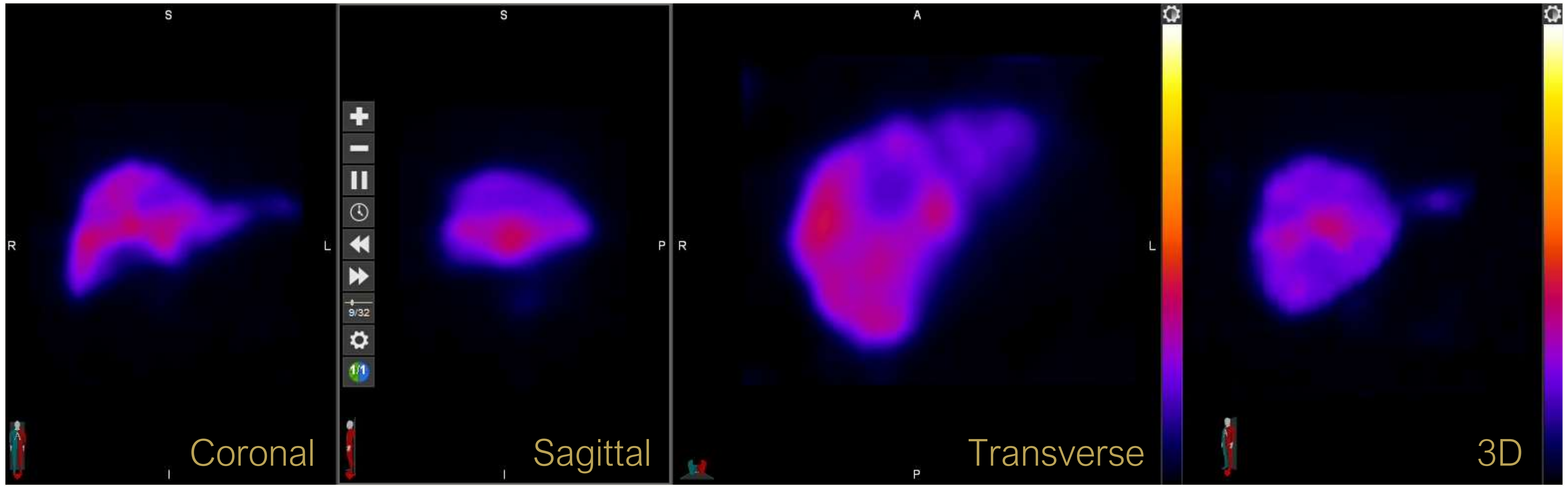
Mairal *et al.* . Eur J Nucl Med Mol Imaging.

Images Courtesy of CHRU Nancy, France

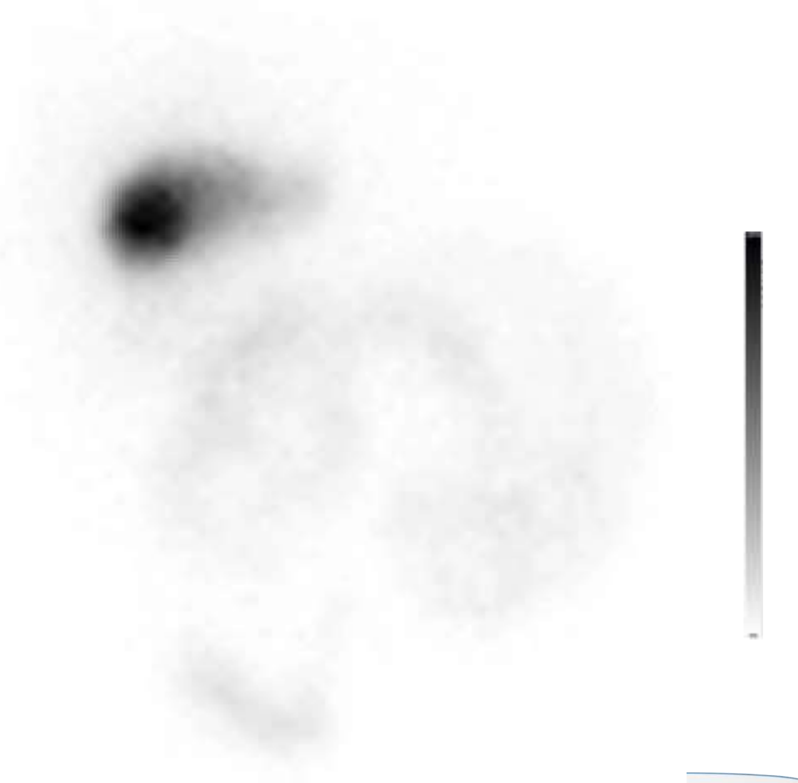
## Full-ring CZT SPECT/CT offers

- **High sensitivity** and **improved spatial resolution** that can enhance image quality and quantitation while reducing the acquisition time and/or injected dose
- CT-based anatomic information that can be used for ROI definition and to aid localization [1-3]
- Enhanced **3D dynamic capability**

**Dynamic SPECT** 30 min (360 frames of 5 sec)




**Planar CCK delayed at 60 min –** *25% Ejection fraction*



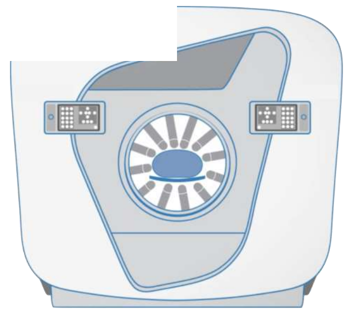
30 frames of 1 min

**Dynamic SPECT-only followed by planar CCK**

- 26y Female; BMI: 41.5
- $^{99m}$Tc-diisopropyl IDA: 5 mCi

[1] Jacene, *et al.* Open Med Imaging 2008.
[2] Arun, *et al.* Nucl. Med. Commun. 2013.
[3] Eldredge, *et al.* Obesity Surgery. 2020.





# SEMI-QUANTITATIVE HEPATOBILIARY IMAGING

**Major Liver Resection** can be performed with **limited morbidity and mortality** when sufficient remnant liver function remains to avoid **P**ost-**H**epatectomy **L**iver **F**ailure (**PHLF**).

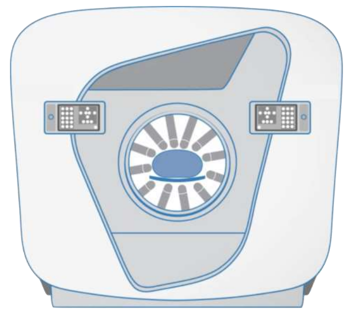
**Pre-operative assessment** of the future remnant liver function **is essential** [1,2]

- **Current Standard – Indirect Imaging Approach**
  1. Dynamic Planar Imaging to assess total liver function (6 min)
  2. Fast **static SPECT/CT** at liver maximum uptake to segment remnant/resected liver regions (10 min)

- **Role for Full-Ring CZT SPECT = 3D Dynamic Imaging**
  - Facilitate the procedure - *single dynamic SPECT only*
  - Direct liver remnant function assessment
  - Enhance quantitative accuracy - *no activity superimposition*

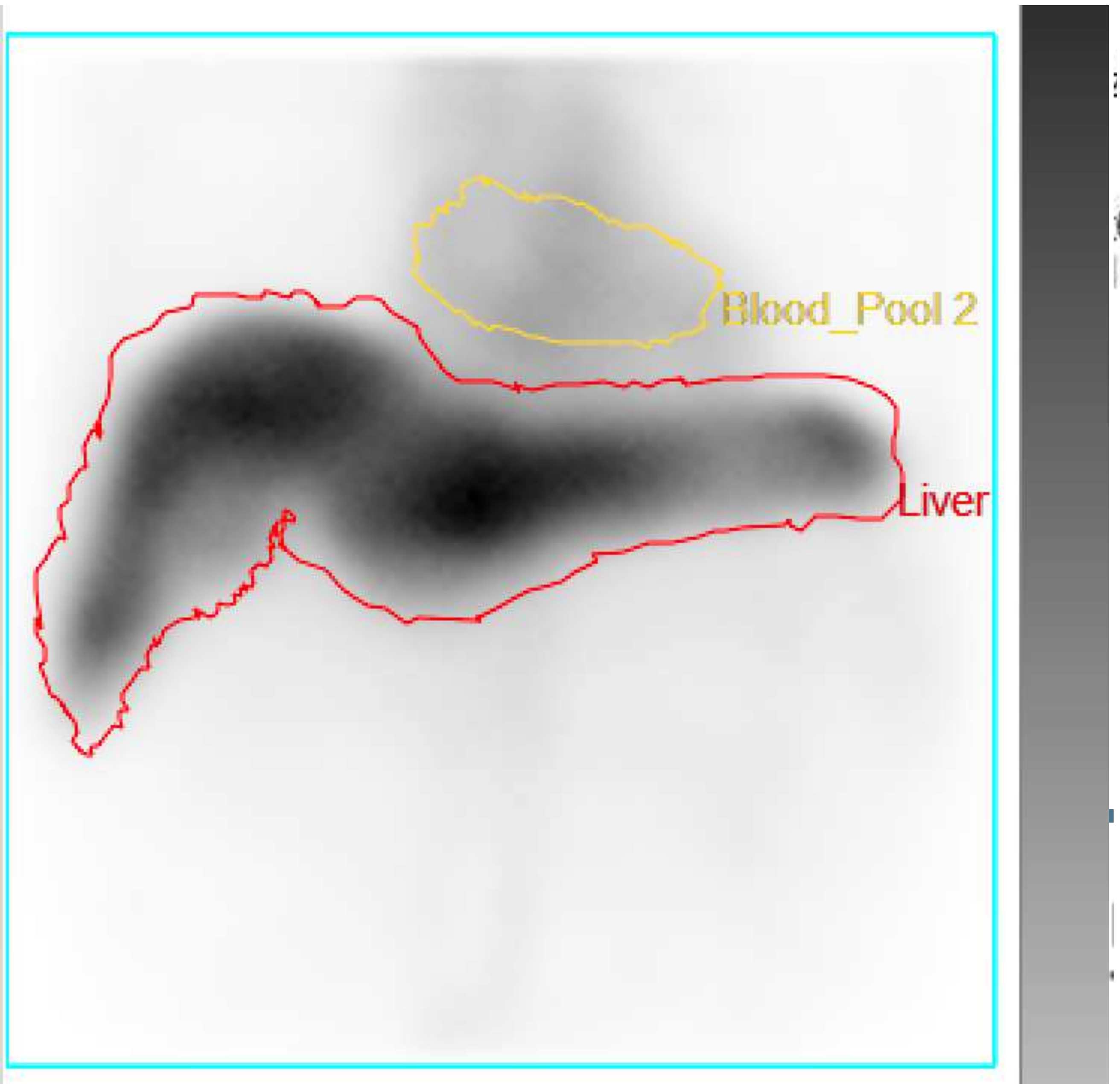
[1] Rassam, *et al.* Nuc. Med. Commun. 2019.
[2] Serenari, *et al.* Ann. Surg. 2018



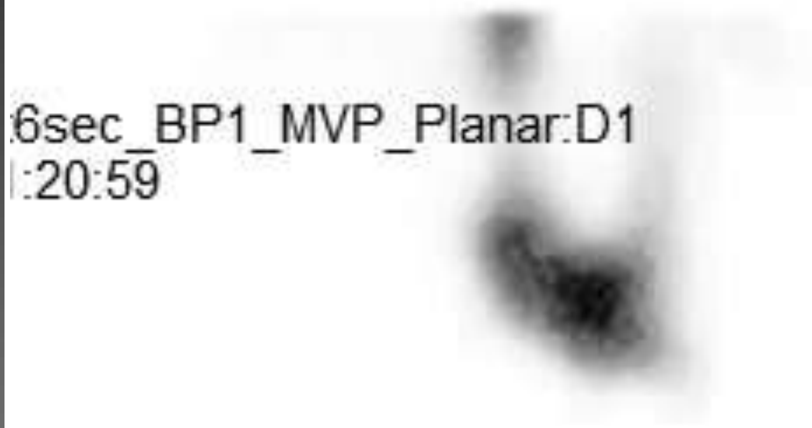


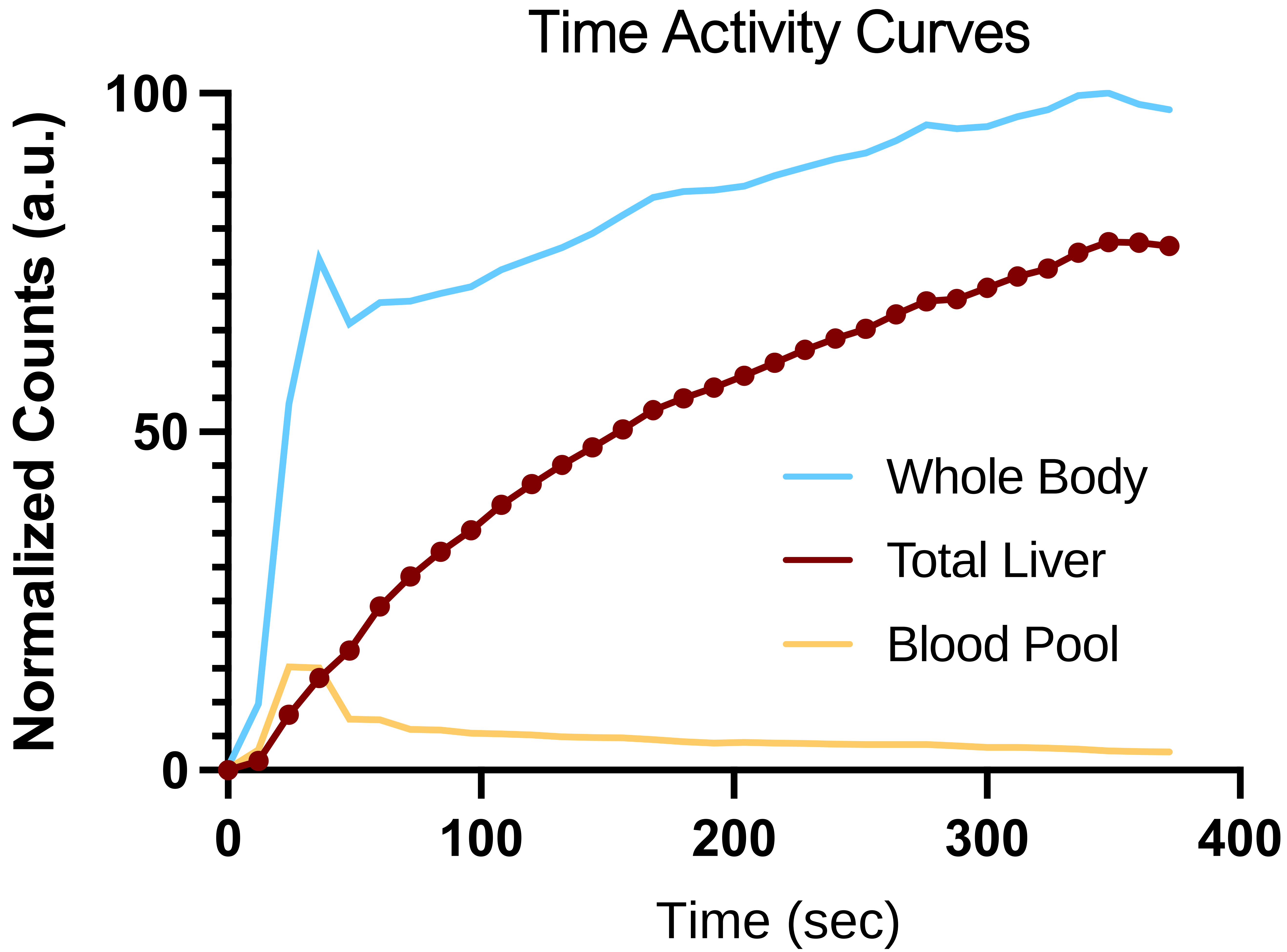
## Total Liver Function

- **99mTc-Mebrofenin** (6.5 mCi)
- **Dynamic Planar Imaging** (*10 sec/frame*)
- **Geometric mean from ANT and POST views to correct for source non-uniformities.**
- ROIs for Liver, Blood Pool, and Total Body/FOV

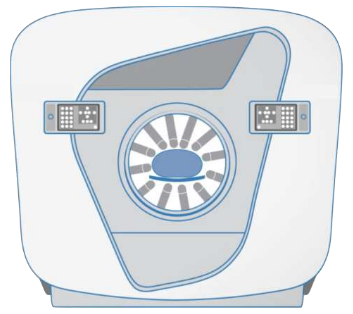



**Dynamic Planar (2D)**

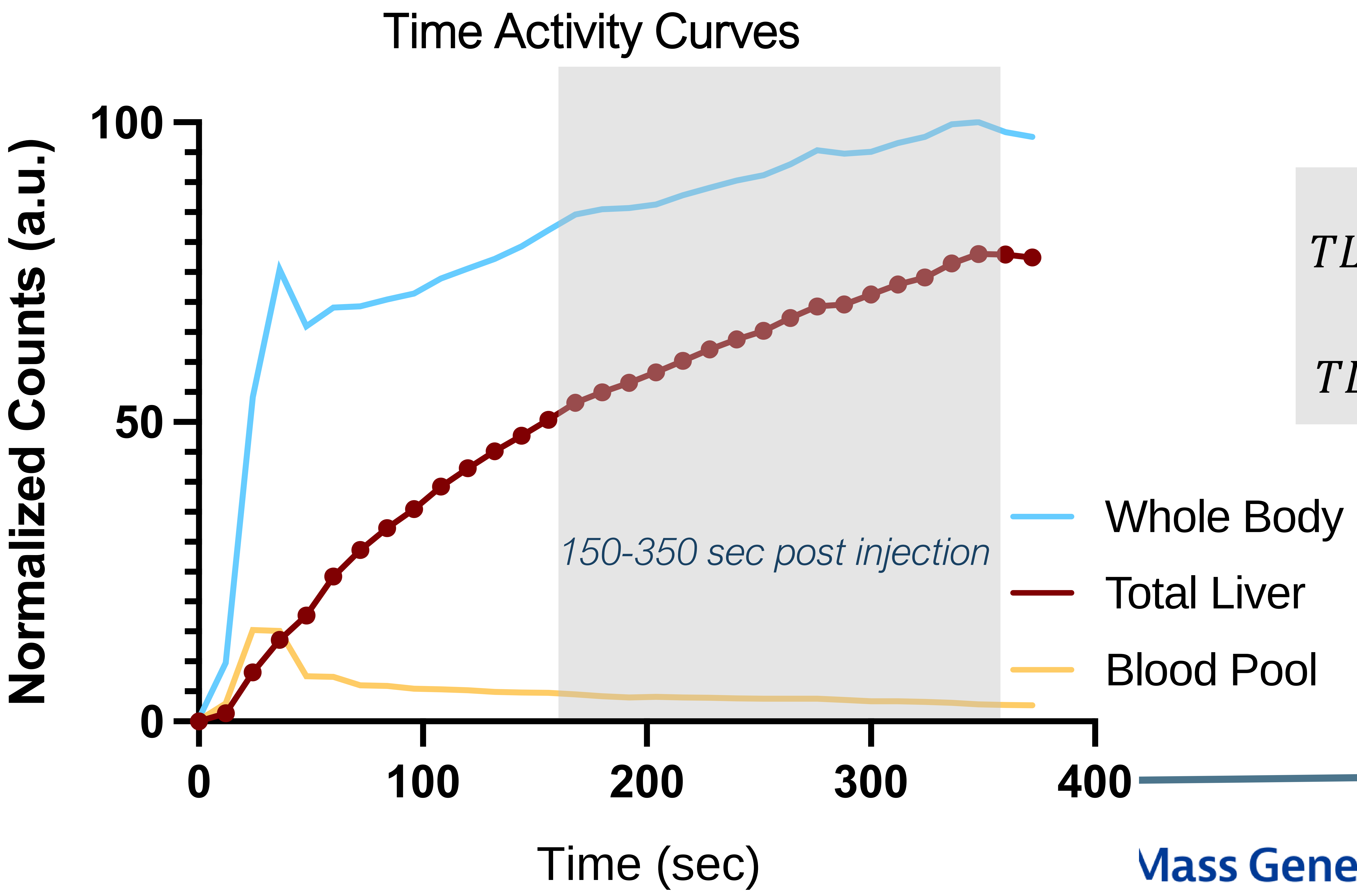




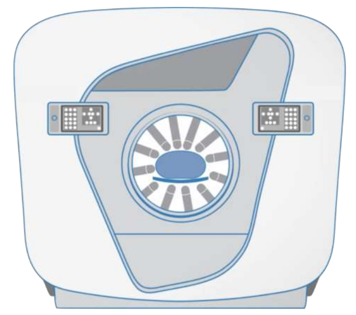
## Total Liver Function Estimated from 2D Dynamic Imaging




### Total Liver Uptake

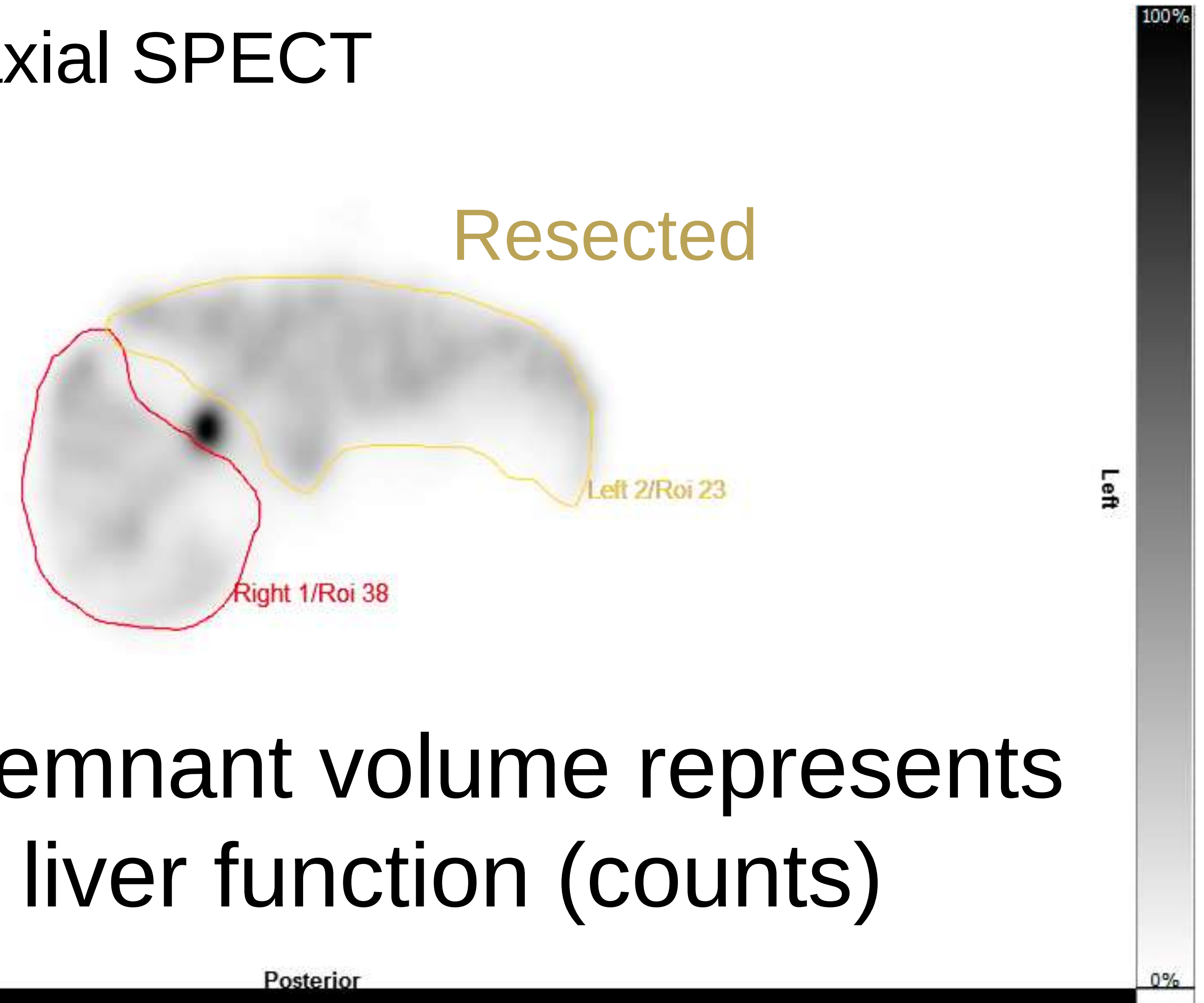
$$TL - U = 100 \times \frac{(AUC_{Liver} - AUC_{BP})}{AUC_{WB}}$$

$$TL - U = \mathbf{66.8\%}$$

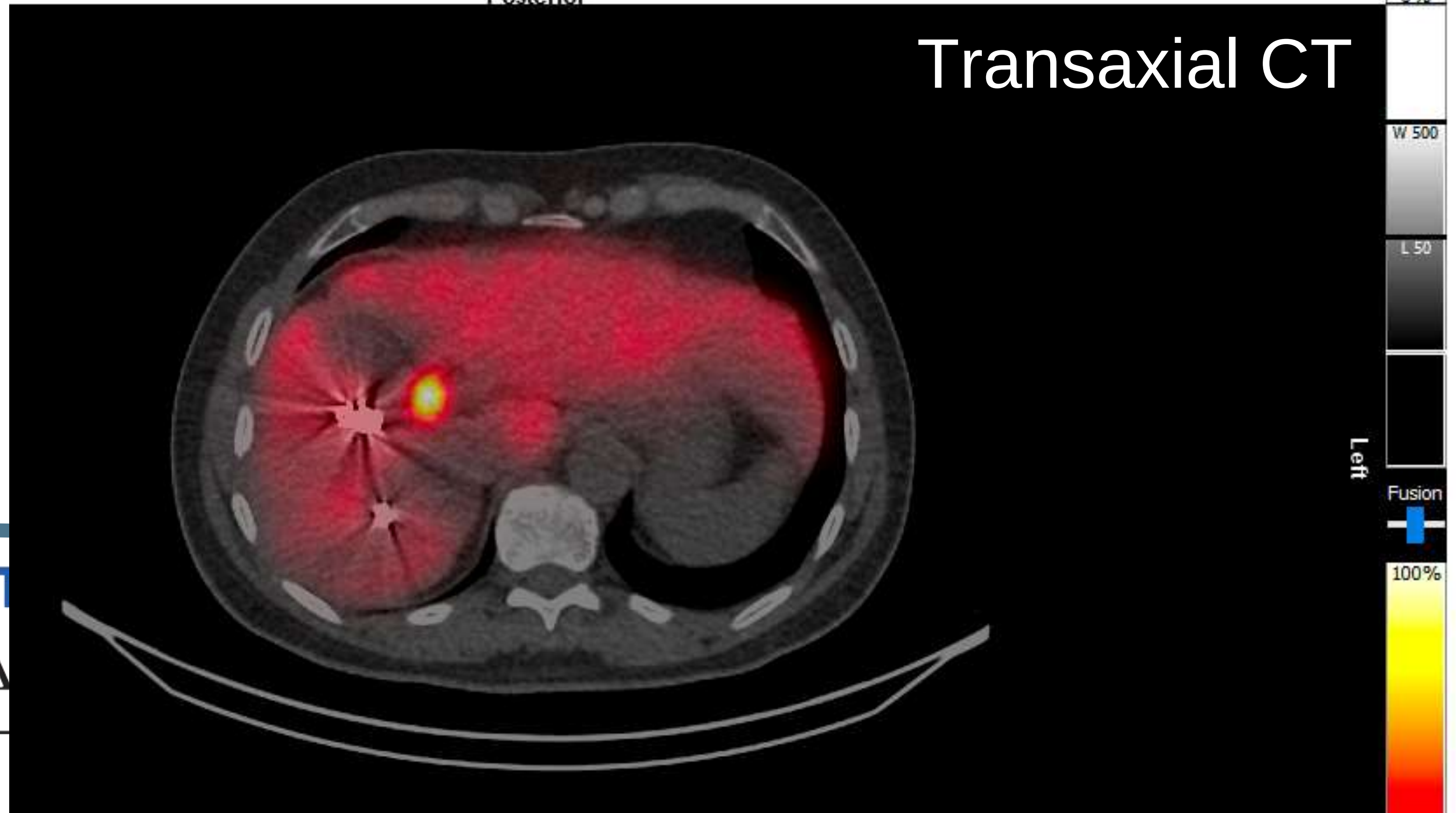


# Remnant/Resected Segmentation - % Counts from Static SPECT/CT

Transaxial SPECT



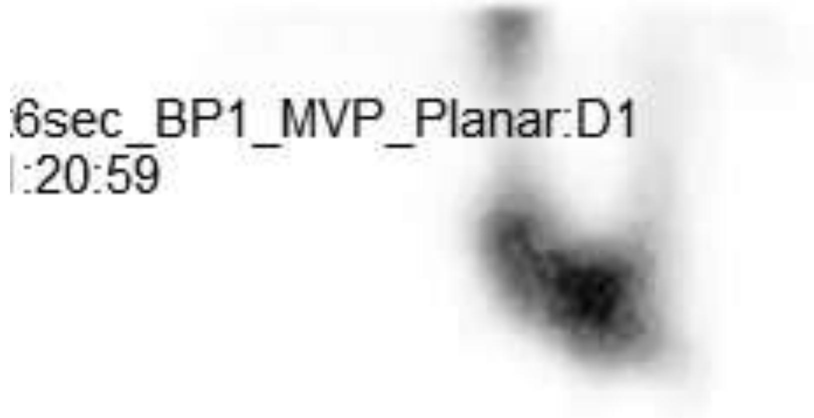

Future Remnant volume represents **52.7%** of liver function (counts)




3D View

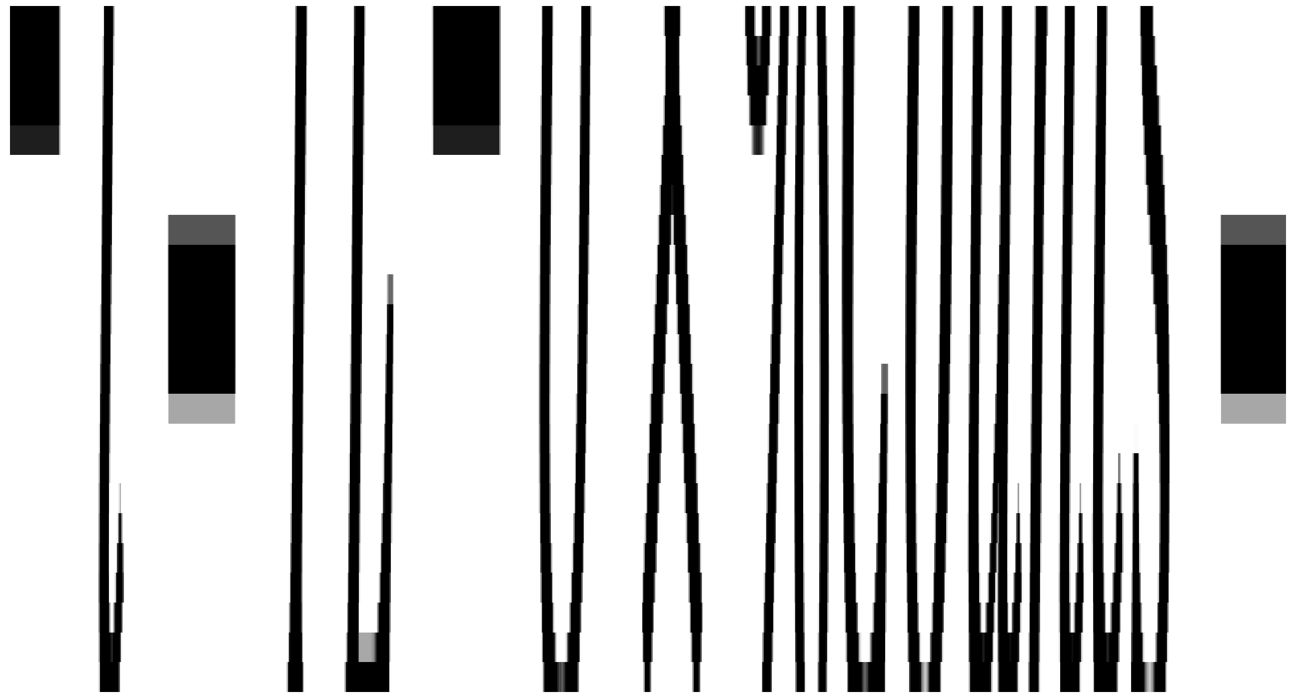
## HIBA-*i* quantitation

### Dynamic Planar




$$TL - U = 66.8\%$$

### Static SPECT/CT



Future Remnant volume represents **52.7%** of liver function (counts)

### HIBA-*index*

*used to predict Post-Hepatectomy Liver Failure (PHLF)*

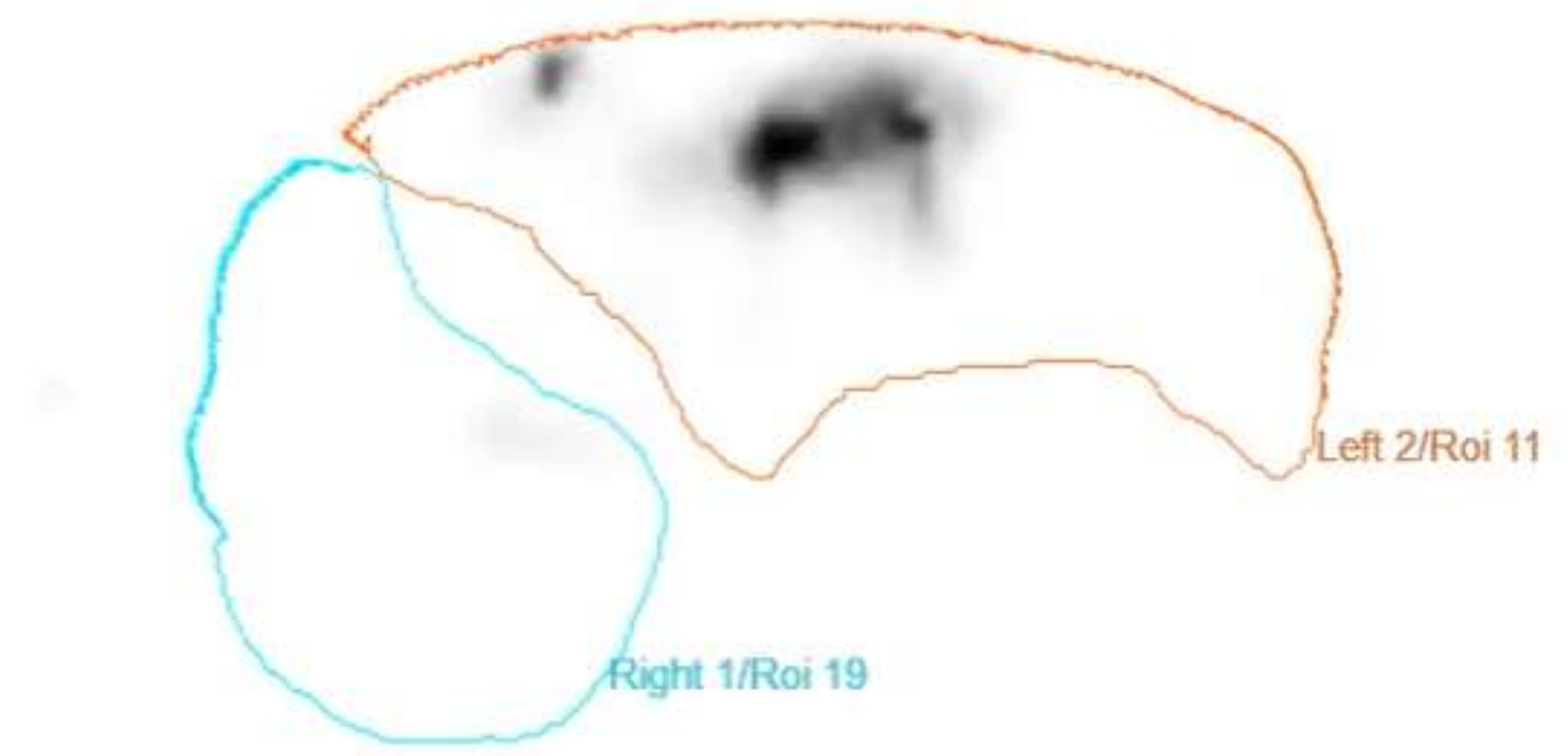
$$HIBA - i = TL - U \times \%Counts = 35.2\%$$

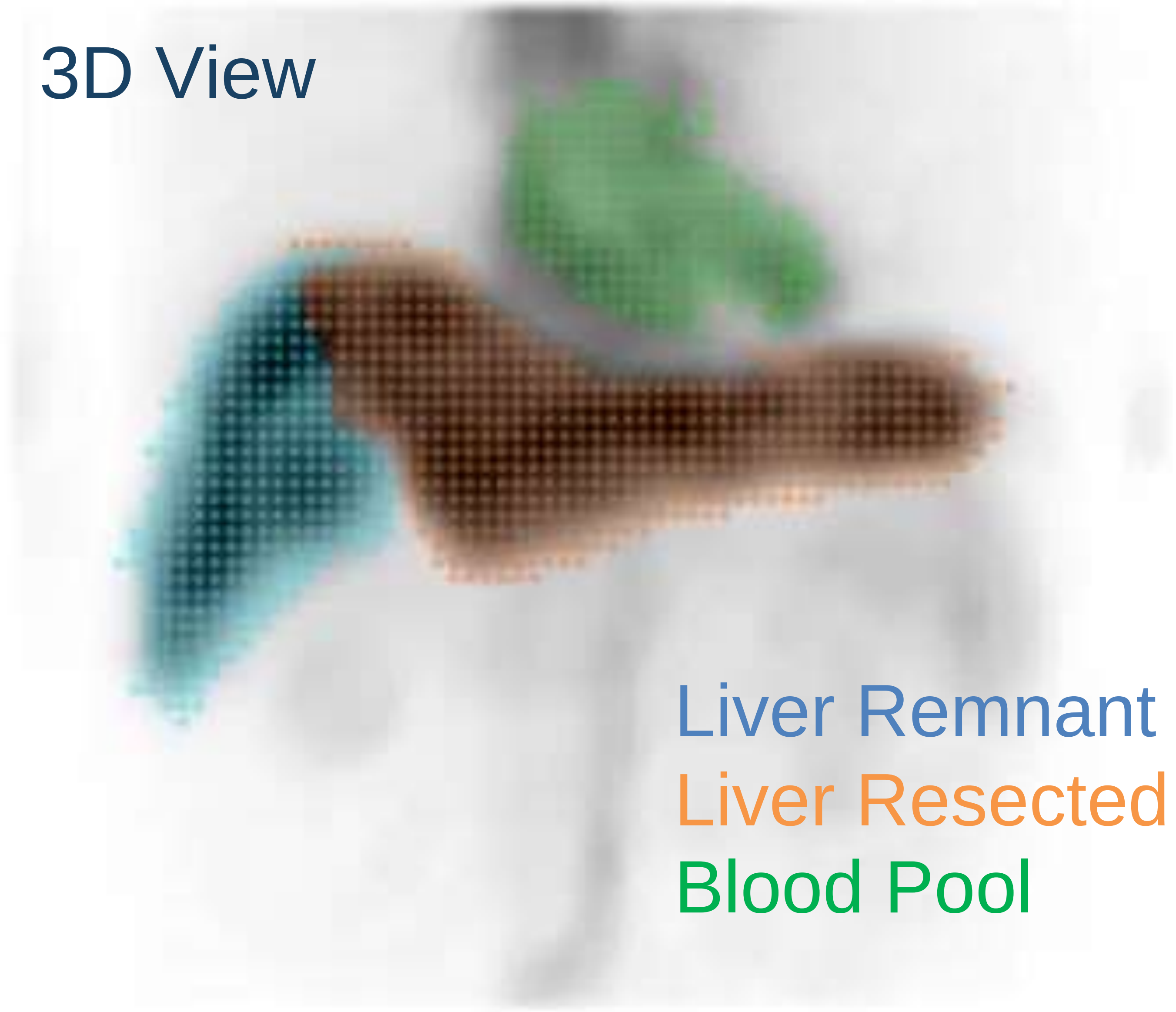
*Compared against population-based cut-off values to determine risk of PHLF (≥ 15%) [1,2]*

[1] Rassam, *et al.* Nuc. Med. Commun. 2019
[2] Serenari, *et al.* Ann. Surg. 2018

## Full-ring CZT Hepatobiliary SPECT/CT,

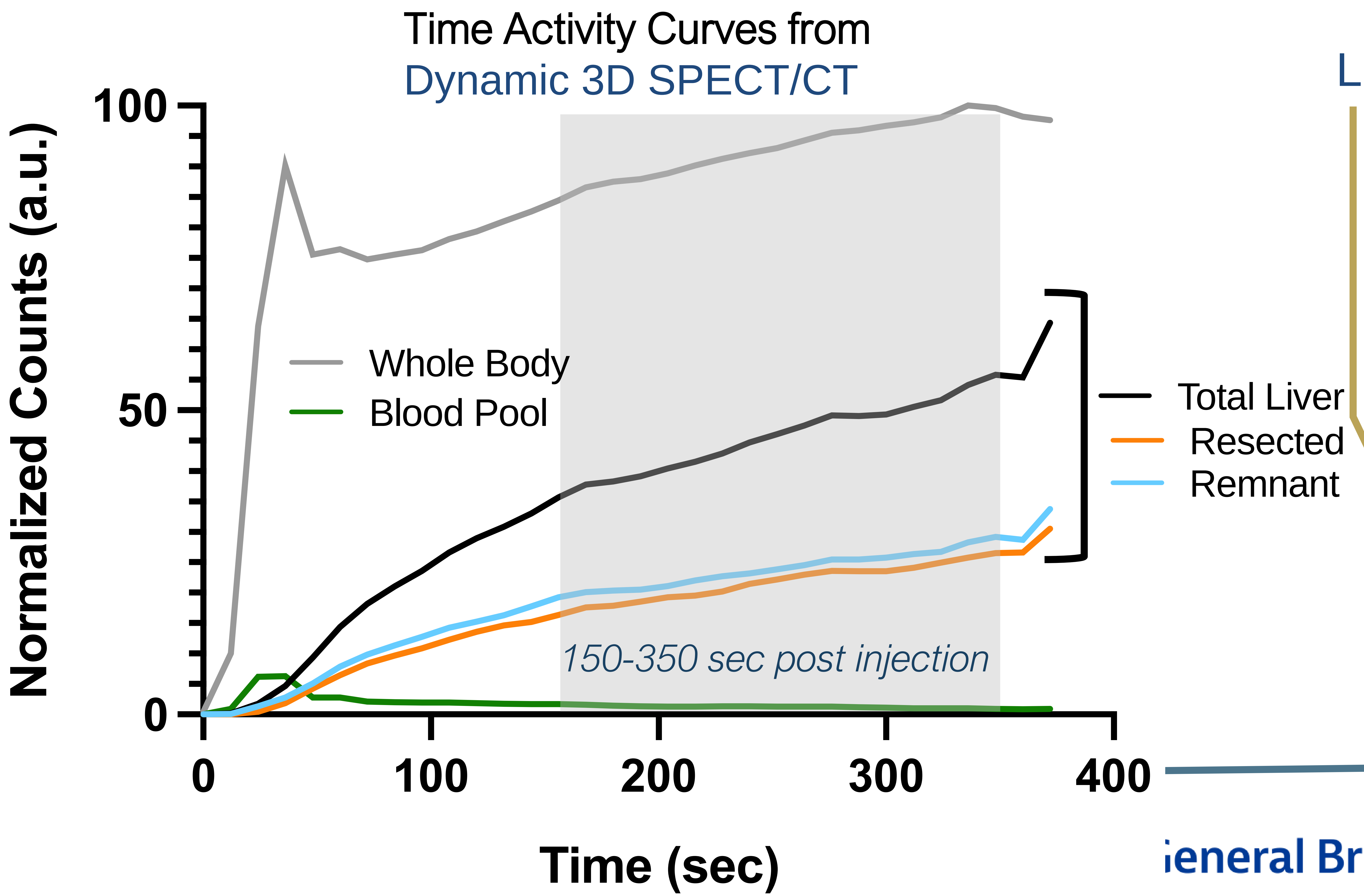
- Enables **3D dynamic quantitative imaging**
- Remnant liver function can be **directly** evaluated from **3D dynamic SPECT/CT**
- More **accurate liver/remnant function estimation** since no superimposition of activity (*tends to be overestimated with planar imaging*)





## HIBA-i from 3D dynamic SPECT/CT




### Liver Remnant Tracer Uptake

$$L - U_{Remnant} = HIBA - i = 24.9\%$$

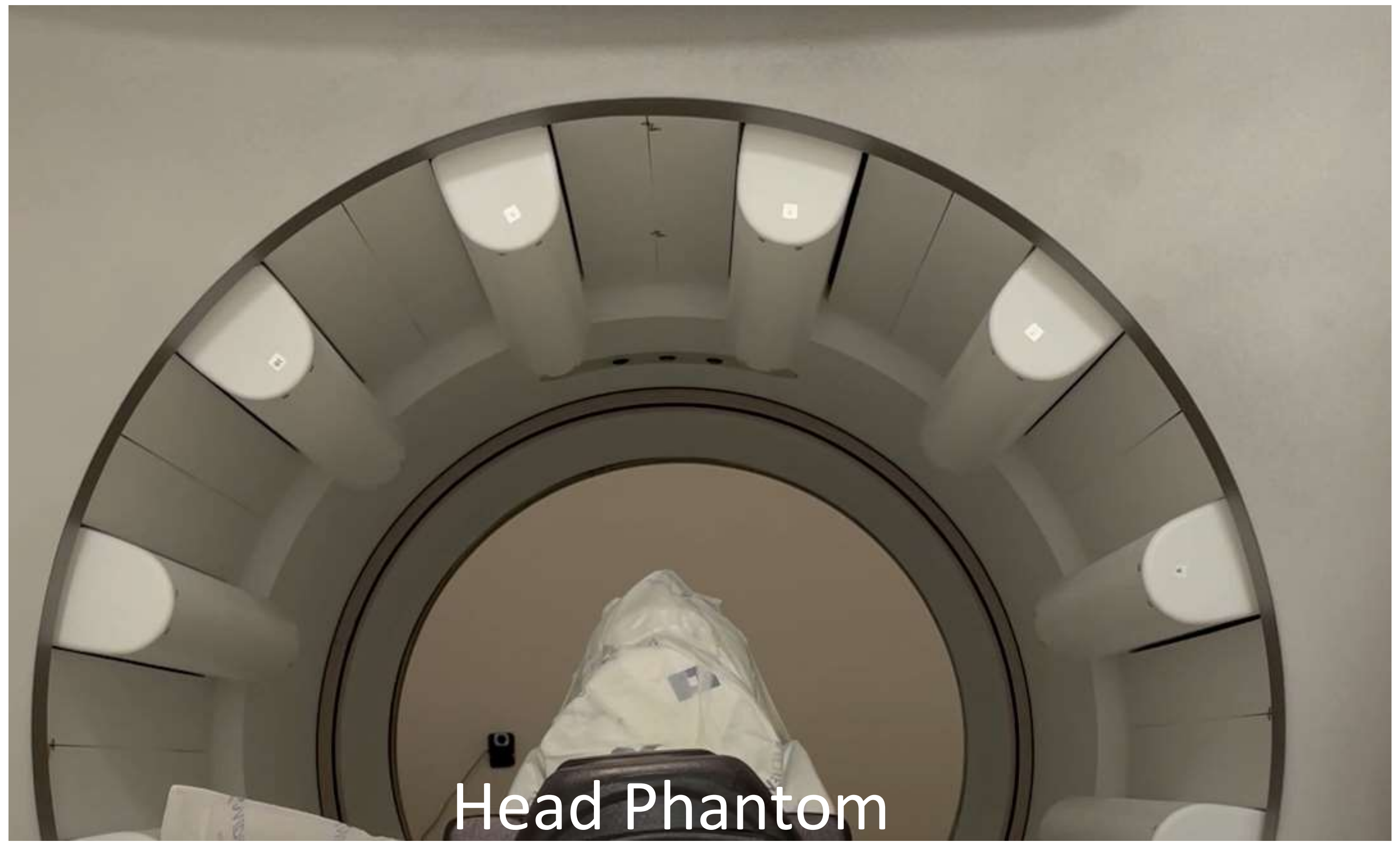
$$L - U_{Resected} = 22.6\%$$

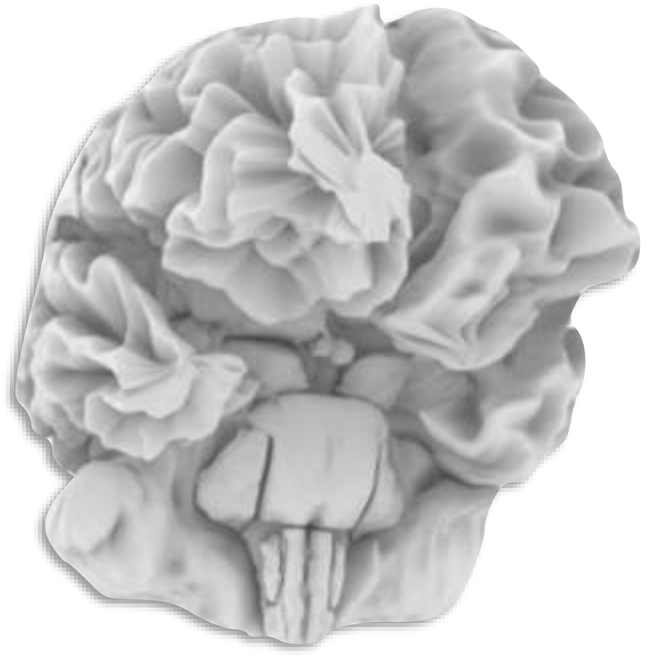
$$TL - U = 47.5\%$$

*Will likely need establishment of new **population-based cut-off** values to determine PHLF*

## Full-ring CZT SPECT/CT

- Allows the detectors to be positioned very close to the patient's head, providing **high sensitivity** and **improved spatial resolution**
- **Can enhance image quality** as well as accuracy and precision of **quantitation** while reducing the acquisition time and/or injected dose [1-4]
- Has the potential to enable **C**erebral **B**lood **F**low (**CBF**) quantification, thanks to **3D dynamic imaging capability**

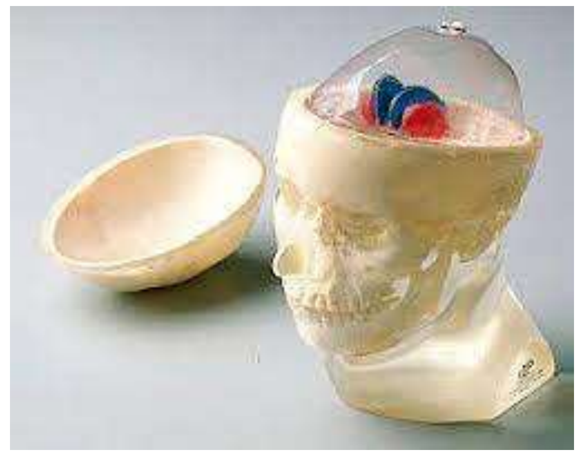


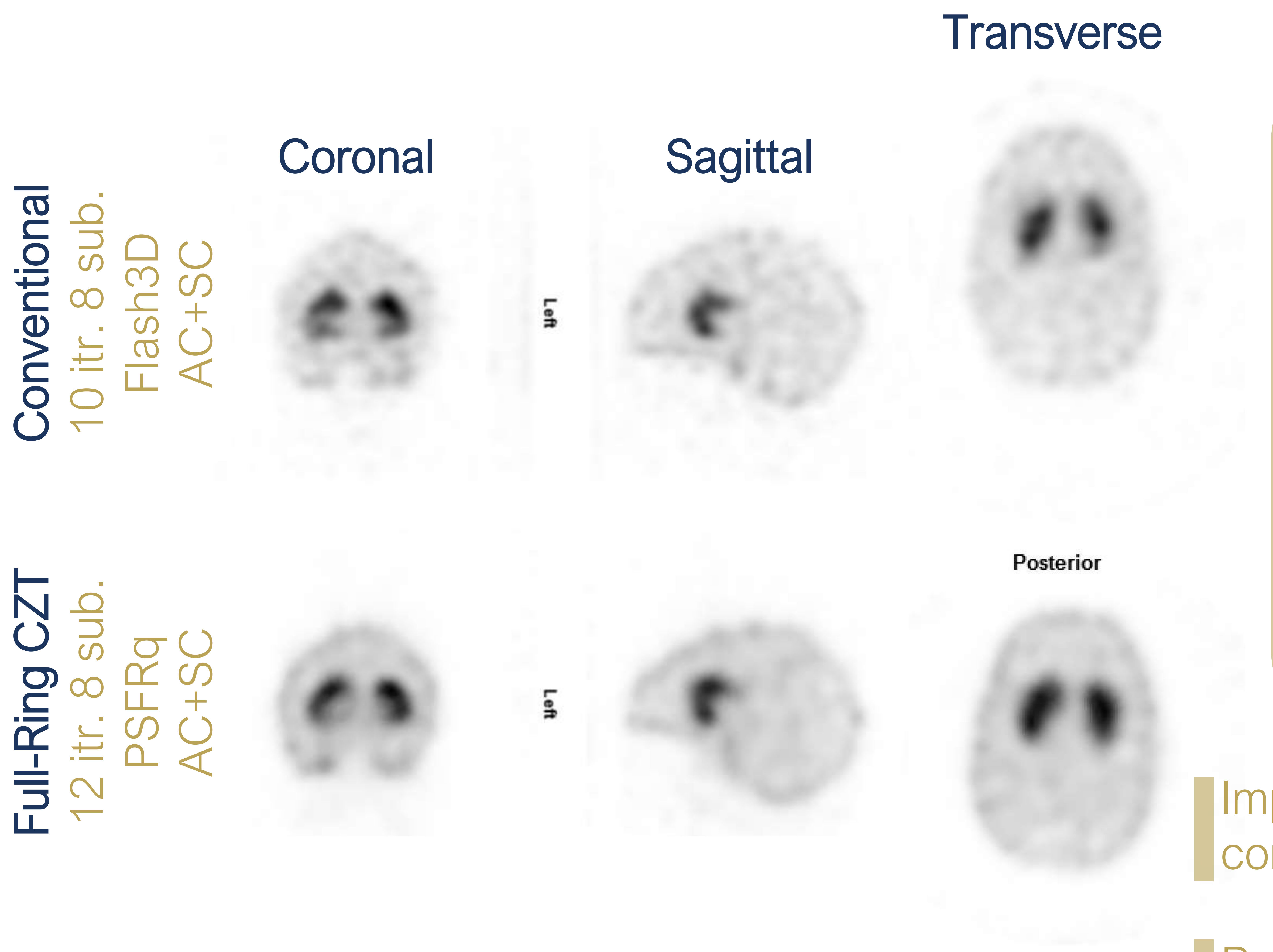
[1] Bordonne, *et al. EJNMMI* 2020.
[2] Piatkova, *et al.* Clinic. Nucl. Med. 2022.
[3] Rogash, *et al.* Nuklearmedizin-NuclearMedicine. 2019.
[4] Huh, *et al.* Med. Phys. 2021.

## SPECT/CT Acquisition ($^{123}$I)

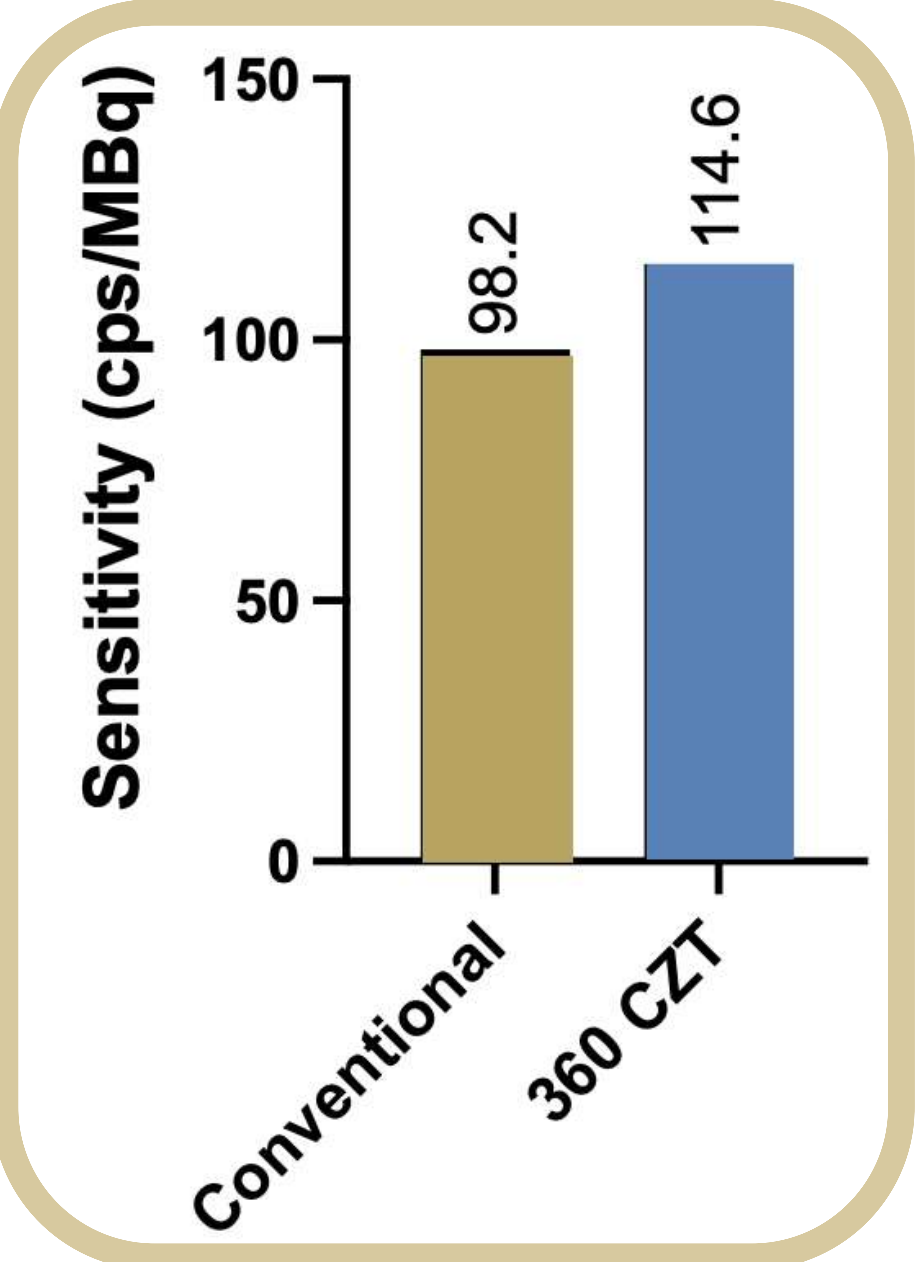
- **Striatal Phantom** study
- Dose: *3.8 mCi*
- Str/Bkg ratio 8:1



- Comparison for an **equal Scan Time** (~3 min) against a conventional SPECT/CT with //-hole LEHR collimator (Siemens Intevo)



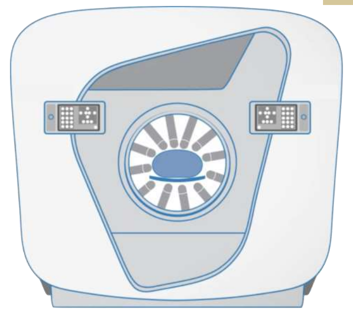

Sensitivity




Improved sensitivity (+16%), contrast, and overall IQ

Reduced penetration



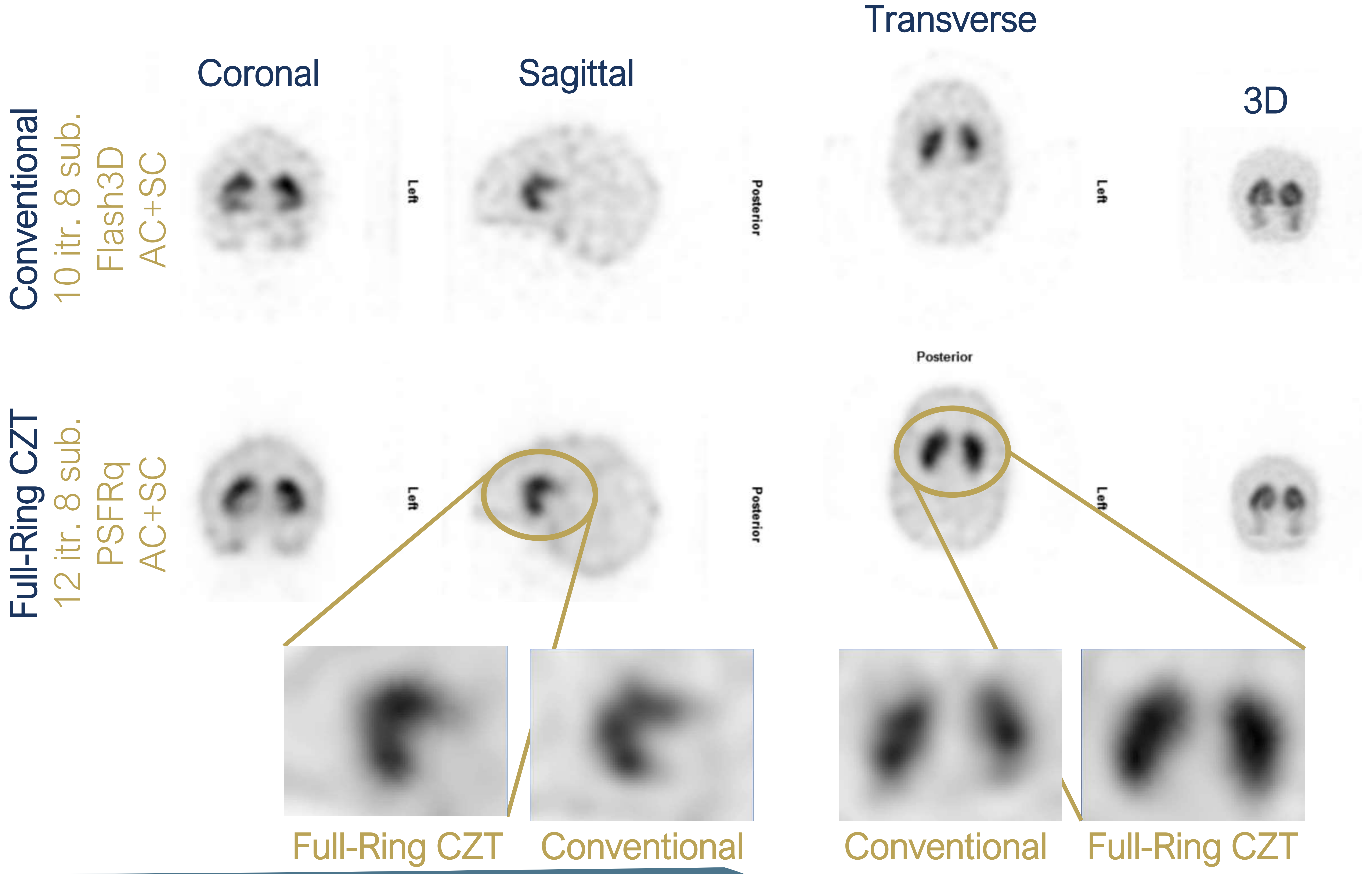


# DAT IMAGING

## SPECT/CT Acquisition ($^{123}$I)

- **Striatal Phantom** study
- Dose: *3.8 mCi*
- Str/Bkg ratio 8:1

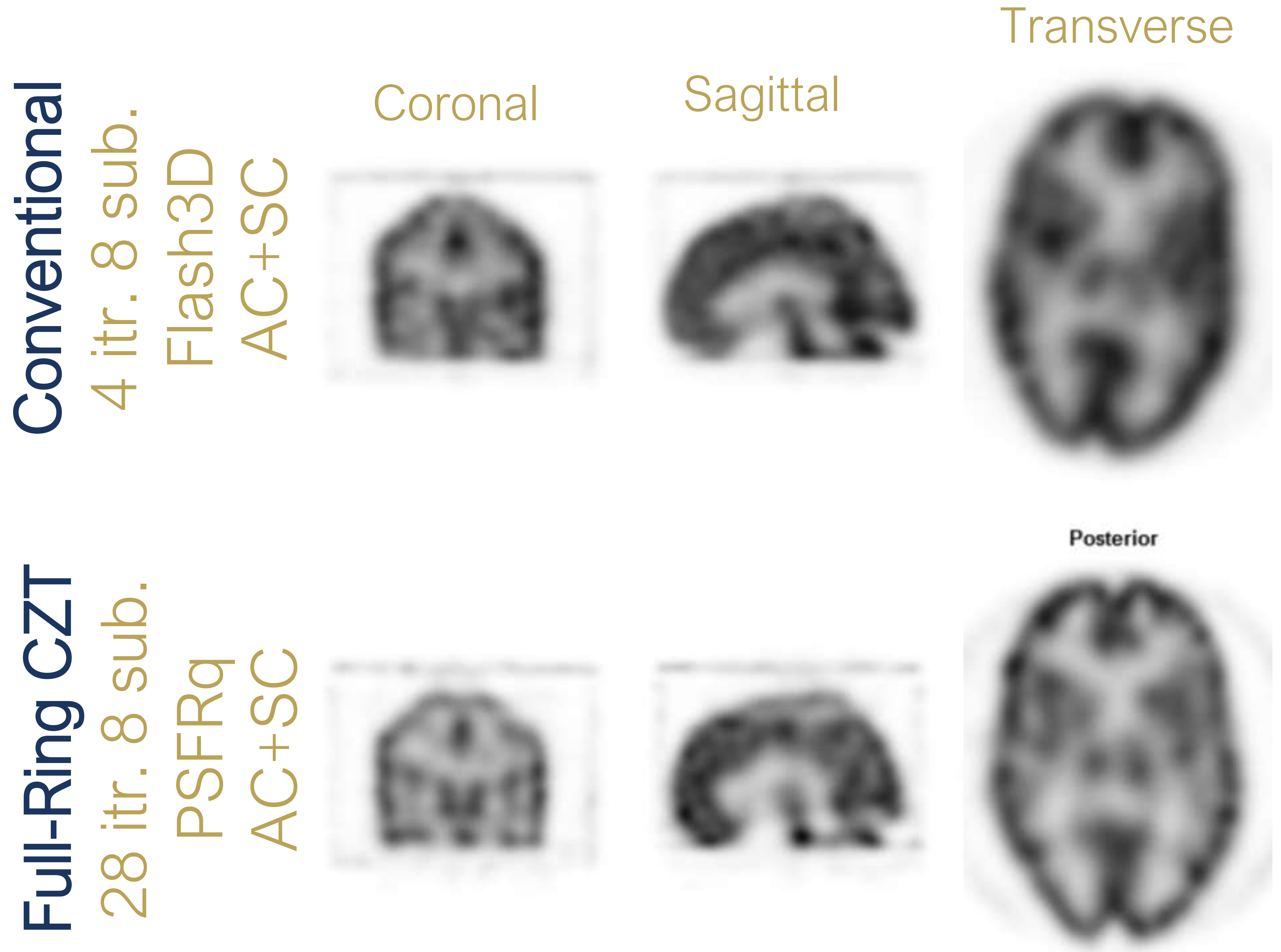
- Comparison for **an equal Scan Time** (~3 min) against a conventional SPECT/CT with //-hole LEHR collimator (Siemens Intevo)



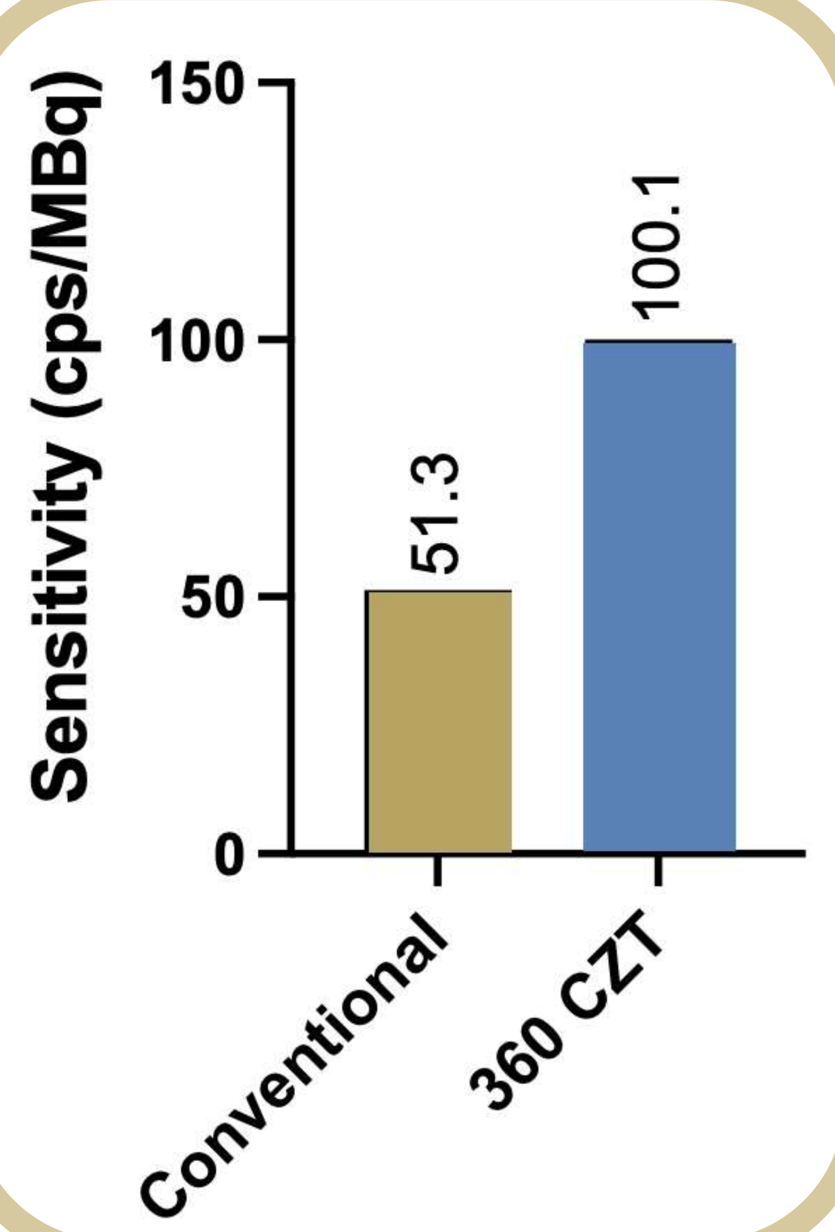
## SPECT/CT Acquisition ($^{99m}Tc$)

- **3D Hoffman Phantom** study
- Dose: *10.5 mCi*
- Gray/White matter ratio 4:1

- Comparison for an **equal Count Level** (5.5 Mcts) against a conventional SPECT/CT with //-hole LEHR collimator (Siemens Intevo)




Sensitivity



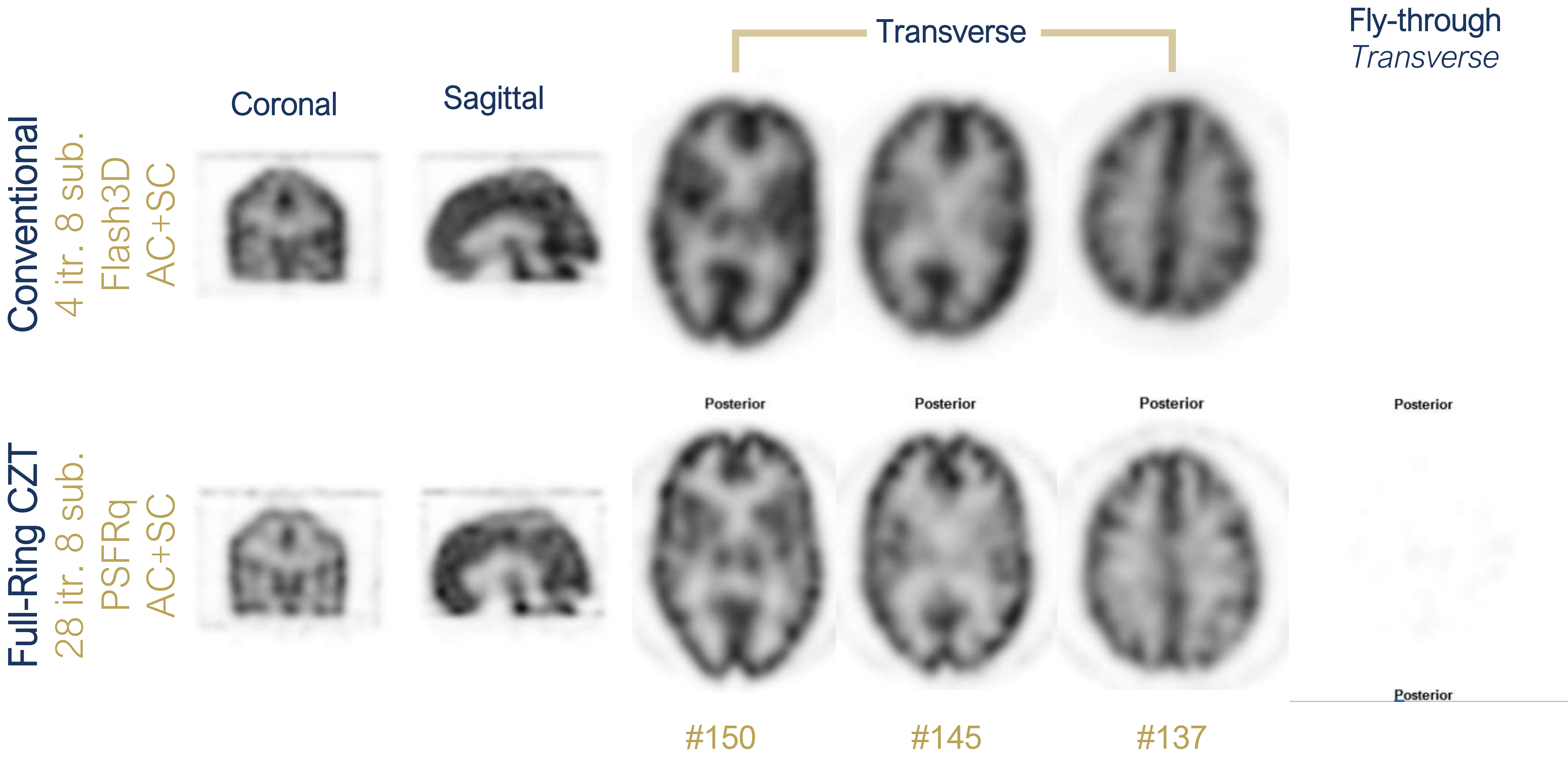

Improved sensitivity (2-fold), contrast, and overall IQ

# BRAIN PERFUSION IMAGING

## SPECT/CT Acquisition ($^{99m}$Tc)

- **3D Hoffman Phantom** study
- Dose: *10.5 mCi*
- Gray/White matter ratio 4:1

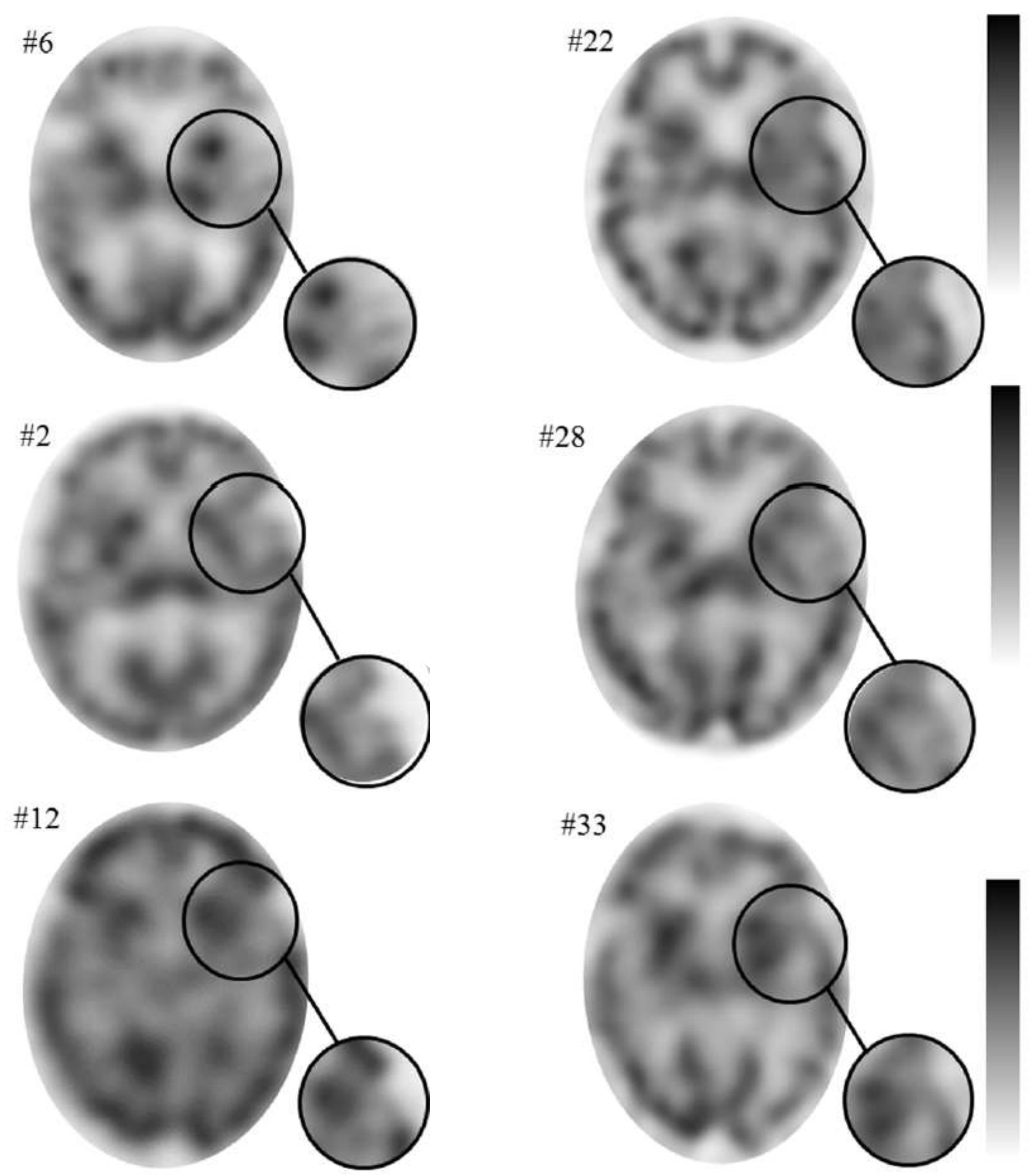
- Comparison for an **equal Count Level** (5.5 Mcts) against a conventional SPECT/CT with //-hole LEHR collimator (Siemens Intevo)

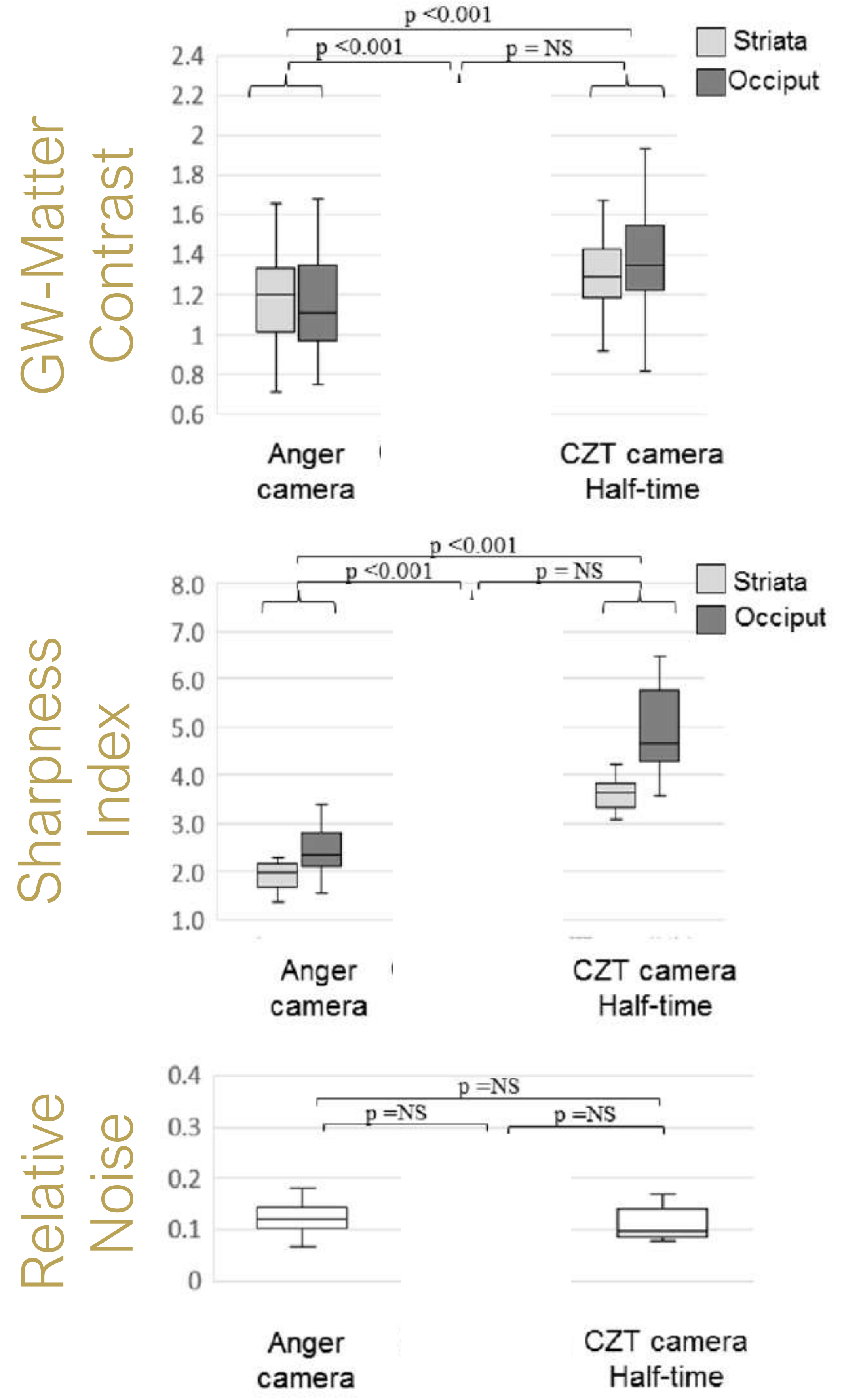


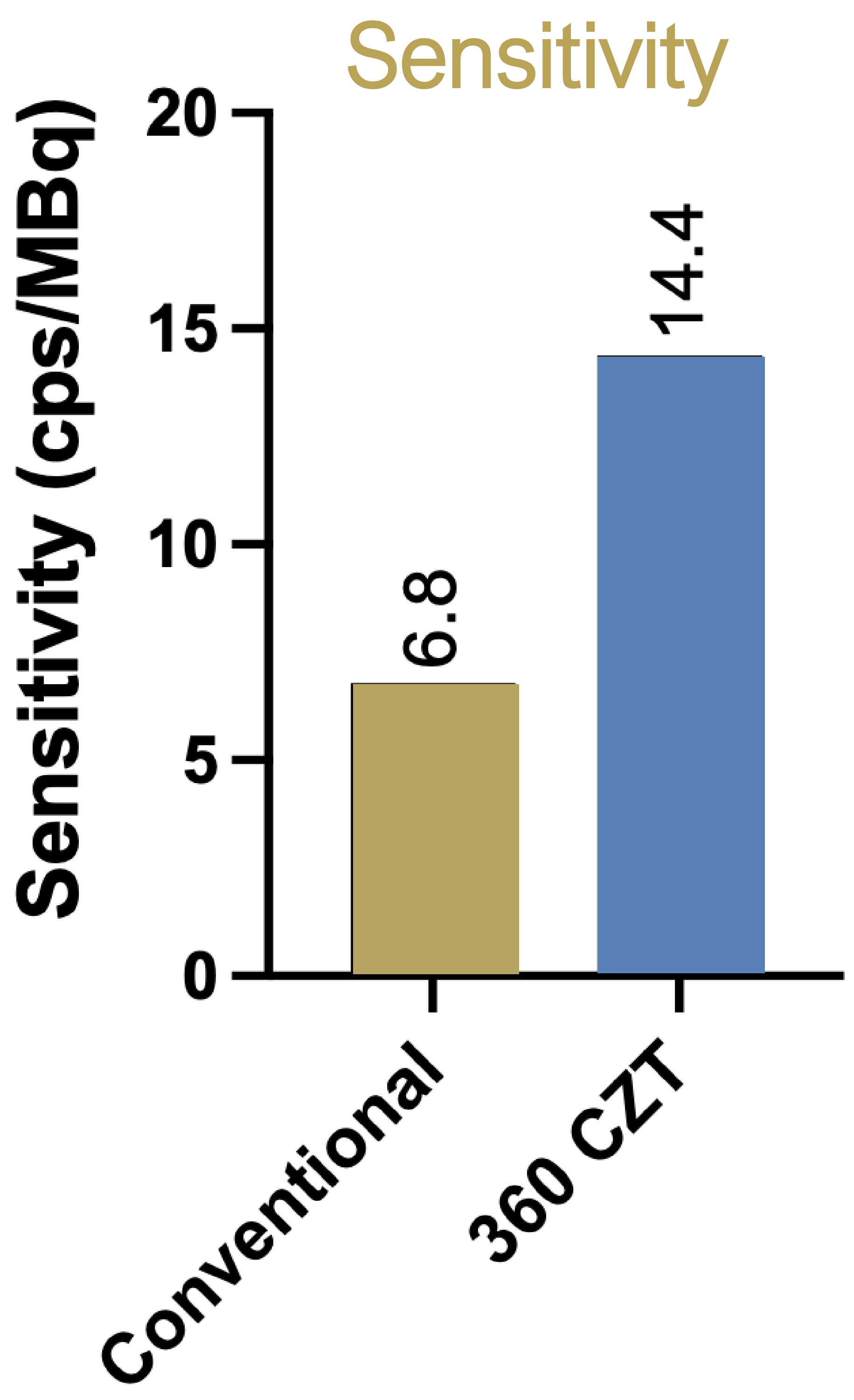
# BRAIN PERFUSION IMAGING

## SPECT/CT Acquisition ($^{99m}$Tc-HMPAO) — Clinical Study

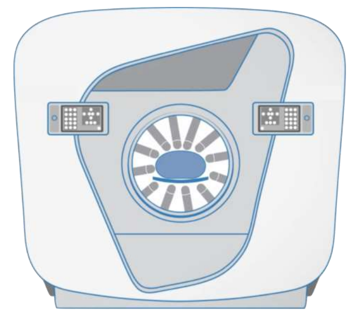
**Adapted** from Bordonne *et al. EJNMMI physics*, *2020*.



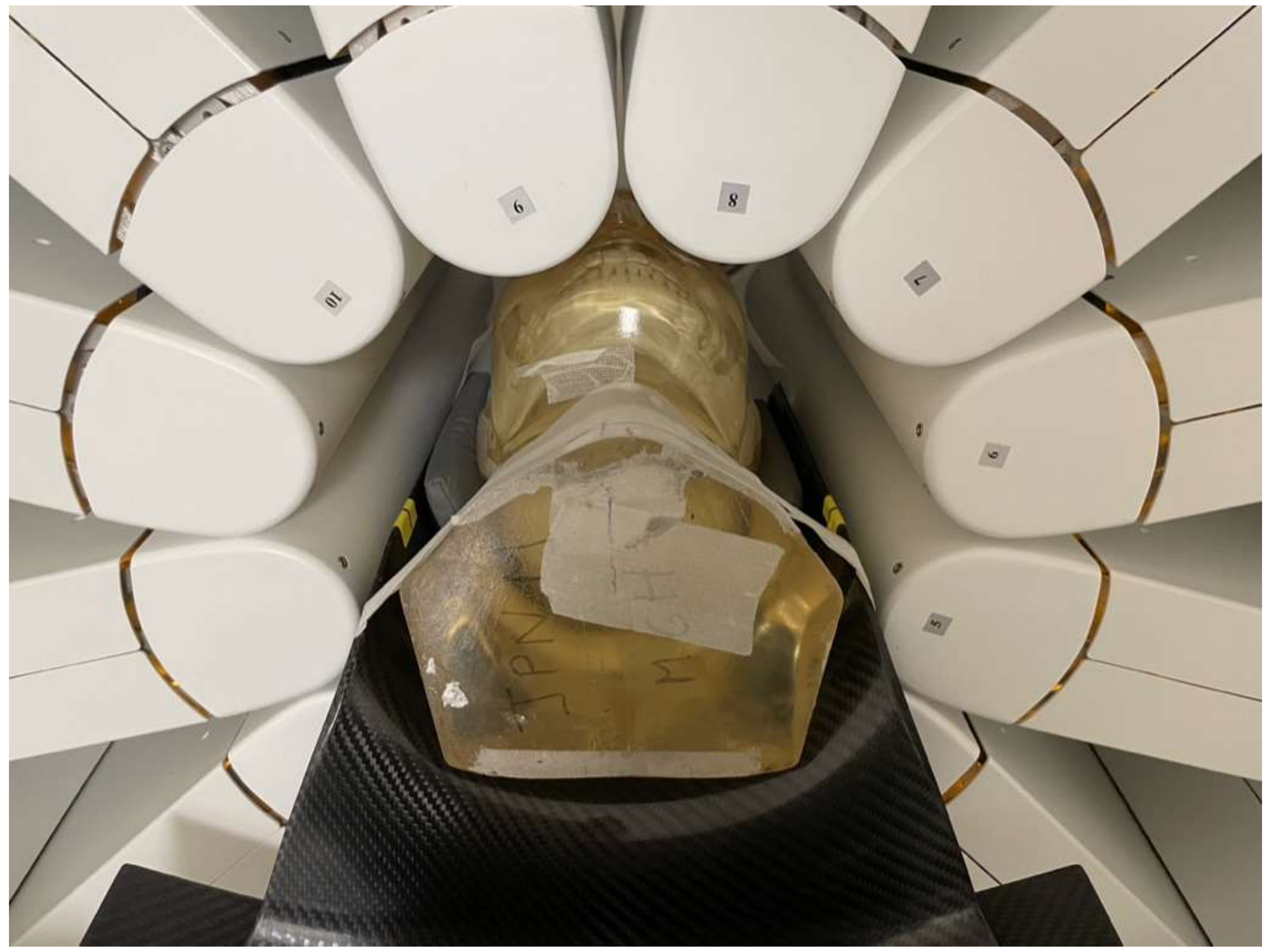


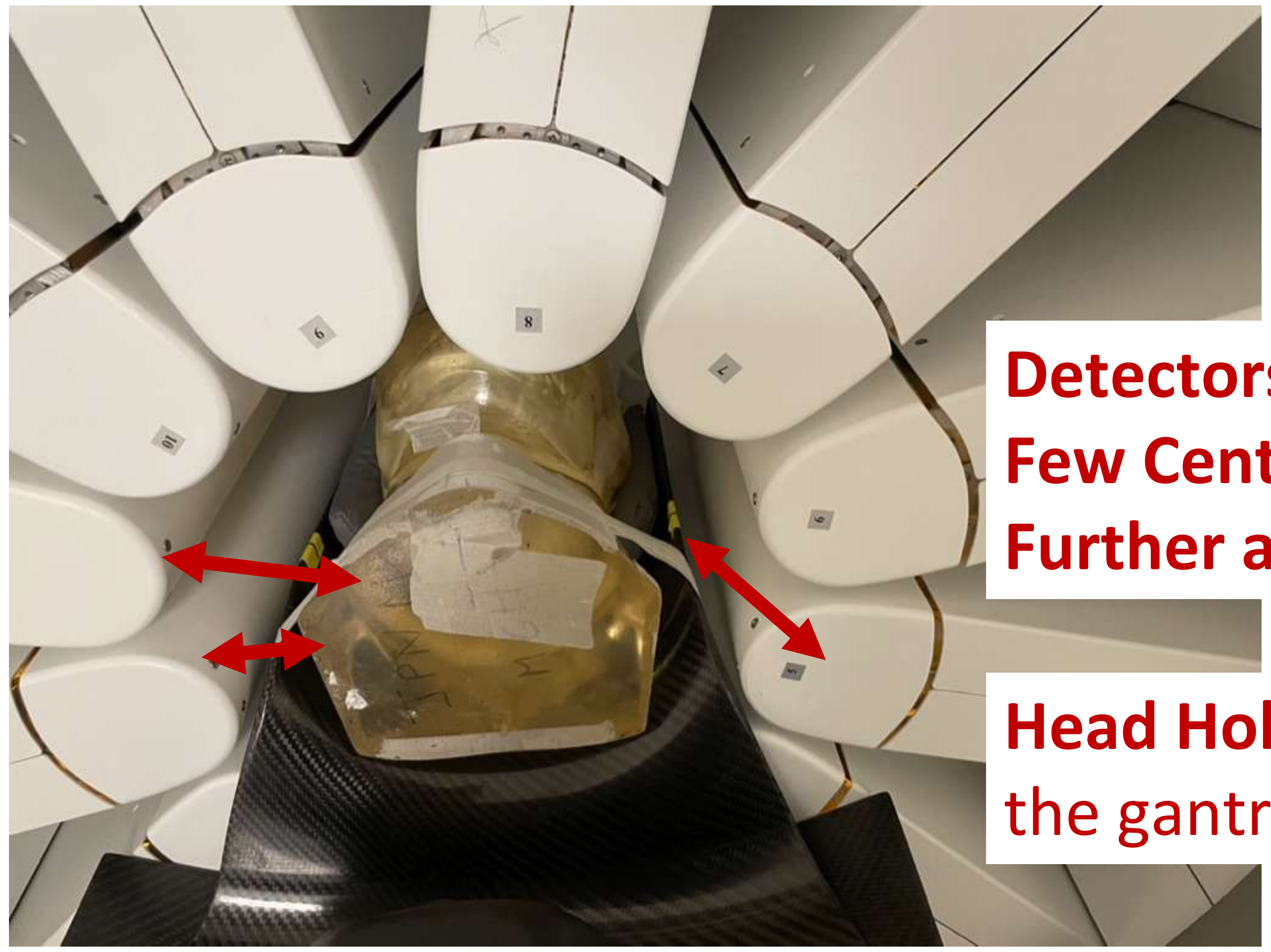
# PITFALL IN BRAIN IMAGING

- **Patient Positioning** is of **critical importance**!
- **Detectors** need to be **positioned as close** as possible to the **brain** for **optimal imaging**
  Otherwise, **loss of spatial resolution**!
- **Shoulders** must be **cleared**. Wider part of the **Head Holder** can also prevent detectors to be close enough!
- Need **1) for technologist training** plus **2) to review data QC**.


**Optimal Positioning**



**Sub-Optimal Positioning**



**Detectors are a Few Centimeters Further away!**

**Head Holder** moved **too far into** the gantry!

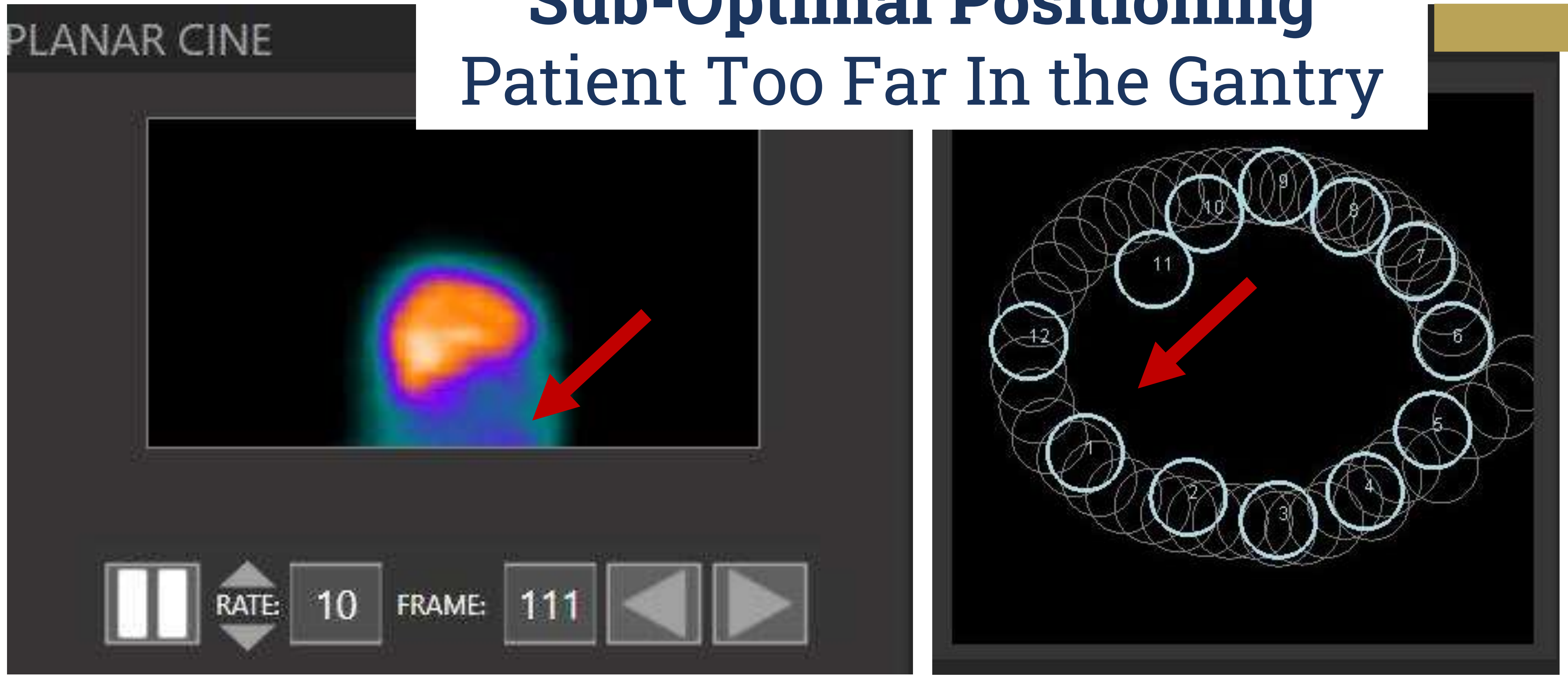
# POSITIONING IN BRAIN IMAGING

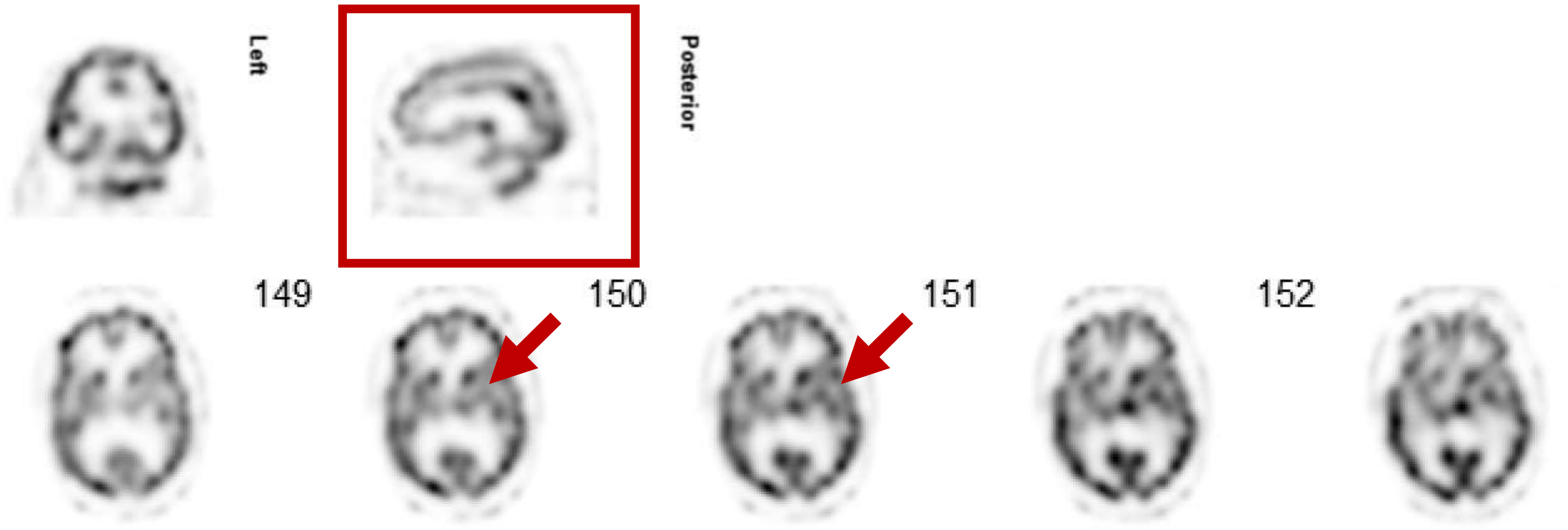
## Brain Perfusion SPECT/CT Acquisition ($^{99m}$Tc-ECD)

- 61y Male; Administrated Activity: *30 mCi*

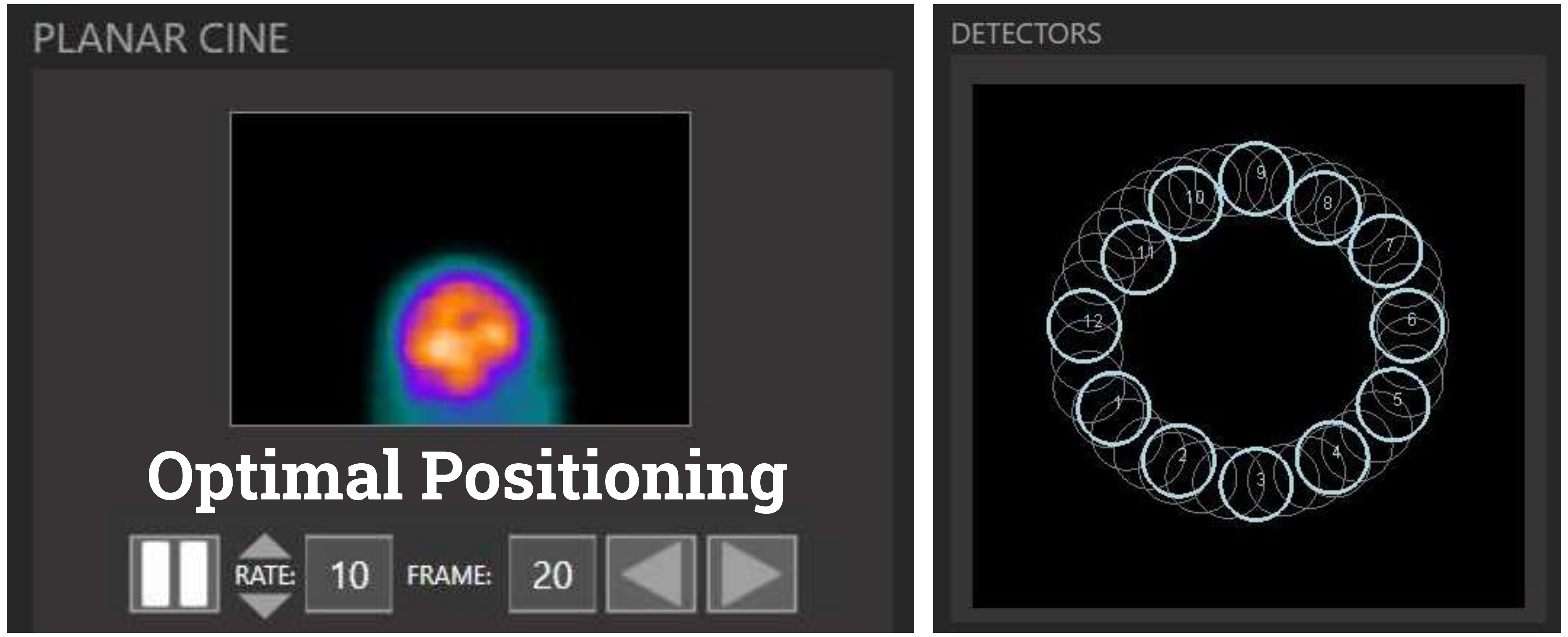
**Sub-Optimal Positioning**
Patient Too Far In the Gantry → **Results in a Loss of Sp Resolution** (*blurring*)

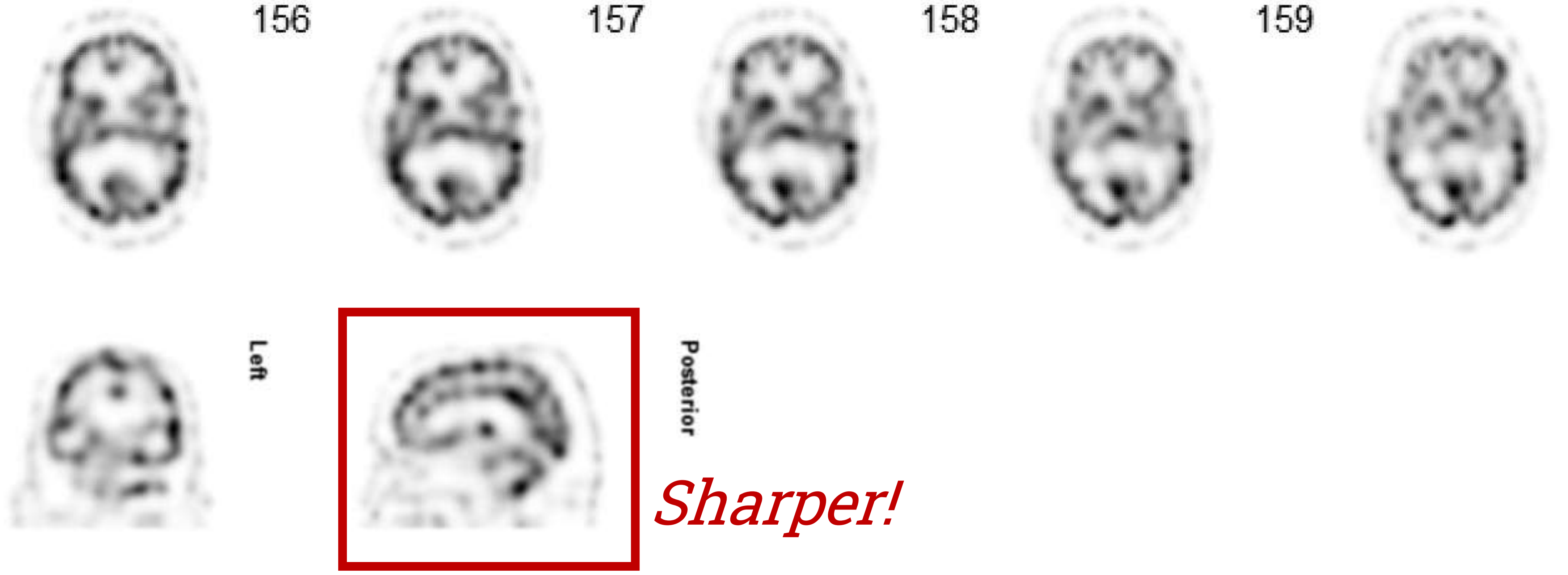
Diamox 10/6




Baseline 10/18



# RAPID WHOLE-BODY 3D IMAGING



**Conventional SPECT** suffers from,

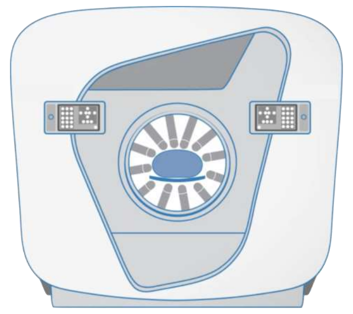
- **Poor sensitivity** (*need to rotate to record data*),
- **Dependence** on **additional package or third-party software** for **absolute quantitation,**
- Being not really designed for **multi-bed SPECT Imaging**

**Conventional SPECT Imaging** relies on a mix of **planar 2D imaging** (*to identify the disease extent*) and **single or dual-bed SPECT** on areas of interest. Results in **Long Acquisition Time!**

**Full-Ring CZT SPECT alleviates these limitations** by enabling **rapid whole-body SPECT/3D imaging,** plus **offers built-in quantitation** [1-4]**!**

[1] Melki, *et al. EJNMMI* 2020.
[2] Imbert, *et al.* J. Nucl. Med. 2019.
[3] Bahloul, *et al. EJNMMI, 2023*
[4] Song, *et al. EJNMMI*. 2023.





# RAPID WHOLE-BODY 3D BONE IMAGING

## Full-Ring CZT SPECT/CT

Provides **high sensitivity** and **improved spatial resolution** that enhance **image quality** and **quantitation** while reducing the acquisition time and/or injected dose compared to conventional SPECT/CT [1-4]

Enables **rapid 3D whole-body imaging**

Improves **image contrast** for bone lesions compared to inherently limited planar imaging, which results in better localization of abnormal accumulations [1-4]

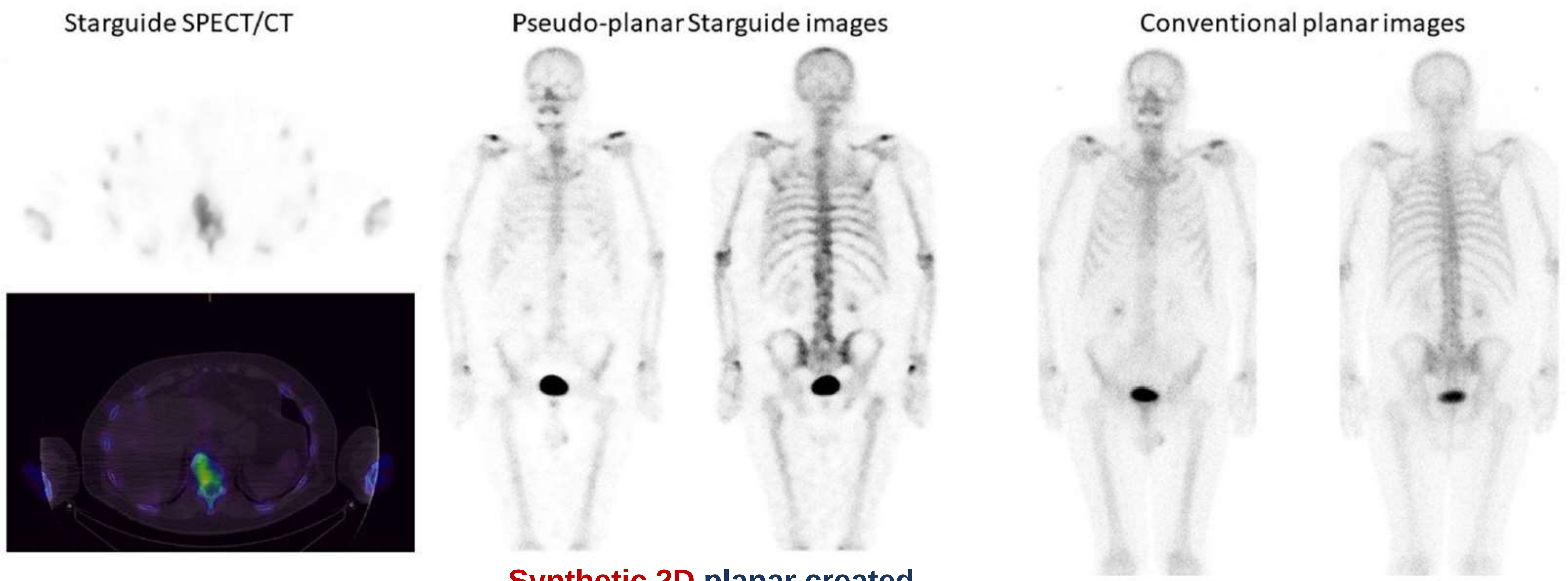
Images courtesy of Dept of Clinical Physiology and Nuclear Medicine at Linköping University Hospital, Region Östergötland, Sweden

### Whole Body SPECT/CT

- Scan time ~ 20 min
- 59y Female
- BMI: 23.8
- $^{99m}$Tc-HMDP 11.7 mCi

[1] Goshen, *et al. EJNMMI Phys.* 2018.
[2] Melki, *et al.* Eur. J. Nucl. Med. Mol. Imaging 2020.
[3] Imbert, *et al.* J. Nucl. Med. 2019.
[4] Yamane, *et al.* Eur. J. Nucl. Med. Mol. Imaging. 2019.

# RAPID WHOLE-BODY 3D BONE IMAGING




Ćerić Andelius, I., Minarik, D., Persson, E., Mosén, H., Valind, K., Trägårdh, E., & Oddstig, J. (2024). First clinical experience of a ring-configured cadmium zinc telluride camera: A comparative study versus conventional gamma camera systems. *Clinical Physiology and Functional Imaging*, *44*(1), 79-88.

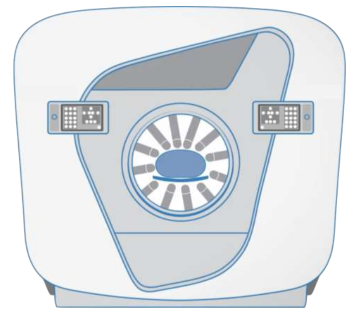
**WB 3D SPECT**

**Synthetic 2D planar created from WB SPECT image**

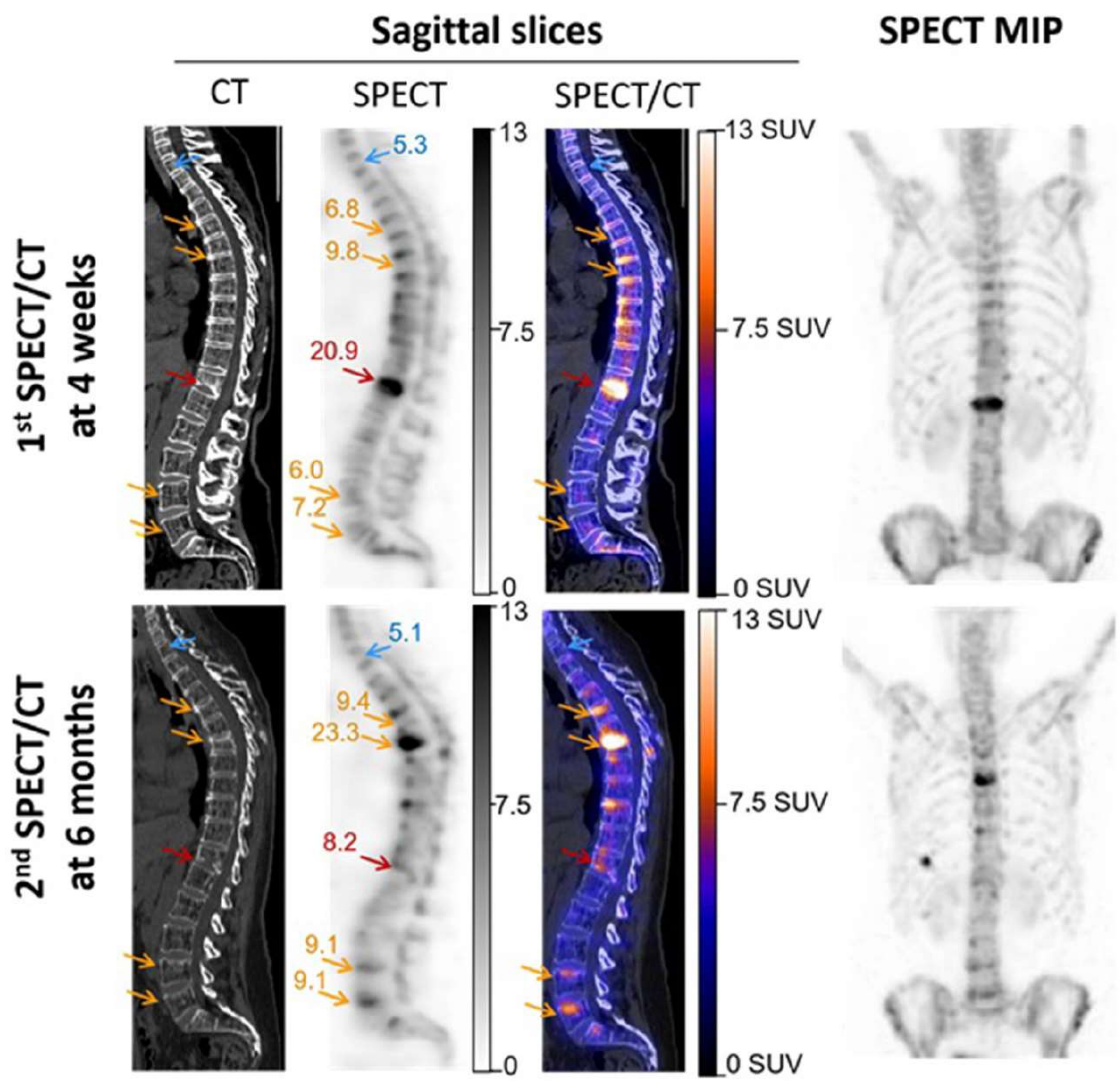
Scan Time ~ **20 min**

**2D Planar Images**

Scan Time = **15 min**
Speed = 16 cm/min

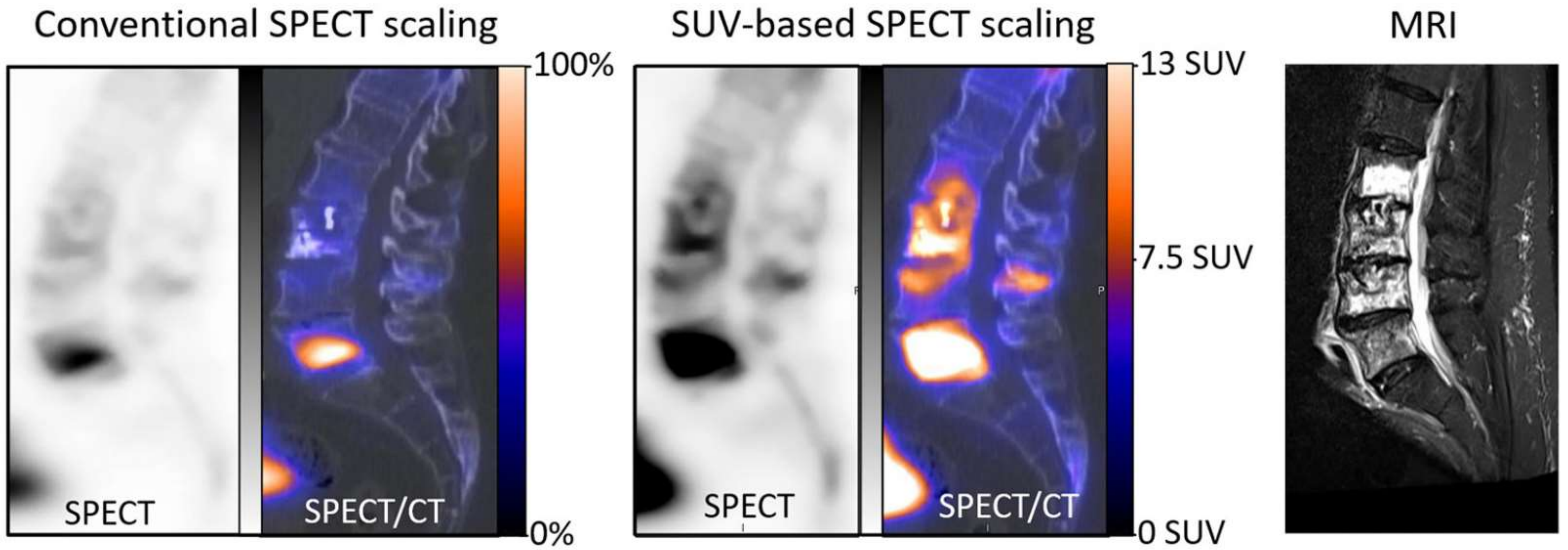


Usually followed by
**Single-bed SPECT**
(*additional **20-30** min*)




## Full-Ring CZT SPECT/CT

- **Rapid Imaging 12-15 min** scan time to acquire the entire spin
- **Enabled-SUV quantitation** to localize fracture

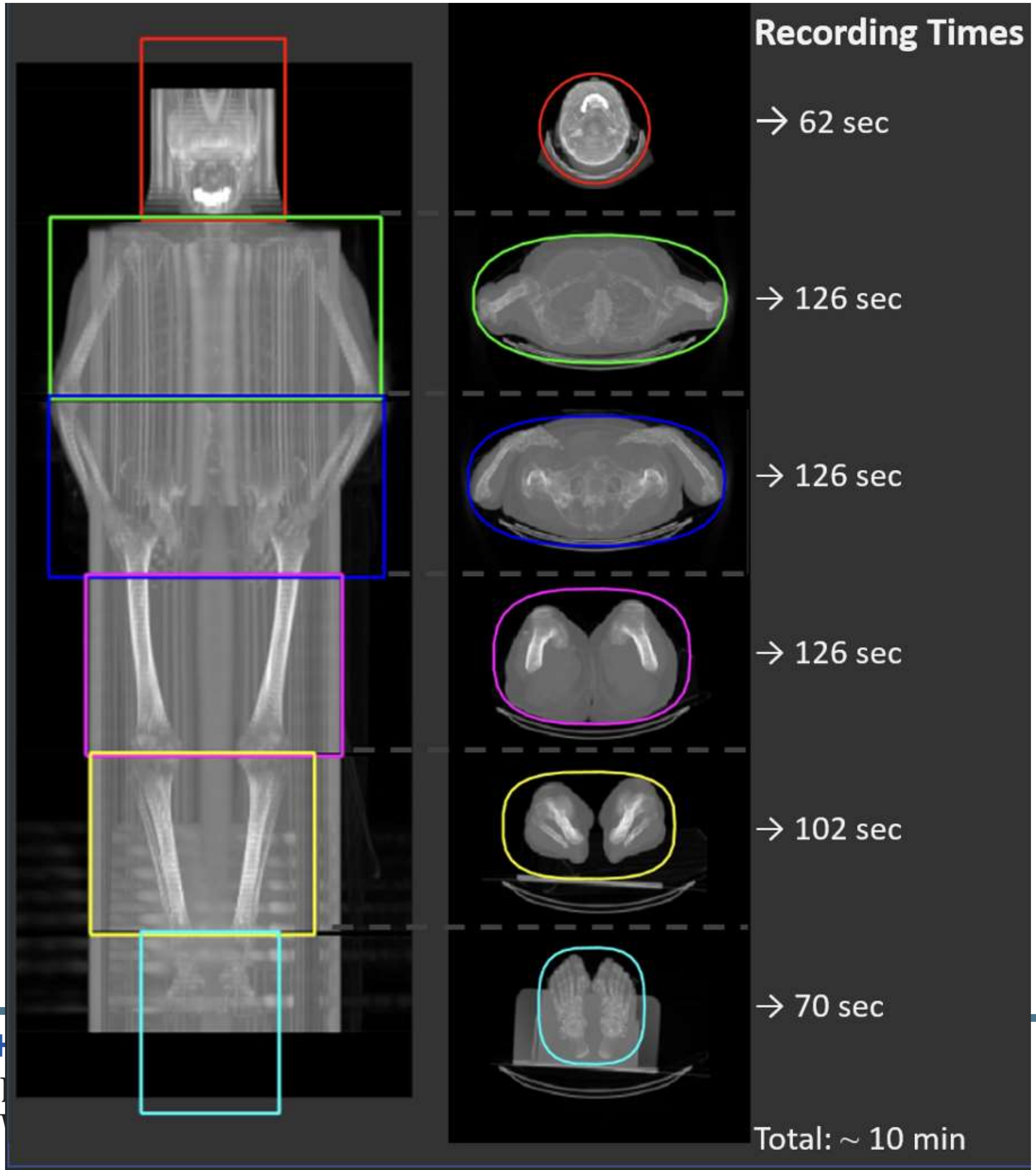



***Adapted from*** *Bahloul, A., Verger, A., Blum, A., Chawki, M. B., Perrin, M., Melki, S., et al. (2021). Bone scintigraphy of vertebral fractures with a whole-body CZT camera in a PET-like utilization. Frontiers in Nuclear Medicine, 1, 740275.*

# RAPID WHOLE-BODY 3D BONE IMAGING



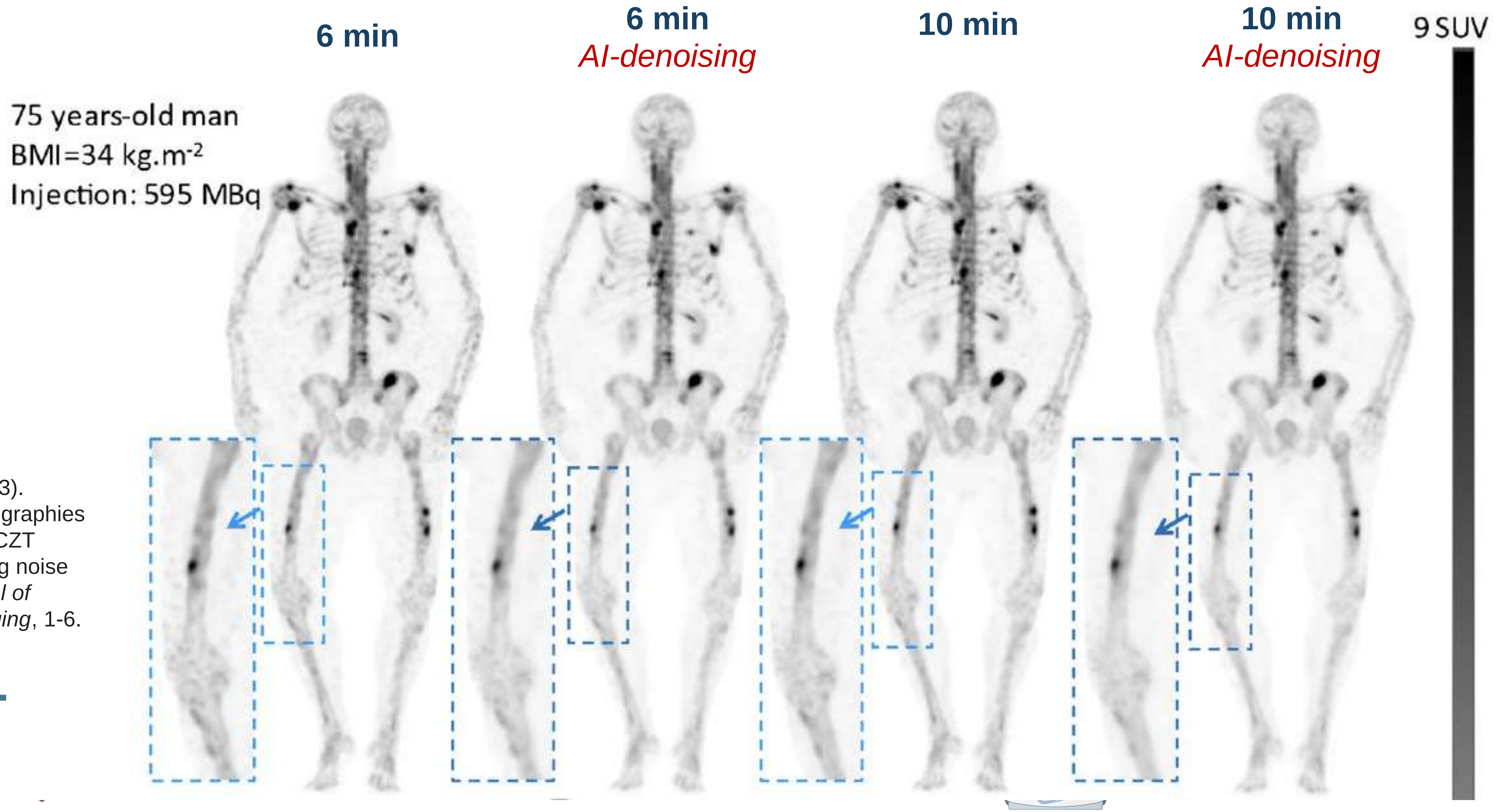
Body Focus Mode




- **Modulation** of the **detector contouring** per **bed**. Focus VOIs derived from CT
- Provides a **uniform scan time** per **millimeter**. Noise equivalent image per bed.
- **Improvement** in sensitivity resulting in **further scan time reduction (*15-20 min down to 10 min*)**

**Adapted from** Bahloul, A., Verger, A., Lamash, Y., Roth, N., Dari, D., Marie, P. Y., & Imbert, L. (2023). Ultra-fast whole-body bone tomoscintigraphies achieved with a high-sensitivity 360° CZT camera and a dedicated deep-learning noise reduction algorithm. *European Journal of Nuclear Medicine and Molecular Imaging*, 1-6.

Further **scan time reduction** can be achieved with **AI-denoising** from **10 min** down to **6 min** (*1 min/bed*)

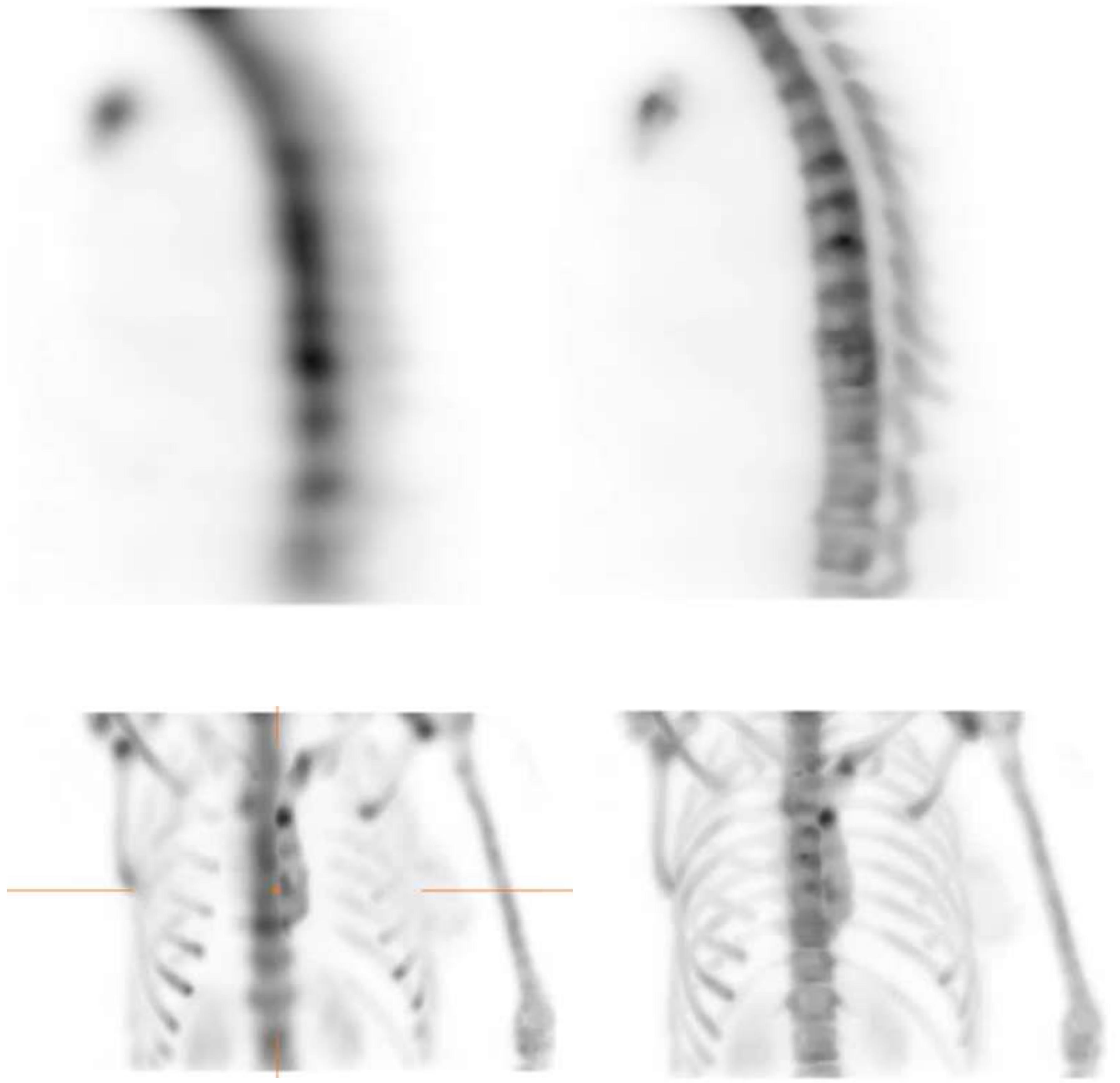



**Adapted from** Bahloul, A., *et al.* (2023). Ultra-fast whole-body bone tomoscintigraphies achieved with a high-sensitivity 360° CZT camera and a dedicated deep-learning noise reduction algorithm. *European Journal of Nuclear Medicine and Molecular Imaging*, 1-6.

# PARTIAL VOLUME CORRECTION (PVC)

## Full-ring CZT SPECT/CT

- Provides high sensitivity and improved spatial resolution that enhance image quality and quantitation while reducing the acquisition time and/or injected dose [1-4]
- Improves image contrast for bone lesions compared to inherently limited planar imaging, which results in better localization of abnormal accumulations [1-4]
- Can provide **CT-based anatomic information** that can be used for **P**artial **V**olume **C**orrection (**PVC**) to further improve **image quality** and **quantitation** compared to SPECT-only and planar imaging




- Scan time: 15 min
- 53y Female
- BMI: 25.5
- $^{99m}$Tc-HMDP 12.1 mCi

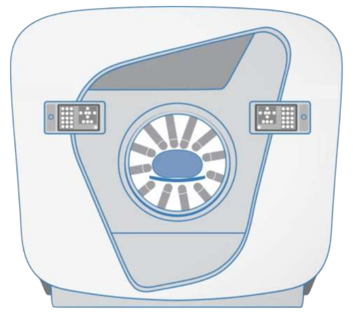
[1] Goshen, *et al. EJNMMI Phys.* 2018.
[2] Melki, *et al.* Eur. J. Nucl. Med. Mol. Imaging 2020.
[3] Imbert, *et al.* J. Nucl. Med. 2019.
[4] Yamane, *et al.* Eur. J. Nucl. Med. Mol. Imaging. 2019.

# APPLICATION TO THERANOSTICS

- **Rapid growth** of **targeted radionuclide therapies**, such as $^{177}$Lu-Dotatate and $^{177}$Lu-PSMA [1,2]
- **Major** Interest in **personalized dosimetry** and **treatment response assessment and monitoring** [3,4]
- **SPECT** has major advantages compared to PET for image-based dosimetry due its **capability to image directly** $^{177}$Lu
- **Growing need** for **high-speed whole-body SPECT/CT**. Conventional SPECT is limited by long acquisition because of poor sensitivity [5]
- **Full-Ring SPECT/CT** can overcome these challenges thanks to its **improved imaging performance**

[1] Sartor, *et al. N Engl J Med*. 2021.
[2] Strosberg, *et al. N Engl J Med*. 2017.
[3] Sgouros, *et al.* J. Nucl. Med. 2021.
[4] Pandit-Taskar, *et al.* J. Nucl. Med. 2021.
[5] Pathmanandavel, *et al.* J. Nucl. Med. 2022.





# LU-177 IMAGING: SENSITIVITY

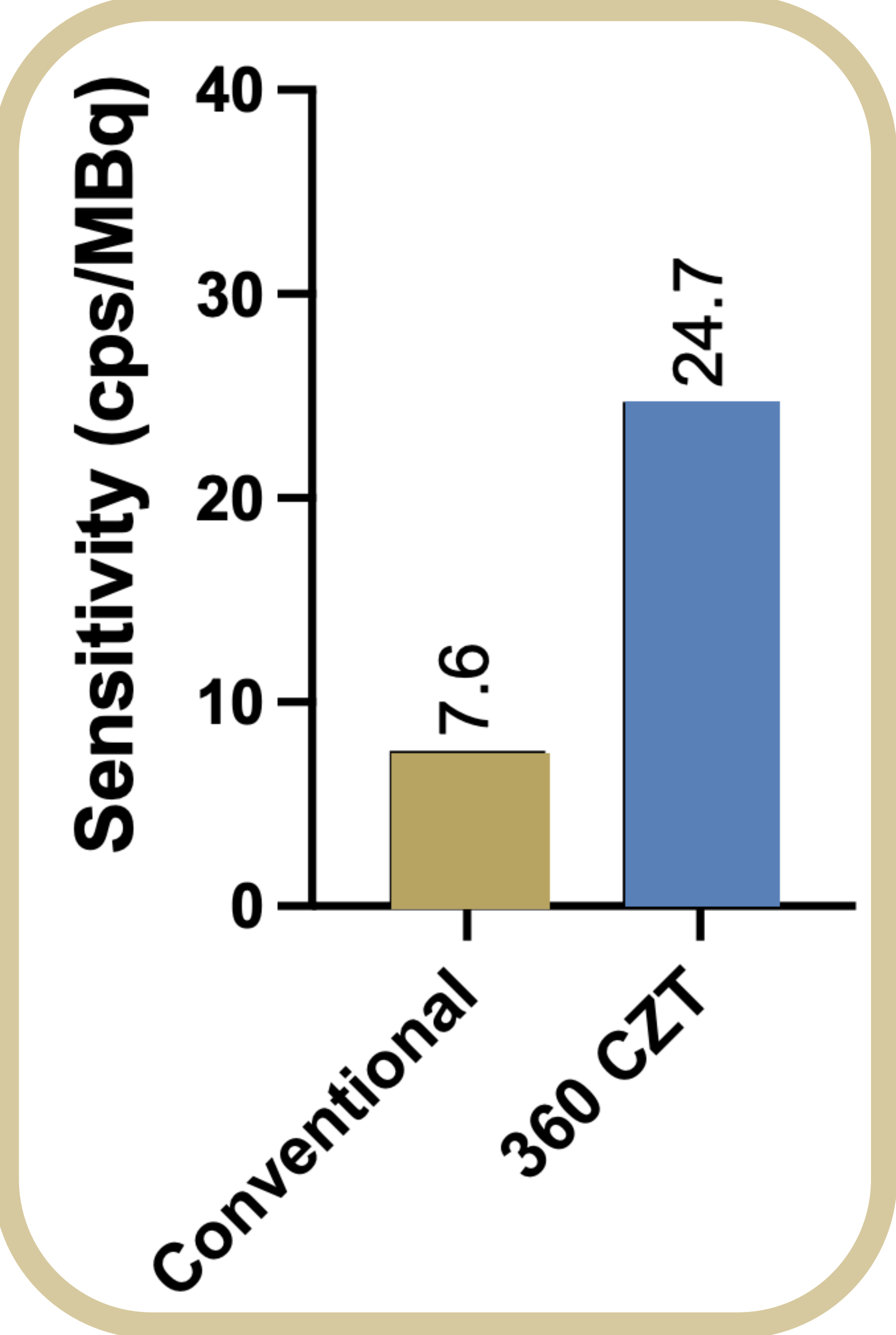
## SPECT/CT Acquisition ($^{177}$Lu)

- Uniform Phantom study
- Dose: 30 mCi
- Volume: 6415 ml

- **Conventional**
  Siemens Intevo w/ MEGP
  208 keV ± 10 %
  Upper/Lower Scatter windows 10%
  CTAC

- **Full-Ring CZT**
  Veriton 200 Series
  113 keV ± 10 %
  Upper/Lower Scatter windows 10%
  CTAC

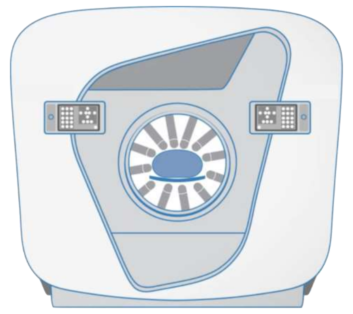
Sensitivity for a uniform cylinder




**Improvement in sensitivity** of **3-fold** for the least abundant $^{177}$Lu-peak

**Further enhancement** with Veriton 400 series and Starguide capable to image both peaks of $^{177}$Lu

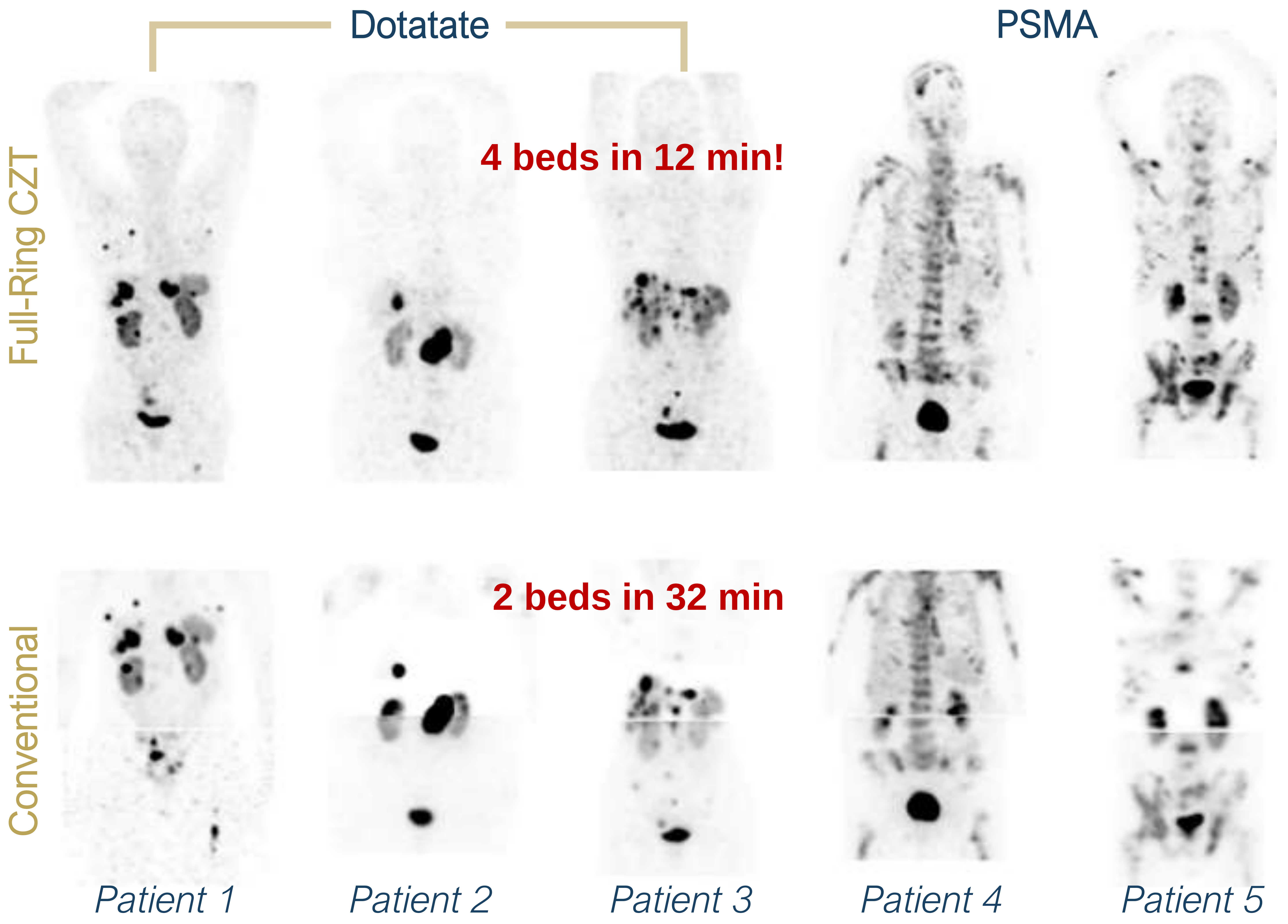




## SPECT/CT Acquisition

- **Full-Ring CZT**
  GE StarGuide
  113 keV ± 10 % & 208 keV ± 6 %
  Upper/Lower Scatter windows 10%
  CTAC
  4 bed positions / 12 min total scan

- **Conventional**
  GE 670 Pro w/ MEGP
  113 keV ± 10 % & 208 keV ± 6 %
  Upper/Lower Scatter windows 10%
  CTAC
  2 bed positions / 32 min total scan






Images courtesy adapted from Song et al. European Journal of Nuclear Medicine and Molecular Imaging. 2023

# LU-177 SPECT/CT IMAGING

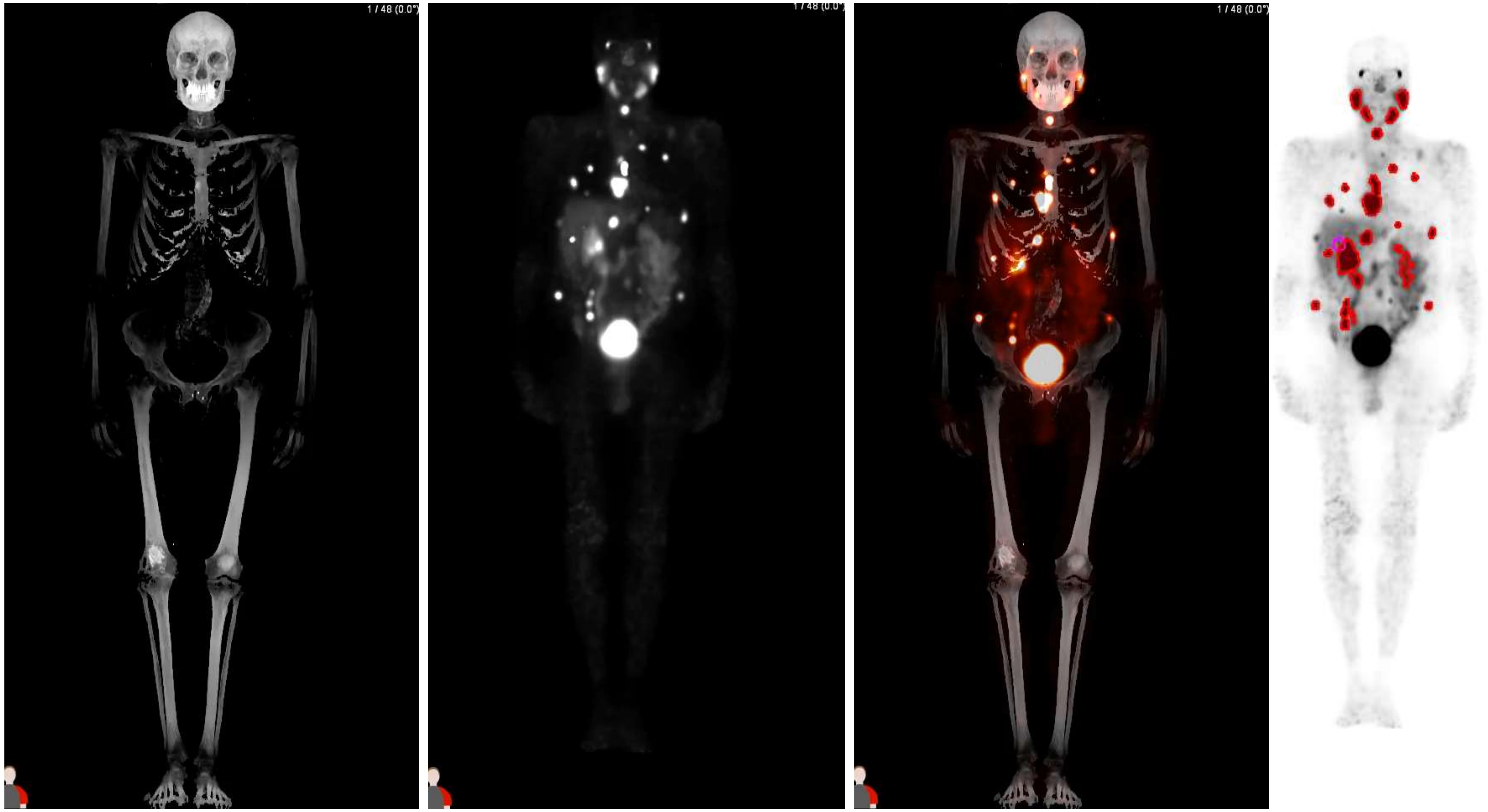
## Total BodySPECT/CT Acquisition ($^{177}$Lu)

- 67y Male
- BMI: 22.6

- Dose: 202.3 mCi of $^{177}$Lu-PSMA
- Acquisition time: 18 min

- **Full-Ring CZT**
  Veriton 200 Series
  113 keV ± 10 %
  Upper/Lower Scatter windows 10%
  CTAC

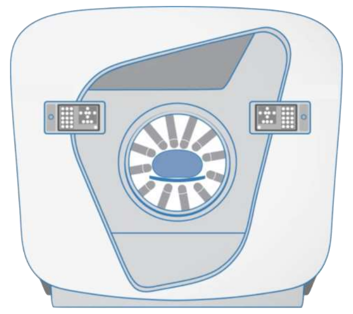
CT | SPECT | SPECT/CT



18 min

Images courtesy of Centre Hospitalier Régional Universitaire (CHRU) de Nancy, Nancy, France

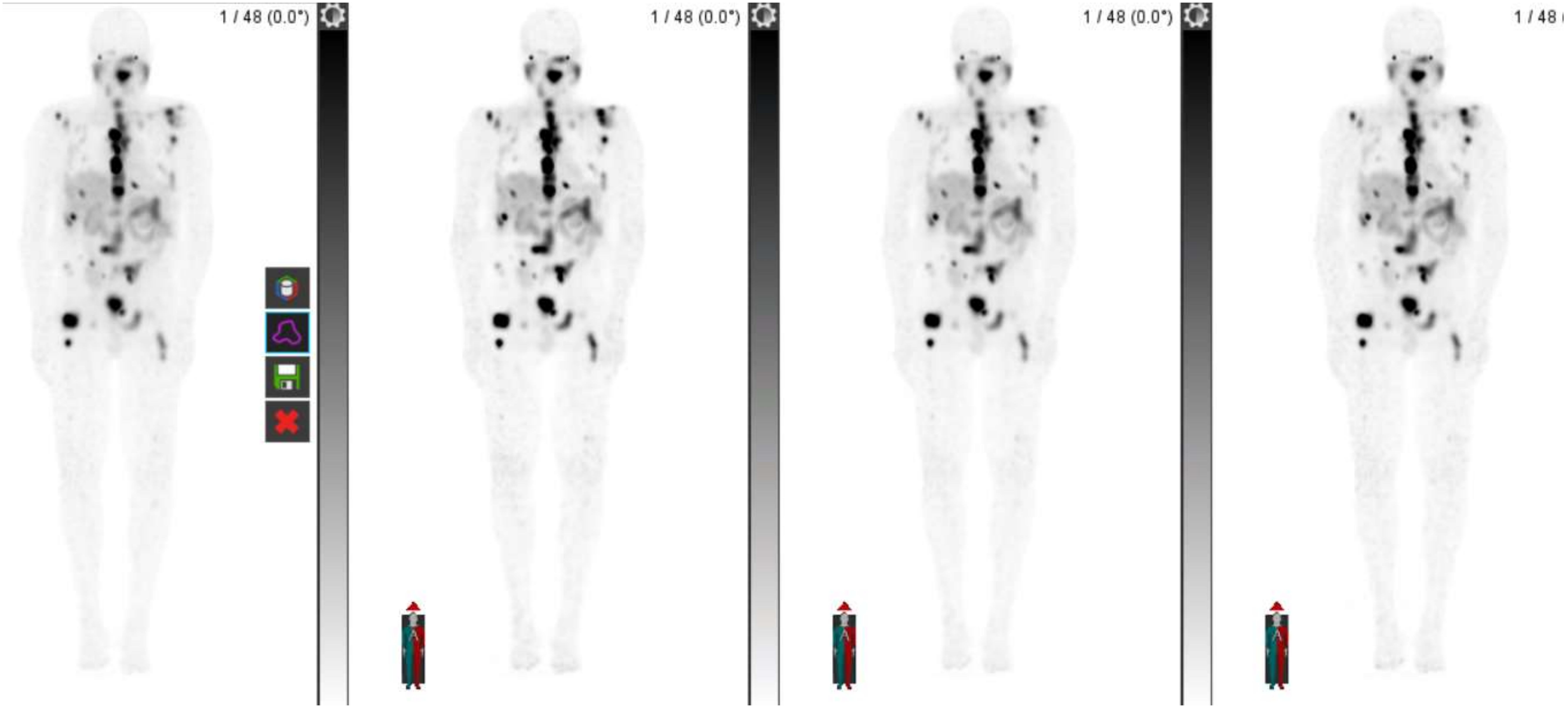




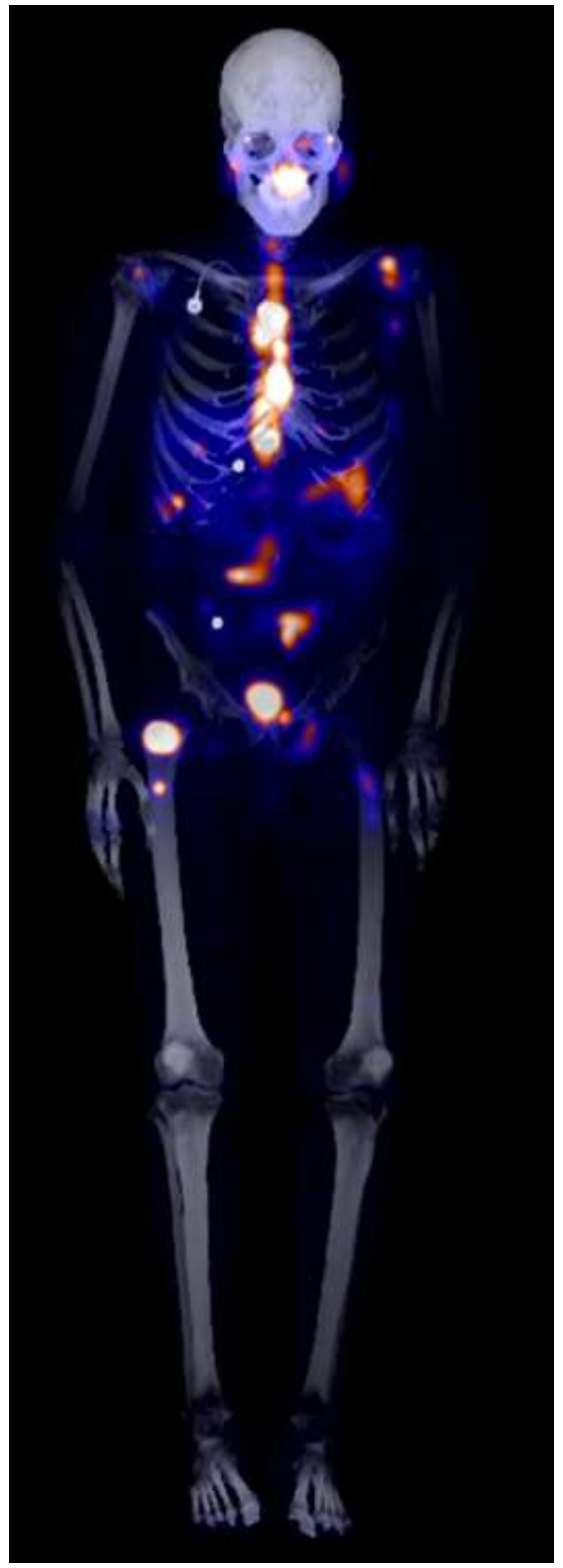
# LU-177 SPECT/CT IMAGING

**Veriton 200 Series** — 113 keV peak

**Veriton 400 Series** — 208 keV | 113 & 208 keV | 113 & 208 keV

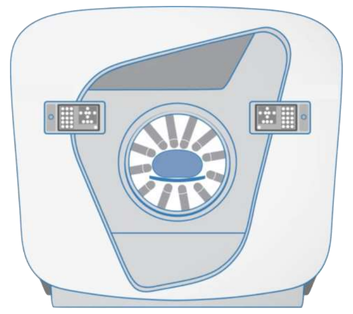



18 min | 18 min | 18 min | **9 min!**

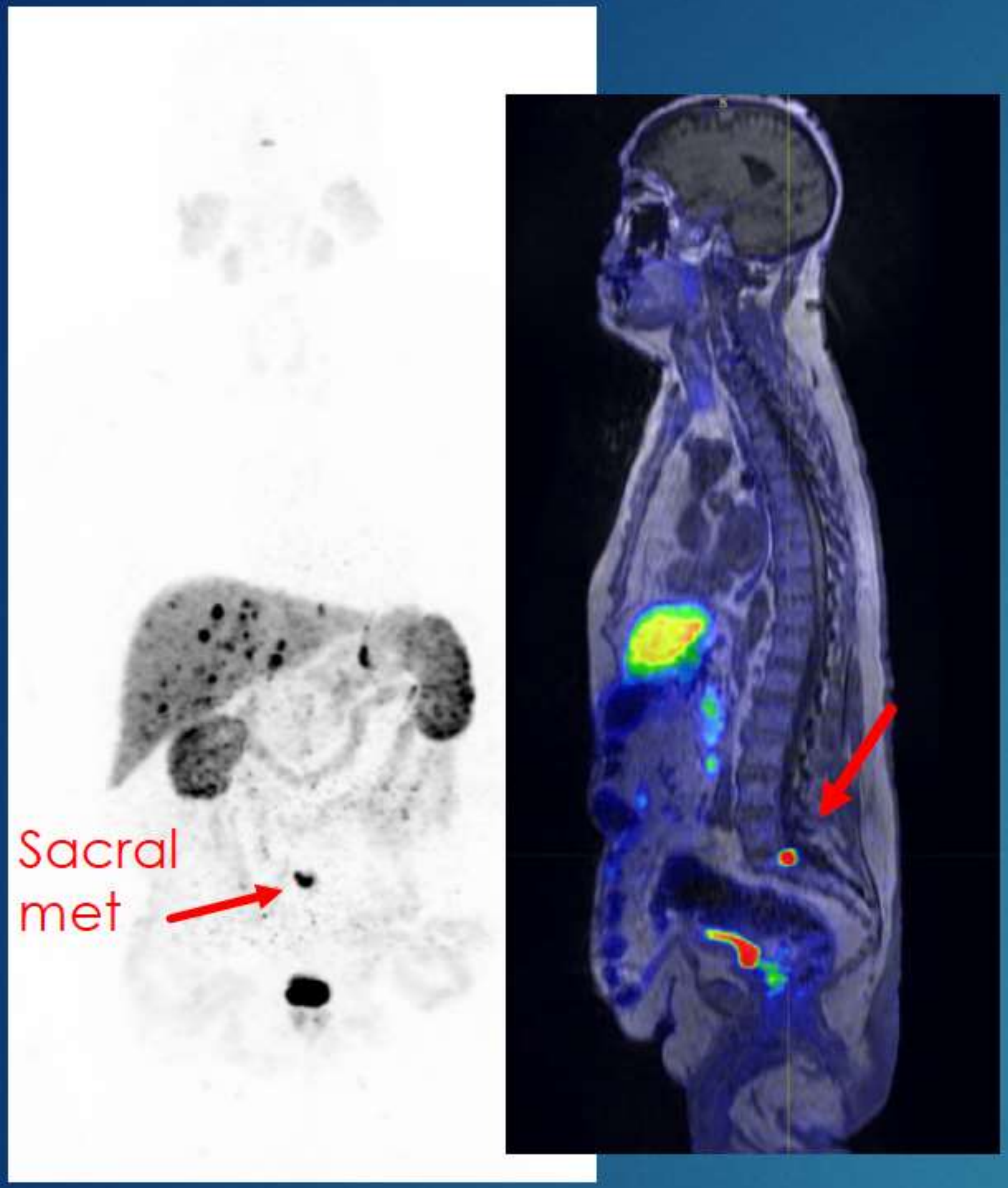


SPECT/CT Fusion

Images courtesy of Centre Hospitalier Régional Universitaire (CHRU) de Nancy, Nancy, France

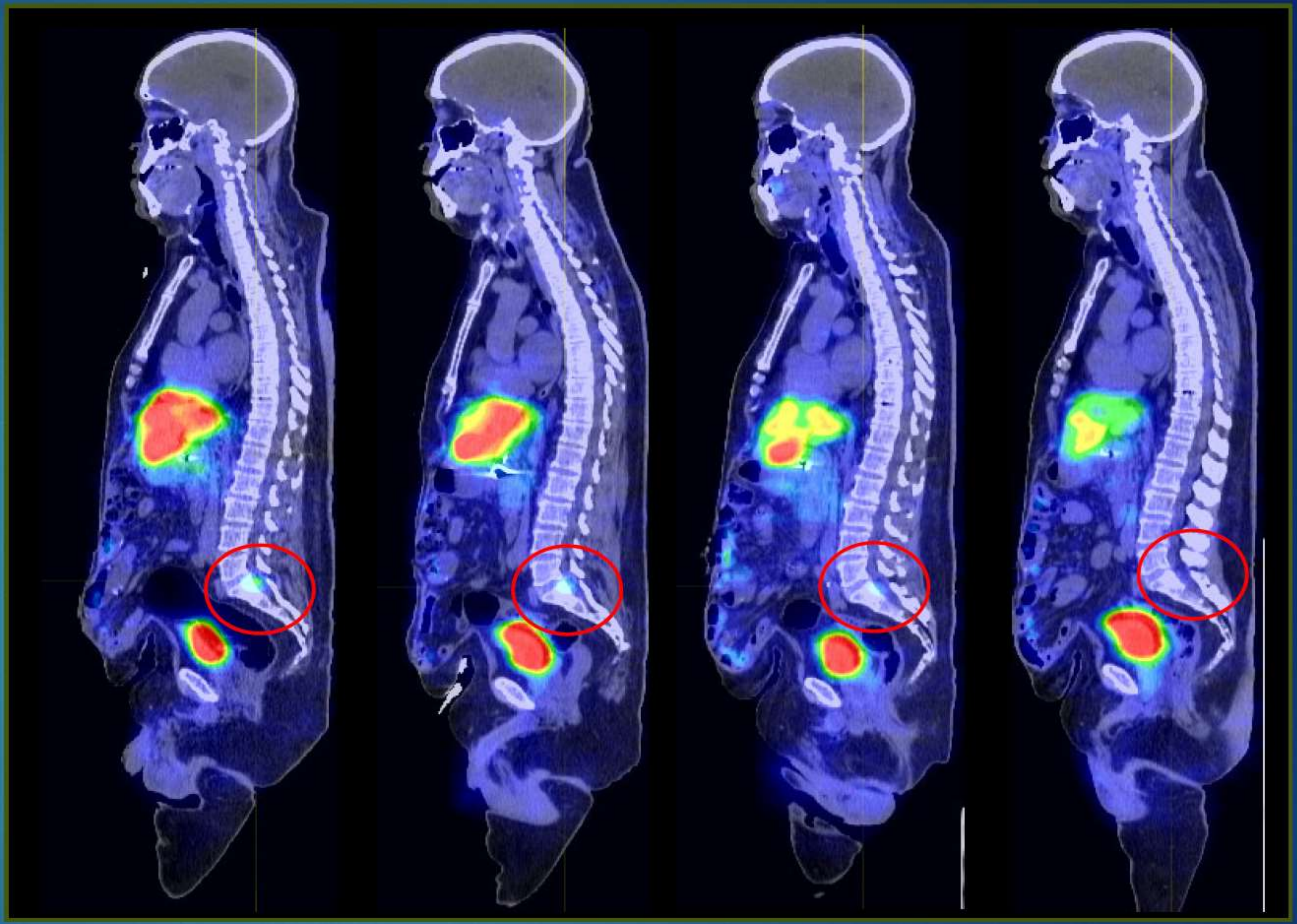


# QUANTITATIVE LU-177 SPECT/CT IMAGING




Ga-68 Dotatate
PET/MR Survey

8 mo prior to Lu-177 therapy

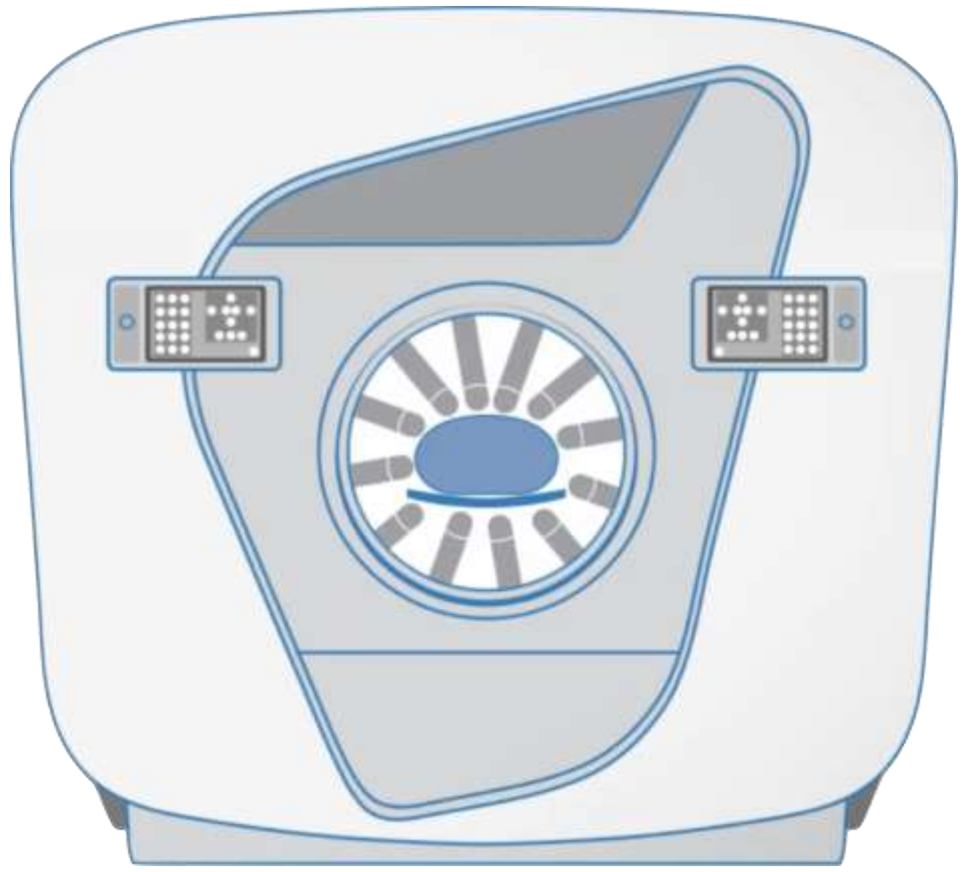


| Cycle 1 | Cycle 2 | Cycle 3 | Cycle 4 |
|---|---|---|---|
| Max SUVbw = 2.9 | 1.9 | 1.5 | 1.0 |

4-6 hrs after Lutathera administration, imaged on Veriton SPECT/CT

Images courtesy of the Mayo Clinic, Rochester, MN, USA

## Absolute Quantitation



CT Attenuation and Scatter Correction
Resolution Recovery
Sophisticated Reconstruction Algorithm

Image natively produced in Activity Concentration (Bq/ml)

→ **Need for Correction Factor!**

# ABSOLUTE QUANTITATION CALIBRATION

## WHAT to Calibrate? — Image Counts Into Activity Concentration (Bq/ml)

**Controllable technical factors** related to image acquisition and formation?

| Parameters | Conventional SPECT | Full-Ring CZT SPECT | PET |
|---|---|---|---|
| Angular sampling | ✓ | ✗ | ✗ |
| Acquisition Range (*180/360*) | ✓ | ✗ | ✗ |
| Orbit type and distance | ✓ | ✓ | ✗ |
| Collimators | ✓ | ✗ | ✗ |
| Matrix Size / Voxel Size | ✓ | ✓ | ✓ |
| Acquired Counts | ✓ | ✓ | ✓ |
| Nuclide / Energy Window | ✓ | ✓ | ✗ |
| Scatter Correction Method | ✓ | ✓ | ✗ |
| Reconstruction Parameters (# iteration, filters, algorithm,…) | ✓ | ✓ | ✓ |

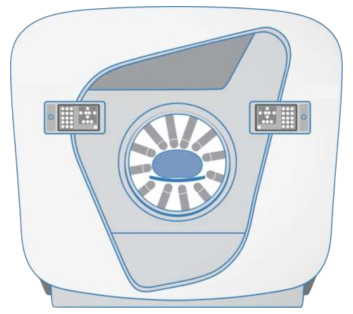
## HOW to Calibrate?

### Cross-Calibration against Dose-Calibrator with Uniform Flood Phantom

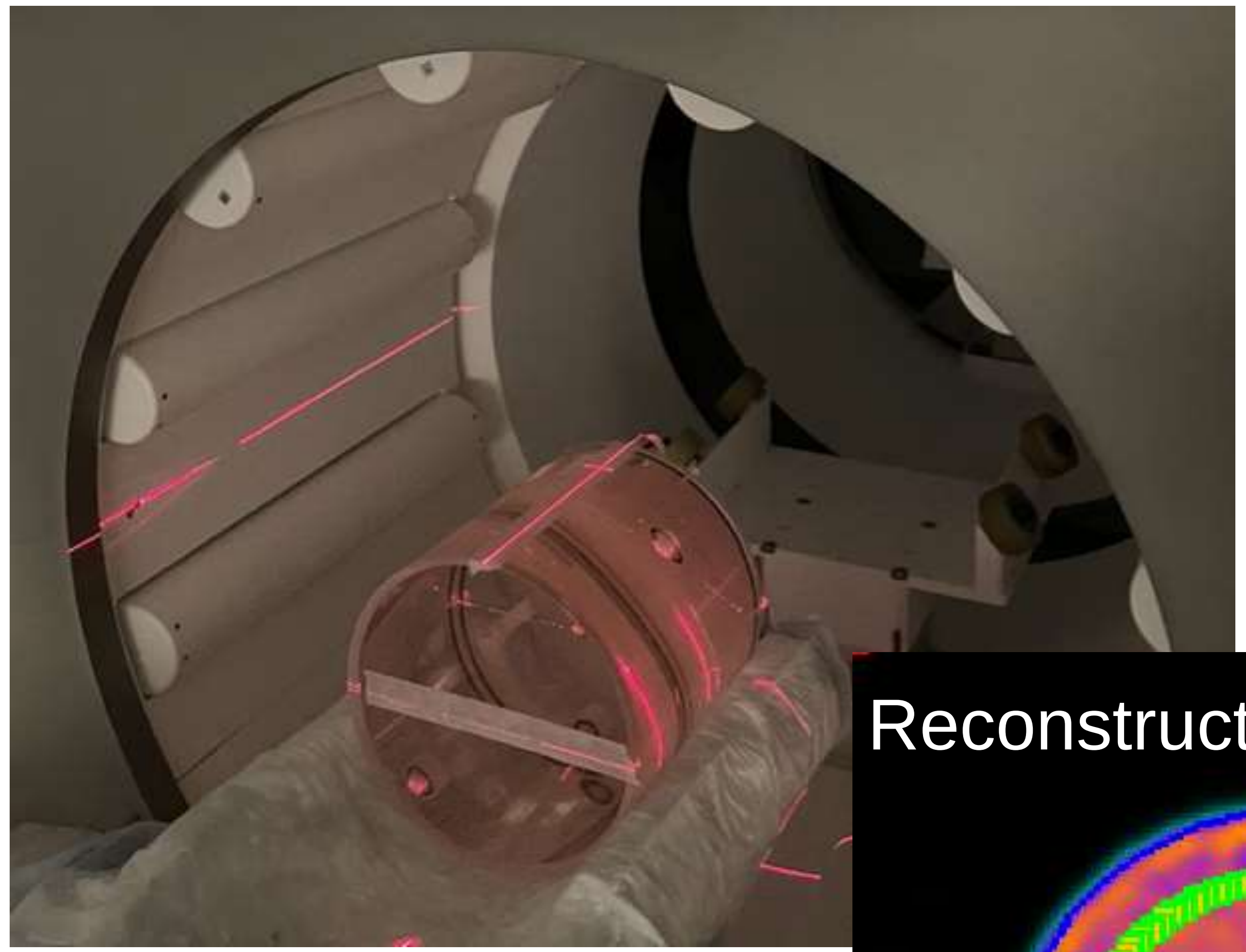
| Parameters | Full-Ring CZT SPECT |
|---|---|
| Angular sampling | ✗ |
| Acquisition Range (*180/360*) | ✗ |
| Orbit type and distance | ✓ |
| Collimators | ✗ |
| Matrix Size / Voxel Size | ✓ |
| Acquired Counts | ✓ |
| Nuclide / Energy Window | ✓ |
| Scatter Correction Method | ✓ |
| Reconstruction Parameters (# iteration, filters, algorithm,…) | ✓ |

Uniform Flood Cylinder (as in PET)
Calibrated against Dose Calibrator
How Robust are these factors? Variability?



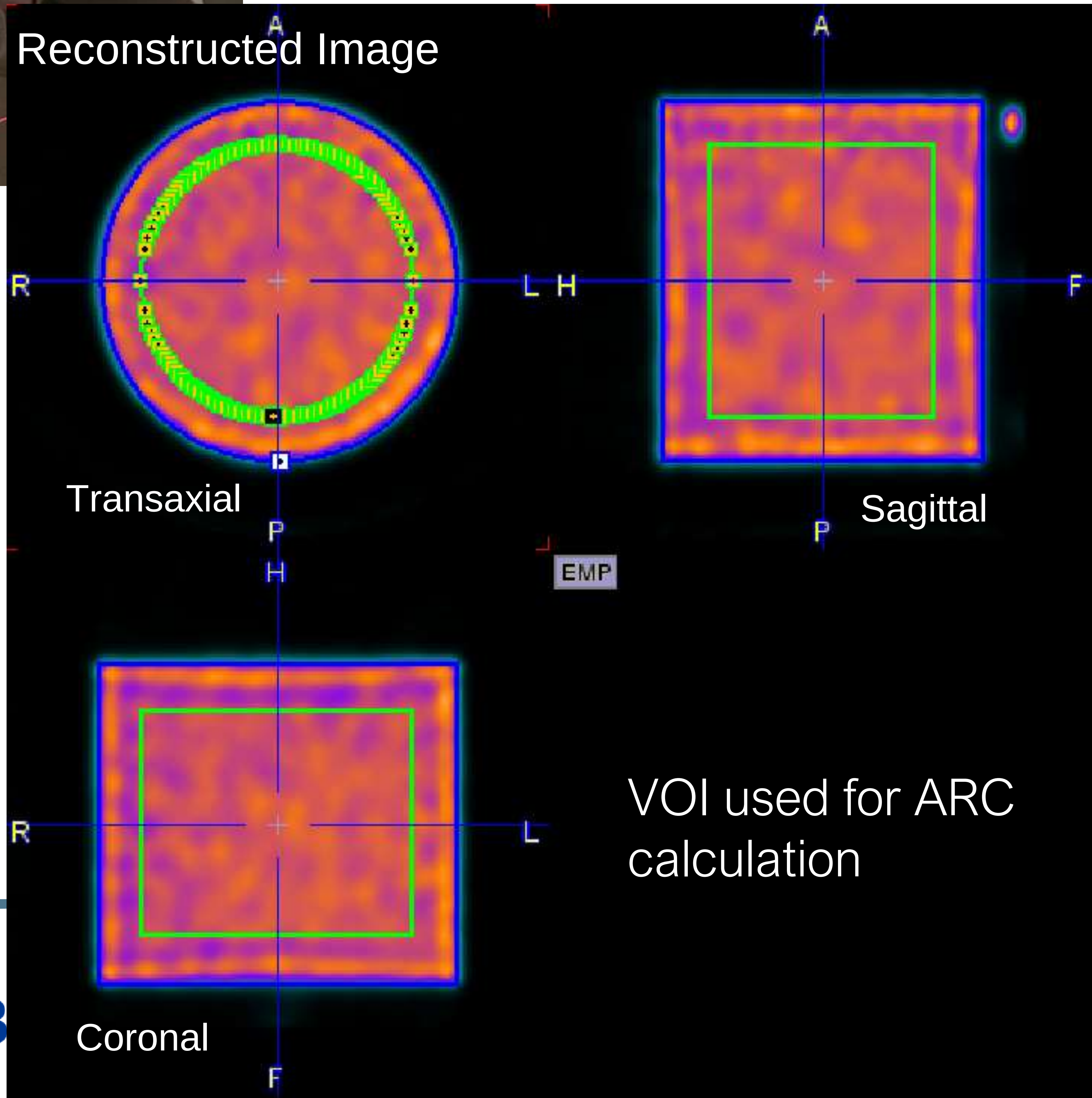


# CROSS-CALIBRATION WITH DOSE CALIBRATOR



## Uniform Flood Calibration

- Acquisition of a **Uniform Flood phantom** with **clinical protocol parameters**
- **High Count level (32 Mcts) to minimize noise**
- **Reconstruction parameters** and **scatter correction** similar to **clinical protocol parameters**
- **Estimation of the Activity Recovery Coefficient ARC or Calibration Factor (=** *image concentration/true concentration***).**
  *True concentration obtained from known activity (DC) and phantom volume (6415 ml)*

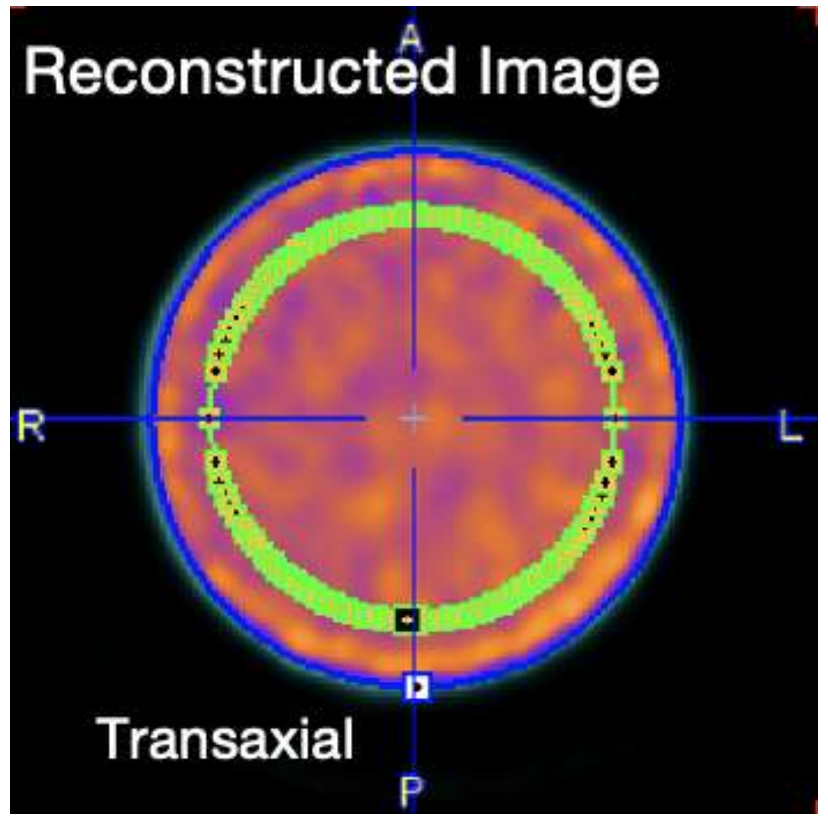


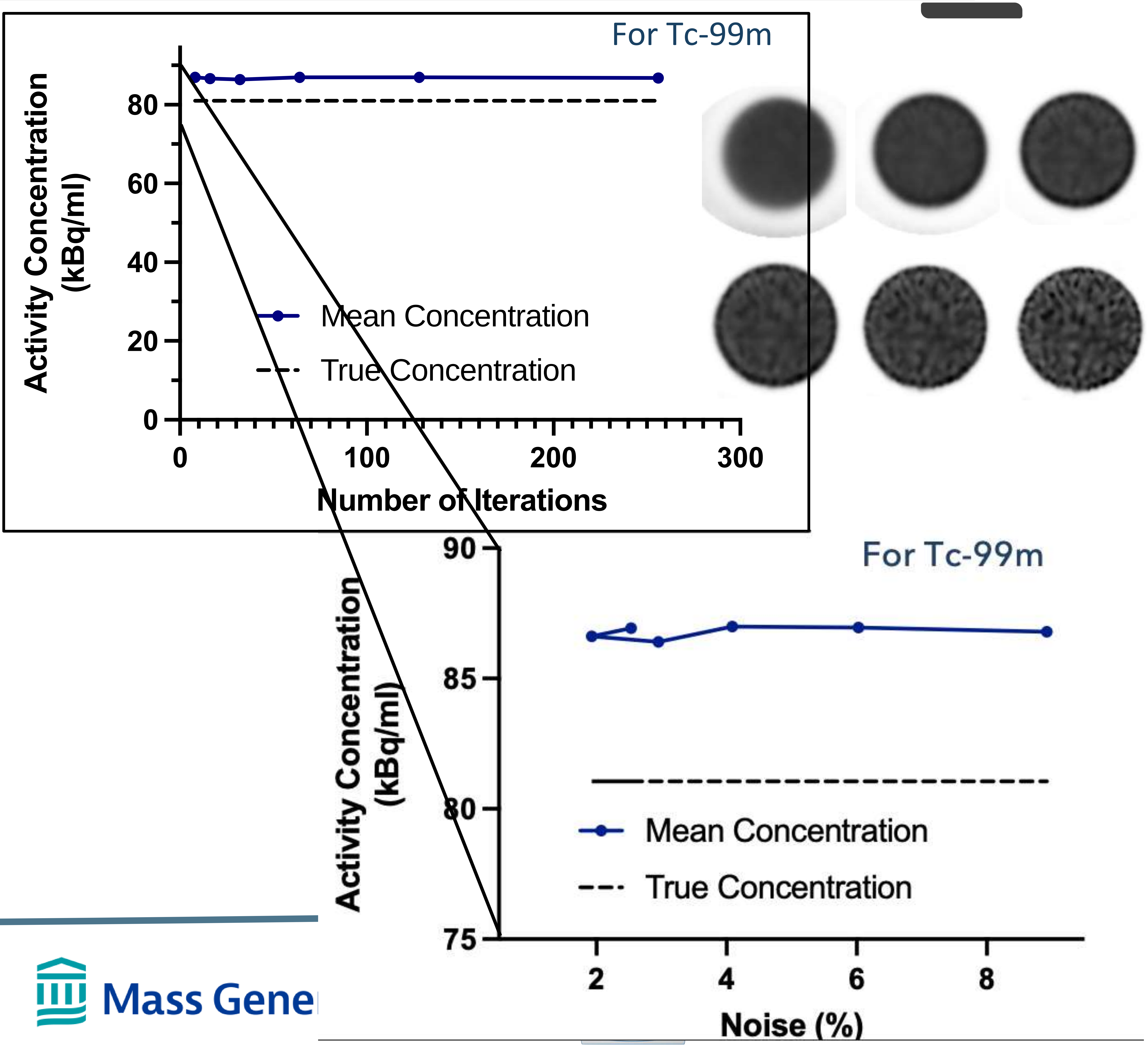
# CROSS-CALIBRATION WITH DOSE CALIBRATOR

## How Many Iterations is Optimal?

- **ARC** is stable over iterations
- **Not too many** to avoid incorporating **excessive noise** (*increases variability*)
- Not **too few** to ensure convergence

VOI used for ARC calculation

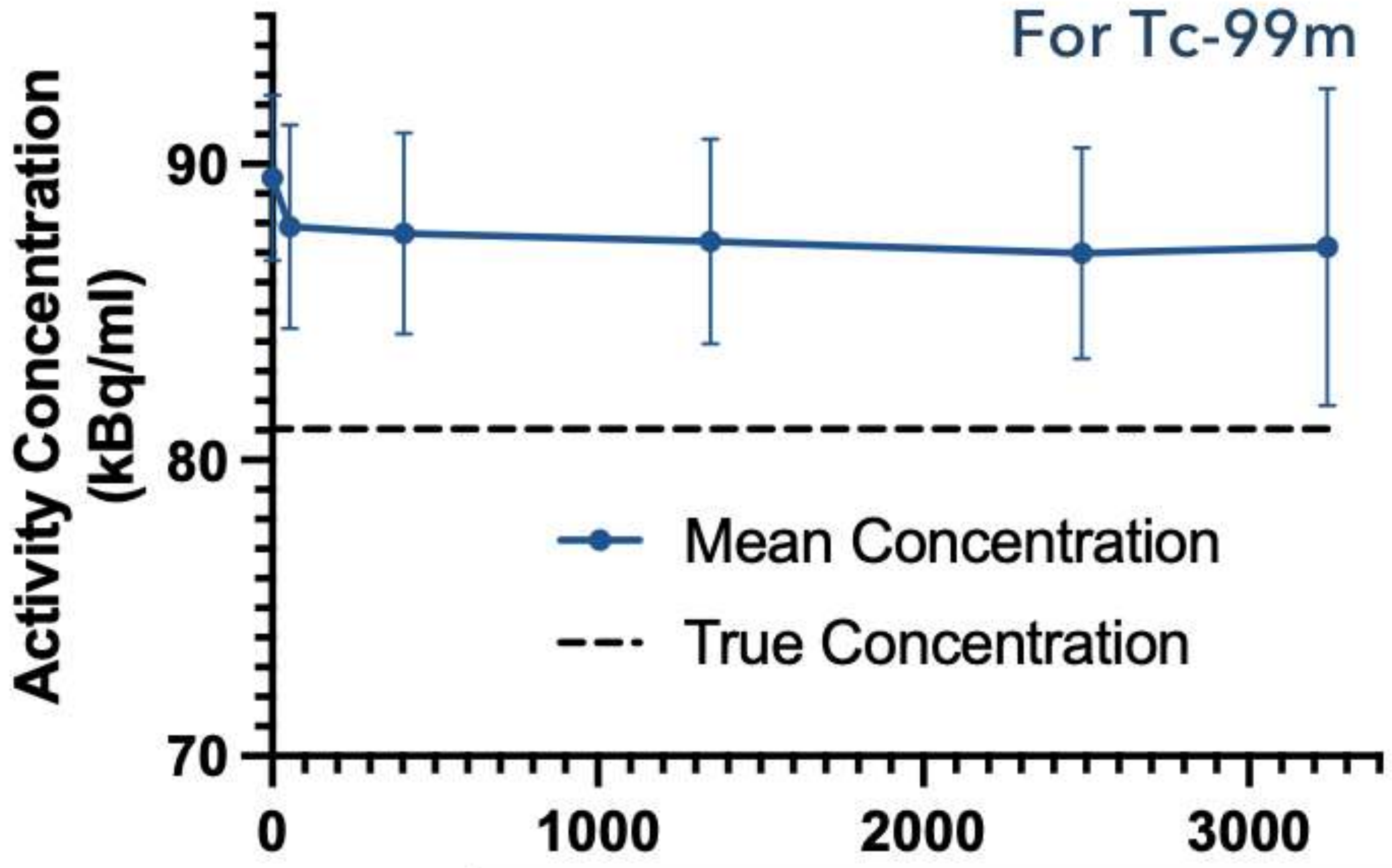


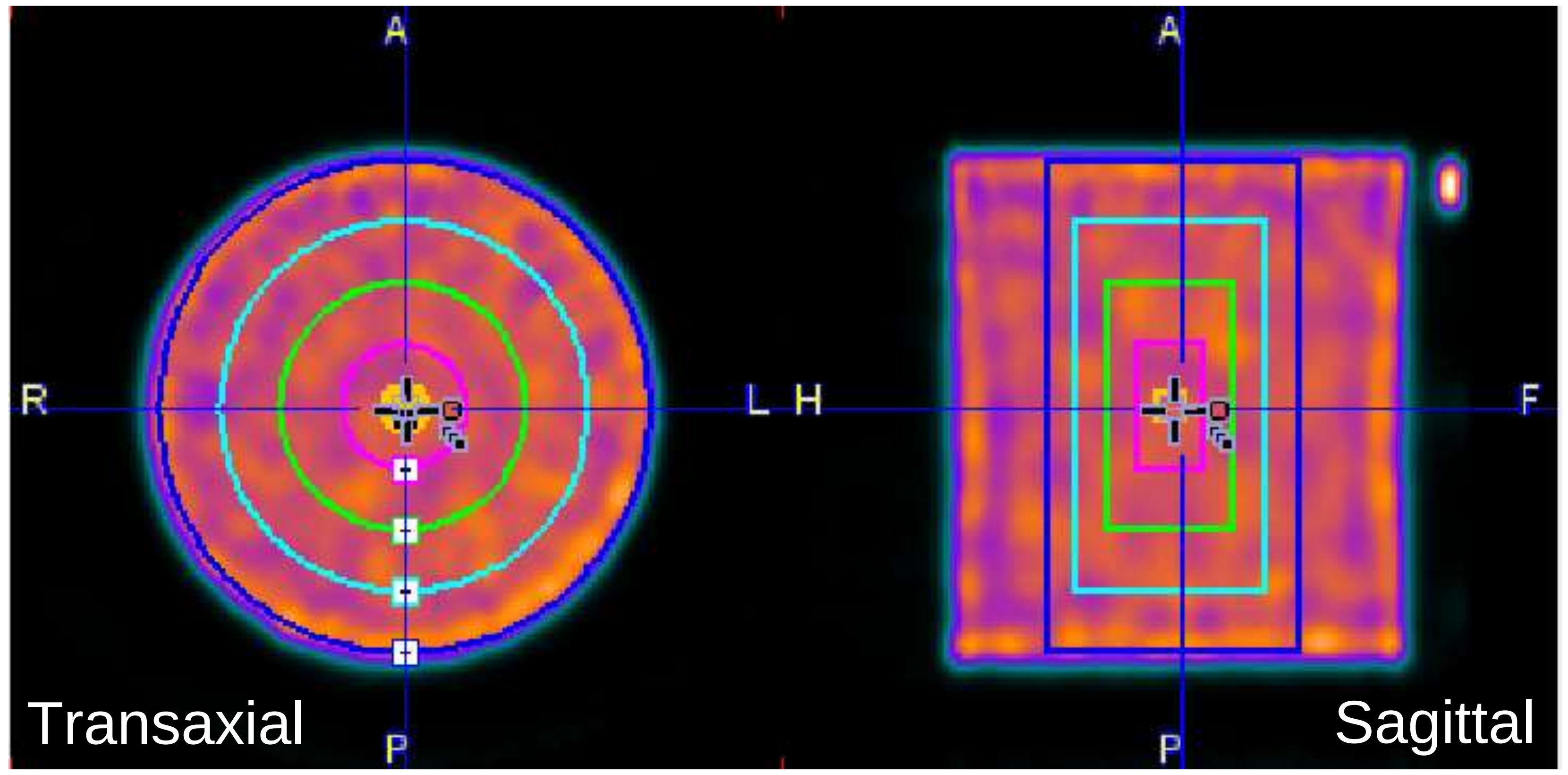
# CROSS-CALIBRATION WITH DOSE CALIBRATOR

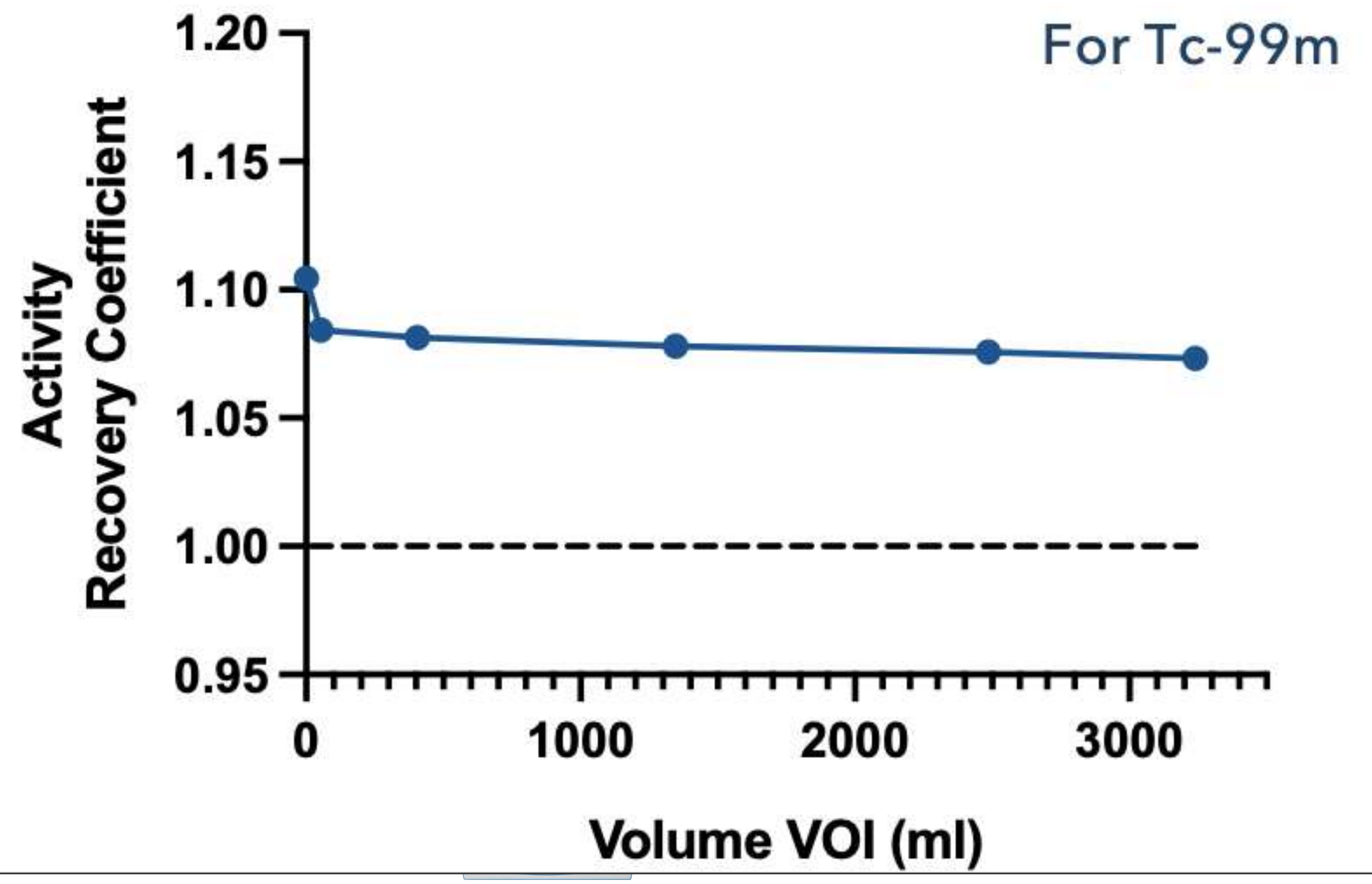
## What Should be the VOI size?

- Not too small to avoid incorporating excessive noise (*increases variability*). Higher likelihood of including more scatter/attenuation effects in small VOIs.
- Not too large to exclude edge effects




VOI used for ARC calculation



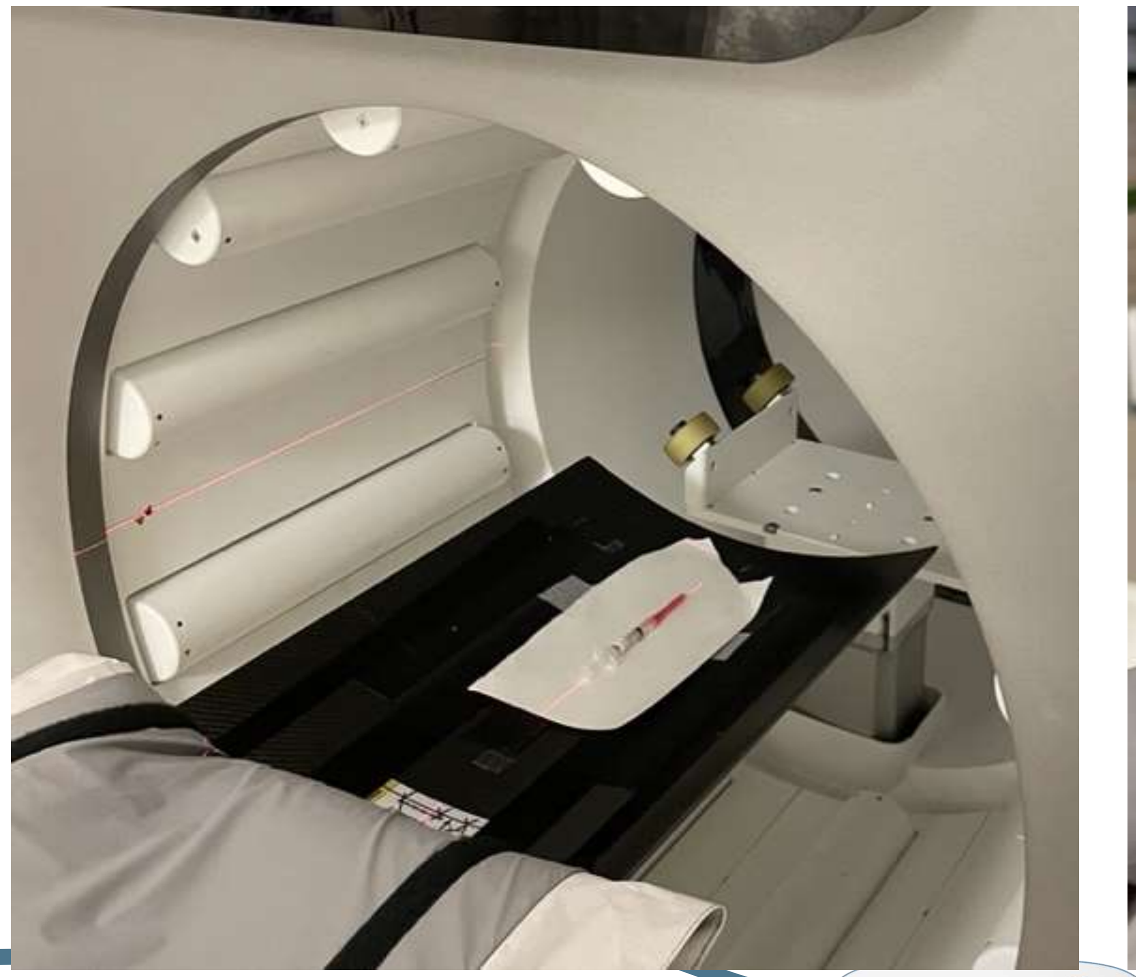
# CROSS-CALIBRATION WITH DOSE CALIBRATOR

## Can any other **source objects** be used for calibration?

- Uniform Flood phantom might not be adequate for long-lived nuclides (e.g., Lu-177, In-111, I-131) in practice as it needs to be stored until it has decayed.

- **Flask** or **Syringe** would be more convenient in practice.

What is the impact of the calibration source objects on absolute quantitation?

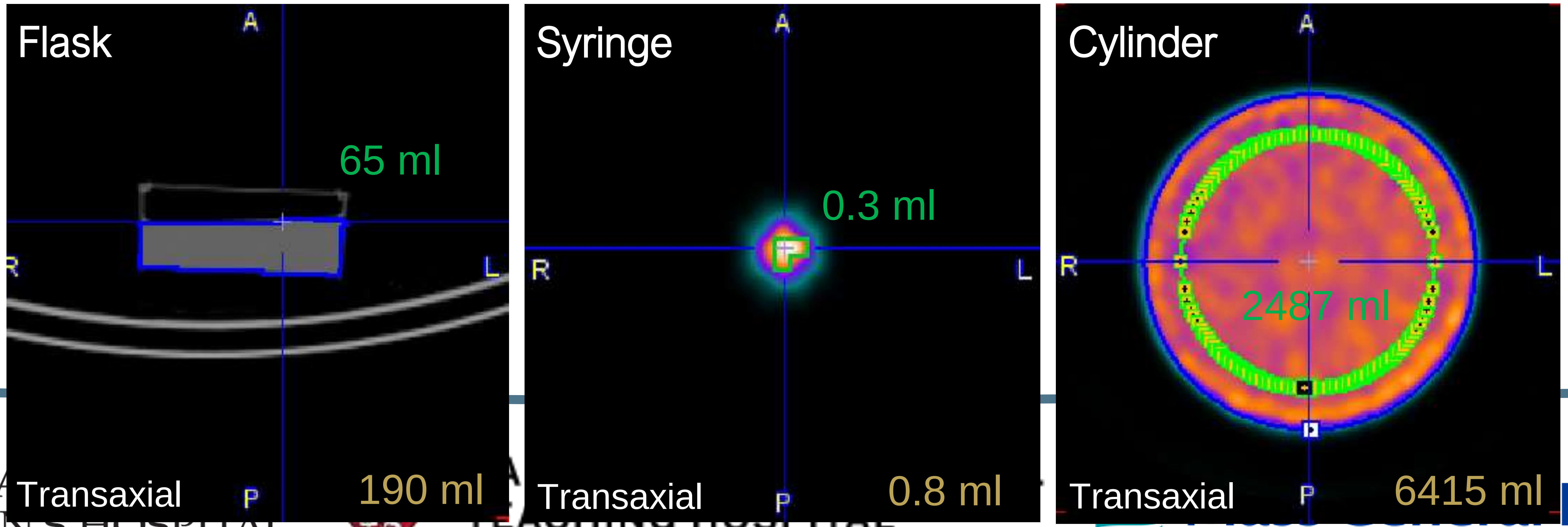

# CROSS-CALIBRATION WITH DOSE CALIBRATOR

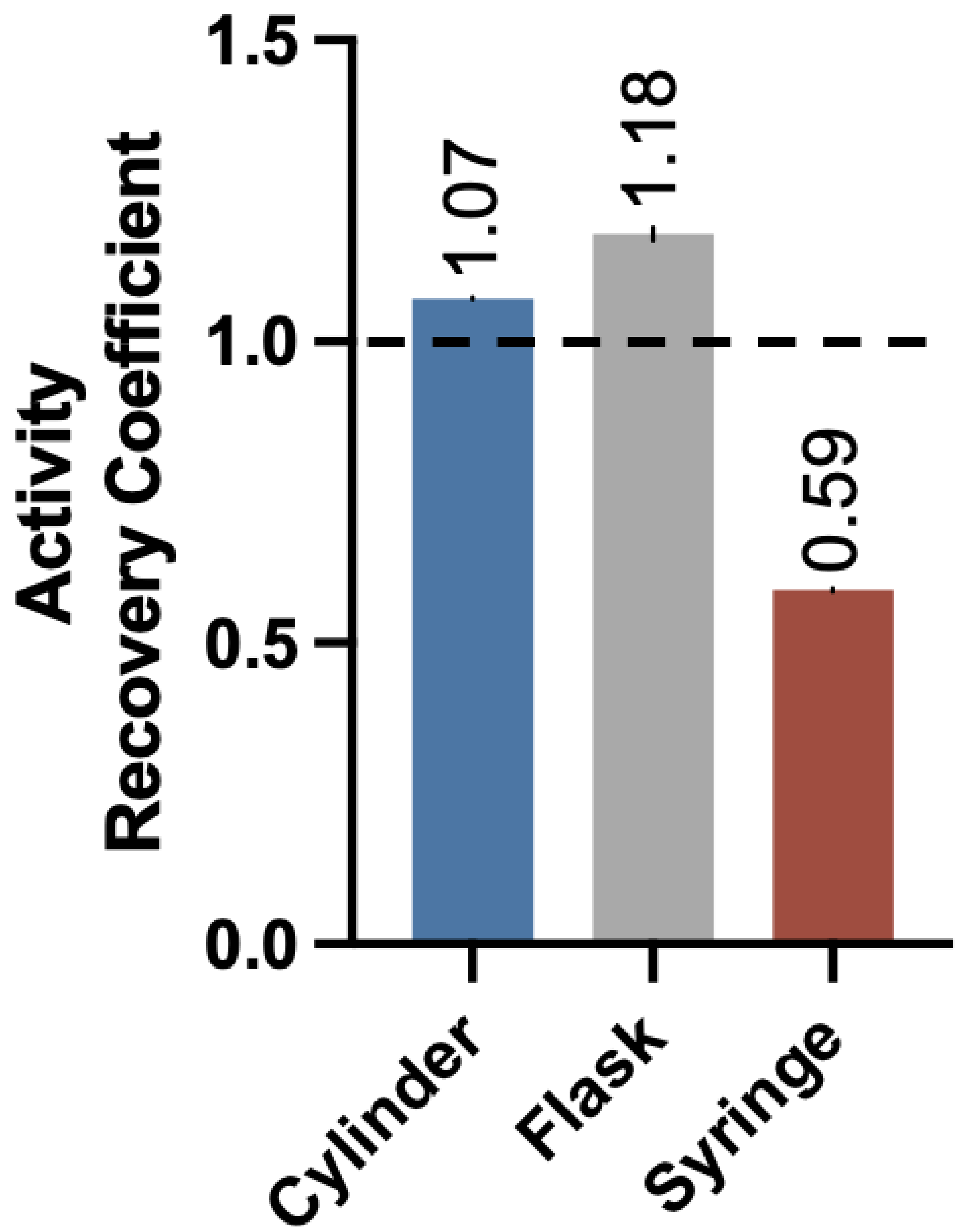
## Can any other **source objects** be used for calibration?

ARC is **overestimated** with the flask (*too many counts detected*) likely du to Gibbs edge artefact (*Resolution Recovery*) [1].
Using this calibration factor will lead to **under-correction.**

**ARC** is **underestimated** with syringe (*too few counts recorded*) due to partial volume effect (spill over).
Using this calibration factor will **over-correct.**

VOI used for ARC calculation




[1] Armstrong *Nuc. Med. Commun.* 2016

## What is the Impact of the Calibration Accuracy on Absolute Quantitation?

**Cardiac Torso Phantom $^{99m}$Tc-MPI** Study

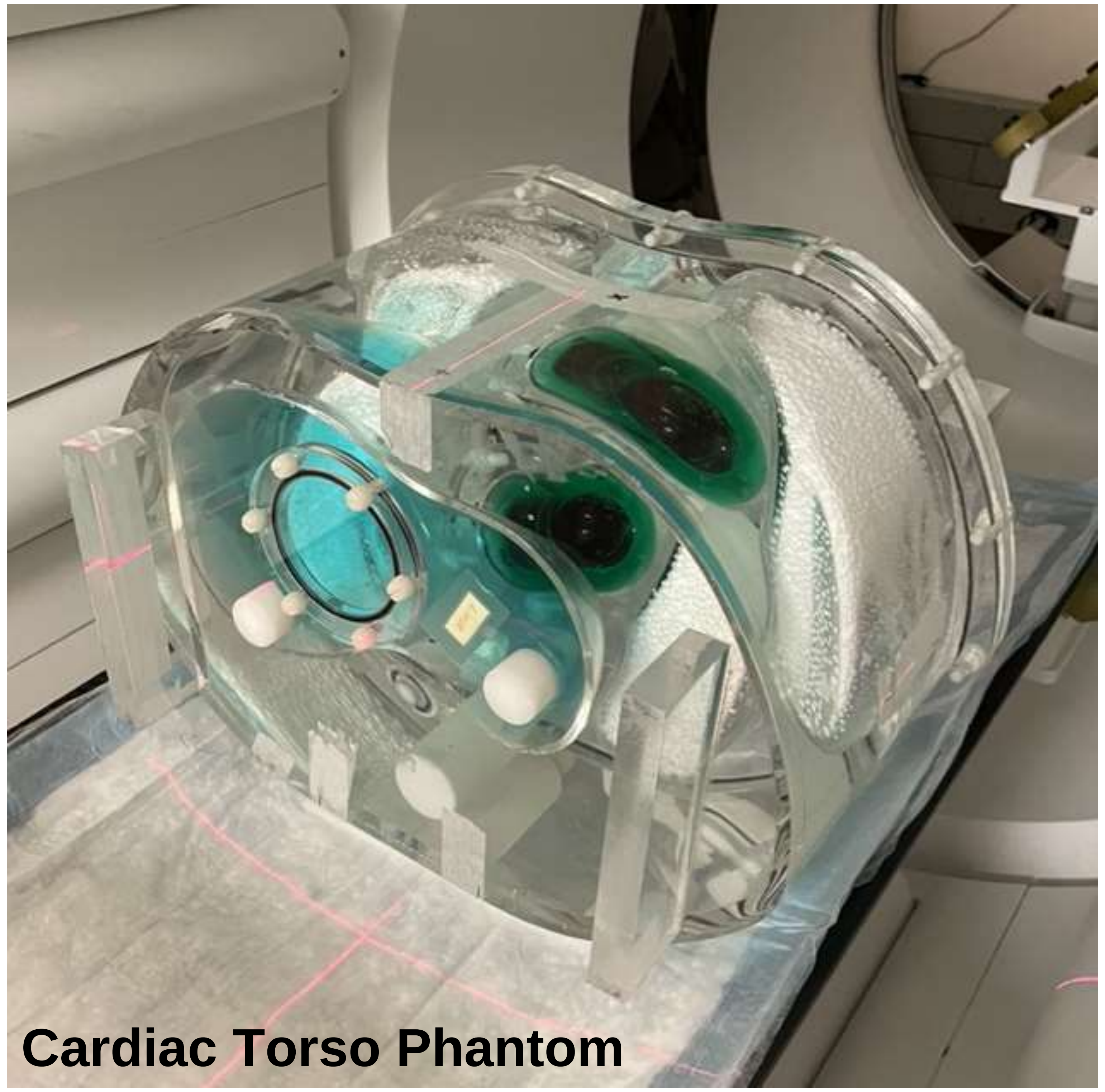
Clinical Count level (stress): 1.6-3 Mcts

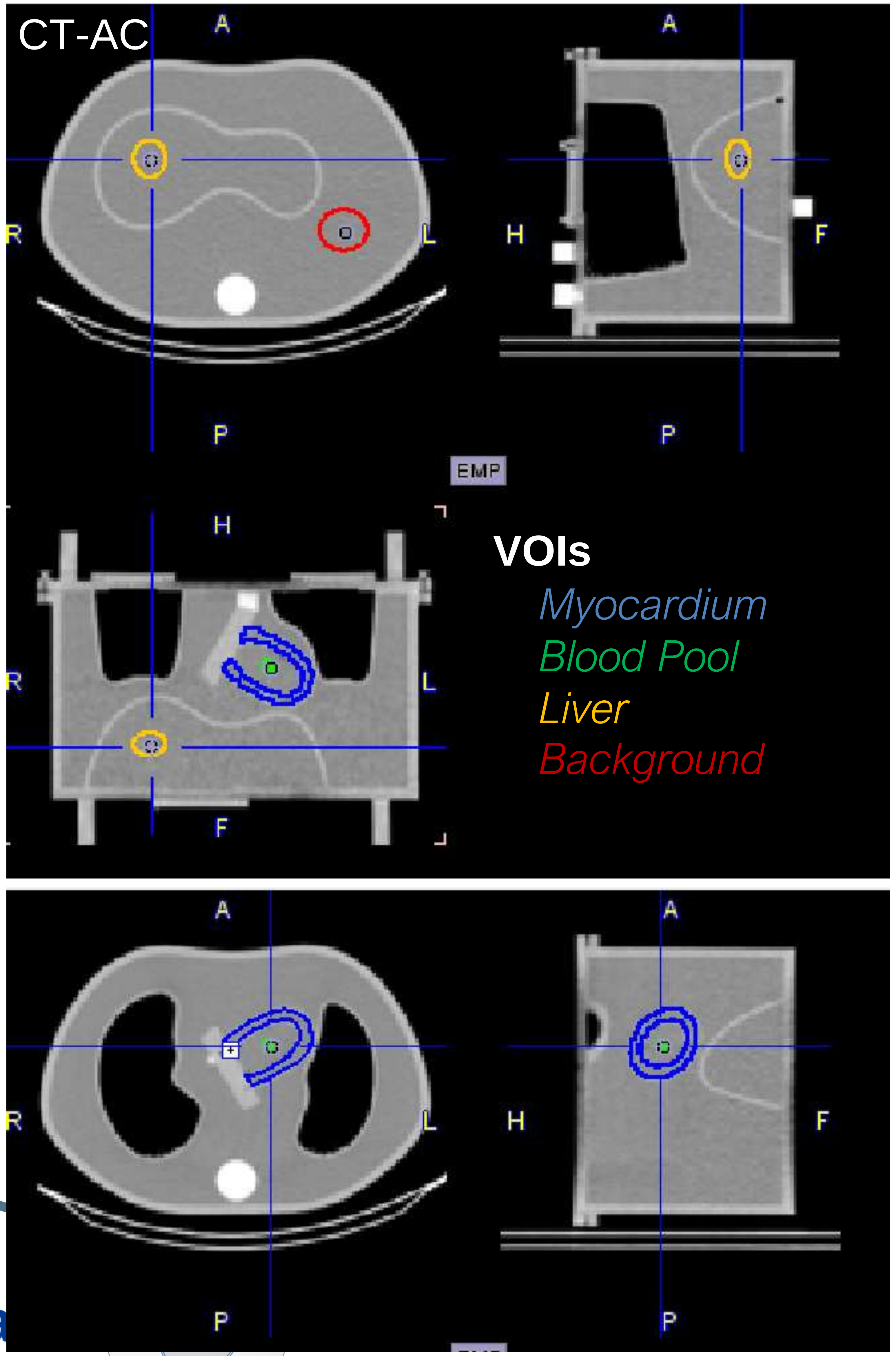
**True** Activity Concentration

- *Myocardium:* 543.3 kBq/ml
- *Blood Pool:* 61.9 kBq/ml
- *Liver:* 148.8 kBq/ml
- *Background:* 49.6 kBq/ml

**VOIs** derived from CT-AC (*for Myocardium*)

- *Myocardium: 99.6 ml*
- *Blood Pool: 0.5* ml
- *Liver: 13.2* ml
- *Background:* 43 ml


Cardiac Torso Phantom



# What is the Impact of the Calibration Accuracy on Absolute Quantitation?

**Cardiac Torso Phantom** Study
Clinical Count levels (Stress $^{99m}$Tc-MPI)
4 it. 8 sub. OSEM + RR/AC/SC

1.6 Mcts


3 Mcts


**1.6 Mcts** (Transaxial Fly Through)

Left

**3 Mcts** (Transaxial Fly Through)

Left

# IMPACT OF CALIBRATION ACCURACY ON QUANTITATION

## What is the Impact of the Calibration Accuracy on Absolute Quantitation?

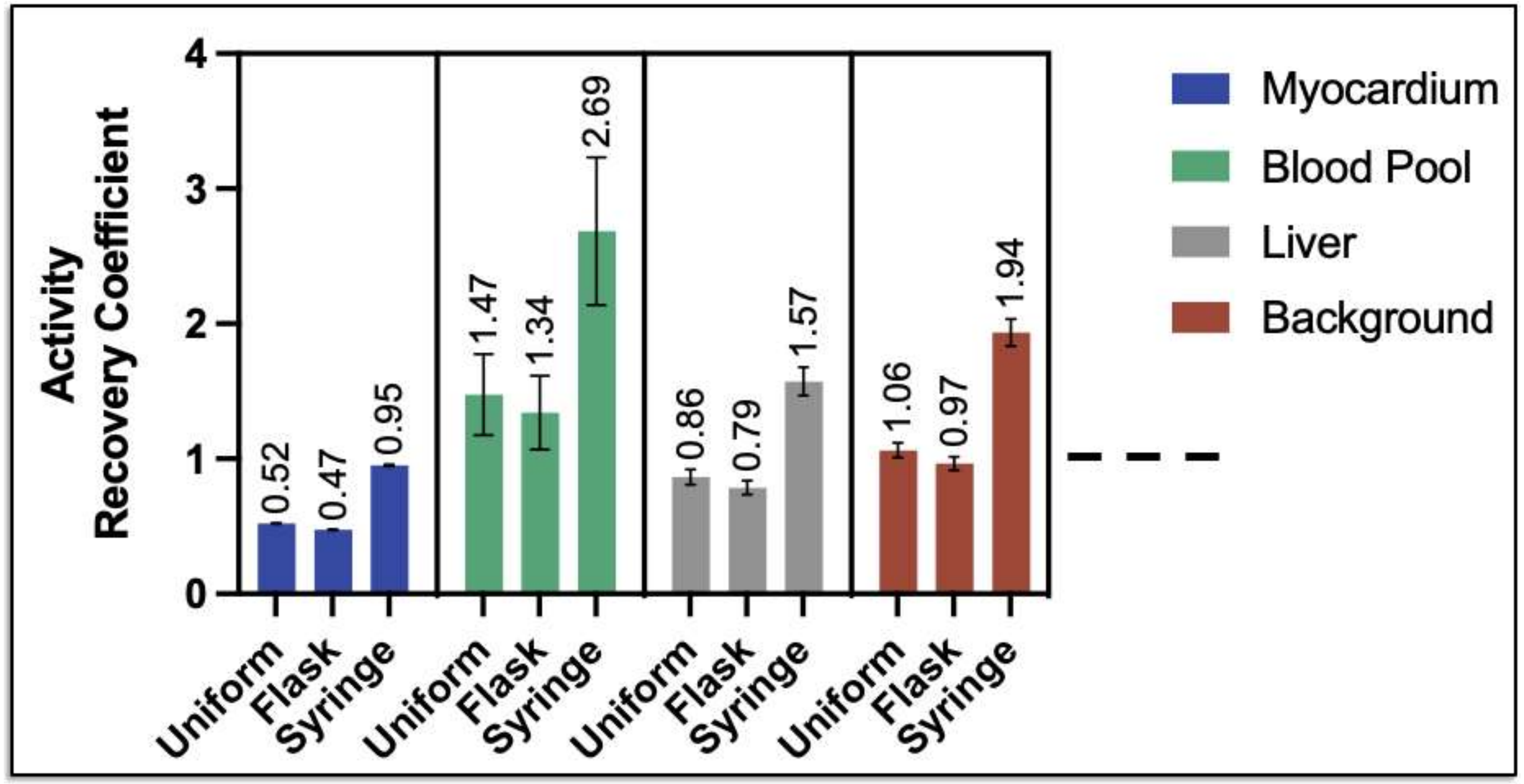
**Cardiac Torso Phantom** Study
Clinical Count levels (Stress $^{99m}$Tc-MPI)
4 it. 8 sub. OSEM + RR/AC/SC

**Calibration** derived from the **uniform cylinder** leads to the **most accurate quantitation** (ARC~1) on overall.

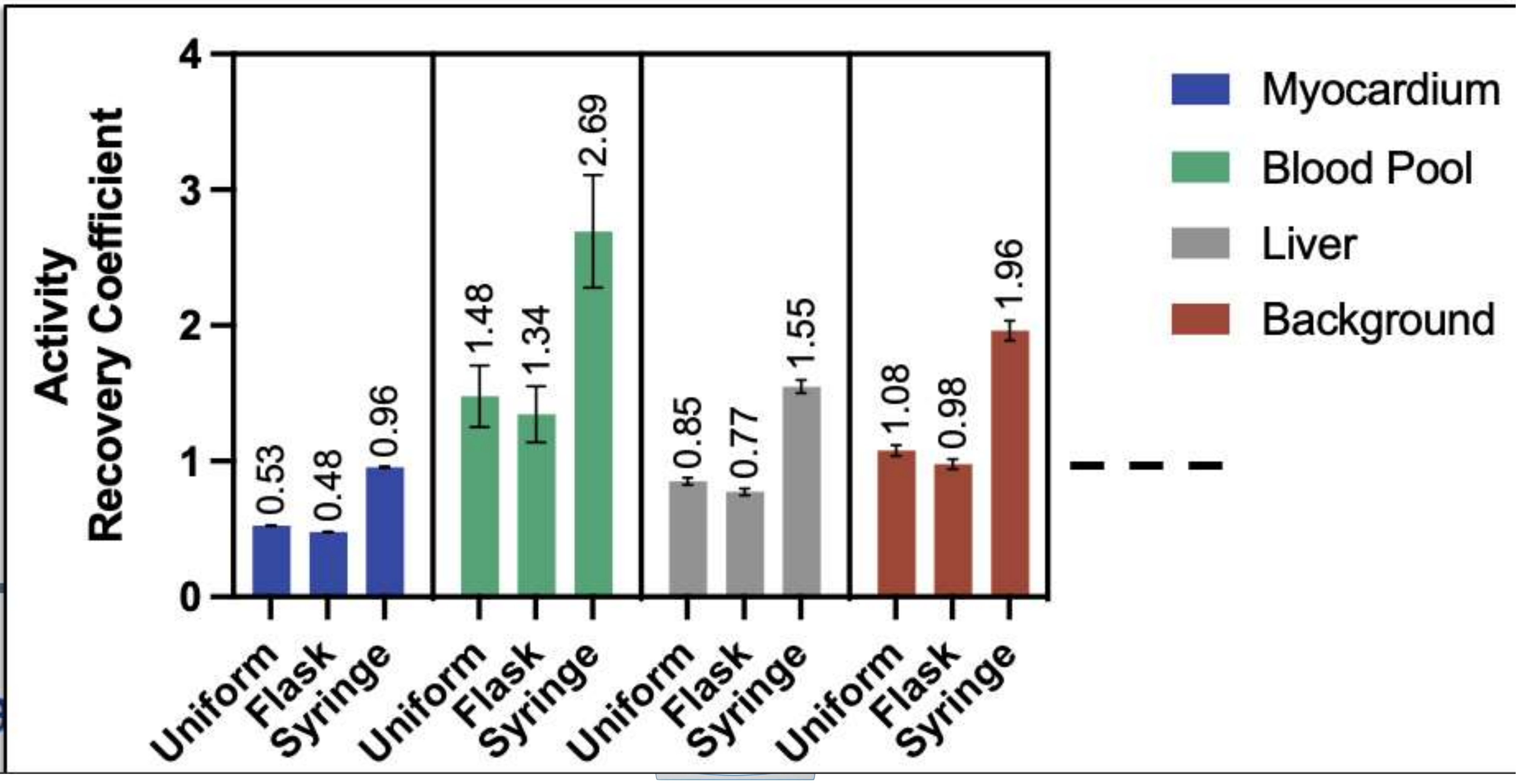
**Flask Calibration underestimates** overall the true concentration, **achieving the lowest ARCs**.

**Syringe Calibration** strongly **overestimates true concentration**. However, by chance, the syringe calibration led to the best **ARC for the myocardium,** as the syringe and the myocardium were **similarly affected** by PVE.

1.6 Mcts




3 Mcts



# CALIBRATION IN CLINICAL PRACTICE

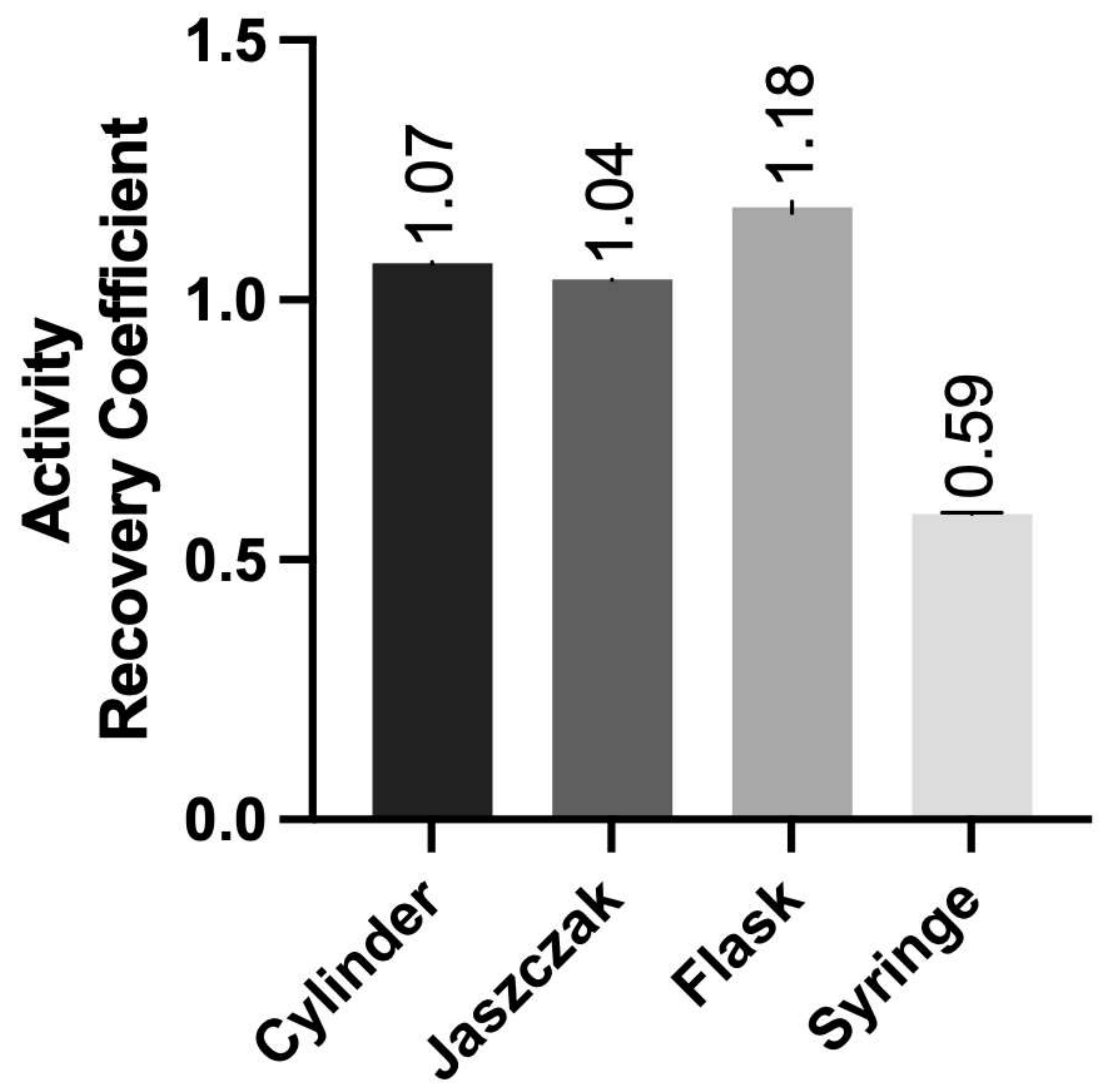
## Absolute Calibration derived from a Jaszczak Phantom Acquisition?

**Calibration Scan**
10 Mcts Non-Focus Mode ($^{99m}Tc$)
4 it. 32 sub. OSEM + RR/AC/SC

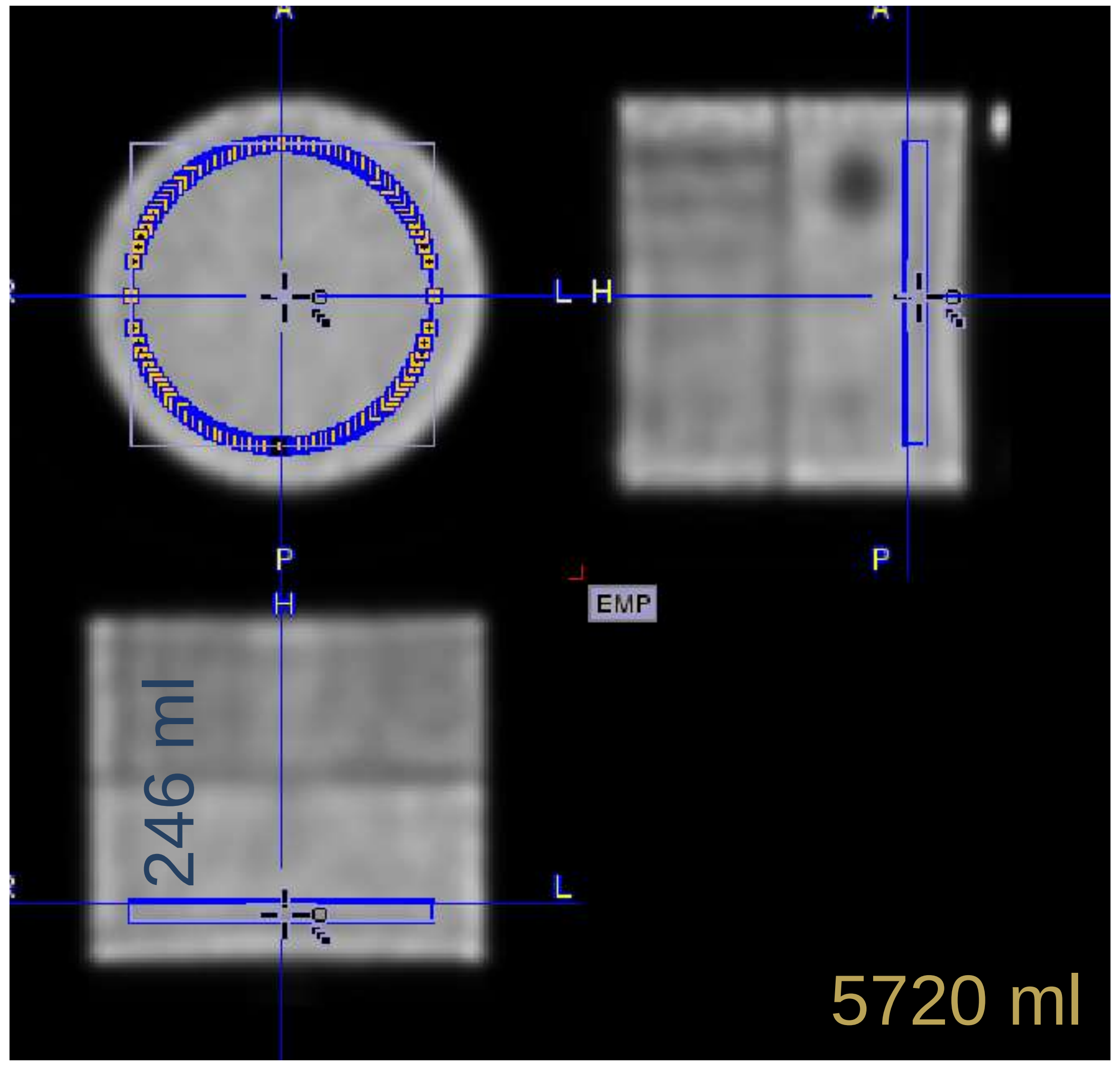
**Jaszczak phantom acquisition** (*usually*) enters **quarterly QC**.

**Easier** to **derive** a **calibration factor** from such **frequent scans** than with uniform phantom!

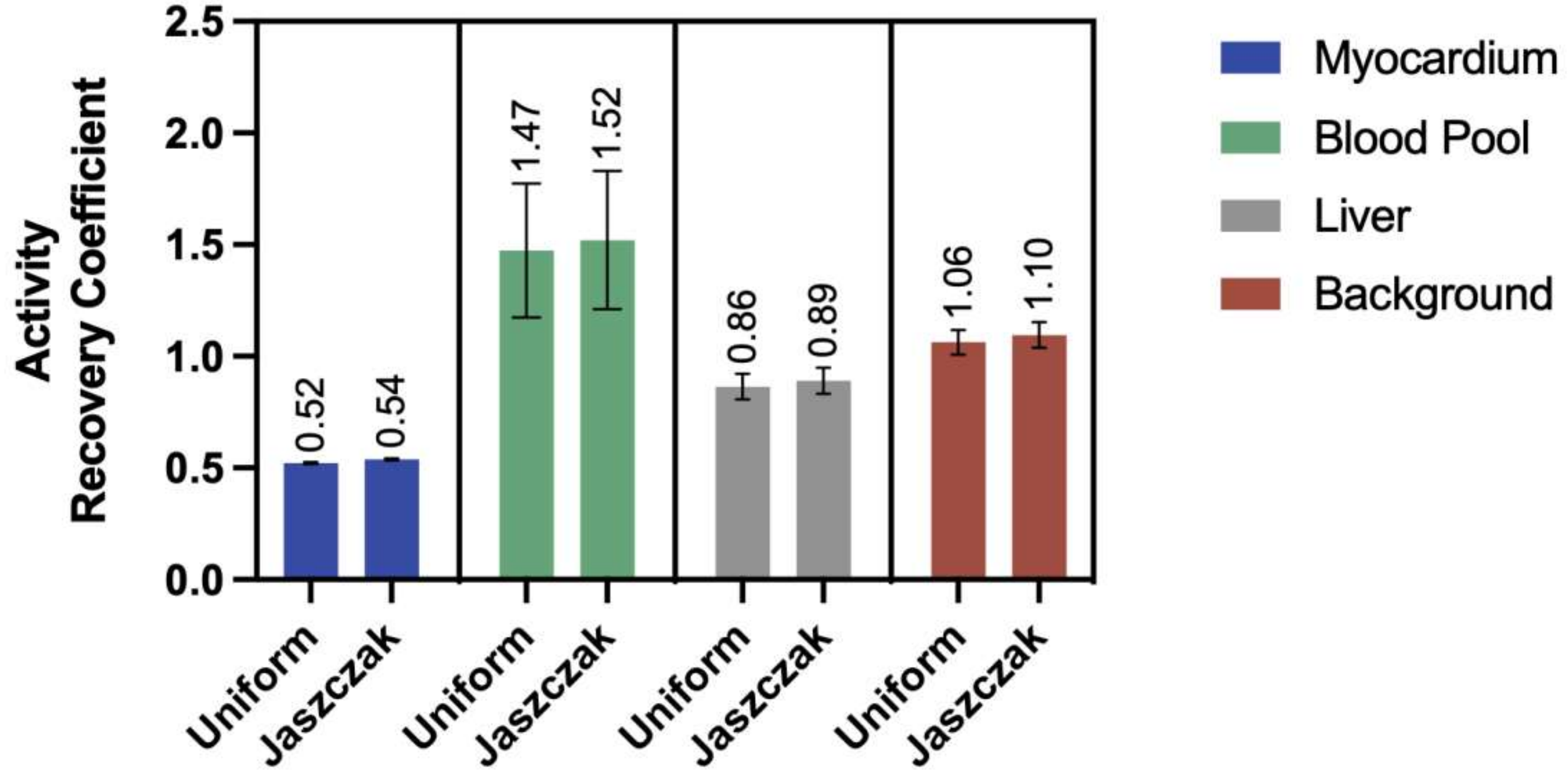
**Calibration factor** remains close to what is **derived from a uniform cylinder**.
**Small Impact** on **Absolute Quantitation** (*assessed torso phantom*)!




VOI used for ARC calculation

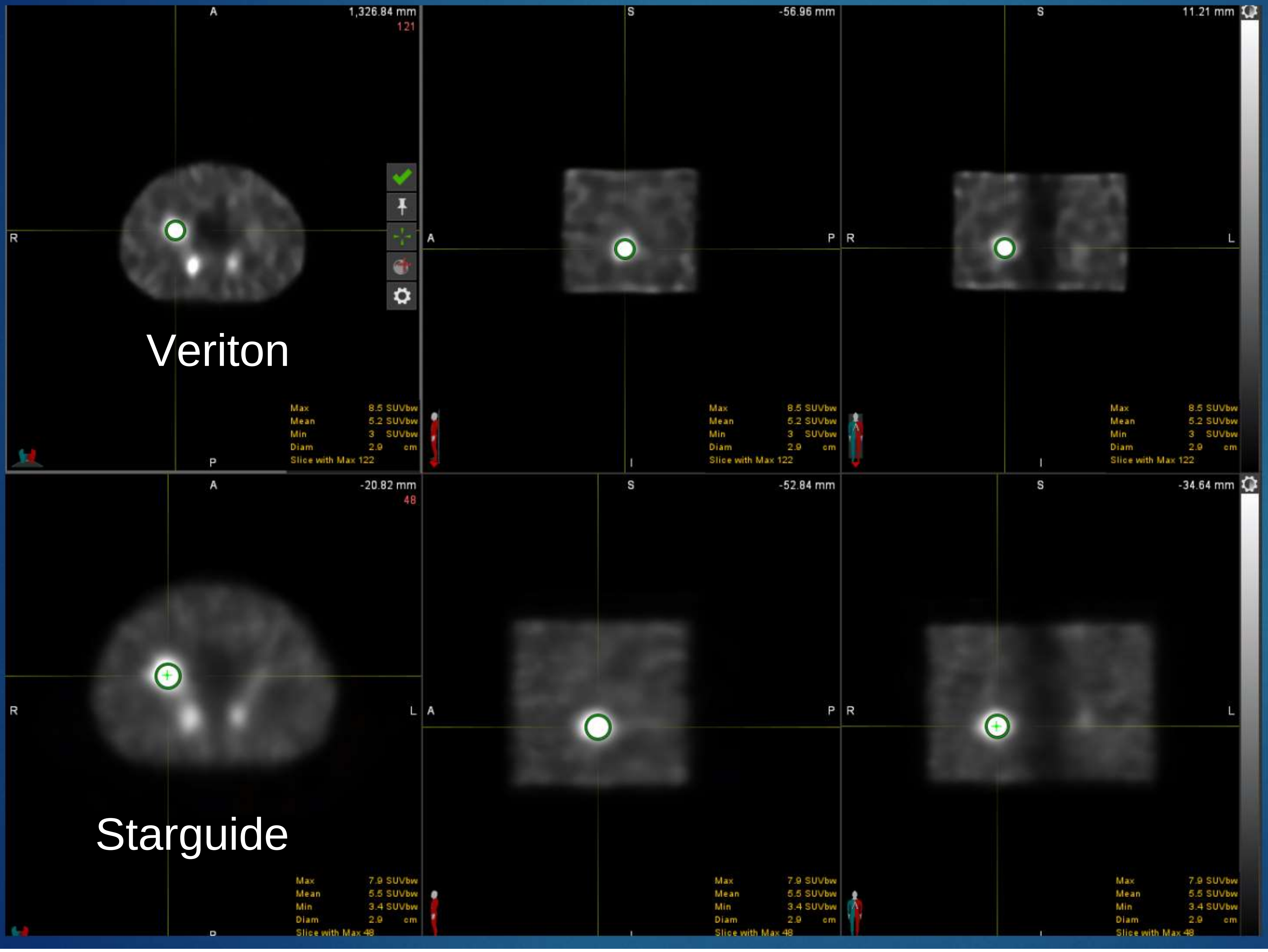



Absolute Quantitation Jaszczak Vs Uniform



# QUANTITATION: VERITON/STARGUIDE

## Veriton or StarGuide? Pretty close



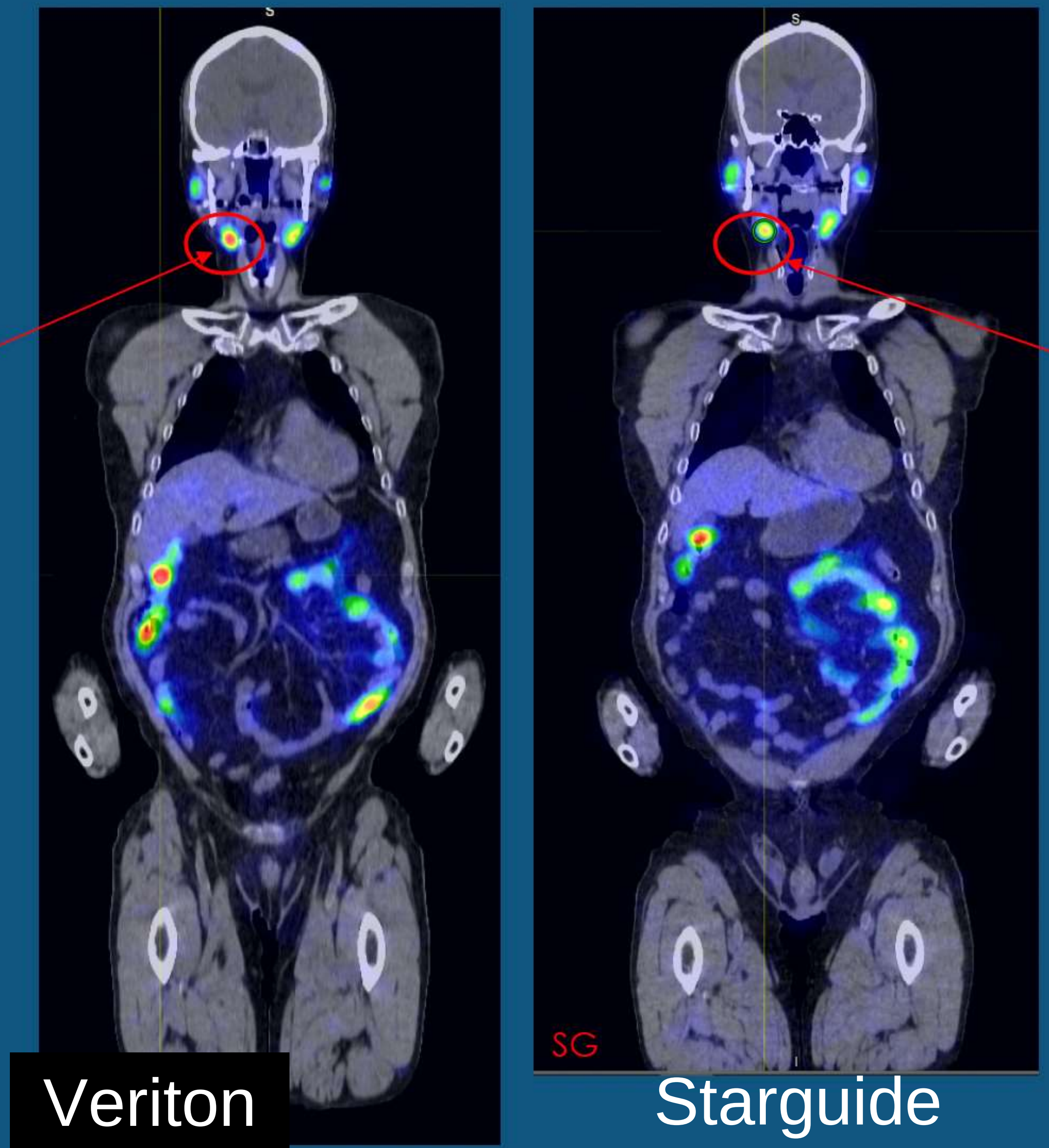

**Veriton**
Max SUVbw = 8.5
Mean SUVbw = 5.2
Min SUVbw = 3

**StarGuide**
Max SUVbw = 7.9
Mean SUVbw = 5.5
Min SUVbw = 3.4

Images Courtesy of the
Mayo Clinic, Rochester, MN, USA

## Veriton or StarGuide? Pretty close

**Veriton**
Max SUVbw = 4.4
Mean SUVbw = 2
Min SUVbw = 0.3




**StarGuide**
Max SUVbw = 3.8
Mean SUVbw = 1.7
Min SUVbw = 0.4

# SUMMARY I

## CZT detector technology enables innovative SPECT system design

## Full-Ring CZT SPECT/CT,

- ✓ Offers improved **sensitivity**, **energy resolution**, and **spatial resolution** compared to conventional SPECT systems leading to **enhanced imaging performance**
- ✓ Permits **quantitative rapid whole-body SPECT/3D imaging essential in high volume practice**
- ✓ Enables **3D dynamic imaging**
- ✓ Has the potential to deliver more **precise quantitative imaging** compared to conventional SPECT/CT systems with promising application in **theranostics** for **treatment monitoring** and **personalized dosimetry**
- ✓ Provides **adaptive** data acquisition for **improved imaging** in a **broad range of clinical applications**

# SUMMARY II

**CZT detectors** are becoming **more common** and **less expensive to manufacture**. However, still significantly **more expensive** than **conventional SPECT/CT systems**.

**Established clinical applications**, including *cardiac, liver, bone, theranostics, and brain*, now **justify the additional cost**. These **specialized applications** are taking **full-advantage** of **full-ring CZT system capabilities** (i.e., **Rapid Scan Time**, **Quantitation**, and **3D Dynamic**). Exciting new possibilities for the future!

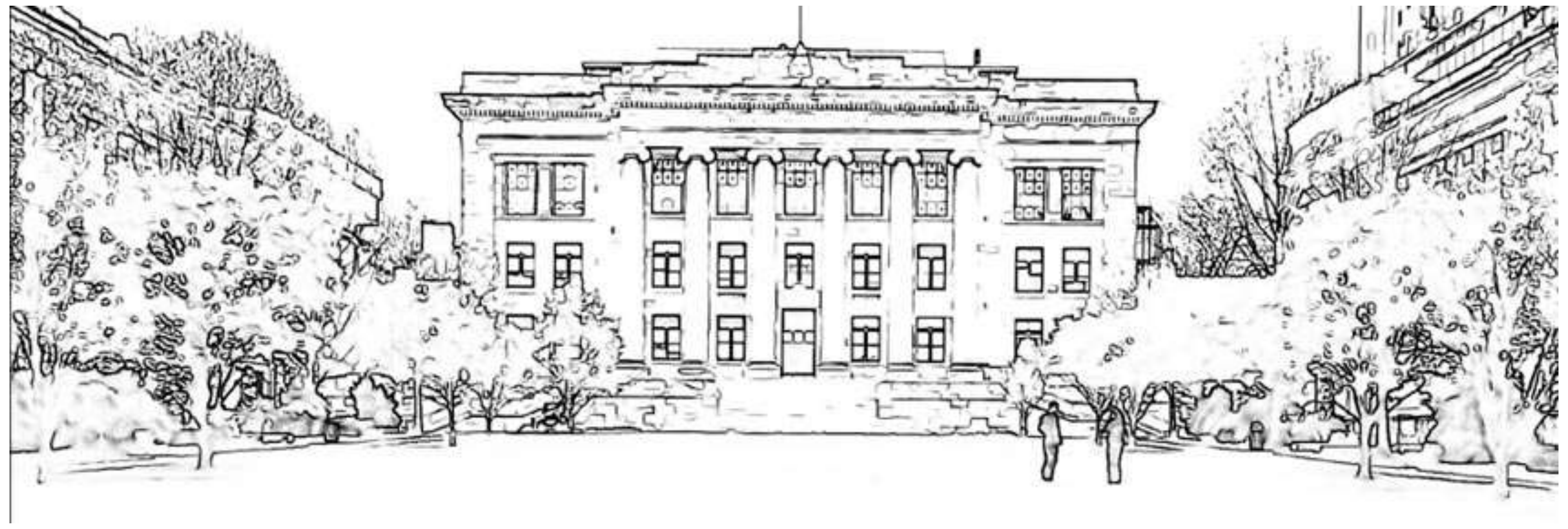
**Conventional SPECT-Only systems** will likely persist in the future. **Lower cost** and **sufficient for certain applications** (*e.g. gastric emptying, thyroid, and renal studies*)

# SUMMARY III

**Absolute Quantitation Cross-Calibration** is easier than with **conventional SPECT** (*fewer technical factors*). Uniform Flood Phantom leads to the best performance. **Jaszczak Phantom** provides a **good alternative** in **routine practice** for **$^{99m}$Tc**.

However, these are not suited for **long-lived nuclides**. **Need for a robust alternative**.

Need to assess **impact of parameters** on **absolute quantitation** and **establish guidelines**.



# THANK YOU FOR YOUR ATTENTION

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