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# Triple modality reconstruction PET-SPECT-CT: application to Y90

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# Use of SPECT and PET for Theranostic

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- PET and SPECT can be used to estimate absorbed dose and monitor treatments and plan follow-up treatment
- Low resolution leads to underestimation of activity
- inaccurate dose can reduce patient survival
- Triple modality synergistic reconstruction could improve lesion quantification
- Different radionuclides are used in Theranostic: Y90 allows both SPECT and PET acquisition.

# Y-90 for selective internal radiation therapy (SIRT)

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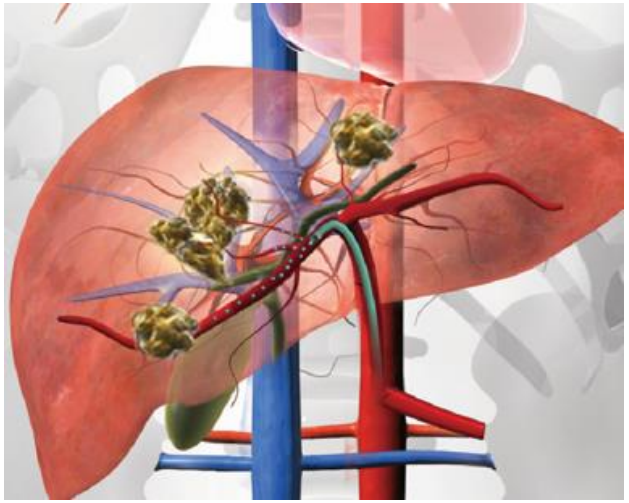
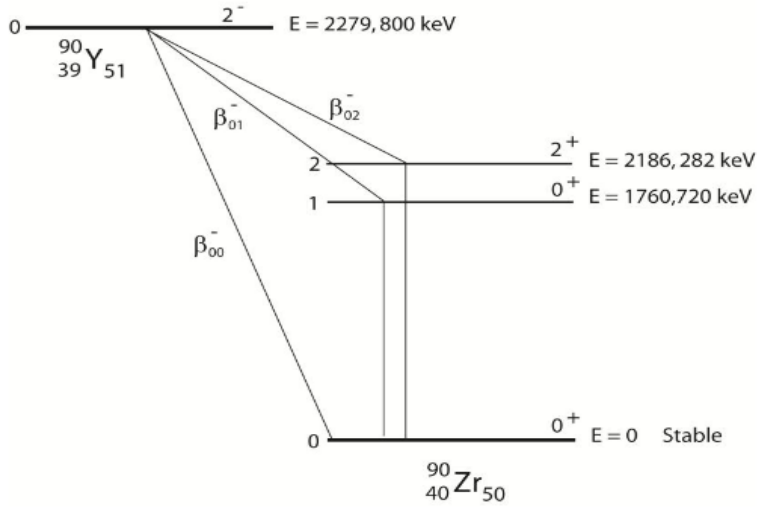
- Used for liver cancer and metastases
- Colorectal cancer is the 3rd common cancer in the UK
- Resin microspheres
- Y-90 is mainly a beta emitter
- Electron interaction with tissues generates Bremsstrahlung radiation (SPECT)
- Internal pair production (PET 32 per million decays)



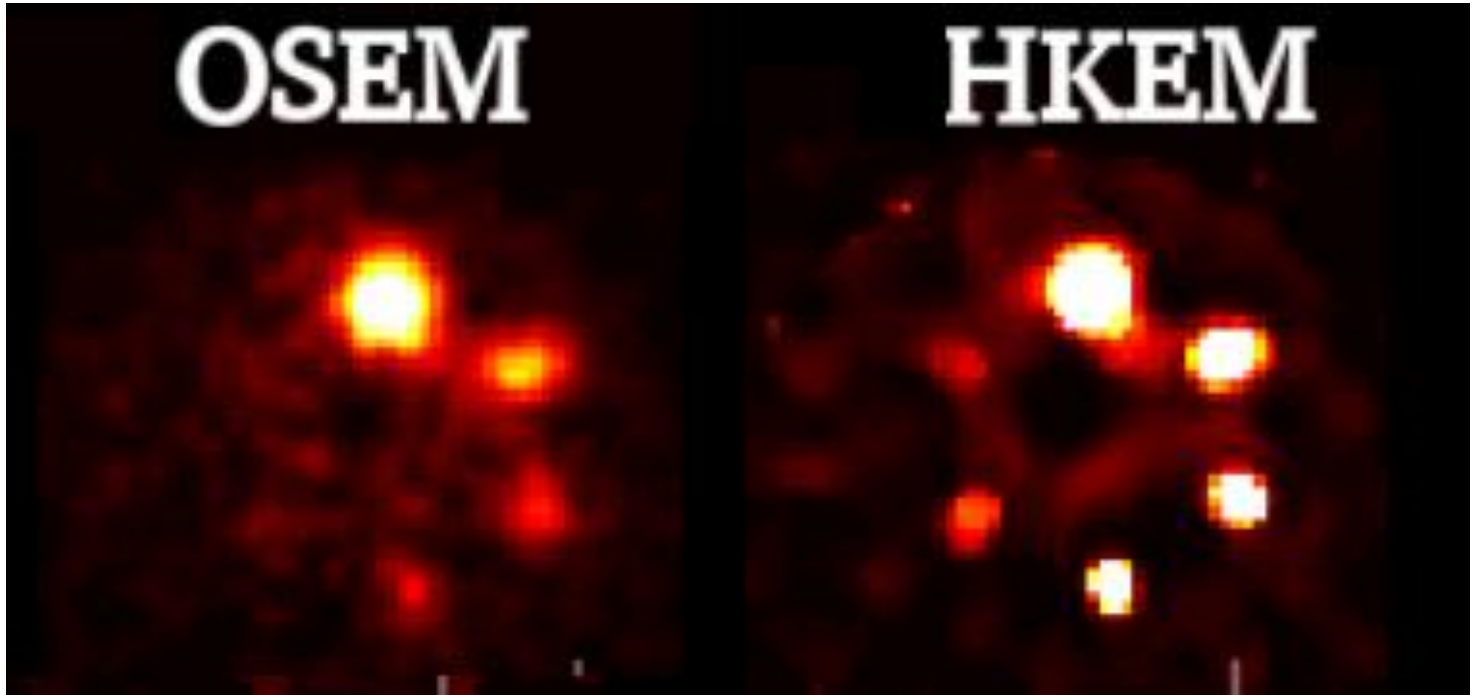
E. Wang *et al*, 2017, JGO




D'Arienzo *et al*, Atoms, 2013

# Objectives

- Investigate triple modality to improve accuracy and image quality
- Investigate  different combination




- Accuracy to better plan dose delivery
- Quality to detect lesion that we want to treat

# Reconstruction Scheme

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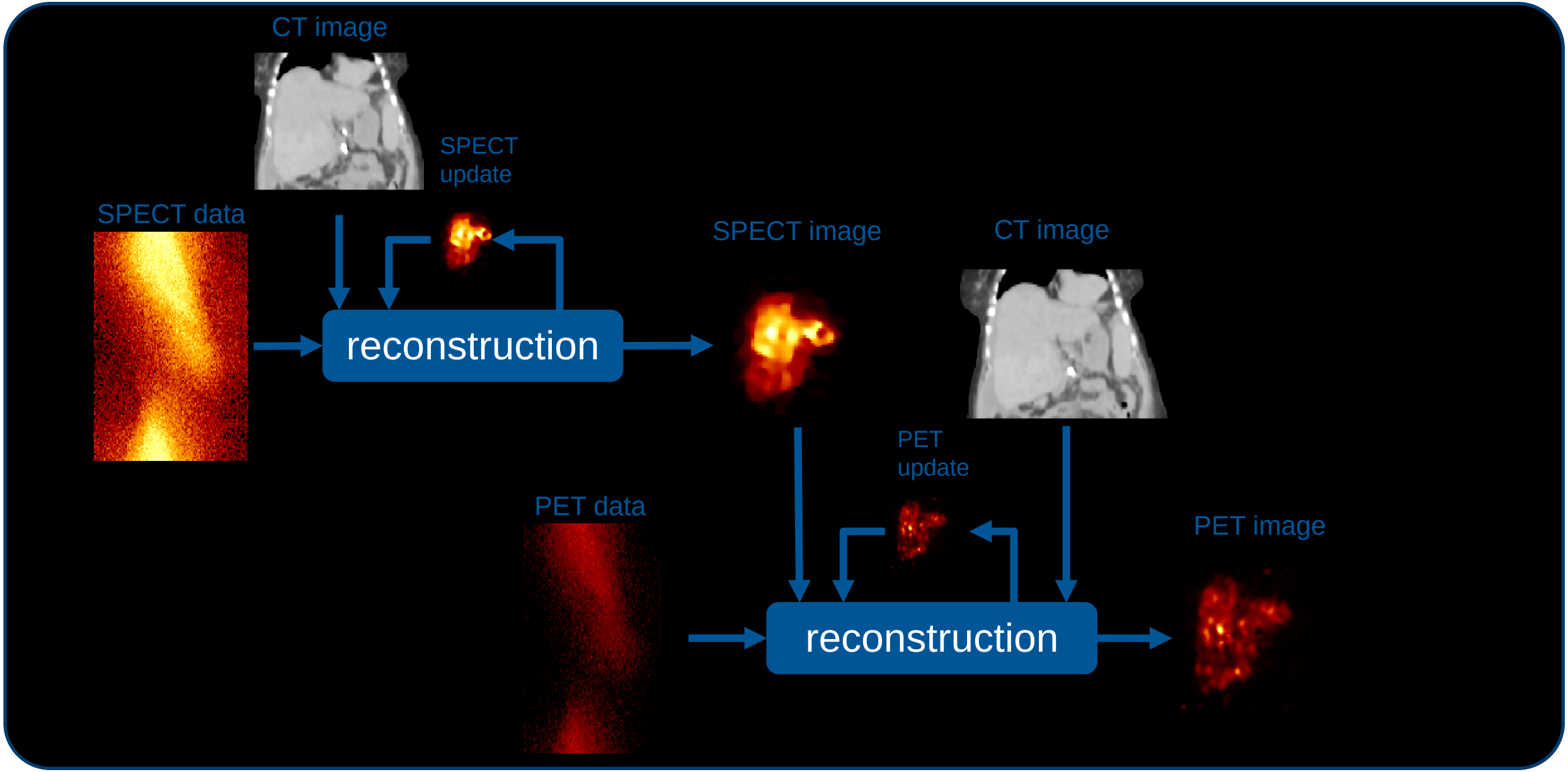

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# Multiplexing HKEM

$$\alpha_j^{(n+1)} = \frac{\alpha_j^{(n)}}{\sum_m k_{jm} \sum_i p_{mi}} \sum_m k_{jm} \sum_i p_{mi} \frac{y_i}{\sum_q p_{iq} \sum_l k_{ql} \alpha_l^{(n)} + s_i}$$

$$k_{jli} = k_{mi}(\boldsymbol{v}_j, \boldsymbol{v}_l) \cdot k_p(\boldsymbol{z}_j, \boldsymbol{z}_l)$$

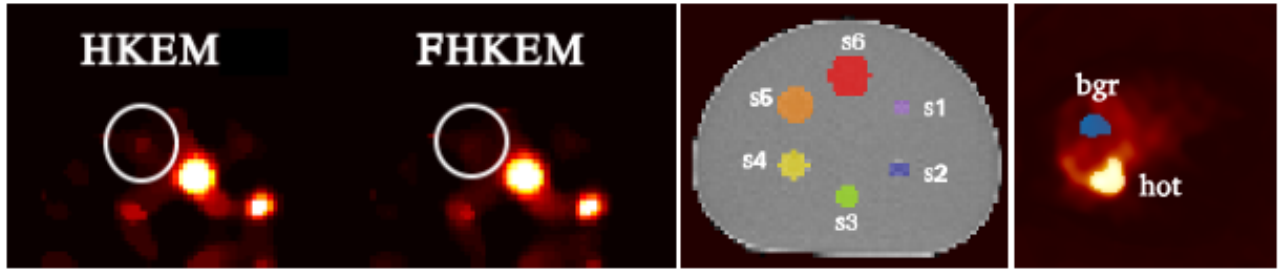
$$k_p(\boldsymbol{z}_j, \boldsymbol{z}_l) = \exp\left(-\frac{\|\boldsymbol{z}_j - \boldsymbol{z}_l\|^2}{2\sigma_p^2}\right) \exp\left(-\frac{\|\boldsymbol{x}_j - \boldsymbol{x}_l\|^2}{2\sigma_{pd}^2}\right)$$

$$k_{mi}(\boldsymbol{u}_j, \boldsymbol{u}_l) = \exp\left(-\frac{\|\boldsymbol{u}_j - \boldsymbol{u}_l\|^2}{2\sigma_{mi}^2}\right)$$

Deidda *et al*, MIC Sidney 2018

# Material and Methods

Deidda *et al. EJNMMI physics, 2022*




## Mediso AnyScan SCP scanner

- detector useful FOV 560 × 425 mm, with a patient aperture of 70 cm;
- NaI(Tl) crystal with 9.5 mm thickness, and an array of 94 photomultiplier tubes (PMT);
- CT gantry has 50 cm FOV with a patient aperture of 70 cm.

## NEMA Phantom ( 1(b))

- spheres size: 10 mm, 13 mm, 17 mm, 22 mm, 28 mm and 37mm;
- filled activity: 0.255± 0.001 MBq, 0.511± 0.003 MBq, 1.19± 0.01 MBq, 2.58± 0.01 MBq, 5.34± 0.03 MBq, 12.58± 0.07 MBq and the background was filled with water. The data were acquired for 2 hours.

## Patients $^{90}$Y resin micro-spheres (Sir-Spheres)( 1(c))

- 5 patients,acquired at the Royal Surrey NHS Foundation Trust in Guildford, using the GE Optima 640 SPECT/CT;
- the injected activity was 1 GBq, the data was acquired for 40 min;

# Frozen HKEM

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$$\alpha_g^{(n+1)} = \frac{\alpha_g^{(n)}}{\sum_{j=1}^{N_g} k_{gj}^{(f)} \sum_{i \in J_g} c_{ij}} \sum_{j=1}^{N_g} k_{gj}^{(f)} \sum_{i=1}^{L} c_{ij} \frac{y_i}{\sum_{l \in I_i} c_{il} \sum_{q=1}^{N_l} k_{ql}^{(f)} \alpha_q^{(n)}}$$

until Fn

$$\begin{cases} f = n, & \text{if} \leq F_n \\ f = F_n, & \text{if} \geq F_n \end{cases}$$

# Results:

## selecting the iteration the kernel freezes

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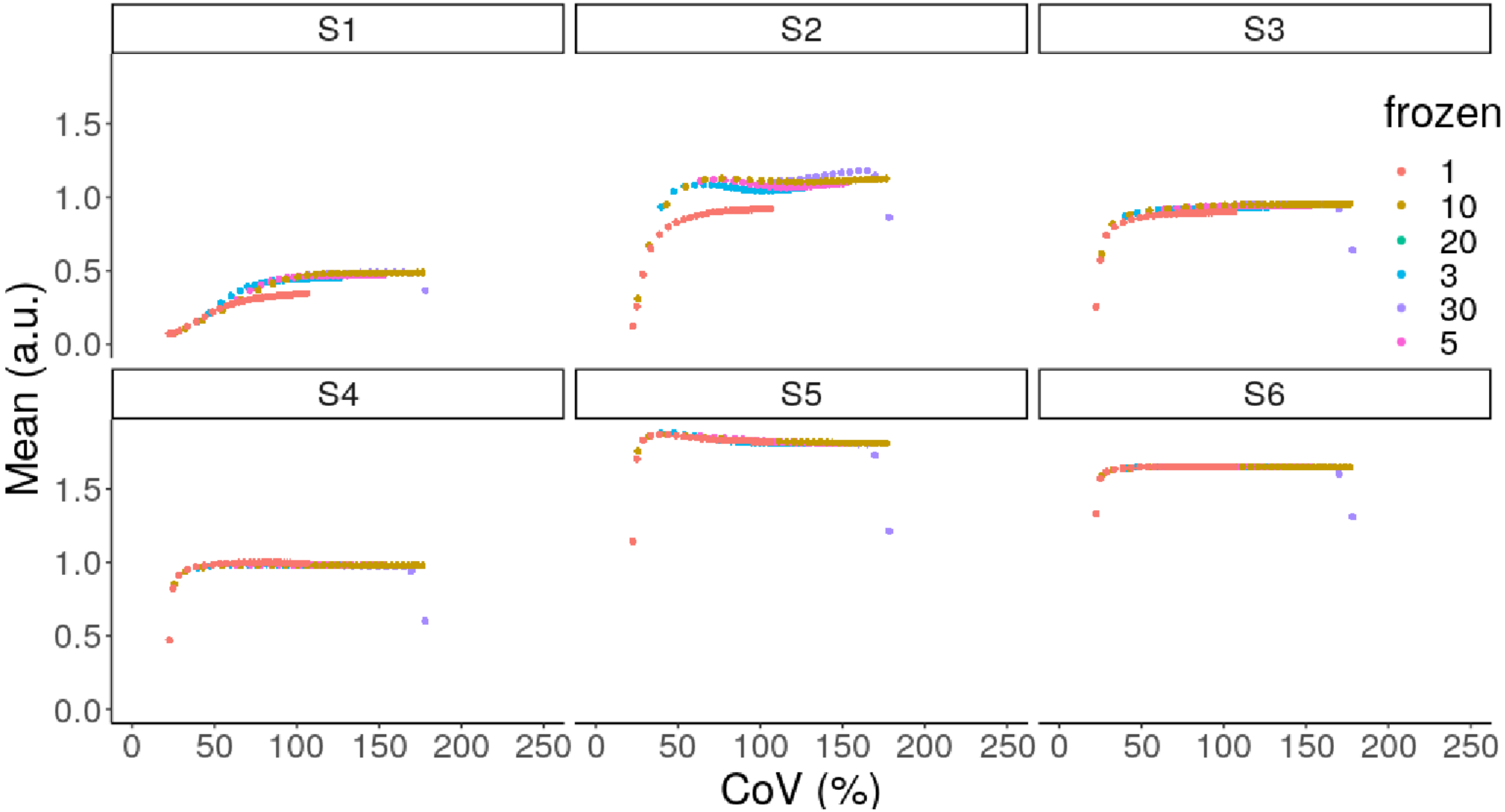
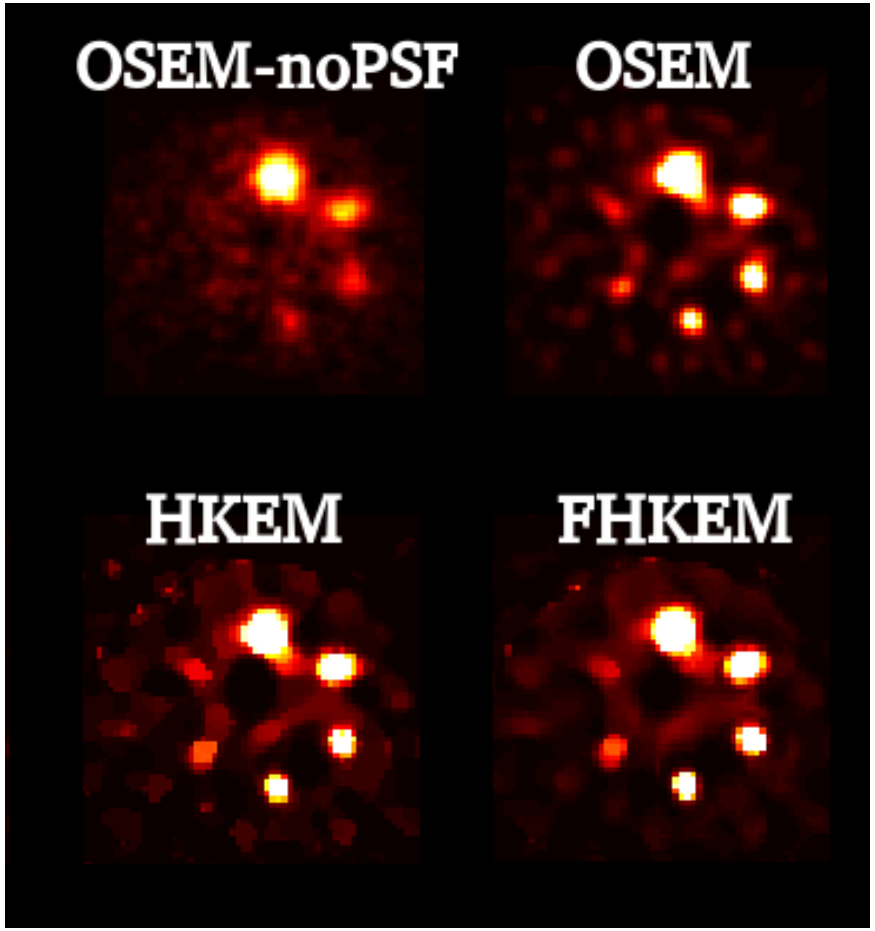
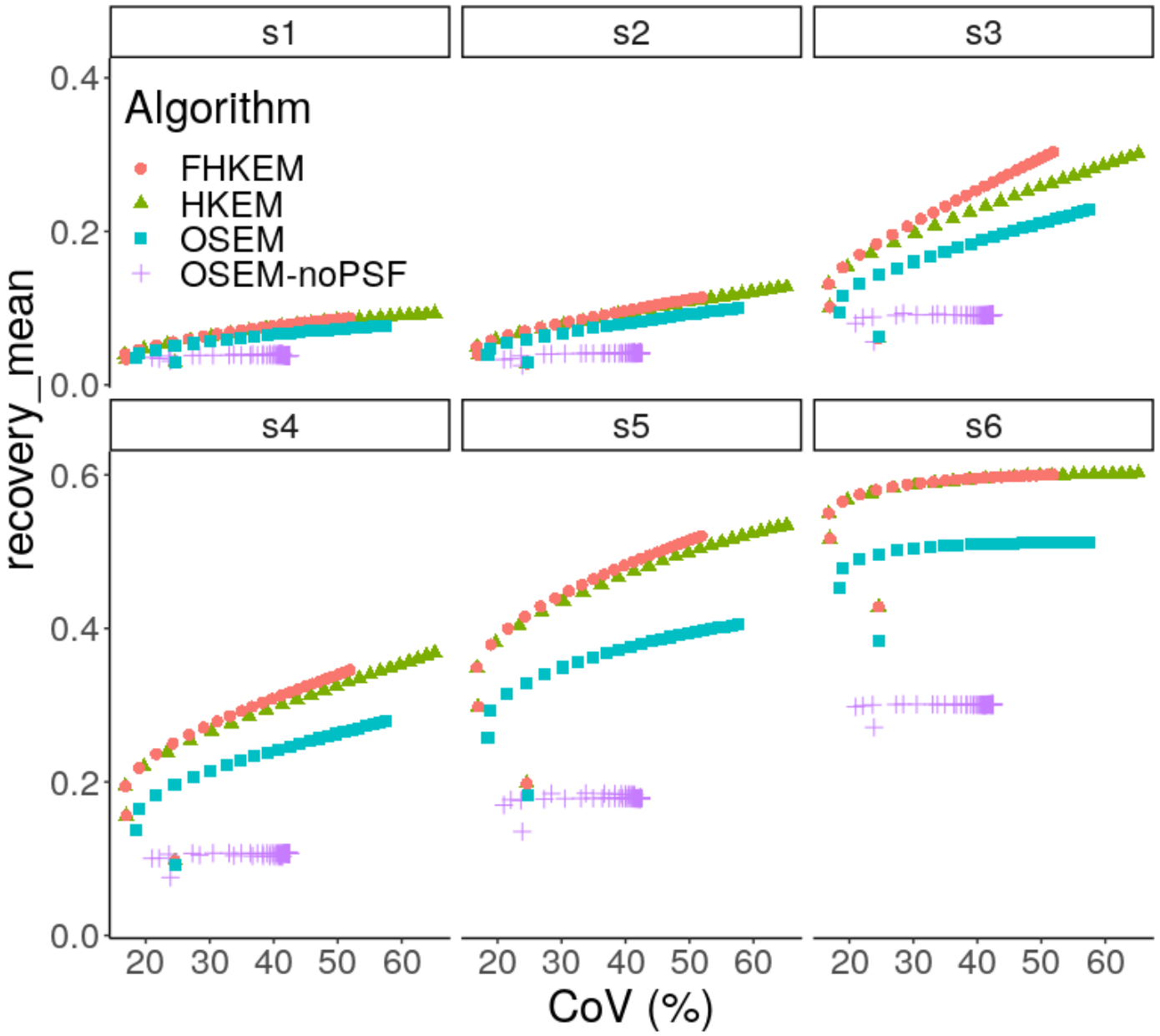
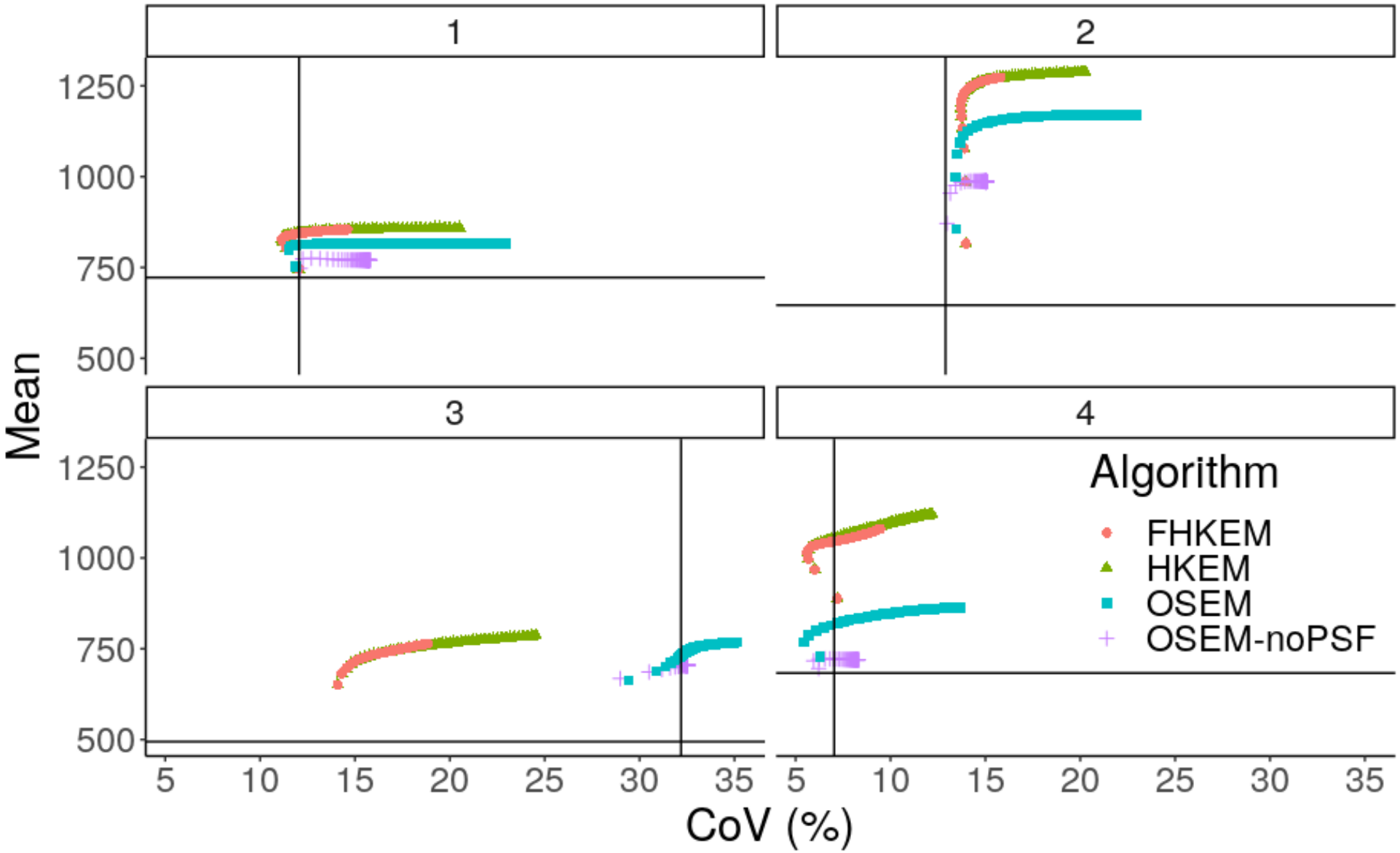


# Results: NEMA



# Results: patients



# Results

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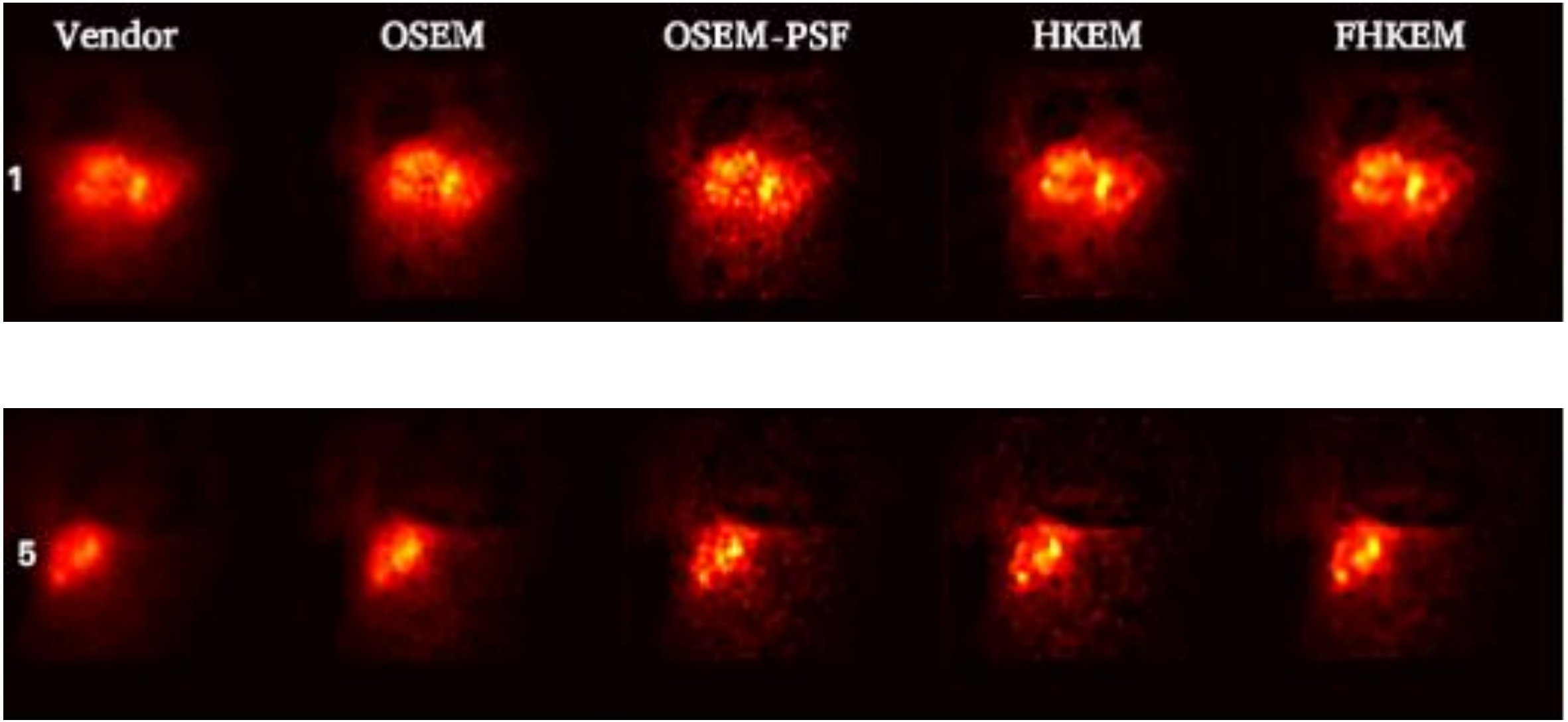

# Results

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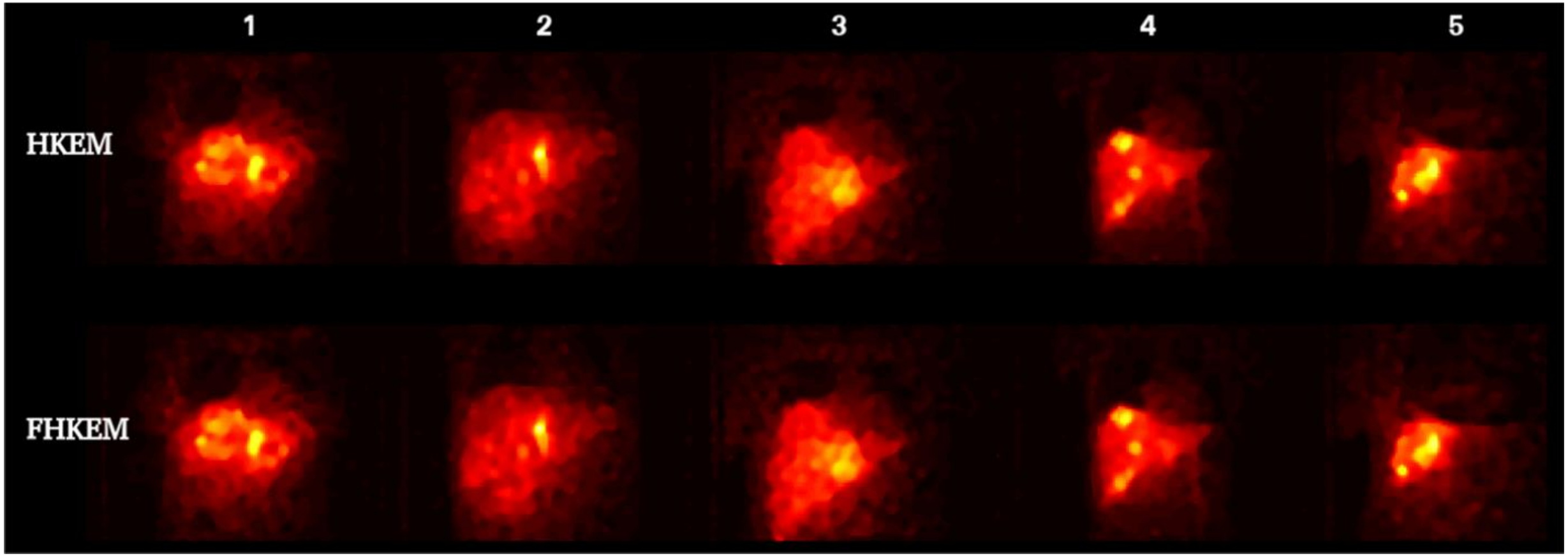

# Conclusion

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- FHKEM allows to make the reconstruction more stable against noise propagation with the iterations.
- Quantitative improvement is seen when using synergistic techniques at lower or comparable noise levels with the vendor and STIR OSEM reconstructions.
- Maximum of 56% improvement in Mean values in hot regions for the NEMA phantom and 47% for the patient data
- FHKEM doesn’t really show improvement at early iteration against HKEM

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# Assess the feasibility triple modality reconstruction

## Scanner: MEDISO AnyScan Trio SPECT-PET-CT

- model implemented in STIR:
  Deidda *et al*, MIC Manchester 2019,
  Deidda *et al*, MIC Boston 2020

## Phantom Data: NEMA

Six hot spheres and cold lung equivalent insert.
background was filled with water.

**Diameter**

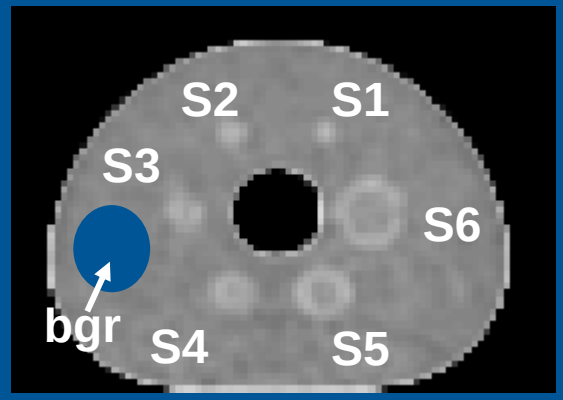
10 mm, 13 mm, 17 mm, 22 mm, 28 mm, 37mm

**Activity (MBq)**

2.152, 3.216, 10.15, 21.69, 44, 189.6

**ROI name**

S1, S2, S3, S4, S5, S6, bgr for the background




**Acquisition:** 60 min for PET, 40 min SPECT

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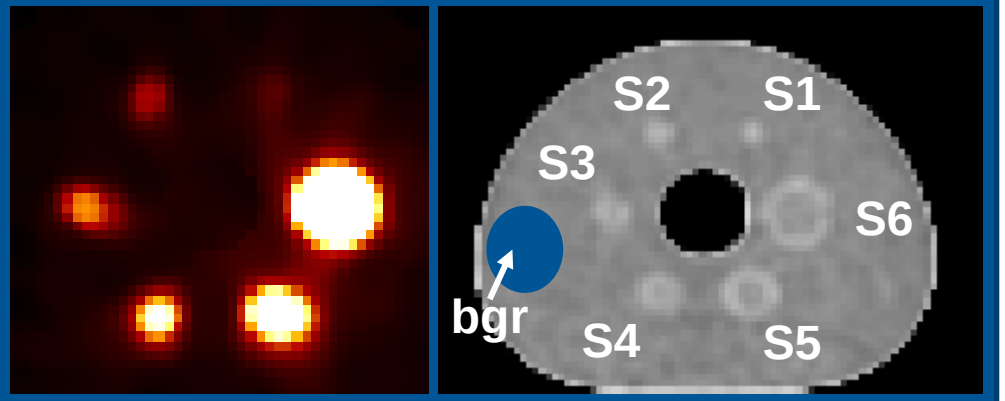
# Reconstruction

## SPECT-CT

- HKEM with CT side information
- 12 subsets, 10 iterations

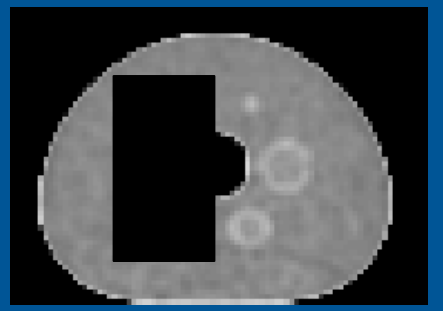
## PET

- 9 subsets, 30 iterations

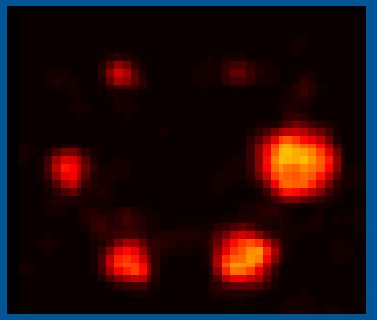



- SPECT, CT and PET (MHKEM)
- SPECT and PET (HKEMspect)
- CT and PET (HKEMct)
- SPECT, CT (MKEM)
- SPECT (KEMspect)
- CT (KEMct)
- noPSF-OSEM, and  OSEM

CT side image

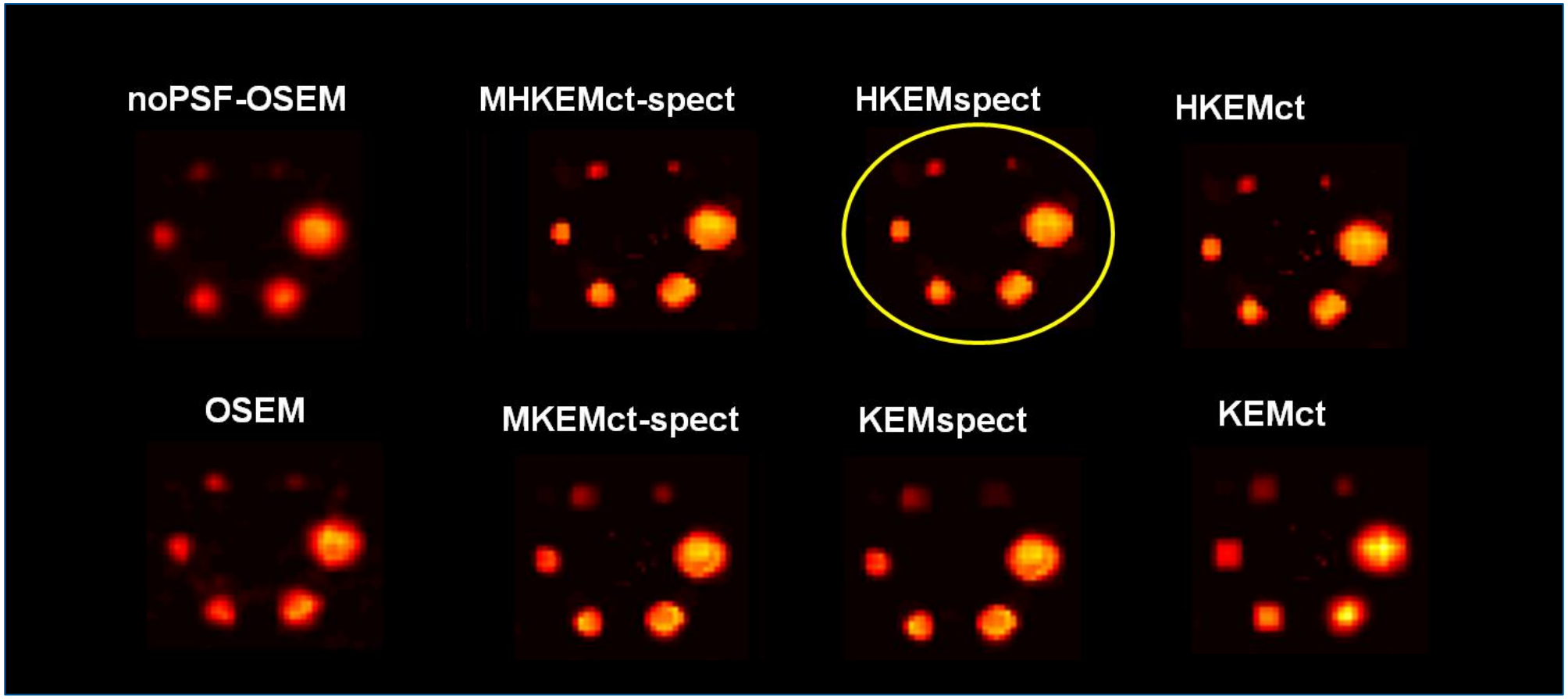


OSEM



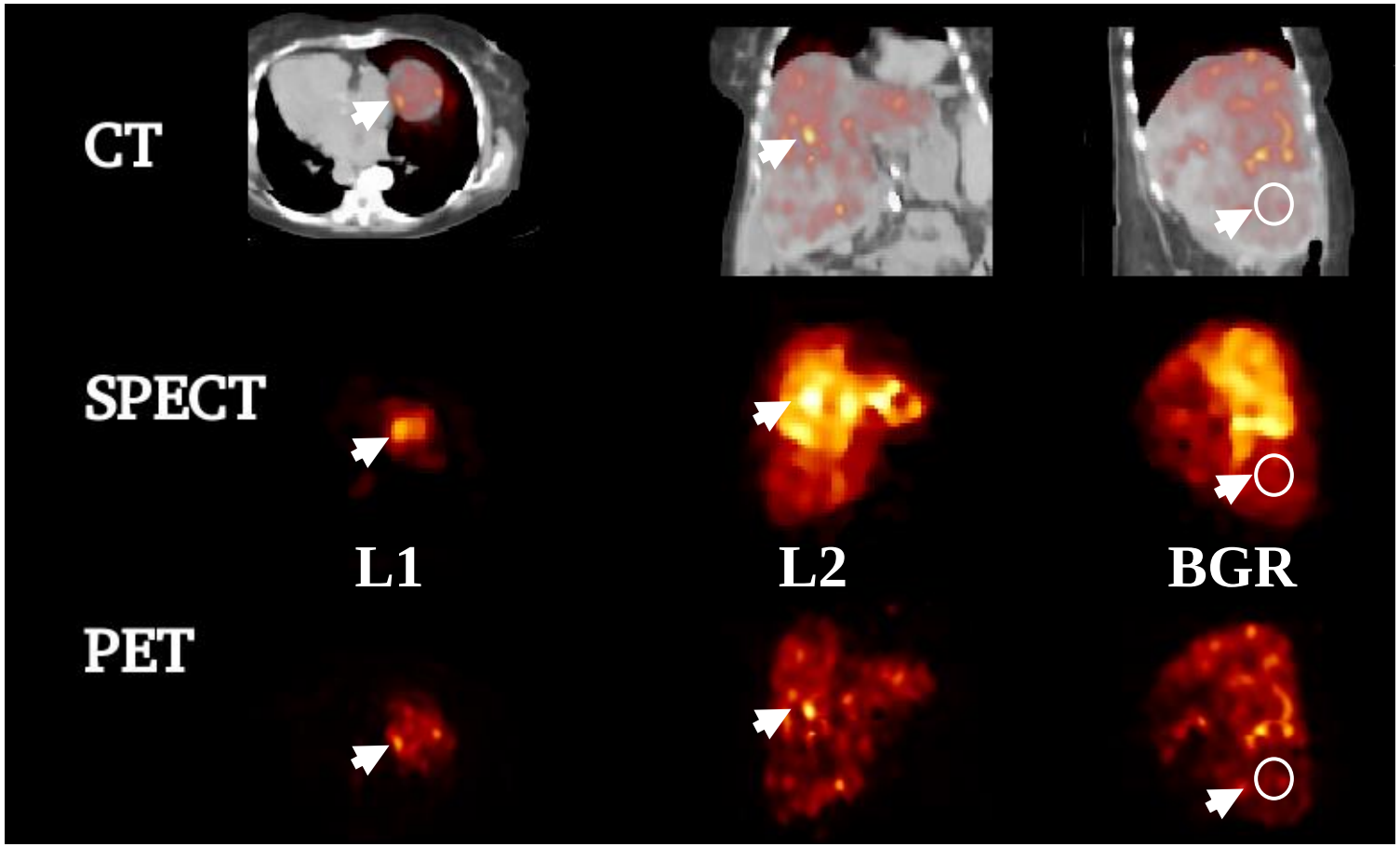
# Preliminary results

- CT artifacts
- No pet update=oversmoothing



# Patient data

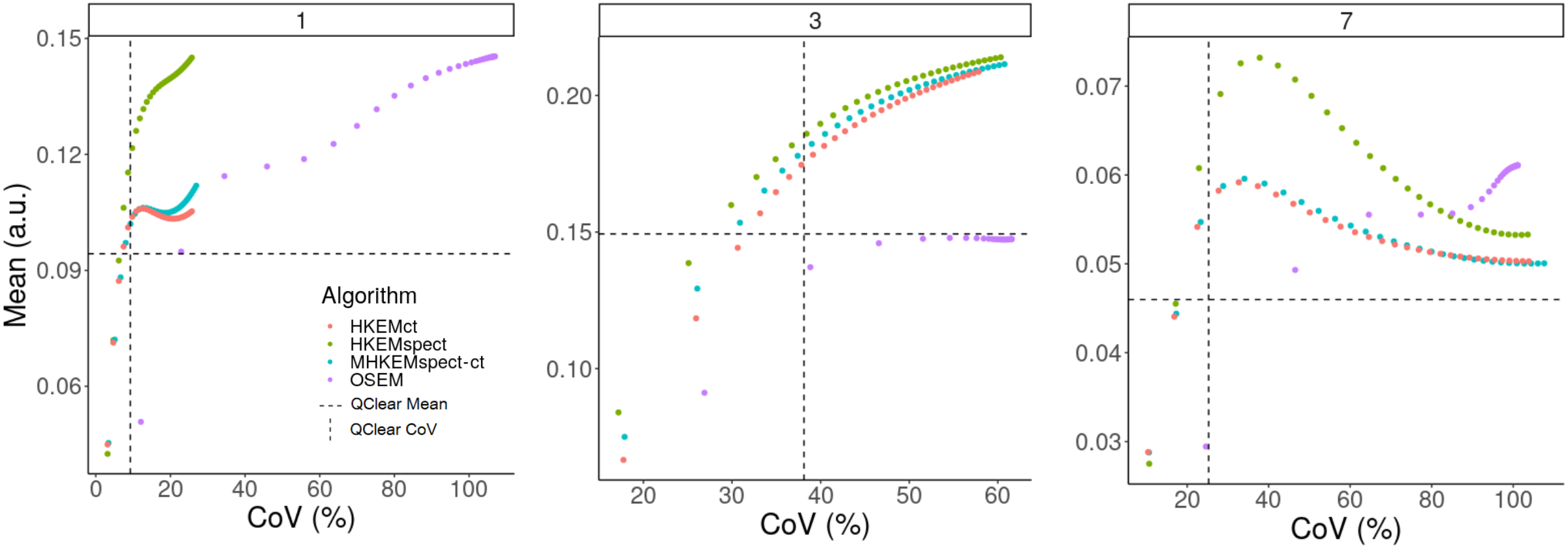
- **Scanner:** GE Discovery 710 PET/CT, GE Discovery 670 for SPECT/CT Oxford University Hospitals NHS (10 patients)
- Images acquired ~18 hours post-SIRT with PET/CT followed by SPECT/CT.
- **SPECT:** 30 min, medium energy collimator, energy window range 50-150 keV.
- **PET:** 15 minutes per bed position (two beds)



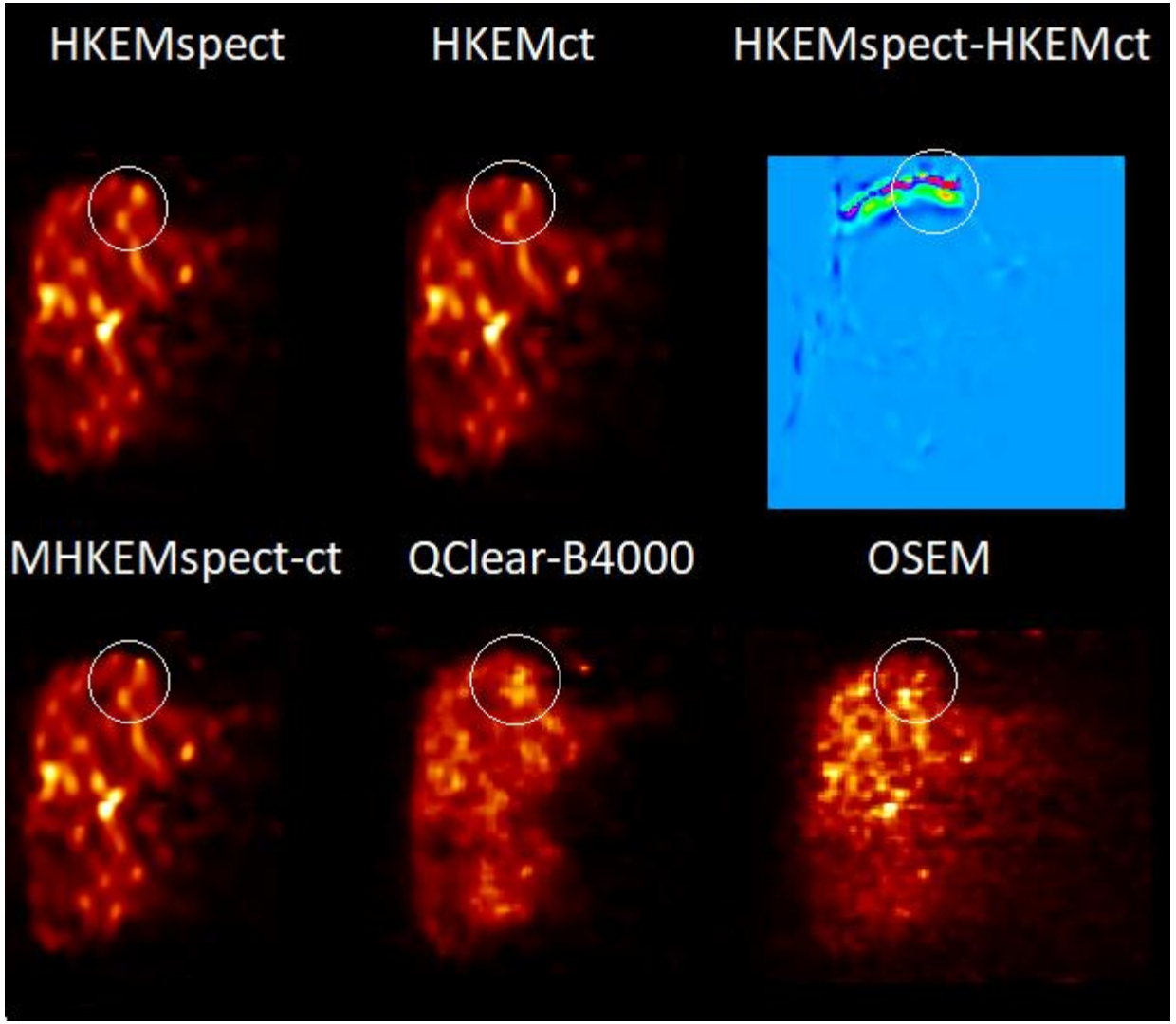

# ROI

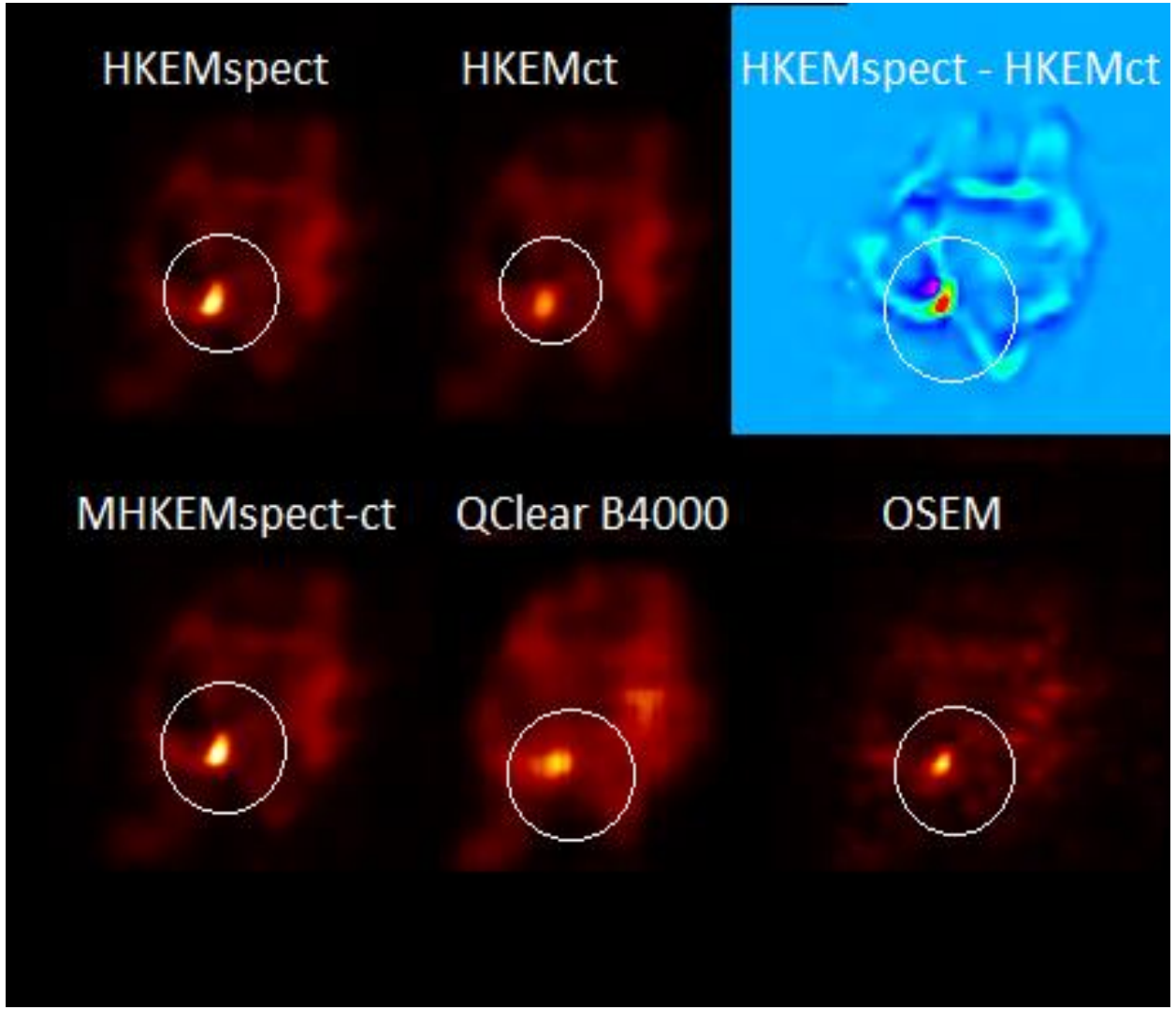
- **L1: lesion at the edge of the liver**
- **L2: lesion with highest uptake**
- **BGR:** part of the liver with no lesions

# Results: ROI L1

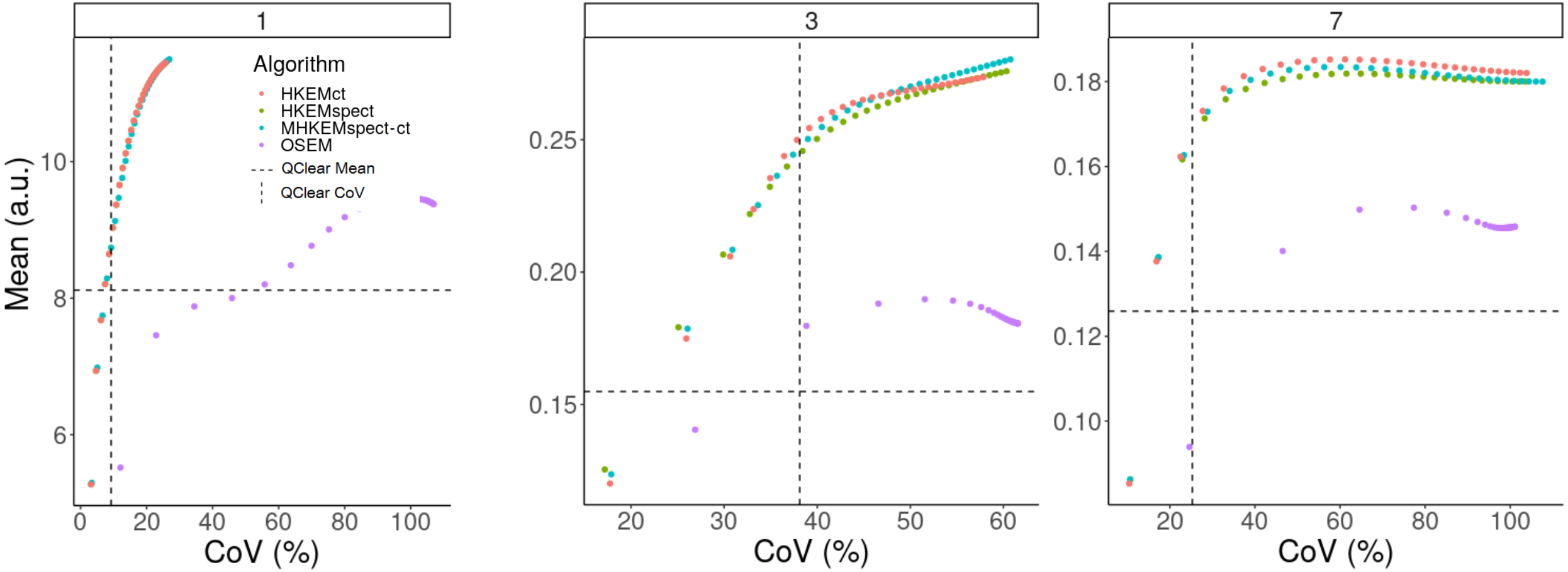


# Results: ROI L1

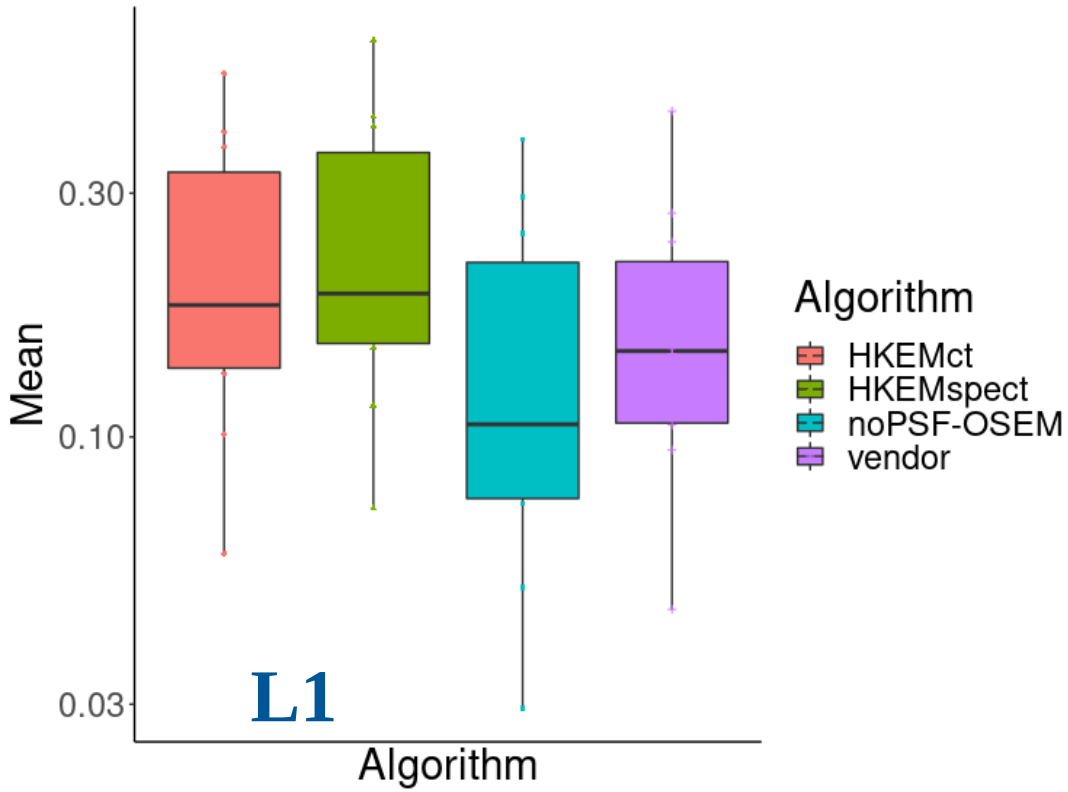


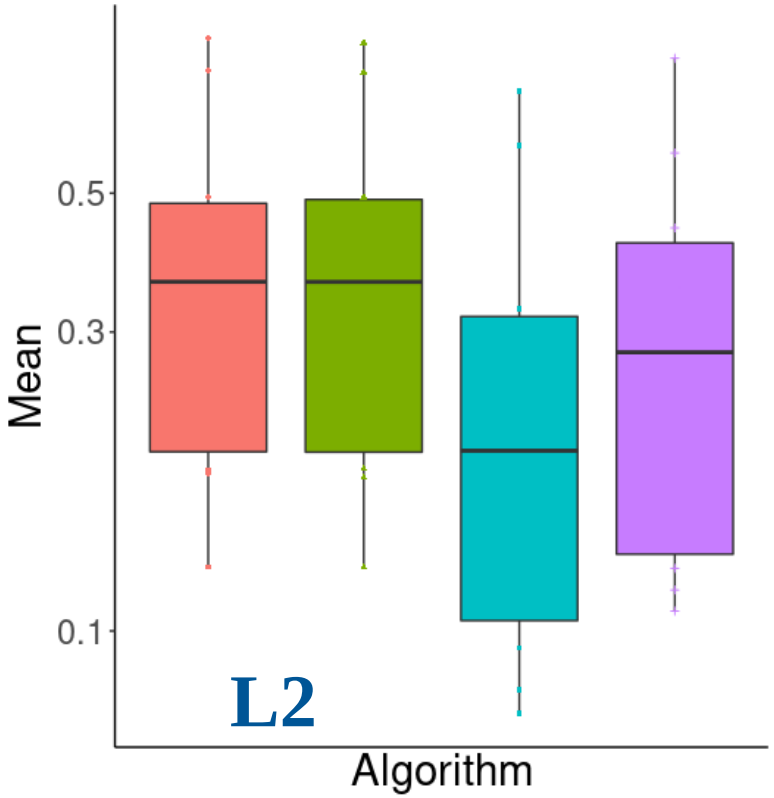



# Results: ROI L2



# Statistical significance




| Paired t-test: null hypothesis means are equal, 95% CI | |
|---|---|
| HKEMspect vs vendor | p-value=0.002 |
| HKEMspect vs HKEMct | p-value=0.008 |
| HKEMct vs vendor | p-value=0.003 |
| OSEM vs vendor | p-value=0.03 |
| OSEM vs HKEMspect | p-value=0.0001 |

| Paired t-test: null hypothesis means are equal, 95% CI | |
|---|---|
| HKEMspect vs vendor | p-value=0.002 |
| HKEMspect vs HKEMct | p-value=0.95 |
| HKEMct vs vendor | p-value=0.001 |
| OSEM vs vendor | p-value=0.002 |
| OSEM vs HKEMspect | p-value=0.0001 |

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# Summary

- Consistency with phantom results
- Using triple modality recon improves quantification
- Improves over a ToF reconstruction
- The standard HKEM with spect(ct) and pet information significantly outperforms the others

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# Future work

- ToF reconstruction could further improve
- Only improvement over PET were investigated but SPECT could also be improved with PET info
- Investigate PET-SPECT joint reconstruction (PhD ongoing)
- Triple modality reconstruction with other theranostic radiotracers (Lu177-Ga68, Cu64-Cu67, etc)

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# Thank you!

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