Framework for Theranostic Digital Twins Generation and Virtual Theranostic Trials

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MEDICAL PHYSICS COMMUNITY INSPIRATION INNOVATION IMPACT
2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

INTRODUCTION

Radiopharmaceutical therapy is established in metastatic castration-resistant prostate cancer. It is given as a fixed administered activity, not tailored to the absorbed dose reaching tumors and organs at risk.

Developing personalized planning needs data that is hard to obtain clinically:

- Serial quantitative SPECT with repeated scans over several days and absorbed dose map
- Prospective trials are costly and carry patient risk
- In real patients the absorbed dose is never truly known

PyTheraTwin is an open-source tool that builds this dataset from patient anatomy alone. It generates synthetic SPECT images and absorbed dose maps from a prescribed activity distribution, so the input activity is known exactly. The framework produces complete synthetic datasets and supports virtual theranostic trials.

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GitHub

https://github.com/qurit/PyTheraTwin

METHODS AND MATERIALS

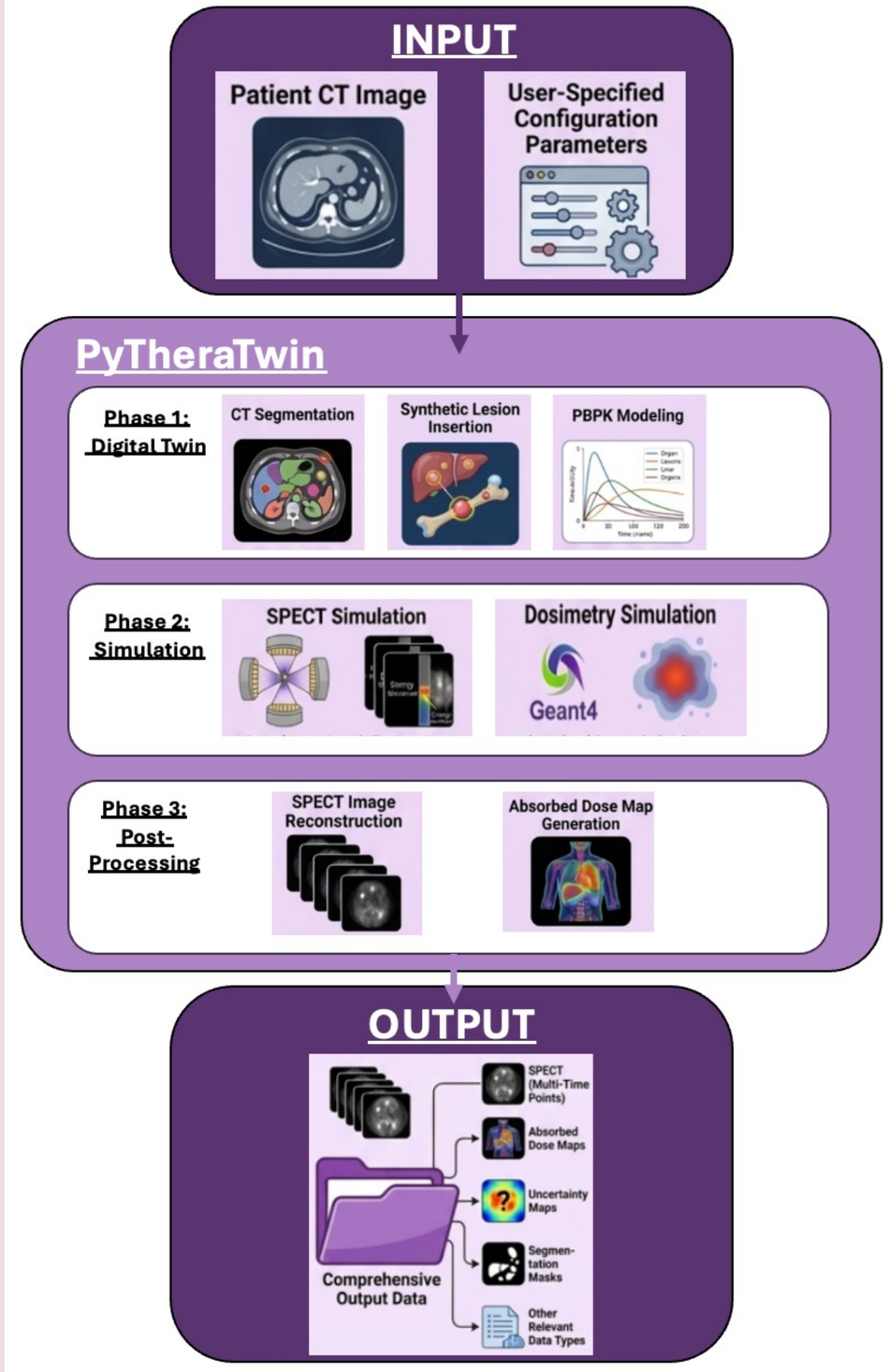

Figure 1. Framework workflow, from patient CT to synthetic SPECT images and absorbed dose maps.

	Parameter	Value	
SPECT & Absorbed Dose	CPU Used	112 Cores	
	XYZ Spacing [mm]	4.8, 4.8, 4.8	
	Radioisotope	Lu-177	
	Simulated ROIs	Kidney, Liver, Salivary Glands, Lungs, Synthetic Lesion(s), Remaining Body	
SPECT Specific	# Photons	1e9	
	# Projections	96	
	Energy Window Width [%]	20 (+/- 10)	
	OSEM (Iterations & Subset)	4 & 8	
	Frame Times [hrs]	1, 2, 3, 8, 12, 24, 48, 72, 96, 120, 144, 168	
Absorbed Dose Map Specific	Histories Per Batch	1e6	
	Target Uncertainty [%]	5	
	Electron Cut Off [mm]	0.5	
Synthetic Lesions Parameters			
	Liver	Bone	Liver & Bone
Patient Number	11, 15, 17, 18	13, 16, 20	12, 14, 19

Table 1. Key framework configuration parameters for the 20-patient cohort.

RESULTS

DIGITAL TWIN

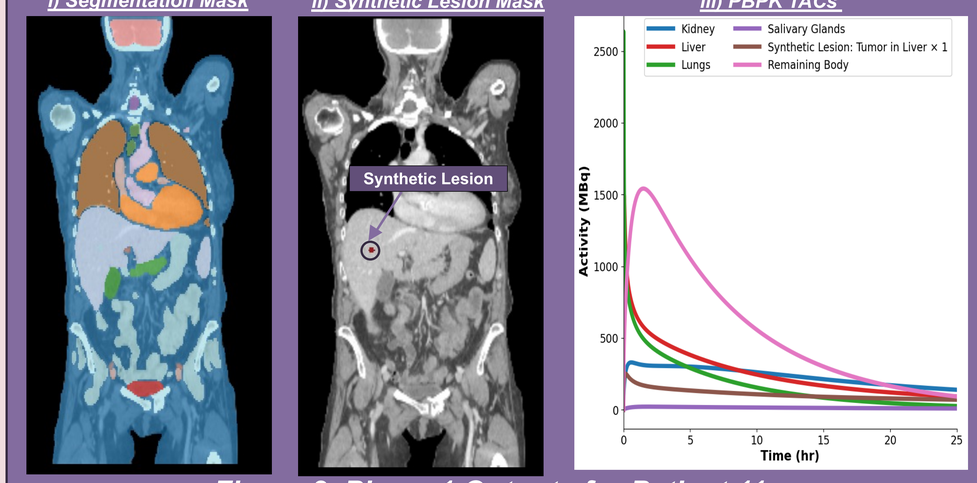

Figure 2. Phase 1 Outputs for Patient 11.

SIMULATION OUTPUTS

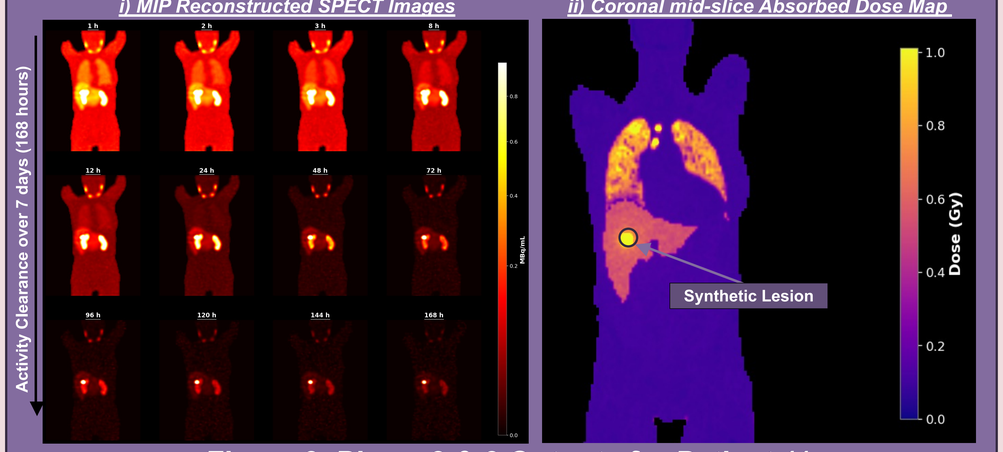

Figure 3. Phase 2 & 3 Outputs for Patient 11.

CONCLUSION

The framework builds patient-specific digital twins and simulates the synthetic SPECT images and absorbed dose maps that follow from a prescribed activity distribution. Because the input activity is modelled rather than measured, the simulated images and dose maps come with an exact reference that real patient scans never have.

We are releasing a complete 20-patient dataset of ground-truth absorbed dose, organ segmentations, and multi-time-point SPECT reconstructions with their activity distributions, which supports:

- Benchmarking dosimetry algorithms against realistic ground-truth absorbed dose maps
- Augmenting deep learning training for theranostics, such as lesion detection and tracking
- Generating realistic synthetic data for Virtual Theranostic Trials

Future work:

- Validate simulation realism against clinical ^{177}Lu-PSMA SPECT
- Add synthetic PET imaging and extend synthetic lesion realism
- Develop a predictive dosimetry model that is trained on PyTheraTwin outputs

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