Calculation methods in Hermes Medical Solutions' dosimetry software

Helena McMeekin MSc. Clinical Applications Scientist, Hermes Medical Solutions

MRTDosimetry Scientific Workshop
"The Principals and Clinical Implementation of Dose Calculation in Molecular Radiotherapy", 26th-27th September 2018, Prague, Czech Republic

HERMES MEDICAL SOLUTIONS

About me

- Disclosure: I work for Hermes Medical Solutions!
  - Clinical applications scientist
  - State registered clinical scientist, trained and worked in London NHS hospitals prior to appointment at Hermes
  - Specified and validated new features of Hermes' dosimetry software
  - Not a sales pitch, please ask me scientific questions!
    Constructive criticism welcome

Summary

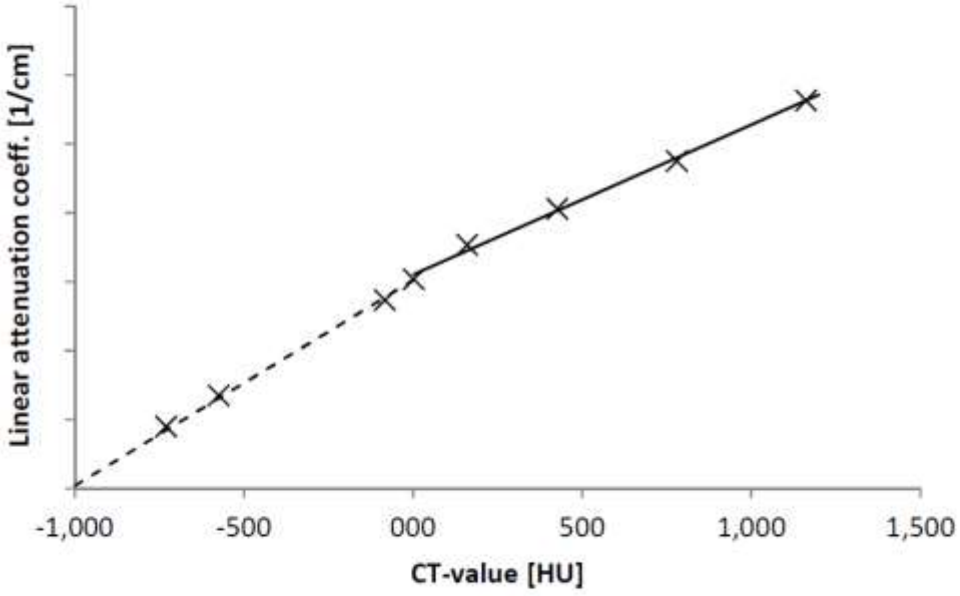
- Quantitative imaging
  - SUV SPECT®
- Hermes’ dosimetry applications
  - Hybrid Viewer Dosimetry™ with Olinda/EXM®
  - Hybrid3D SIRT™
  - In development: voxel-based dosimetry

SUV SPECT®

- Reconstruct SPECT data from any camera with any radionuclide with voxel values in Bq/ml or SUV
- Requires reconstruction algorithm with accuracy compensations
  - CT attenuation correction
    HU to linear attenuation coefficient can be measured or taken from manufacturer specifications
  - Monte Carlo scatter correction
  - Resolution recovery
    Collimator geometry can be measured or taken from manufacturer specifications

SUV SPECT® *CT attenuation correction*

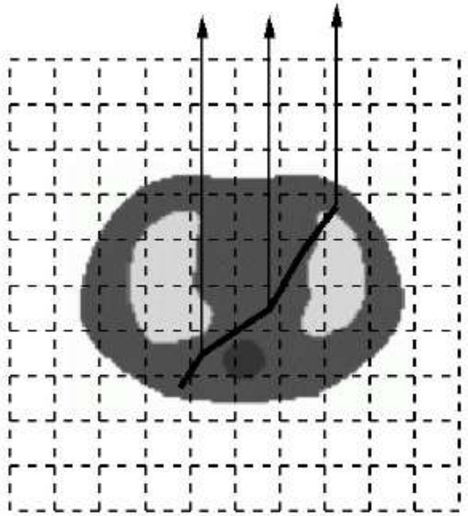
- Bilinear conversion of HU to linear attenuation coefficients, CT kV dependant
  - Dashed line = soft tissue, continuous line = bone tissue



SUV SPECT® *Monte Carlo scatter correction*

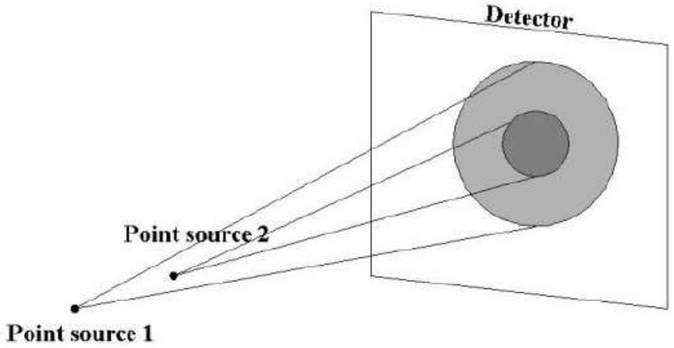
- Challenging! Dependent on several factors: activity distribution; attenuation map; camera energy resolution; energy window settings
- Scatter inside the patient is simulated during forward projection with Monte Carlo modelling according to a convolution-based forced detection algorithm[1,2]

At each scattering site, the photon is forced to scatter towards the collimator/detector and the subprojection map with current energy is updated. At the end of the simulation, subprojection maps are convolved with the Gaussian or Monte Carlo simulated point-spread functions and attenuation is modelled.



SUV SPECT® *Resolution recovery - Gaussian*

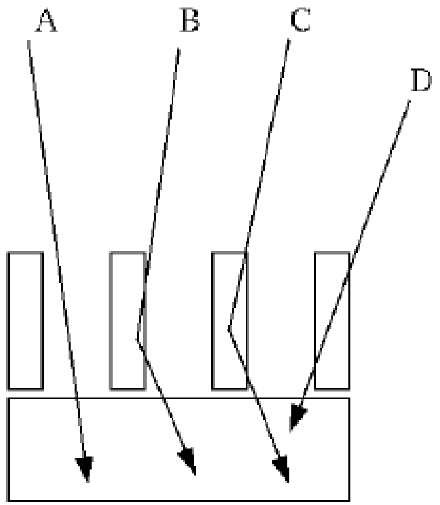
- Image blur: gamma camera intrinsic resolution 3-4 mm + finite size of the collimator holes
- Model collimator resolution during forward and back projections: convolve the reconstruction voxel with the camera's PSF before projection
- Gaussian point-spread-function model: combined collimator-detector response is a 2D Gaussian function, FWHM depends on:
  - intrinsic camera resolution
  - collimator hole length
  - collimator hole diameter
  - distance to the front face of the detector



HERMES MEDICAL SOLUTIONS

SUV SPECT® *Resolution recovery - Monte Carlo*

- Gaussian model suitable where there is little collimator septal penetration or collimator scatter e.g. Tc-99m



The MC model is based on detailed MC simulations of the collimator and detector

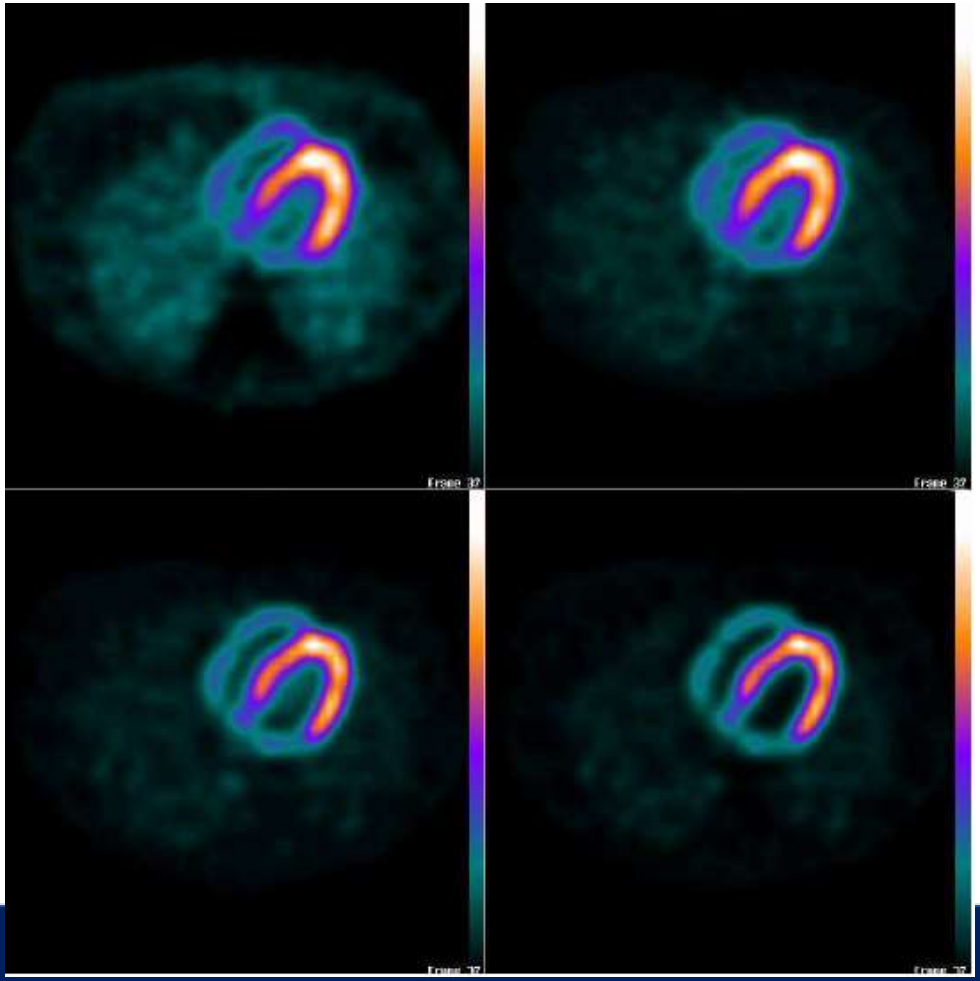
A. Geometric collimation
B. Scatter off collimator septa
C. Absorption by collimator septa and emission of K-edge x-ray
D. Septal penetration

- Good for isotopes with high energy emissions e.g. I-123, I-131, and Y-90

SUV SPECT® *Clinical images*

No compensation

Attenuation correction



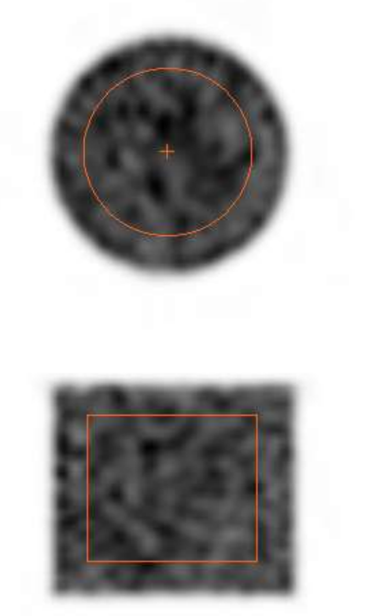
Attenuation correction
+ resolution recovery

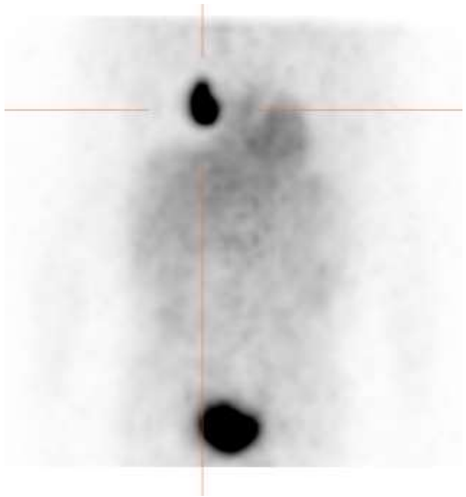
Attenuation correction
+ resolution recovery
+ scatter correction

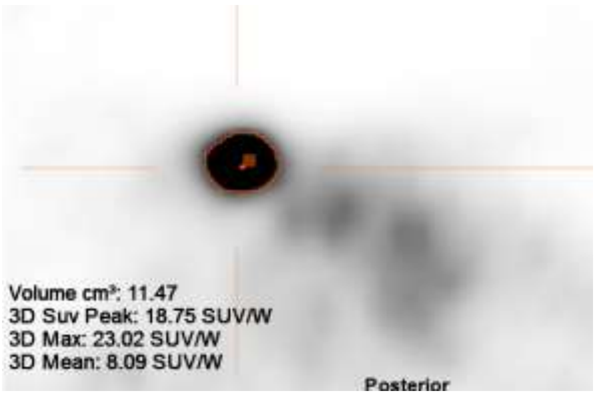
SUV SPECT® *Sensitivity calibration*

- Calibration phantom scan for camera + collimator + radionuclide needed to measure sensitivity → voxel values Bq/ml
- Details of injection activity and patient weight/height for SUVs

Calibration phantom





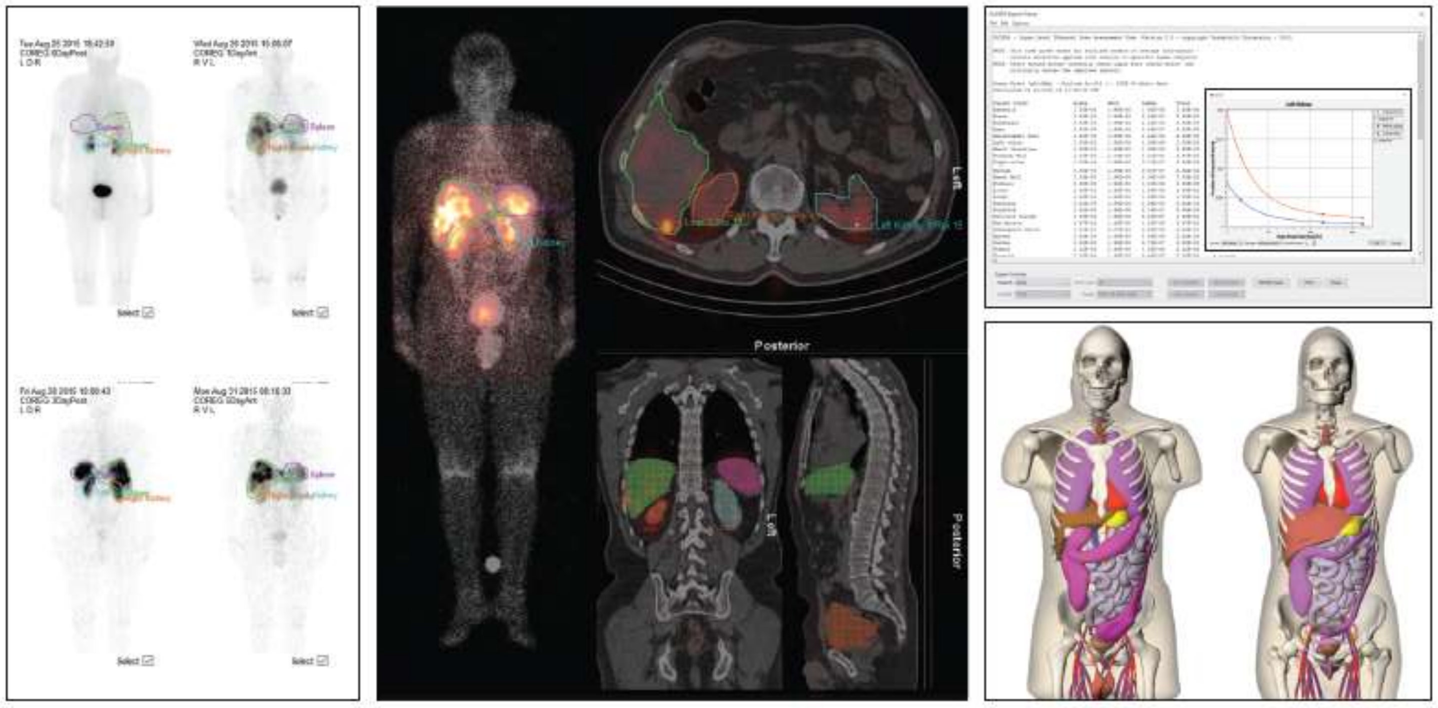


Paediatric neuroblastoma I-123 MIBG

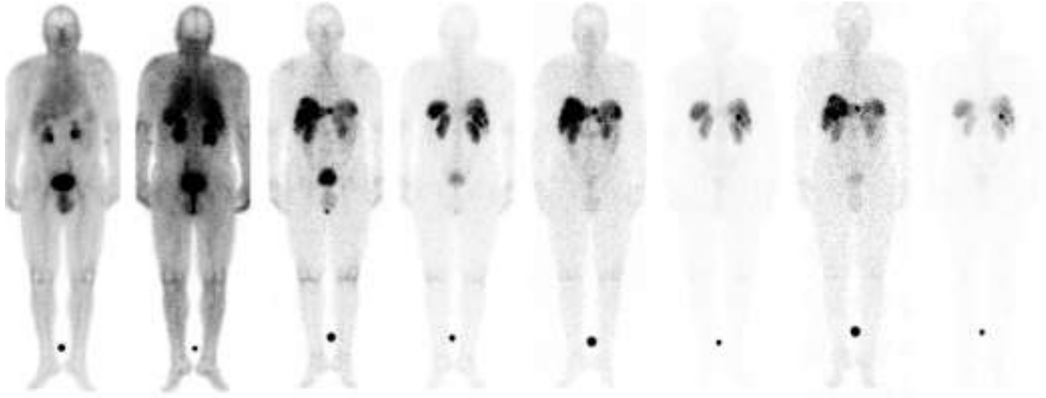
HERMES MEDICAL SOLUTIONS

Hybrid Viewer Dosimetry™ with Olinda/EXM®

- Olinda: MIRD model s-factor dosimetry calculation
- Hybrid Viewer Dosimetry: calculate residence time, pass to Olinda



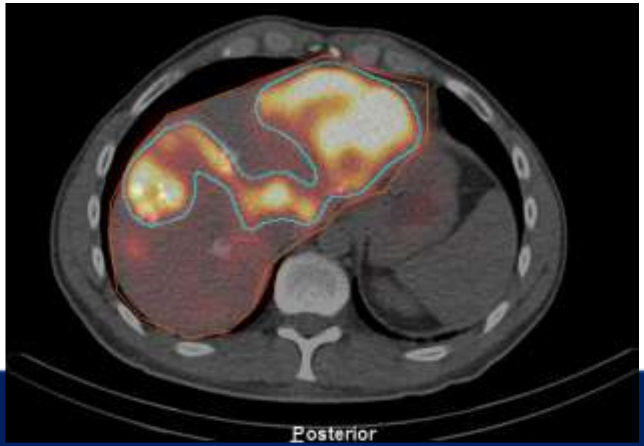
Hybrid Viewer Dosimetry™ with Olinda/EXM®



- Input datasets
  - Multiple WBs
  - Multiple WBs + SPECT
  - Multiple SPECT
  - 1 WB + external dose rate measurement
  - 1 SPECT + external dose rate measurement
- Calibration methods
  - First time point = administered activity (- excreted before first measurement)
  - Planar sensitivity factor cps/MBq
  - SPECT sensitivity factor cps/MBq or SUV SPECT recon

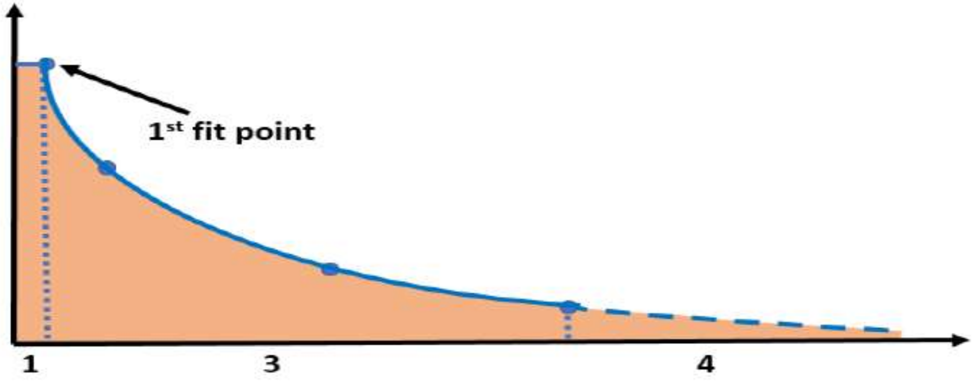
Hybrid Viewer Dosimetry™ with Olinda/EXM®

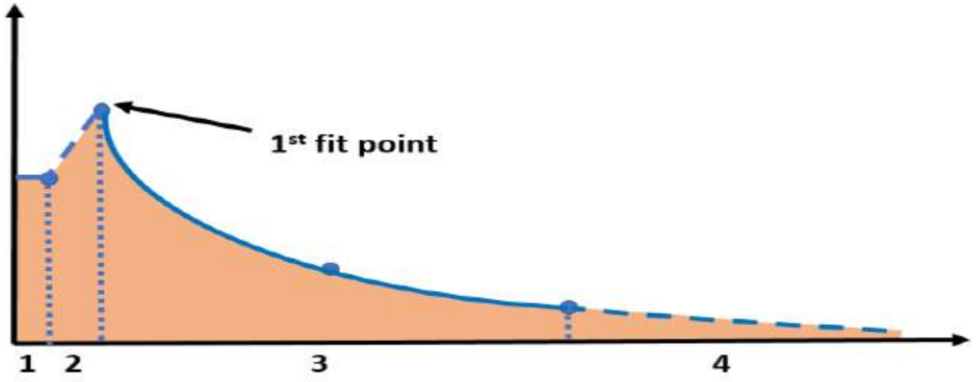
- Accuracy improvements
  - Change target organ mass
  - Enter recovery coefficients for organs and tumours
  - Sphere model for tumours, self dose only
  - Remove tumour activity from healthy organ activity



HERMES MEDICAL SOLUTIONS

Hybrid Viewer Dosimetry™ with Olinda/EXM®

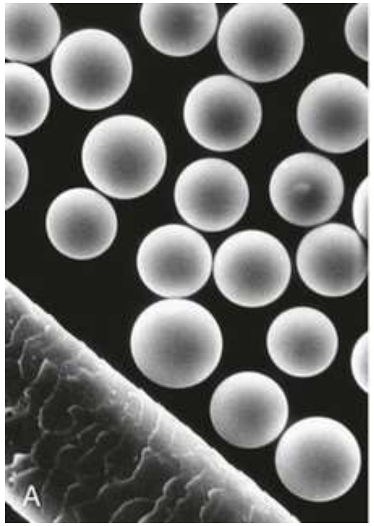




Fitting the TAC

1. Assume instantaneous uptake
2. Trapezoidal integration
3. Exponential or bi-exponential fits using Levenberg-Marquardt technique
4. Extrapolate fit in (3) unless effective $T_{1/2}$ greater than radionuclide $T_{1/2}$, use radionuclide physical $T_{1/2}$ if so

Hybrid3D SIRT™



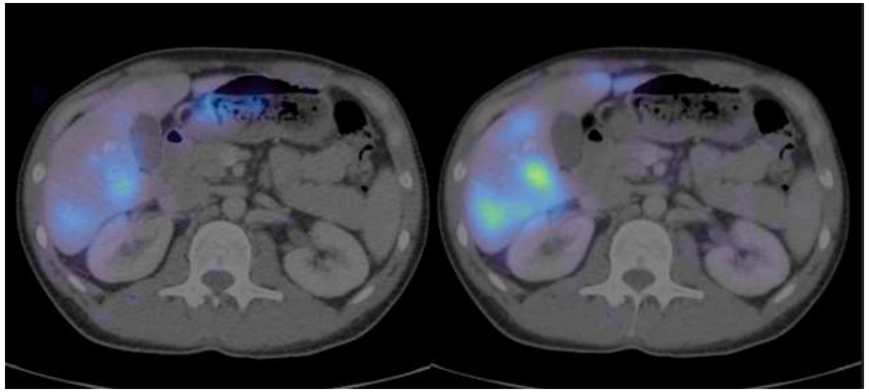
- Planning
  - Resin microspheres: Body surface area or partition model
  - Glass microspheres: Planning tumour volume
  - *Volumetric: voxel-based scaling directly from Tc-99m MAA SPECT*
  - Lung shunt: Planar (2D) *or SPECT/CT (3D)*
- Verification: Y-90 activity calibration
  - Quantitative PET/SPECT
  - All counts in field of view = implanted activity
  - All counts in liver VOI = implanted activity

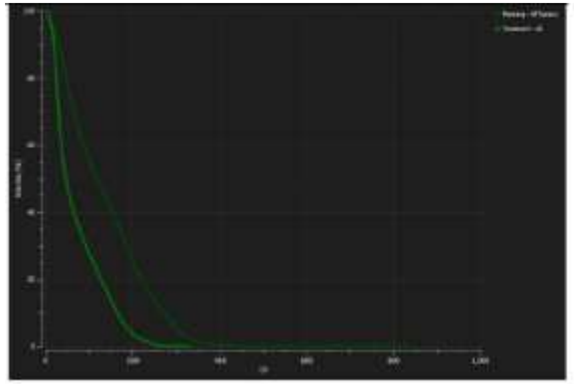
HERMES MEDICAL SOLUTIONS

Hybrid3D SIRT™ *Dose map comparison*

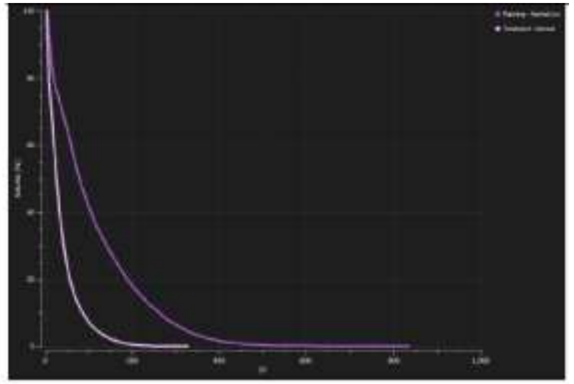
Create dose maps from Tc-99m MAA SPECT and Y-90 Bremsstrahlung SPECT or PET using local absorption multiplying factor for Y-90 [4]

$$D(Gy) = \frac{A(MBq)}{m(g)} \times 49.8\ (\frac{Gy}{GBq/_{kg}})$$

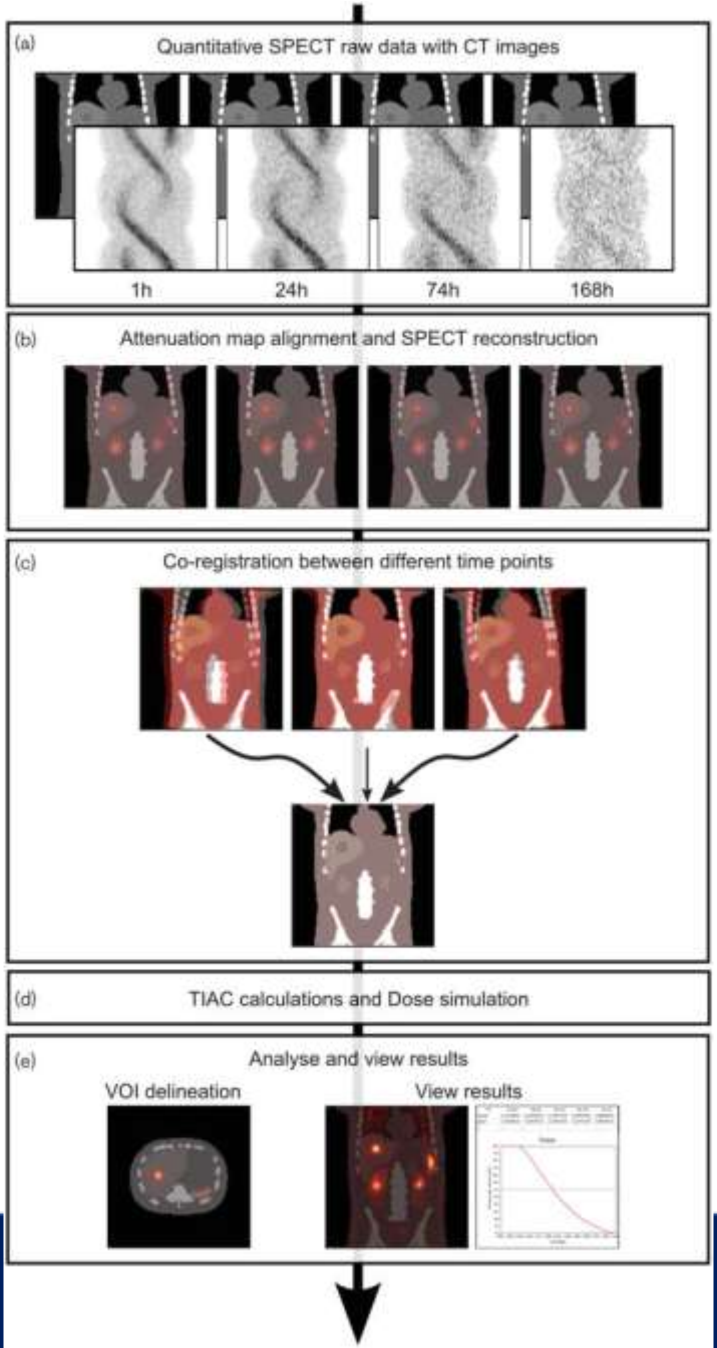




All Tumors



Normal Liver



In development: voxel-based dosimetry

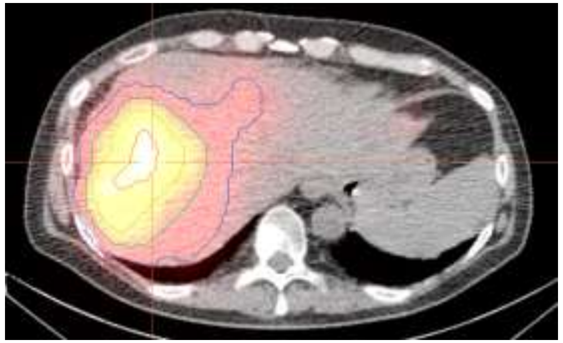
Workflow

a. Input multiple raw SPECT with CT
b. Align mu-map and perform quantitative SPECT recon
c. Coregistration (NM-NM or CT-CT)
d. TAC calculation for each voxel and simulate dose
e. Output 3D dose map with VOIs + DVHs

HERMES MEDICAL SOLUTIONS

In development: voxel-based dosimetry

- TAC calculation and dose simulation algorithm
  - Trapezium rule integration for each voxel though time points
  - 'Semi' Monte Carlo: simulate photon interaction through CT mu-map until energy < 15 keV, assume local absorption for electrons[5]
    - Delta-scattering algorithm[6] tracks photons
    - Cross-section tables by Berger et al[7] used to sample interactions
    - Recoil electrons produced in Compton scattering are locally absorbed



  - Validated for Lu-177 vs Olinda for kidney dosimetry[8,9]

HERMES MEDICAL SOLUTIONS

Future requirements

- Automated organ segmentation methods ?machine learning
- Faster/better registration algorithms for multiple time point data ?deformable registration

References

1. de Jong H, Slijpen E, Beekman F. Acceleration of Monte Carlo SPECT simulation using convolution based forced detection. IEEE Trans Nucl Sci. 2001; 48:58-64.
2. Sohlberg A, Watabe H, Iida H. Acceleration of Monte Carlo-based scatter compensation for cardiac SPECT. Phys Med Biol. 2008; 21:N277-285.
3. Sohlberg A, Kajaste M. Fast Monte Carlo-simulator with full collimator and detector response modelling for SPECT. Ann Nucl Med. 2012; 26:92-98.
4. Stabin M G, Sparks R B and Crowe E OLINDA/EXM: the second-generation personal computer software for internal dose assessment in nuclear medicine J. Nucl. Med. 46 (2005) 1023–7
5. Hippeläinen E, Tenhunen M, Sohlberg A. Fast voxel-level dosimetry for ^{177}Lu labelled peptide treatments. Phys. Med. Biol. 60 (2015) 6685–6700
6. Woodcock E, Murphy T, Hemmings P and Longworth S 1965 Techniques used in the GEM code for Monte Carlo neutronics calculation Proc. Conf. on Applications of Computing Methods to Reactor Problems p 557
7. Berger M J, et al. XCOM: Photon Cross Section Database (version 1.5). 2010; (Gaithersburg, MD: NIST) (http://physics.nist.gov/xcom)
8. Hippeläinen E et al. Dosimetry software Hermes Internal Radiation Dosimetry: from quantitative image reconstruction to voxel-level absorbed dose distribution. Nuclear Medicine Communications 2017, 38:357–365
9. Hippeläinen E. Voxel-level dosimetry of ^{177}Lu-octreotate: from phantoms to patients, PhD thesis, University of Helsinki, 2017, 43 pages. University of Helsinki, Report Series in Physics, HU-P-D255