CAP 2021 Congress
On the need for a standardised segmentation for pre-clinical quantitative PET imaging

Philippe Laporte

Ph.D. Student in Medical Physics,
Université de Montréal,
Under the supervision of Dr. Jean-François Carrier, MCCPM
philippe.laporte.3@umontreal.ca

June 7 2021

Context

- Positron Emission Tomography (PET) is a method of imaging relying on the emission of photons.
- In Quantitative PET imaging, the quantitative data of an image is used to compute specific aspects.
- In the dynamical context, a 4-D image of a subject can be acquired, whose quantitative content gives important biological and anatomical information.
- Many physical and practical components make the segmentation of the image tricky.

Overview

The principles of PET imaging: Positron P

In Nuclear Medicine, a radioisotope decays and yields a positron, which then interacts with the surrounding matter, emitting photons that can be captured by the device.

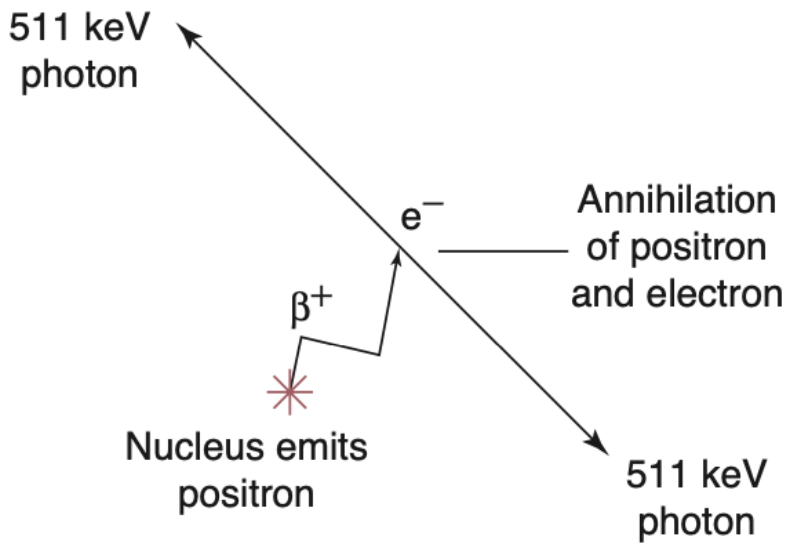


Figure: Positron Emission [Buschberg, 2012, p.723]

The principles of PET imaging: Emission E

- The location of the positron annihilation determines where the rays will be emitted.
- Thus, the location of where the radiopharmaceutical aggregates in the body will yield more or less photons.
- The detectors measure many incidences over a certain timelapse.

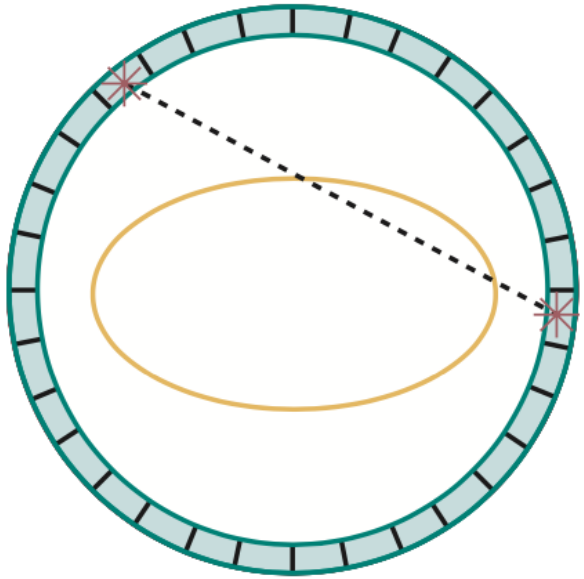


Figure: Positron Emission [Buschberg, 2012, p.723]

The principles of PET imaging: Tomography T

- The acquired data for a slice can be stored in a sinogram, a 2-D array, where one axis represents the distance along the length of the detector array and the other is the angle relative to the center of the device.
- After a relevant transformation, the sinogram can create the usual 2-D image.
- By stacking these 2-D images, it is possible to create a 3-D image of the subject.

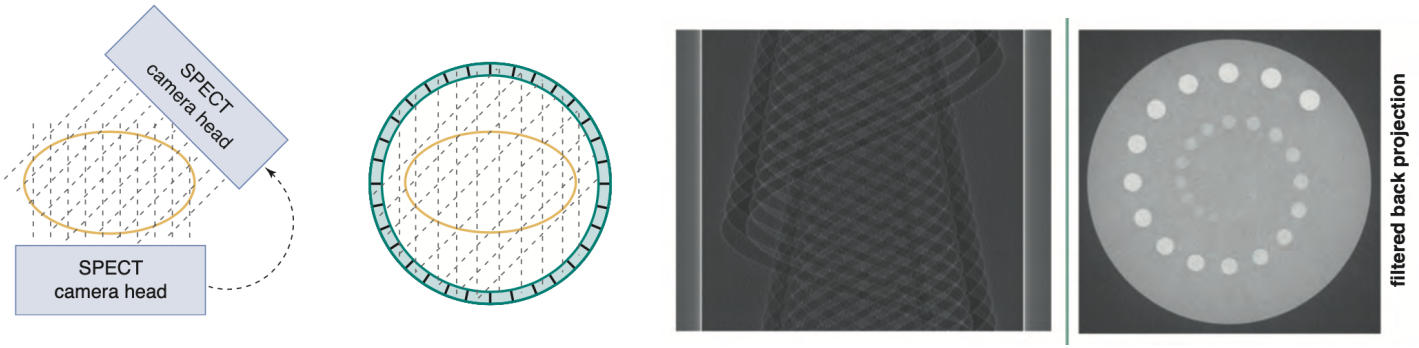


Figure: Sinogram & Acquisition [Buschberg, 2012, p.726 & p.355]

PET: Spatial Resolution

There are different aspects in PET imaging that reduce the spatial resolution:

- Inherent to the acquisition: random and scatter coincidences, deadtime of detectors, dimensions of the detectors, type of reconstruction algorithm, etc.
- Inherent to the subject: movement during the acquisition, metabolic absorption, transformation, and diffusion, etc.

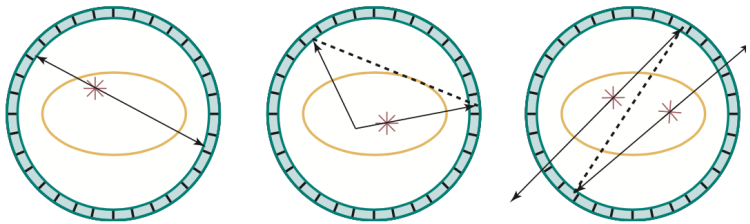


Figure: Intrinsic uncertainties in PET imaging [Buschberg, 2012, p.723].
In order: true, scatter and random coincidences.

Dynamical PET Imaging

In the case of dynamical PET imaging (dPET), many static acquisitions are done in sequence:

- The result is a 4-D array representing a 3-D volume evolving through time.
- It allows, notably, to monitor the movement of a radiotracer through the subject.
- An important thing to note is that the images are functional, not anatomical.

dPET: Spatial Resolution

- In a dPET sequence, the individual timeframes also have the same features reducing spatial resolution.
- Other aspects will arise from the timelapse, such as inter-frame movement and inter-frame diffusion.
- Whereas the reduction in spatial resolution in PET will generally increase the blurriness of the image, the reduction of spatial resolution inherent to the dPET will shift around the voxels of interest and the concentrations.
- Individually, these aspects are straightforward to quantify, but, all put together, they become much trickier.

Quantitative PET: the content of the voxel

- A PET image registers, for each voxel of the image, a certain count.
- This count is related to the concentration of radiotracer in the specific voxel and in adjacent ones (in the case of partial volume effects).
- These quantitative values can be used to determine features and properties of specific functional regions of the subject (or in whole).
- Again, a PET image is functional, and not anatomical: it reflects the concentration of radiotracer in various functional regions.

Quantitative dPET

- In the context of dPET imaging, a specific voxel can be followed throughout the evolution of the acquisition.
- The curve obtained from following that voxel is a **time-activity curve** (TAC).

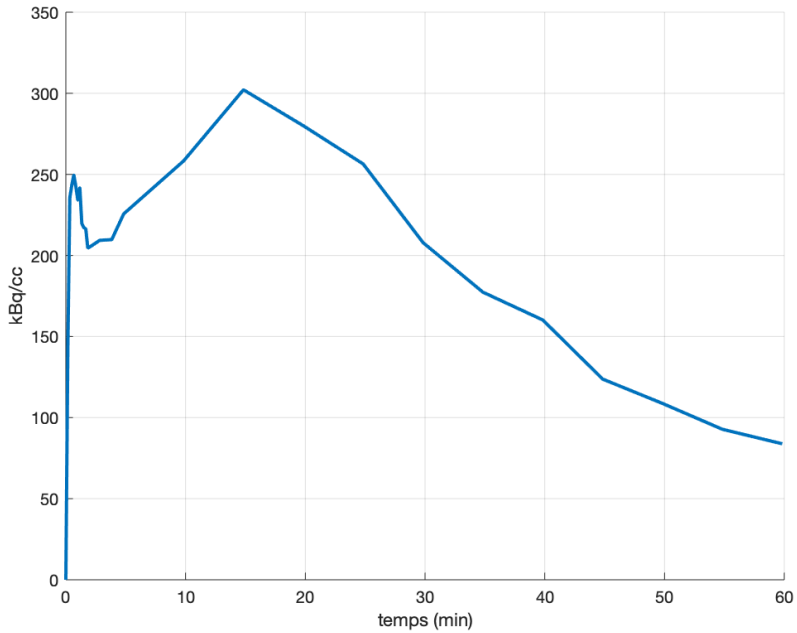


Figure: TACs for specific groups of voxels in a dynamical PET acquisition.

Segmentation

- To determine a TAC, a specific region of the image has to be selected.
- This act of segmenting the image can be done in many ways, among which:
  - M [1] Manual segmentations by an expert;
  - A [2] Gradient-based segmentations;
  - A Statistics-based segmentations;
  - A Filling-based segmentations;
  - A Machine learning-based segmentations.
- The exact method used will determine the exact TAC obtained.

[1] Manual

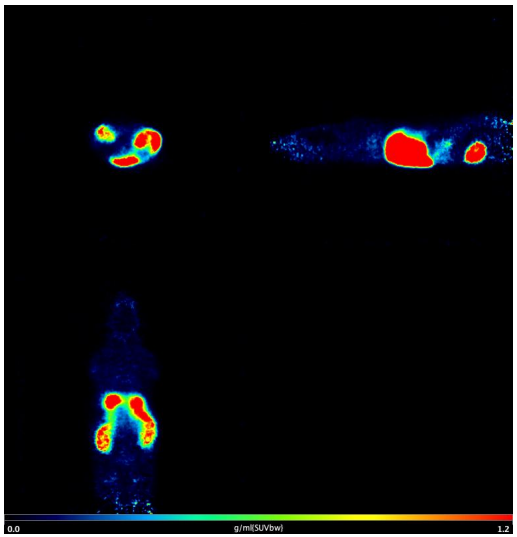
[2] Automatic

Double Trouble: many uncertainties

- In dPET, the radiotracer might move between timeframes due to metabolic activities and diffusion, such as the blood flow in the veins.
- When coupled with the factors related to the movement of the subject (and of the organs), it becomes highly difficult to pinpoint exactly the voxels of interest: the anatomical region in a voxel might move out of it.
- In a dPET image, there is no sure way to determine whether the voxel's anatomy changed or whether only the concentration moved on account of metabolism.

A Real Example: Radiotracer in the Kidney

- A specific radiopharmaceutical marked with F18 was injected in rats. The interest was in the concentration in the left kidney of the animal.
- In pharmacokinetic, the usual technique is to use an ellipsoid on the 2/3 of the kidney and take only voxels with an intensity 50% or higher of the maximal value.
- The trouble is to account for the movement of the subject over the 60 minutes and the metabolic rates.



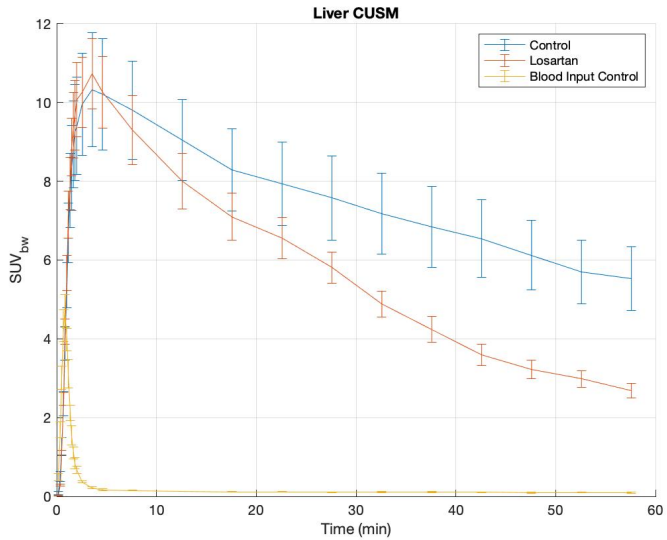


Figure: dPET of a rat (left) and TACs of the kidney for different subjects.

Where to go from now?

- Some of the main current difficulties of quantitative dPET have been hereby put forward.
- To continue in a good way, it is necessary to be able to quantify by itself either the subject's movements or the subject's metabolism, in order to have a good segmentation through time.
- Data in a more stable manner needs to be obtained, either through concurrent CT/MRI or with known true values.

References


Bushberg, J. T. et al. *The Essential Physics of Medical Imaging, 3rd edition*. Lippincott Williams & Williams: Philadelphia. 2012.


Hatt, M. et al. *Classification and evaluation strategies of auto-segmentation approaches for PET: Report of AAPM task group No. 211*. Med. Phys. 44(6), June 2017.


Lortie, M. et al. *Analysis of [^{11}C]methyl-candesartan kinetics in the rat kidney for the assessment of angiotensin II type 1 receptor density in vivo with PET*. Nuclear Medicine and Biology 40 (2013) 252-261.


Maguire, R. P. et al. *PET Pharmacokinetic Course Manual*. Montreal Neurological Institute: Montreal. 2003.


Maroy, R. et al. *Segmentation of Rodent Whole-Body Dynamic PET Images: An Unsupervised Method Based on Voxel Dynamics*. IEEE Transactions on Medical Imaging, Vol 27, No. 3, March 2008.


Meikle, S. R. et al. *Quantitative PET in the 2020s: A Roadmap*. Phys. Med. Biol. in press. doi: 10.1088/1361-6560/abd4f7