Introduction to Medical Imaging

Nuclear Imaging

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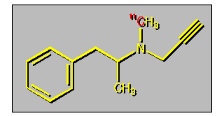
Overview

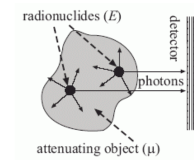
SPECT: Single Photon Emission Tomography

PET: Positron Emission Tomography

Idea:

- inject (into the bloodstream) a tracer molecule labeled with a radionucletide
- there are specific tracer molecule for specific targets
  - example: Deprenyl triggers the production of dopamine in the human brain

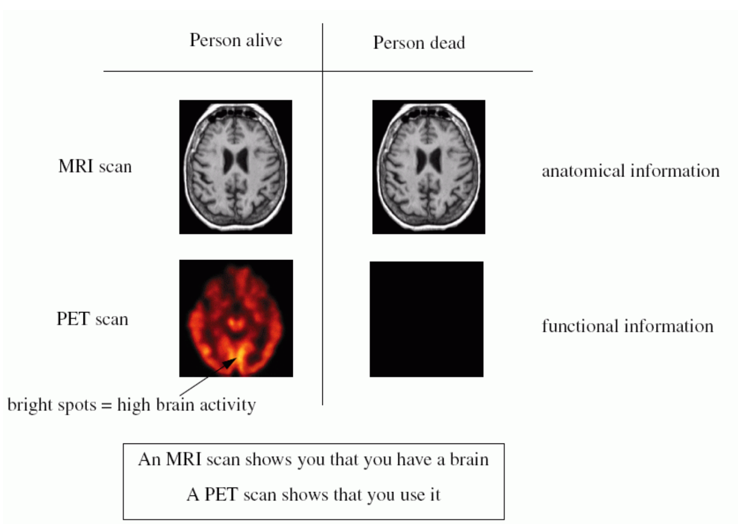




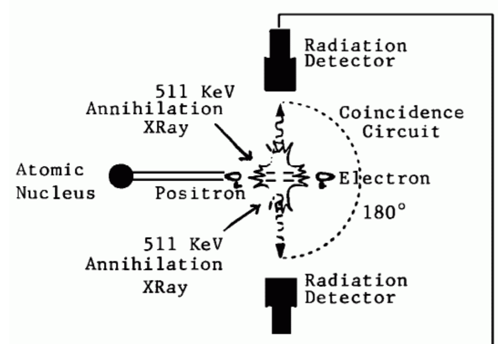
- the molecule will go to the target anatomic site with metabolic activity (e.g., a brain area)
- tracer will give rise to X-rays that can be detected

Just like fMRI it is a metabolic imaging modality, but with much higher SNR (orders of magnitude higher)

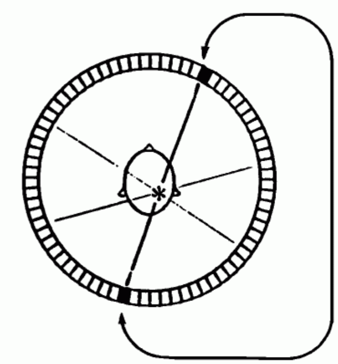
Relation To Anatomic Imaging



PET: Concept (1)

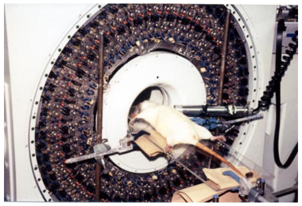


Principles of Decay and Detection



PET Detector Ring Coincidence Imaging

PET: Concept (2)



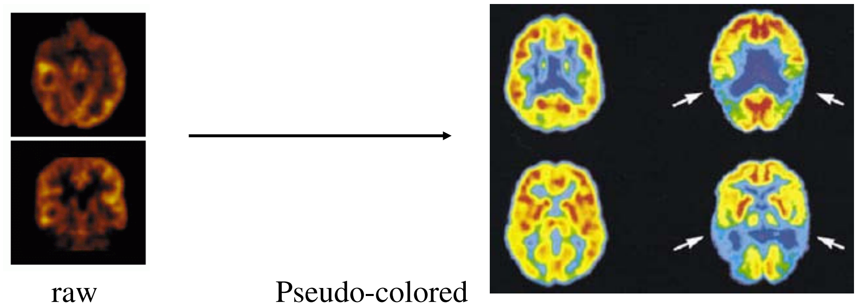
PET: Case Study

PET scan takes usually 30 min (brain) to 60 min (whole body)

Usually displayed pseudo-colored:

- red, yellow: high activity
- green, blue: low activity

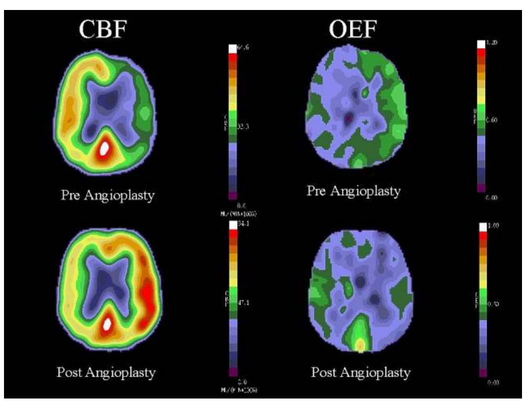
normal Alzheimer's



raw Pseudo-colored

PET: Case Study

Reduced Cerebral Blood Flow (CBF) and elevated compensatory Oxygen Extraction (OEF) before and after carotid artery angioplasty (stroke risk)



SPECT: Concept

A labeled tracer (e.g., glucose) is injected into the blood stream:

- only a single photon is emitted
- slower decay than PET
- study length about 20 min (heart)

Applications:

- measure blood flow through arteries and veins
- brain, heart, renal

gamma cameras

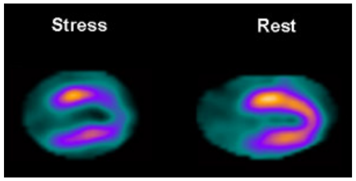
SPECT: Case Studies

Brain: uncontrolled complex partial seizures

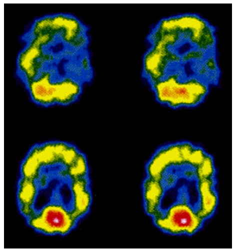
- left temporal lobe has less blood flow than right
- indicates nonfunctioning brain areas causing the seizures

Heart: perfusion of heart muscle

- orange, yellow: good perfusion
- blue, purple: poor perfusion



heart

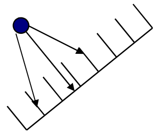


brain metabolism

PET vs. SPECT (1)

SPECT:

- a single photon is produced (need collimator on the detector to determine its path)
- low resolution (6-8 mm)
- tracer decay slower
  - therefore longer-lasting effects can be monitored
  - tracers don't have to be produced on site



PET vs. SPECT (2)

PET:

- no collimators needed -- annihilated positrons yield detectable dual gamma rays 180° apart
- tracers decay fast
  - transient processes can be monitored
  - scan time short (less than a minute)
  - tracers must be produced in nearby cyclotrons
- more expensive equipment (detector hardware)
- higher resolution than SPECT (2-3 mm)
- best for the study of brain receptors with particular neurotransmitters (over fMRI)
- also much better SNR than fMRI

Reconstruction: Iterative Methods

Iterative methods are advantageous in these cases:

- limited number of projections
- irregularly-spaced and -angled projections
- non-straight ray paths (example: refraction in ultrasound imaging)
- corrective measures during reconstruction (example: metal artifacts)
- presence of statistical (Poisson) noise and scatter (mainly in functional imaging: SPECT, PET)

Simultaneous Algebraic Reconstruction Technique (SART)

Iteratively solves W V=P

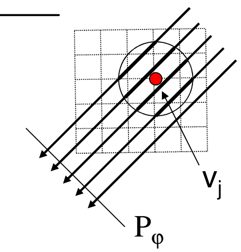
$$v_j^{k+1} = v_j^k + \lambda \frac{\sum_i \dfrac{p_i - \sum_j v_j^k w_{ij}}{\sum_j w_{ij}} w_{ij}}{\sum_i w_{ij}}$$

SART

Projection

Projection (into pixel)

$$v_j^{k+1} = v_j^k + \lambda \frac{\sum_i \dfrac{p_i - \sum_l v_l^k w_{il}}{\sum_l w_{il}} w_{ij}}{\sum_i w_{ij}}$$



SART

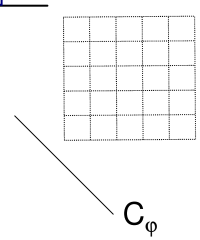
Correction factor computation

Projection (into pixel)

Scanned pixel

Normalization at pixel *i*

$$v_j^{k+1} = v_j^k + \lambda \frac{\sum_i \dfrac{p_i - \sum_l v_l^k w_{il}}{\sum_l w_{il}} w_{ij}}{\sum_i w_{ij}}$$



SART

Backprojection

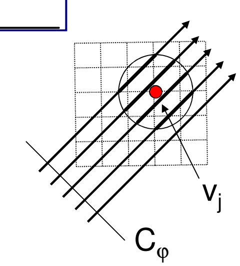
Projection (into pixel)

Backprojection (into voxel)

Scanned pixel

Normalization at pixel *i*

$$v_j^{k+1} = v_j^k + \lambda \frac{\sum_i \dfrac{p_i - \sum_l v_l^k w_{il}}{\sum_l w_{il}} w_{ij}}{\sum_i w_{ij}}$$



SART

Voxel normalization

$$v_j^{k+1} = v_j^k + \lambda \frac{\sum_i \frac{p_i - \sum_l v_l^k w_{il}}{\sum_l w_{il}} w_{ij}}{\sum_i w_{ij}}$$

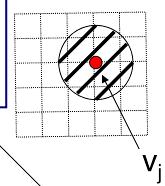
Projection (into pixel)

Backprojection (into voxel)

Scanned pixel

Normalization at pixel *i*

Normalization at voxel *j*



SART

Voxel update

$$v_j^{k+1} = v_j^k + \lambda \frac{\sum_i \frac{p_i - \sum_l v_l^k w_{il}}{\sum_l w_{il}} w_{ij}}{\sum_i w_{ij}}$$

Projection (into pixel)

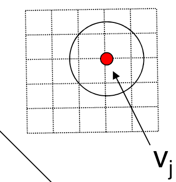
Backprojection (into voxel)

Scanned pixel

Normalization at pixel *i*

New (*k*+1) and previous (*k*) values of voxel *j*

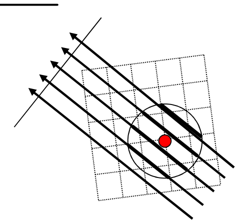
Normalization at voxel *j*



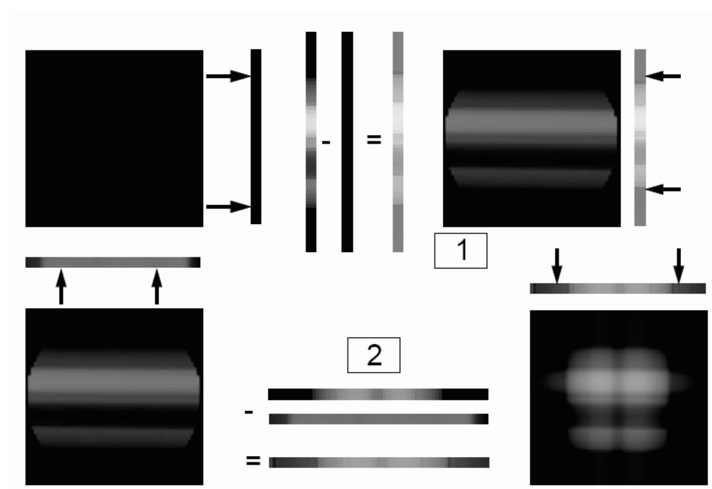
SART

Next projection

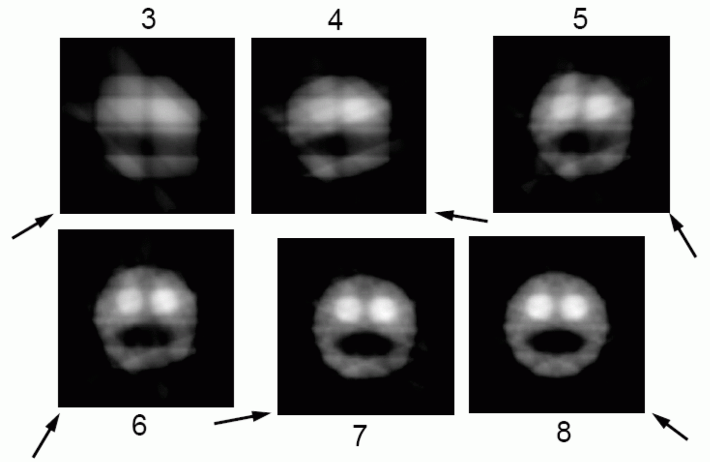
$$v_j^{k+1} = v_j^k + \lambda \frac{\sum_i \frac{p_i - \sum_l v_l^k w_{il}}{\sum_l w_{il}} w_{ij}}{\sum_i w_{ij}}$$



Iterative Reconstruction Demonstration: SART



Iterative Reconstruction Demonstration: SART



Maximum Likelihood Expectation Maximization (ML-EM)

Maximizes the likelihod of the values of voxels *j*, given values at pixels *i*

$$v_j^{k+1} = \frac{v_j^k}{\sum_i w_{ij}} \sum_i \frac{p_i}{\sum_j v_j^k w_{ij}}$$

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New (*k*+1) and previous (*k*) values of voxel *j*

Backprojection (into voxel *j*)

Normalization at voxel *j*

Projection (into pixel *i*)

Algorithm Comparison

SART:

- projection ordering important
- ensure that consecutively selected projections are approximately orthogonal
- random selection works well in practice

EM:

- convergence slow if all projections are applied before voxel update
- use OS-EM (Ordered Subsets EM): only a subset of projections are applied per iteration