PET vs SPECT Imaging for Diagnosing Coronary Artery Disease

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What is SPECT and PET

- They are both nuclear cardiac imaging modalities
- Single Photon Emission Computed Tomography
- Positron Emission Tomography
Noninvasive Testing Options

- Stress–exercise or pharmacologic vs rest
- Myocardial accumulation of radioactivity in proportion to blood flow
- Ischemia defined by diminished perfusion during stress vs rest

Courtesy of Howard Lewin, MD, of San Vicente Cardiac Imaging Center.
Single photon emission computed tomography (SPECT) is a nuclear medicine imaging technique using gamma rays.

Images primarily the biological process or function of organs rather than anatomical structure.

Uses a gamma camera to acquire multiple 1D projection images which are then processed and converted into 2-D images using the mathematical technique of computer tomography.

Multiple slices are obtained simultaneously and stacked to form a 3D representation.

To acquire the images, the gamma camera is rotated around the patient. Projections are typically acquired every 3-6 degrees. Generally, a full 360 degree rotation is used to obtain an optimal reconstruction.

http://www.spect.net/
Multi-headed gamma cameras can provide accelerated acquisition.

15 – 20 seconds is the typical time to obtain each projection. This gives a total scan time of 15-20 minutes.

A nuclide in a radiopharmaceutical is placed into the body by either injection, oral or inhalation. It consists of an emitting isotope.

Photons travelling in the desired direction pass through the collimator towards the detector; other photons are absorbed by the collimator.

**EXAMPLE RADIONUCLIDES**

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-life</th>
<th>Typical radiation</th>
<th>Typical target organs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorus 32</td>
<td>14.3 days</td>
<td>Beta (1.71 MeV)</td>
<td>Liver</td>
</tr>
<tr>
<td>Chromium 51</td>
<td>27.8 days</td>
<td>Gamma (320 KeV)</td>
<td>Red blood cells, urinary</td>
</tr>
<tr>
<td>Barium 131</td>
<td>11.6 days</td>
<td>Gamma (54 - 1000 KeV)</td>
<td>Intestinal</td>
</tr>
<tr>
<td>Iodine 131</td>
<td>8.1 days</td>
<td>Gamma (80 - 723 KeV)</td>
<td>Thyroid: blood</td>
</tr>
<tr>
<td>Technetium 99m</td>
<td>6.0 hr</td>
<td>Gamma (142.7 KeV)</td>
<td>Brain</td>
</tr>
<tr>
<td>Xenon 127</td>
<td>36.4 days</td>
<td>Gamma (57 - 375 KeV)</td>
<td>Lung</td>
</tr>
</tbody>
</table>
Electronics and Computer
Sensors to convert green light into an electronic signal
Each gamma-ray is converted to green light, one at a time
Collimator gives a sharp image by accepting only gamma-rays aligned with holes

GAMMA CAMERA COMPONENTS:
PHOTOMULTIPLIER TUBES
DETECTION CRYSTAL

GAMMA CAMERA ASSEMBLED
Image is displayed on computer screen
Lead housing ensures only gamma-rays from patient are detected

www.frankswebspace.org.uk/.../gammaCamera2.gif
SPECT

SHORT AXIS, VERTICAL & HORIZONTAL LONG AXIS ORIENTATION
NORMAL IMAGES

SPECT Reoriented Views

Horizontal Long Axis  Short Axis  Vertical Long Axis
## Spect radiotracers

<table>
<thead>
<tr>
<th>tracer</th>
<th>half life</th>
<th>injections</th>
<th>dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tc99m sestamibi/tetrofosmin</td>
<td>6 hrs</td>
<td>two</td>
<td>8 to 10 mci at first study 20 to 30 mci at second study</td>
</tr>
<tr>
<td>Tl 201</td>
<td>73 hrs</td>
<td>single</td>
<td>4 to 6 mci</td>
</tr>
</tbody>
</table>

**Protocols**

**Stress & rest study**
- done in the same day or separately

**Only rest study**
20 SEGMENTS OF LV SCORING

Myocardial Perfusion SPECT 20-Segment Scoring

- Short Axis Distal
  - Anterior
  - Septal
  - Lateral
  - Inferior

- Short Axis Mid
  - Anterior
  - Septal
  - Lateral
  - Inferior

- Short Axis Basal
  - Anterior
  - Septal
  - Lateral
  - Inferior

- Vertical Long Axis Mid
  - Anterior
  - Lateral
  - Apex

0 = Normal
1 = Slight reduction of uptake
2 = Moderate reduction of uptake
3 = Severe reduction of uptake
4 = Absent of radioactive uptake

- LAD
- LCX
- RCA
Normal Study
Computer-rendered, 3-D Image of Left Ventricular Surfaces
Myocardial ischemia
Myocardial infarct
Single Vessel Disease- RCA
### SPECT MPI

#### Advantages
- Operator independent
- Reproducibly good image quality
- Gating allows acquisition of LV volumes
- Simultaneous perfusion and function assessment
- Able to assess myocardial viability

#### Disadvantages
- Ionizing radiation required
- Attenuation artifacts in small percentage of patients
- Time required for imaging
Noninvasive Testing Options

- Rest and pharmacologic stress
- Images radioactive tracers of flow and metabolism
- Ischemia defined as difference in regional blood flow during pharmacologic stress

Courtesy of Howard Lewin, MD, of San Vicente Cardiac Imaging Center.
Physics of PET scanning

- Radionuclide decays by emitting a positron ($\beta^+$).
- $\beta^+$ annihilates with $e^-$ from tissue, forming back-to-back 511 keV photon pair.
- 511 keV photon pairs detected via time coincidence.
Neutron-deficient isotopes can decay by emitting positrons.

Net effect: one proton replaced by
- neutron
- anti-neutrino
- positron
Positron annihilation

- Annihilation gives
  - 2x 511 keV gamma rays
  - 180 degrees apart
  - Line of response

- Positron range & gamma noncollinearity

- Scanner is just a photon counter!
  - Counts gamma-ray pairs vs. single gammas
  - Time window ~ 1 ns
Raw Data & Image Reconstruction

0° projection

90° projection

180° projection

“sinogram”

image reconstruction
Rb-82 Infusion System
PET Scanner
# CARDIAC PET TRACER

## Table 1. Positron-emitting tracers of myocardial blood flow.

<table>
<thead>
<tr>
<th>Agent</th>
<th>Physical half-life</th>
<th>Mean positron range</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-13 ammonia</td>
<td>9.8 min</td>
<td>0.7 mm</td>
<td>Cyclotron</td>
</tr>
<tr>
<td>Rubidium-82</td>
<td>75 sec</td>
<td>2.4 mm</td>
<td>Generator</td>
</tr>
<tr>
<td>O-15 water</td>
<td>2.0 min</td>
<td>1.1 mm</td>
<td>Cyclotron</td>
</tr>
</tbody>
</table>

## Medical Nuclides

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Half-life</th>
<th>Production</th>
<th>Radio-pharmaceuticals</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>18F</td>
<td>109.8 min</td>
<td>Cyclotron</td>
<td>[18F] FDG</td>
<td>Metabolism</td>
</tr>
<tr>
<td>15O</td>
<td>2.03 mins</td>
<td>Cyclotron</td>
<td>[15O] Water</td>
<td>Perfusion</td>
</tr>
<tr>
<td>82Rb</td>
<td>1.25 mins</td>
<td>Generator</td>
<td>[82Rb] Rubidium</td>
<td>Perfusion</td>
</tr>
</tbody>
</table>

PET Tracer: Rubidium

CardioGen-82®
(Rubidium Rb 82 Generator)

- Generator replaced every 28 days
- Rb-82 dose is provided within 10 minutes
- Infusion System is automated for the infusion and patient dose
- Permits accurate dosing with minimal operator interface, thus decreasing radiation exposure
- Contains shielding vault for CardioGen-82® Generator and waste container
PET Perfusion Agents

• Rb-82 Chloride and N-13 ammonia are both extractable agents which passively diffuse across cell membranes

• Both tracers have high first-pass myocardial extraction fractions, which are inversely related to flow in a non-linear manner.
## PET Perfusion

<table>
<thead>
<tr>
<th>Author</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th># Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gould</td>
<td>95%</td>
<td>100%</td>
<td>50</td>
</tr>
<tr>
<td>Demer</td>
<td>94%</td>
<td>95%</td>
<td>193</td>
</tr>
<tr>
<td>Go</td>
<td>93%</td>
<td>78%</td>
<td>202</td>
</tr>
<tr>
<td>Schelbert</td>
<td>97%</td>
<td>100%</td>
<td>45</td>
</tr>
<tr>
<td>Yonekura</td>
<td>93%</td>
<td>100%</td>
<td>49</td>
</tr>
<tr>
<td>Williams</td>
<td>98%</td>
<td>93%</td>
<td>146</td>
</tr>
<tr>
<td>Stewart</td>
<td>84%</td>
<td>88%</td>
<td>319</td>
</tr>
<tr>
<td><strong>Weighted Avg.</strong></td>
<td><strong>93% +/- 8</strong></td>
<td><strong>92% +/- 5</strong></td>
<td><strong>766</strong></td>
</tr>
</tbody>
</table>

Noninvasive Testing Options

Advantages
- Good image quality
- Allows quantification of myocardial blood flow
- Gold standard for viability assessment

Disadvantages
- Very limited availability
- High cost
- On-site cyclotron may be required
- No ECG or hemodynamic data available from exercise

PET
Patient 1

- 65yo male 280 lbs
- Chest pain syndrome
- Cannot exercise due to knee arthritis
The Power of PET

- Perfusion images reveal reversible perfusion defects involving the anterior/anterior septal and septal walls consistent with LAD obstruction.
- Coronary catheterization revealed 85% proximal stenosis of the LAD.
SPECT Vs PET Imaging: Diagnostic accuracy comparison

- Bateman et al, Diagnostic accuracy of rest/stress ECG gated Rb-82 myocardial perfusion PET: comparison with ECG-gated Tc-99m Sestamibi SPECT. J Nucl Cardiology 2006 Jan-Feb

- 112 SPECT/PET studies matched for gender, BMI, presence and extent of ASCAD
Diagnostic Accuracy

- PET image quality excellent 78% and 79% for rest and stress
- SPECT image quality excellent 62% and 62% for rest and stress

Interpretations
- Definitely normal/abnormal
  - PET 96%
  - SPECT 81%
## Diagnostic Accuracy

<table>
<thead>
<tr>
<th></th>
<th>PET</th>
<th>SPECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stenosis (70%)</td>
<td>89%</td>
<td>79%</td>
</tr>
<tr>
<td>Stenosis (50%)</td>
<td>87%</td>
<td>71%</td>
</tr>
<tr>
<td>Men vs Women</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Obese vs. nonobese</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>
Figure 3. Overall diagnostic accuracy for PET and SPECT: 50\% coronary stenosis threshold (A) and 70\% stenosis threshold (B).
Figure 2. Comparison of degrees of interpretive certainty of SPECT and PET studies.
## Patient Radiation Dosimetry

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Effective Dose Equivalent</th>
<th>Per study</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rb-82</td>
<td>1.6 mrem/mCi</td>
<td>50 mCi</td>
<td>80 mrem</td>
</tr>
<tr>
<td>Tc-99m miibi</td>
<td>51 mrem/mCi</td>
<td>30 mCi</td>
<td>1500 mrem</td>
</tr>
<tr>
<td>Th-201</td>
<td>850 mrem/mCi</td>
<td>4 mCi</td>
<td>3200 mrem</td>
</tr>
<tr>
<td>CT mu-map</td>
<td>440 mR</td>
<td>1 scan</td>
<td>440 mrem</td>
</tr>
</tbody>
</table>
Case study

- 50yo female patient with breast implants
- MPS ordered for evaluation of chest pain syndrome with equivocal GXT
- Patient underwent MPS with Tc-99m Sestamibi
- Patient then underwent Rb-82 PET perfusion
Case Study

- Comparison between SPECT and PET
- Normal scan with Rb-82 PET
- Abnormal with SPECT
- False positive SPECT, patient risk stratified away from invasive evaluation
- No cardiac events in follow up
Examples of improved diagnostic reliability of PET vs. SPECT MPI in the same patients. (A) A 70-y-old man status post CABG with no history of MI. Exercise/rest SPECT images are normal but left ventricular ejection fraction was surprisingly reduced at 0.39. PET MPI within 2 wk discloses a clinically occult posterobasal MI. (B) A 53-y-old man with exertional left arm pain. SPECT images with dipyridamole stress are normal. PET MPI within 2 wk demonstrates a reversible inferoseptal perfusion defect. Ninety percent circumflex stenosis found on coronary arteriography. (C) A 46-y-old woman with chest pain. SPECT images are equivocal for reversible ischemia in inferolateral wall. PET images are normal. (D) A 59-y-old woman with chest pain. SPECT images are equivocal for reversible inferolateral ischemia as in C. PET images demonstrate reversible inferoseptal perfusion defect, treated with PTCI of 95% dominant right coronary artery stenosis.
The Myth of Rb-82

Cost comparison PET/SPECT

Cost of perfusion agent
Cost of Rb-82/day
Cost of MIBI/day

Patients per day
Transitioning the perfusion market

- Why Rb-82 now?
  - Improved patient outcomes/lower false positives
  - Appointment times reduced to 30-45 minutes
  - Improved accuracy irrespective of body mass index, sex, etc.
  - Lower radiation exposure
  - Improve throughput and reimbursement-favorable economic drivers
SPECT perfusion imaging

Low diagnostic accuracy in some patient populations - Balanced ischemia

Long Acquisition times

Higher radiation exposure

Decreasing reimbursement
PET perfusion imaging

High diagnostic accuracy regardless of patient status - Gate both stress and rest

Shorter acquisition times

Lower radiation exposure

Increasing reimbursement
Economic impact on society

- Single missed diagnosis of CAD-$90,000
- Comparison of SPECT and PET
  - 300 patients
  - SPECT over 32% referred for coronary angiography
  - PET only 10% referred for coronary angiography
  - Additionally 20% of catheterization were normal in the face of an abnormal SPECT study (false positives)
  - PET imaging lead to a cost savings of 30-40%

Impact of PET on health care cost prepared for General Motors 1996
PET Vs SPECT Imaging: Conclusion

- More sensitive and specific test
- Better spatial resolution
- More accurate attenuation correction
- Gives information about myocardial blood flow, assessment of function and metabolism
- Less radiation exposure
- Cost saving in the long run