Myocardial perfusion scintigraphy:

- **Pharmaceuticals:** [Tl-201] Thallium-chloride or [Tc-99m] isonitrile derivatives (e.g. "MIBI")
- **Phenomenon imaged:** Myocardial perfusion after ergometric or pharmaceutical stress and in resting state.
- **Abnormalities shown:**
  - "Fix defect" (decreased activity in both the stress and rest images) in scars.
  - Reversible perfusion defect in ischaemic regions: relatively decreased activity uptake (as compared to the healthy myocardium) in the regions of stenosed coronary arteries, not or less shown in rest (Tl: delayed) images.

Comparison of radiopharmaceuticals for MPI

- **Thallium-chloride:**
  - K-analogue
  - Redistribution may occur
  - A single injection during stress
    - Early images after 15'
    - Late images after 3-4 h
- **Methoxy-iso-butyl-isonitril (MIBI):**
  - Passes cell membranes passively (negative membrane potential), accumulates in the mitochondrias
  - No redistribution
  - Separate injections for stress and rest study (images after 60')
  - Single-day protocol:
    - Starting with rest preferred
    - ~250 + 750 MBq

TL UPTAKE

![TL Uptake Diagram](image)

Fig. 4.24

**Tracer uptake in healthy and ischaemic myocardium.**

- Percentage uptake in healthy myocardium:
  - 4%
  - Maximal uptake in ischaemic regions:
  - 20-40%
  - MIBI can be used for imaging, although its other properties (less lung uptake, lower half-life) may make it preferred for imaging.

Myocardial perfusion scintigraphy:

- **Indications - 1**
  - Suspicion of CAD with abnormal rest or indeterminate stress ECG
  - Localization and severity of ischaemia
  - Interpreting the (abnormal) result of coronary angiography (collaterals, microvasculature); assessing haemodynamic effects of the stenosis
  - Result of surgical or catheteric intervention
  - Prognosis of CAD

Myocardial perfusion scintigraphy:

- **Indications - 2**
  - Assessing the location and severity of ischaemia in case of post-infarct angina for angioplasty
  - Assessing myocardial viability in severe left ventricular insufficiency after infarct
  - Cardiac risk stratification before major (chest, abdominal) surgery

**Imaging techniques:**

I. planar
II. tomographic (SPECT; PET)

SHORT AXIS SLICES

- A. RCA
- B. Aortic arch
- C. Pulmonary artery
- D. LCA
- E. LCX
- F. LAD
Coronary artery territories on SPECT views

Reversible defect: short axis slices

Reversible defect: vertical long axis slices

Reversible defect: horizontal long axis slices

Myocardial perfusion: „Bull’s eye” (polar mapping)

Reversible defect: bull’s eye
Reversible apical defect – 3D

Fix defect: horizontal long axis slices

Fix defect: bull’s eye

Viable: short axis slices

Perf./metabolic. Mismatch: Viable
(Good prognosis for bypass surgery)

Perf+metab. fixed defect: short axis

Matching Perf+metab. Defect
(Poor prognosis for bypass surgery)

MIBI: Report sheet
**MIBI: Reversible septal perf. defect**

- Image of myocardial perfusion scan showing a reversible septal perfusion defect.

**MIBI: Fixed perfusion defect (inferior)**

- Image of myocardial perfusion scan showing a fixed perfusion defect in the inferior region.

**MIBI: Apical aneurism**

- Image of myocardial perfusion scan showing an apical aneurism.
- **Features:**
  - Huge apical perfusion defect
  - Dilated ventricle

**Decision tree**

- Diagram of a decision tree for myocardial perfusion imaging.
- **Branches:**
  - Normal pump function
  - Stress: defect, Rest: better or normal
  - Glucose metab?
  - Fixed defect
  - Scar
  - Viable hibernation
  - Coronarography
  - Revascularization
  - Viable
  - Scar
  - Nothing to do

**Summary: states of the myocardium**

<table>
<thead>
<tr>
<th>Wall motion</th>
<th>Blood supply</th>
<th>Stress perf.</th>
<th>Rest perf.</th>
<th>Metabolism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Present</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Stunning</td>
<td>Decreased</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Ischaemia</td>
<td>Decreased</td>
<td>Decreased</td>
<td>Abnormal</td>
<td>Norm.</td>
</tr>
<tr>
<td>Hybernating</td>
<td>Decreased</td>
<td>Decreased</td>
<td>Abnormal</td>
<td>Abnormal</td>
</tr>
<tr>
<td>Scar</td>
<td>Decreased (missing)</td>
<td>Abnormal</td>
<td>Abnormal</td>
<td>Missing</td>
</tr>
</tbody>
</table>

**Difficulties with myocardial emission tomography**

<table>
<thead>
<tr>
<th>Technical:</th>
<th>Biological:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low resolution</td>
<td>Moving heart wall</td>
</tr>
<tr>
<td>Attenuation in the body</td>
<td>Attenuation: breast, diaphragm</td>
</tr>
<tr>
<td>Scatter</td>
<td>MIBI accumulation: liver, bile</td>
</tr>
<tr>
<td>Statistical error (noise)</td>
<td></td>
</tr>
</tbody>
</table>

**180° arc for cardiac studies (RAO to LPO)**

- Diagram showing the 180° arc for cardiac studies from RAO (Right Anterior Oblique) to LPO (Left Posterior Oblique).

**Source:** J.R. Halama, Loyola Univ.
Orbit with contour detection

Gamma cameras for cardiac imaging

Prone position may prevent artifacts

What should you check after acquisition?
- Patient movement ⇒ restart acquisition
- High activity near the heart ⇒ wait, then restart acquisition
- Spatial matching of SPECT and CT ⇒ correction if necessary and possible

DIAG: prefiltering
- Pre-reconstruction 2D Wiener (restoration) filter

Limits
- Check orientation

Set parameters for reslicing
Most common software packages for myocardial perfusion imaging

- QGS (Quantitative Gated SPECT)
- ECT (Emory Cardiac Toolbox)

What’s in ECToolbox?

- CEqual (Quantitative Perfusion Analysis)
- Emory Gated SPECT (EGS - Quantitative Functional Analysis)
- PerSPECTive Display (3-D Display of Perfusion)
- Perfex (Expert System Analysis)
- Prognostic Evaluation
- Automatic Derivation of Visual Scores
- Generic Coronary Artery Fusion
- HeartFusion™ - PET/CT actual patient coronary fusion
- PC Based Normal Limit Generator (NLG™)
- NCTb (PC based Emory Cardiac Toolbox application)
- Nuclear Report Professional (NRP™)

Some of the listed items are optional

---

Reversible defect

Data base #1: Stress
Data base #2: Rest
Data base #3: Reversibility

T.I.D.

- "Transient ischaemic dilation ratio":
  Ratio of the areas of stress & rest short axis slices
- Only after physical stress


---

3D activity distribution

3D: Extent of abnormal areas
3D + arteries

Extent of abnormal regions: masses

Defects in the supply area of each coronary artery branch

Summary

Scoring:

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>1</td>
<td>Equivocal</td>
</tr>
<tr>
<td>2</td>
<td>Moderate</td>
</tr>
<tr>
<td>3</td>
<td>Severe</td>
</tr>
<tr>
<td>4</td>
<td>Complete defect</td>
</tr>
</tbody>
</table>

Summed stress score (SSS):

-4 Normal
-4 - 8 Mild abnormality
-9 - 13 Moderately abnormal
-13< Severe deterioration

Survival and severity score

Survival and severity score

Survival curve with quantitative severity stress score.
Myocardial perfusion SPECT: Corrections

- **Attenuation correction:**
  - Measured attenuation map is necessary (with external radiation source or CT)
  - Chang’s method must not be applied for myocardial SPECT!
  - Should be applied together with scatter correction.
- **Scatter correction:**
  - Should be applied together with attenuation correction
  - Can be included in iterative reconstruction
- **Resolution degrades with distance:**
  - No general correction method in the routine
  - May be included in iterative reconstruction

Effect of attenuation correction

Source: Ficaro et al., Circulation 95: 463, 1996

Reports from stress myocardial perfusion studies

Proportion of ambiguous reports can be decreased using attenuation correction and/or gating


Cardiac PET methods: NH$_3$ flow & FDG viability

13-N-NH$_3$ rest oblique slices 13-N-NH$_3$ stress

18-F-FDG viability

- low $&$ viability at the same high sensitivity, on the same day
- partial match
- as blood supply vanishes, myocardium dies
- dynamic/gated study possible

Images courtesy of Dr. A. Alavi, Univ. of Pennsylvania Hospital, Philadelphia

Cardiac PET methods: Rb-82 flow studies

1850 MBq $^{82}$Rb, 4 min. p.i., total acq. time: 4.5 min including emission + transmission

• very short half life (72 s) tracer w. long positron travel range
• generator product
• still good image quality without artifacts from high activity in the liver

Images courtesy of Dr. Blaufox, Montefiore Hospital, New York

Common tomographic imaging methods of the heart

<table>
<thead>
<tr>
<th>Method</th>
<th>SPECT</th>
<th>MIBI</th>
<th>Stress/Rest perfusion</th>
<th>Perfusion defect (reversible or fix)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Gated perfusion</td>
<td>Wall motion, EF</td>
</tr>
<tr>
<td>RBCs</td>
<td></td>
<td></td>
<td>Rated blood pool</td>
<td>Wall motion, EF</td>
</tr>
<tr>
<td>PET</td>
<td></td>
<td>NH$_3$</td>
<td>Perfusion</td>
<td>Perfusion defect (reversible or fix)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rb-82</td>
<td>Perfusion defect (reversible or fix)</td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td></td>
<td>- Low dose</td>
<td>Attenuation correction</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Ca-score</td>
<td>Calcium deposits</td>
<td></td>
</tr>
<tr>
<td>CTA</td>
<td>Cont.</td>
<td>CT angiography</td>
<td>Stenosis</td>
<td></td>
</tr>
<tr>
<td>PET</td>
<td></td>
<td></td>
<td>+ Ultrasound, Coronarography, MRI</td>
<td></td>
</tr>
</tbody>
</table>

Is perfusion more accurate with PET? #2

Rogers B., American College of Cardiology (ACC) meeting, 2007

- 4500 Rb-82 myocardial perfusion PETs; 380 normals among them
- Death within 1 year after normal perfusion PET is 10$^*$ more frequent than after normal MPI SPECT
- LVEF<55% within the normal Rb-82 group increases risk of death in 1 year by 2.5$^*$

Conclusions:
- The clinical value of Rb-82 PET is inferior to that of MIBI SPECT
- Taking into account the EF value may improve the results.

Is perfusion SPECT useful? #1

- 42 patients
- Ca score
- CTA (Sensation 64, Siemens)
- MIBI rest/stress SPECT
- OCA (quant. coronarography) + ventriculography
- Accuracy of detecting SPECT perfusion defects:

<table>
<thead>
<tr>
<th>CTA results</th>
<th>40% success</th>
<th>60% success</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>83%</td>
<td>77%</td>
</tr>
<tr>
<td>Specificity</td>
<td>69%</td>
<td>67%</td>
</tr>
<tr>
<td>PPV</td>
<td>77%</td>
<td>72%</td>
</tr>
<tr>
<td>NPV</td>
<td>50%</td>
<td>55%</td>
</tr>
</tbody>
</table>

- **Worse results for identifying matching defects**
- **Conclusion:**
  - CTA & OCA only moderately correlate with ischemia shown on perfusion SPECT
  - but well correlate with each other
  - wall motion measured by CTA correlates well with MPI

<table>
<thead>
<tr>
<th>SPECT</th>
<th>MIBI</th>
<th>Stress/Rest perfusion</th>
<th>Perfusion defect (reversible or fix)</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td>Gated perfusion</td>
<td>Wall motion, EF</td>
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<tr>
<td>PET</td>
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<td>NH$_3$</td>
<td>Perfusion</td>
</tr>
<tr>
<td></td>
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<td>Rb-82</td>
<td>Perfusion defect (reversible or fix)</td>
</tr>
<tr>
<td>CT</td>
<td>- Low dose</td>
<td>Attenuation correction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Ca-score</td>
<td>Calcium deposits</td>
<td></td>
</tr>
<tr>
<td>CTA</td>
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<td>CT angiography</td>
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<tr>
<td>PET</td>
<td></td>
<td></td>
<td>+ Ultrasound, Coronarography, MRI</td>
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</tbody>
</table>
Hendel et al: ASNC and SNM joint position statement

The normalcy rate, used as a surrogate for specificity, is defined as the rate of normal perfusion scans in patients with <5% likelihood of CAD on the basis of clinical and ECG stress test data.

Role of attenuation correction for myocardial perf. SPECT

Table 1: Diagnostic value of attenuation correction systems

<table>
<thead>
<tr>
<th>Author</th>
<th>System</th>
<th>n</th>
<th>NC</th>
<th>AC</th>
<th>NC</th>
<th>AC</th>
<th>NC</th>
<th>AC</th>
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<tbody>
<tr>
<td>Kooi</td>
<td>UMich</td>
<td>110</td>
<td>78</td>
<td>64</td>
<td>86</td>
<td>85</td>
<td>98</td>
<td></td>
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<tr>
<td>Iskandar</td>
<td>K2SNC</td>
<td>200</td>
<td>76</td>
<td>76</td>
<td>44</td>
<td>90</td>
<td>86</td>
<td>96</td>
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<tr>
<td>Jost</td>
<td>SPECT</td>
<td>112</td>
<td>64</td>
<td>56</td>
<td>75</td>
<td>67</td>
<td>75</td>
<td>71</td>
</tr>
<tr>
<td>Gellerstedt</td>
<td>Siemens</td>
<td>49</td>
<td>80</td>
<td>54</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leclercq</td>
<td>Siemens</td>
<td>171</td>
<td>93</td>
<td>73</td>
<td>54</td>
<td>95</td>
<td>73</td>
<td>80</td>
</tr>
<tr>
<td>Composite</td>
<td></td>
<td>604</td>
<td>81</td>
<td>66</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NC: Non attenuation corrected SPECT; AC: attenuation corrected SPECT; NC: not available.

Table 2: Clinical value of attenuation correction

| Conformed Potential |
|---------------------|-----------------|
| Improved accuracy    | Increased reliability |
| Increased sensitivity | Improved visualization of small and LE |
| Improved diagnostic accuracy | Enhanced progression, viability |
| Improved myocardial viability | Absolute flow quantification |
| Increased coronary artery disease | ENK and coronary artery disease |

Myocardial SPECT is useful!


Table 5: Effect of CT-based AC on SPECT defect size in all patients with angiographic CAD (>50% stenosis) and its impact on radiation and morbidity
defects

<table>
<thead>
<tr>
<th></th>
<th>Attenuation corrected SPECT defect size</th>
<th>Attenuation corrected SPECT defect size</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All patients</td>
<td>8% ± 9% of LV</td>
<td>10% ± 10% of LV</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Anterior defects (n = 25)</td>
<td>12% ± 16% of LV</td>
<td>17% ± 14% of LV</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Inferior defects (n = 42)</td>
<td>9% ± 7% of LV</td>
<td>10% ± 8% of LV</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

False positive rate improved

Attenuation correction:
- Improves uniformity of normal myocardium
- Detected defects are larger (especially anterior)

Myocardial SPECT is useful!


- Promises not fulfilled yet (for the routine):
  - MRI as a one-step solution for heart imaging (ACC, 25 years ago)
  - 3D stress ultrasound
- SPECT: diagnosis and prognosis (PET: not)
- Dedicated heart SPECT ~ 200 k$: cheaper than heart ultrasound

Proven and potential advantages of attenuation corrected myocardial SPECT