HYBRID IMAGING: SPECT / CT

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Hybrid Imaging in Cardiac Nuclear Medicine

1. Attenuation Correction
2. May derive some information from CT such as,
   a) Non-cardiac findings
   b) Pericardial abnormalities
3. Calcium score.
4. Combined CTCA and SPECT
Why Attenuation Correction

• Anatomical regions usually uneven or heterogeneous and therefore photon attenuation is unavoidable.
• Unavoidable problems do affect quality.
• Attenuation correction therefore desirable.
1. PHOTON ATTENUATION

- Gamma photons emitted by radiopharmaceuticals interact with tissues as they pass through the body
  - Absorbed (attenuated)
  - Scattered (Compton)
  - Attenuation is energy-dependent

![Graph showing photon transmission through different tissues]
Most anatomical regions are heterogeneous – radionuclide data contains errors due to photon attenuation (artifacts).

Photon attenuation is unavoidable.

Photon attenuation seriously affects quality of diagnostic information.

**BREAST ATTENUATION IN MPS**

**DEPTH ATTENUATION**

\[ b \gg a \]
1. PHOTON ATTENUATION (CONT)

• Exponential relationship for photon attenuation:

\[ I = I_0 e^{-\mu x} \]

where

- \( I_0 \) = incident photon energy
- \( I \) = transmitted photon energy
- \( x \) = tissue thickness (cm)
- \( \mu \) = linear attenuation coefficient (cm\(^{-1}\))

• Attenuation Correction is **vital** to the production of artifact-free data

REF: ZAIDI, 2006
2. DETERMINATION OF $\mu$-MAP

- Need to generate an attenuation map
  - Spatial distribution of $\mu$ values ($\mu$-map)
  - Incorporated into reconstruction algorithm to correct for photon attenuation and scatter
- Patient-specific $\mu$-map can be generated from CT data
2. DETERMINATION OF $\mu$-MAP (CONT)

- But raw CT data is normalised for variations in x-ray spectrum

\[ CT = \frac{\mu_{CT}(x, y) - \mu_W}{\mu_W} \times 1000 \]

where

- $CT = $ CT number (Hounsfield Units)
- $\mu_{CT} =$ LAC of irradiated tissue (cm$^{-1}$)
- $\mu_W =$ LAC of water (0.1504 cm$^{-1}$)

- E.g., Air = -1000 HU, fat = -100 HU, water = 0 HU, bone = 1000 HU

- Need to transform CT numbers back into $\mu$ values at correct energy
2. DETERMINATION OF $\mu$-MAP (CONT)

- Acquire CT scans of known $\mu$ values using phantom
- Generate a lookup table using bilinear scaling:
Improved Outcome Prediction by SPECT Myocardial Perfusion Imaging After CT Attenuation Correction

The low event rate in patients with a CT-AC SSS of 0 was maintained over at least 4 y, perhaps suggesting a warranty period of more than 4 y for this low-risk population. By contrast, many events were observed in the intermediate-risk group (CT-AC SSS, 1–8) after 2.8 y, leading to a merging with the high-risk group (CT-AC SSS, >8) after 3.5 y (Fig. 3B). This merge may be interpreted as a process of atherosclerosis precipitating after 2.8 y, causing a shift toward the high-risk population.

FIGURE 2. Rates of MACEs (cardiac death or myocardial infarction) are given for different ranges of SSS. With attenuation correction, prognostically relevant SSS cutoff is shifted toward lower values.


Zurich University Hospital
There is substantial and convincing scientific evidence for health risks following high-dose exposures. However, below 5–10 rem [50-100 mSv] (which includes occupational and environmental exposures), risks of health effects are either too small to be observed or are nonexistent.

Linear-No-Threshold Model
(Any radiation = harmful even at low doses) : controversial ? inaccurate
Conclusions The increased incidence of cancer after CT scan exposure in this cohort was mostly due to irradiation. Because the cancer excess was still continuing at the end of follow-up, the eventual lifetime risk from CT scans cannot yet be determined. Radiation doses from contemporary CT scans are likely to be lower than those in 1985-2005, but some increase in cancer risk is still likely from current scans. Future CT scans should be limited to situations where there is a definite clinical indication, with every scan optimised to provide a diagnostic CT image at the lowest possible radiation dose.
Radiation Protection Primer

Most radiation workers adopt the ALARA principle = As Low As Reasonably Achievable

- Conventional diagnostic Cardiac Imaging with NM & CT: generally already low radiation exposure & can be justified if clinically indicated (CAD = potentially life-threatening)

- With CZT SPECT CT: radiation dosage even lower → comparable to natural exposure in magnitude
- With NO compromise on image & diagnostic quality
Calcium Score

• In Hybrid model using SPECT /CT there are different ways to score calcium
• Visual
• Qualitative
• Quantitative
Coronary Calcification (DST 16 slice)

No Calcification

Moderate Calcification

Severe Calcification

Left Main

LAD

LCX

Brigham and Women's Hospital
Coronary Calcium Score

-Routinely performed in patients with no known CAD (unless specifically requested not to)
-Low dose (<1mSv), non-contrast CT breath-hold, prospective ECG gating, software detection of HU >130 in coronary distribution
-CT also used for attenuation correction,
We followed-up 1,126 generally asymptomatic subjects without previous cardiovascular disease who had a CACS and stress SPECT scan performed within a close time period (median 56 days). The median follow-up was 6.9 years. End points analyzed were total cardiac events and all-cause death/myocardial infarction (MI).

An abnormal SPECT result increased with increasing CACS from $<1\%$ (CACS $\leq 10$) to $29\%$ (CACS $>400$) ($p < 0.001$). Total cardiac events and death/MI also increased with increasing CACS and abnormal SPECT results ($p < 0.001$). In subjects with a normal SPECT result, CACS added incremental prognostic information, with a 3.55-fold relative increase for any cardiac event (2.75-fold for death/MI) when the CACS was severe ($>400$) versus minimal ($\leq 10$). Separation of the survival curves occurred at 3 years after initial testing for all cardiac events and at 5 years for death/MI.

The CACS and SPECT findings are independent and complementary predictors of short- and long-term cardiac events. Despite a normal SPECT result, a severe CACS identifies subjects at high long-term cardiac risk. After a normal SPECT result, our findings support performing a CACS in patients who are at intermediate or high clinical risk for coronary artery disease to better define those who will have a high long-term risk for adverse cardiac events. (J Am Coll Cardiol 2009;54:1872–82) © 2009 by the American College of Cardiology Foundation
Figure 5 Adjusted Annualized Event Rates Based on CACS and SPECT Results

Adjusted annualized total cardiac death, MI, and coronary revascularization (A) and all-cause death/MI (B) event rates based on CACS and SPECT results. Abbreviations as in Figures 1 and 2.
Figure 1  Relation Between CACS and SPECT Results

Relation between coronary artery calcium score (CACS) severity and stress single-photon emission computed tomography (SPECT) results in 717 subjects who underwent both tests within 6 months. The percentage of subjects with an abnormal SPECT result ($p < 0.001$) and those with a large stress-induced total ($≥15\%$) and ischemic ($≥10\%$) left ventricular (LV) perfusion defect size (PDS) ($p < 0.001$) significantly increased with increasing CACS severity.

JACC 2009; 54: 1872-82
Figure 1. The frequency of an ischemic myocardial perfusion single-photon emission computed tomography (≥5% ischemic) (stippled bars) and of a moderate to severe ischemia (>10% ischemic) (black bars) for patients divided into six coronary artery calcium (CAC) score groupings.
Coronary Calcium Score: Incremental Dx Value over SPECT

**FIGURE 3.** ROC curve for detection of significant CAD (≥50% stenosis) in patients with normal MPI results (n = 42) by use of CAC score. CAC score of greater than or equal to 709 was optimal cutoff for detecting patients with CAD missed by SPECT (arrow). AUC = area under curve.

Detection of Significant CAD (n = 77) (≥50% stenosis)

<table>
<thead>
<tr>
<th>Imaging</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
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<tr>
<td>SPECT alone</td>
<td>76</td>
<td>91</td>
<td>91</td>
<td>76</td>
</tr>
<tr>
<td>SPECT plus CAC score</td>
<td>86</td>
<td>86</td>
<td>88</td>
<td>83</td>
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Combining SPECT with the CAC score (at a cutoff of 709) improved the sensitivity of SPECT (from 76% to 86%) for the detection of CAD, in association with a nonsignificant decrease in specificity (from 91% to 86%).
49-year-old female
- Chest pain, positive EST
- Normal stress /rest MIBI
- Normal CACS = 0

confirming that she did not have significant CAD.

J Nucl Cardiol 2005;12: 392-400
68-year-old female without known CAD
- chest pain
- risk factors: age & positive family history.
- Normal stress / rest MIBI
- CACS = 1753, marked calcification in LAD, LCx, LM
- reclassified from no significant CAD to significant disease, and aggressive medical therapy was started.
COMMENTS on CACS

- Simple, fast, no contraindications, no contrast
- Screen patients with intermediate risk: Positive CAC ➔ increased risk ➔ alter therapeutic goals (LDL, BP etc)
- **Further stratify higher risk patients with normal stress-rest MIBI**
- Identify patients who do not need further cardiac evaluation (CACS = 0, low clinical risk)
- Monitor progression of atherosclerosis
- Improve compliance
GE Hybrid CZT SPECT-CT Discovery 570C

- Better image quality
- In less time
- Less radiation to patients
CT - Prospective ECG-Triggering

Zurich University Hospital


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<tr>
<th>CT</th>
<th>Radiation Dose</th>
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<td>64-slice CT unmodulated</td>
<td>25 mSv</td>
</tr>
<tr>
<td>64-slice CT modulated</td>
<td>15 mSv</td>
</tr>
<tr>
<td>64-slice CT optimized protocols</td>
<td>&lt;9 mSv</td>
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| 64-slice CT prospective gating          | ~ 2 mSv         | Eur Heart J 2008

Invasive angiography 2-20 mSv (mean 7) Circulation. 2007;116:1290-1305

Together with ASIR software (Adaptive Statistical Iterative Reconstruction) Markedly reduced radiation dose in CTCA and also in low dose CT for AC & coronary calcium score
Validation of CT attenuation correction for CZT camera

Non-attenuation corrected MIBI images (NC)

Attenuation Map from low dose CT

Attenuation corrected MIBI images (AC)

Normal stress/rest MPI with inferior attenuation artefact corrected with CT AC for CZT Camera

University Hospital Zurich  
J Nucl Med 2010; 51:1539–1544
Method: Compare conventional state-of-the-art (Philips Precedence) SPECT-CT hybrid camera with the Discovery 570c SPECT-CT hybrid camera in 25 randomly selected patients from each camera (single day scan protocol).

Conclusion:
- CZT SPECT-CT with ASIR: major reductions in both radiation dose & scanning time while maintaining high image quality.
- An ultralow dose stress only (100MBq) SPECT-CT protocol including calcium score with total effective radiation dose of 1.6mSv is achievable.

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If Ultra-low dose stress only & CAC
• Her recent chest pains were most likely not due to myocardial ischaemia. Given her age and dyslipidaemia she is however at risk for coronary artery disease. I arranged for her to have an ultralow radiation stress only MIBI scan and a Coronary Artery Calcium Score at Bankstown Hospital. If she has significant coronary artery calcifications I would have a low threshold in commencing her on lipid lowering medication. Obviously if she has evidence of ischaemia I would perform coronary angiography.
Normal scan. Female MIBI: 165cm 84kg. 100MBq MIBI rest & 300MBq stress images Sestamibi Study
The best (or the prettiest) for last
Incremental value of CTCA & software SPECT/CT fusion
Assess Stent patency

M63 asymptomatic aircraft pilot for F/U MPI 6 months after Drug Eluting Stent of significant mid LAD stenosis. Small reversible apical ischaemia is due to overstented thin second Diagonal at its origin and the LAD stent is deemed patent. As no further interventional options available, his pilot license had to be downgraded to copilot.

Zurich University Hospital | Gaemperli et al.

European Heart Journal 2006
Incremental value of CTCA & software SPECT/CT fusion over CA

Anatomical Anomaly

FIGURE 3. (A) Perfusion polar maps at stress (dobutamine stress) and rest show reversible anteroseptal perfusion defect. (B and C) 64-slice CTA revealed myocardial bridging (MB) of mid LAD of >2-cm length and calcified plaque at origin of first diagonal branch (DA). (D) Fused 3D SPECT/CT images could allocate reversible perfusion defect to DA, whereas MB seemed to be hemodynamically insignificant.
Incremental value of CTCA & software SPECT/CT fusion over CA

FIGURE 2. (A) Stress and rest perfusion polar maps of SPECT-MPI study show mixed basal anterolateral defect and reversible inferoapical perfusion defect (arrowheads). (B and D) Fused SPECT/CT images reveal total occlusion of LAD and subtotal occlusion of first diagonal branch (DA1), which are confirmed by conventional CA (C). Anterolateral perfusion defect is caused by lesion of partially calcified small intermediary branch (IM); however, this vessel is not well visualized by CA.

Where will this technology take us

• Clinical relevance?
• Will this technology change or influence management
• Outcomes: will combining technologies- CTCA and MPS change or improve outcomes
• Radiation burden
• Cost
CONCLUSION

1. Attenuation Correction- use it but can't always rely on it. Never ignore the NC data. Caveat: Quantification with commercially available software

2. Calcium score- Is the evidence trending towards doing it routinely with the hybrid model
CONCLUSION

1. Combined anatomical and functional assessment of the heart is a reality with Novel CZT SPECT CT with major reduction in radiation while maintaining high image quality.

2. Ultralow dose stress only SPECT-CT with CAC with total dose <2mSv feasible.

3. Hybrid SPECT / CTCA : Not sure maybe for the low SDS to prevent ICA and provide one stop shop
Potential Uses of CT in Acute Chest Pain

- **Coronary calcium score**
  - Negative predictive value for TCS of 0 is >95%
  - Assess preclinical atherosclerosis
  - Independent predictor of:
    - Obstructive CAD
    - Risk of event

- **Coronary CT angiography**
  - High negative predictive value for normal CTA

- **Attenuation correction in SPECT/CT scanners**

- **Identification of other causes of chest pain**
  - Dissecting aneurysm
  - Pulmonary embolism

(may miss soft plaque)
Thank You
Log hazard ratio for revascularization (Revasc) vs medical therapy (Medical Rx) as a function of % myocardium ischemic based on final Cox proportional hazards model.