Overcoming Attenuation Artifacts: How to use attenuation correction
Is SPECT/CT Superior to SPECT?

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Artifacts in SPECT MPI

- **Mechanical & electronical**
  - Energy window

- **Biological**
  - Myocardial hypertrophy

- **Patient-related artifacts**
  - Soft-tissue attenuation
    - breast lateral chest-wall fat diaphragm
    - Superimposed abdominal visceral activity

- **Technical artifacts**
  - Selection or cardiac axes
  - Selection of apex and base for polar map
ATTENUATION

As a gamma camera head rotates around the body, the attenuation of the projected radiation varies with the amount of tissue and the type of tissue that it had to travel through.
The attenuation equation is:
\[ A_x = A_0 e^{-ux} \]

The most frequently noted effects of attenuation in myocardial SPECT are artifacts associated with breast attenuation in women and diaphragmatic attenuation in men.

Attenuation artifacts are more severe using Tl\textsuperscript{201} than with Tc\textsuperscript{99m} due to Thallium’s lower energies.
Attenuation causes quantitative errors as well as distortions in the projection profiles that are propagated into the reconstructed images. Knowledge of the attenuating distribution is required for attenuation correction. Solid lines depict true profile; dotted lines depict attenuated profile.
Soft-tissue attenuation

- Soft-tissue attenuator overlie the left ventricle
- => decrease in count density
- Location: depend on the position of soft-tissue attenuator
- Severity: depend on size, density, energy of radioisotope, 360 or 180 degree acquisition
- Artifact: fix, reversible defect or reverse redistribution
Breast attenuation

• Most commonly encountered attenuation artifact in cardiac SPECT
• Extremely variable in appearance
• Consider the position and configuration of the breasts with patients in supine position
• Breast prosthesis
Breast attenuation

- Women of average body habitus: anterior, anteroseptal, anterolateral walls
- Women with large, pendulous breasts: lateral attenuation artifacts
- Elderly women with very large, pendulous breasts: lateral abdominal wall
- Not necessarily directly proportional to breast size, but may vary considerably according to the position, configuration, and density of the breast.
Diaphragmatic attenuation

- Left hemidiaphragm, right ventricle (lesser degree) => decrease count density in inferior wall of left ventricle
- Diaphragmatic elevation: obesity, pleural or pulmonary parenchymal disease, atelectasia, loss of lung volume, diaphragmatic paralysis, gastric dilation.
Diaphragmatic attenuation

- Attenuation artifacts usually constant (fixed)
- Ascites, peritoneal dialysis: Upright exercise => ascites fluid may shift to the pelvis => less marked attenuation than in resting images
- Barium contrast
ATTENUATION CORRECTION

• One method of handling attenuation artifacts is simply to reduce their clinical impact through scanning techniques and knowledge of their location and severity when they occur.
Conventional Correction Methods

- The most common correction methods have been a pre-reconstruction method based on work by Sorensen and a post reconstruction method developed by Chang.

- Not used in myocardial perfusion because the thorax is too varied for a constant attenuation coefficient to be effective.
Sealed source transmission scan-based correction methods

- Most common sealed source is gadolinium-135
- Used as a sealed line source with a collimator on top and passed along the patient either after or at the same as the gamma camera is reading
- Important to realize that defects in transmission scan can have a detrimental effect to the attenuation corrected images
A collimated planar beam of photons traverses the patient forming a complete projection profile as the source moves across the full field of view parallel to the system axis. Within the detector, an electronic mask defines a narrow spatial window” opposite the source and moving in unison. external radionuclide source approach whereby a series of 14
external radionuclide source approach whereby a series of 14 collimated and shuttered line sources are positioned in an “array” opposite each detector such that the full detector field of view is irradiated simultaneously.
2 point sources collimated to be incident at oblique angles on the opposing detectors. 133Ba point sources (t1/2 10.5 years, 356 keV gamma emissions) translate along the system axis simultaneously or sequentially with the emission acquisition. The transmission source is positioned such that the beam is incident on the detectors at an angle to the hole axes. Transmission photons penetrate the collimator septa for detection.
Sealed Source

- Many of the SPECT QC procedures transfer over to the transmission imaging systems.
- You must check the transmission tomogram for artifacts (motion, gating, missing frames).
- Other problems arise from old line sources decayed beyond being usable and body truncation.
Attenuation Map

A CT image is a measure of attenuation profiles in different angular projections.

The reconstructed image is a two-dimensional map of linear attenuation correction \( \mu(x,y) \) of the X radiation.
\( \mu(x,y) \) is depending on the energy of the X ray and it is expressed as Hounsfield Units.

\[
\text{CT-number} = \frac{\mu - \mu_{\text{water}}}{\mu_{\text{water}}} \cdot 1000
\]
Conversione #CT in funzione delle diverse energie del fascio

COEFFICIENTE LINEARE DI ATTENUAZIONE

Mix aria-acqua
Mix osso-acqua
Rapporto tra i coefficienti di attenuazione lineare in funzione dell’energia del fotone per diversi tessuti
Beam hardening

L’aumento della energia media del fascio di raggi X è funzione: della densità dell’assorbitore dello spessore dell’assorbitore

Correzione mediante calibrazione e correzione iterativa
Normalization for matrix size

CT scan $512 \times 512$

SPECT Image $64 \times 64$

Attenuation Image $64 \times 64$
Motion artifacts: Upward creep

• A patient’s rate and depth of respiration increase markedly during dynamic exercise, resulting in more marked, increased lung volume, and a lower position of the diaphragm. During the acquisition, as the depth of respiration decreases, the height of the diaphragm will progressively rise, with a gradual upward shift of the heart.

• Due to abdominal relaxation and modification of diaphragmatic excursion a upward-shift of the heart is commonly observed during acquisition even after rest injection.
A new source of errors:

- Misregistration of Emission and Transmission Scans
Stress

Rest
Single Photon Emission Computerized Tomography (SPECT/CT)
A multicenter evaluation of commercial attenuation compensation techniques in cardiac SPECT using phantom models

O'Connor MK et al. J Nucl Cardiol 2002;9:361-76
A multicenter evaluation of commercial attenuation compensation techniques in cardiac SPECT using phantom models  
O'Connor MK et al. J Nucl Cardiol 2002;9:361-76
Clinical validation of SPECT attenuation correction using x-ray CT

Previous Inferior MI
109 Consecutive pts with inferior MI

<table>
<thead>
<tr>
<th></th>
<th>ATN uncorrected</th>
<th>ATN corrected</th>
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<tbody>
<tr>
<td>SSS</td>
<td>14.02±7.9</td>
<td>9.4±7.1</td>
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<tr>
<td></td>
<td>P&lt;0.001</td>
<td>P&lt;0.001</td>
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<tr>
<td>SRS</td>
<td>9.5±7</td>
<td>5.6±6.1</td>
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<tr>
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<td>P&lt;0.001</td>
<td>P&lt;n.s.</td>
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<tr>
<td>SDS</td>
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<td>3.8±2.8</td>
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<td>P&lt;n.s.</td>
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Kaplan-Meier survival curves (end point cardiac death) based on the location of reversible perfusion abnormalities.

CONTROVERSIES IN NUCLEAR CARDIOLOGY

- Attenuation correction in cardiac SPECT: The boy who cried wolf?

Although no one would deny that accurate AC could improve SPECT MPI, the question as to whether current implementations are sufficiently robust remains unanswered, especially with regard to the average user.
Clinical value of attenuation correction in stress-only Tc-99m sestamibi SPECT imaging

CONTROVERSIES IN NUCLEAR CARDIOLOGY

• SPECT attenuation correction: An essential tool to realize nuclear cardiology’s manifest destiny
  – E.V. Garcia (J Nucl Cardiol 2007;14:16-24.)

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity %</th>
<th>Specificity %</th>
<th>Normalcy %</th>
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<tr>
<td></td>
<td>Years</td>
<td>Pazienti</td>
<td>NC</td>
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<tr>
<td>totale - media</td>
<td>1996 - 2006</td>
<td>1327</td>
<td>86</td>
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AC markedly improves diagnostic accuracy over no AC regardless of:
✓ clinical site,
✓ radionuclide used,
✓ camera manufacturer,
✓ whether quantitative versus qualitative techniques are used,
✓ whether an obese versus a non obese population is studied
✓ whether exercise or pharmacologic stress is used
What is needed?

• Adequate technology
• Application specialists aware of technical and physiopathological issues
• A quick automatic quality control on MPI SPECT and CT realignment
• A possibility of manual realignment for SPECT and CT
Shielding (1/16-inch lead) is usually required at the walls along the sides and back of the gantry.
# EXPERIMENTAL EVALUATION

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Pixel size</td>
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<tr>
<td>range</td>
<td>180°</td>
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<tr>
<td>step</td>
<td>3°</td>
</tr>
<tr>
<td>collimator</td>
<td>cast HR</td>
</tr>
<tr>
<td>BPF</td>
<td>Butt. 0.35 - 5</td>
</tr>
<tr>
<td>Max count density (wall)</td>
<td>95 counts</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
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<tbody>
<tr>
<td>LV wall Volume</td>
<td>110 cc</td>
</tr>
<tr>
<td>External source Volume</td>
<td>150 cc</td>
</tr>
<tr>
<td>Source-myocardial wall distance</td>
<td>30 - 50 mm</td>
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</table>

<table>
<thead>
<tr>
<th>Uptake ratio</th>
<th>LV wall</th>
<th>ext.souce</th>
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<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
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<tr>
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<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>4</td>
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Results:

Ratio 1 : 1

Ratio 1 : 2

Ratio 1 : 4
Minimize superimposed abdominal visceral activity

• Exercise Tl-201 studies: maximal exercise
• Dipyridamole Tl-201 and Tc-99m sestamibi studies: add dynamic, submaximal exercise (walking, biking)
  – Exercise is performed immediately after the infusion of dipyridamole, and radiotracer is injected during exercise, at least 1 minute before its cessation.
• Tc-99m sestamibi: wait 60 min, fat meal after injection, 2 glasses of water before imaging
Conclusion:

• SPECT myocardial perfusion imaging

• Poor specificity caused by image artifacts.

• Recognize the sources of artifacts to avoid misinterpretations

• => Improve the specificity
11th statement