Software and Hardware Advances in Nuclear Cardiology

Roger Fulton
Department of Medical Physics, Westmead Hospital, Sydney
Faculty of Health Sciences, University of Sydney
Software Advances:

Iterative Reconstruction Algorithms
Maximum Likelihood Expectation Maximisation (MLEM)

Patient

Original projections

BP

NO CHANGE

update (x ratio)

Estimated projections

FP

Current estimate
Iterative reconstruction algorithms can

• model the imaging system and other factors affecting the measured projections, such as
  • attenuation
  • noise
  • scatter
  • factors degrading spatial resolution
  • patient motion
Modelling the system response for resolution recovery

Maximum Likelihood Expectation Maximization (MLEM)

Patient → Original projections → Estimated projections

BP → NO CHANGE

update (x ratio) → Current estimate

FP ←
Accelerating Iterative Reconstruction:

Ordered Subsets EM (OSEM)
‘Ordered Subsets’ reconstruction

Acceleration factor = Number of subsets
Acceleration with Ordered Subsets (OSEM)

A)

1 subsets

B)

4 subsets

C)

16 subsets

D)

16 subsets filtered

PET point spread function (PSF) modelling
PSF modelling

Casey M. (2007) Siemens Molecular Imaging
PSF modelling – realistic conditions

Anthropomorphic Torso Phantom with four 12mm 1.4 MBq $^{68}$Ge spheres in warm background.

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Casey M. (2007) Siemens Molecular Imaging
PET resolution recovery with OSEM

Le Meunier L et al., J Nucl Cardiol 2010;17(3):414-426
SPECT Hardware Advances
Dedicated cardiac imaging systems

- Optimized for cardiac imaging
- New solid state detectors
- Multi-pinhole or high-sensitivity parallel-hole collimators.

Goals

- reduced acquisition time
- reduced radiation dose
Cadmium zinc telluride (CZT) detectors

- high count rate capability (> 10 million photons/s/mm²).
- superior intrinsic spatial resolution (~2.5mm FWHM)
- superior resolution (~1.5% @ 140 keV)
- expensive.
- Convert γ-ray energy directly to electrical signal – no need for PMTs.
- enable smaller and more efficient devices
D-SPECT (Spectrum Dynamics)

- Detector columns swivel through 110°
- Pixelated as 16x16 CZT elements.
- High-sensitivity parallel hole collimator
Discovery NM 530c (GE)

- 19 pinhole collimators, each with 4 pixelated CZT detectors
- No detector motion
• Confocal collimators with conventional SPECT/CT camera.
• Converging holes magnify the heart
• Sensitivity more than double conventional SPECT.
Cardius 3 XPO (Digirad)

- 3 solid state detectors
- Pixelated CsI(Tl), silicon photodiodes
- Rotating chair
Dedicated Cardiac SPECT cameras

- Better image resolution and improved count sensitivity than conventional dual-head SPECT systems.
- Improved sensitivity => shorter imaging times (or lower injected dose), dynamic studies.

Attenuation correction

- Offered by most vendors;
  - IQ SPECT, NM 530c – SPECT/CT configuration available
  - Cardius 3 XPO – x-ray based system optional
  - D-SPECT – not available
- If hardware unavailable AC can be performed using a separately acquired CT scan.

PET Hardware Advances
PET/CT Cardiac Imaging

- $^{18}$F-FDG for viability, $^{13}$N-ammonia or $^{82}$Rb for perfusion imaging.
- Higher spatial and temporal resolution, and sensitivity, than SPECT
- Combines structure and function
- High-end CTs => CT-coronary angiography and calcium scoring.
Time-of-Flight (TOF) PET

\[ x = \frac{(T2 - T1) \times c}{2} \]

\[ c = \text{speed of light} \]

Courtesy M. Conti, Siemens Medical Solutions
Time-of-Flight (TOF) PET

Non-TOF

TOF
TOF and RR reconstruction (\(^{82}\)Rb PET/CT)

OSEM

OSEM with TOF and RR

PET/MR

- Concurrent imaging => simultaneous cardiac gating of PET and MR data.
- No radiation exposure from CT
- Advanced functional and molecular cardiac imaging with MR
- Deriving attenuation map is challenging
- Electromagnetic fields problematic for patients with pacemakers, implantable defibrillators.
Conclusions

Software advances

• Efficient iterative reconstruction algorithms with ability to model and compensate for physical effects that degrade image quality, e.g.
  • attenuation
  • noise
  • scatter
  • spatial resolution loss
  • motion
Conclusions

SPECT Hardware

• new dedicated cardiac SPECT systems give up to 2x improvement in spatial resolution and 7x reduction of radiation dose or time compared with conventional SPECT.
• dedicated scanners are relatively costly.
• conventional SPECT systems will be around for a while
• some vendors offer retrofitting of dedicated cardiac collimators to conventional scanners.
• not all offer attenuation correction
Conclusions

PET Hardware

• Hybrid PET/CT
• New detectors - digital silicon photomultipliers (Si-PMs) and avalanche photodiodes (APDs) have enabled simultaneous PET/MR
• Si-PMs => good timing resolution
• TOF imaging
• Simultaneous PET/MR has entered the clinical arena.
• Time will tell its ultimate clinical role.
Thank you
Recent PET state-of-the-art

- Fast scintillators (LSO, LYSO) for improved high count rate performance, and better random rejection than previous BGO
- 3D acquisition for improved sensitivity
- Smaller detector elements for increased spatial resolution (~ 4.5mm FWHM)
- Large axial coverage (up to 25cm)
SUMMARY

Recent software and hardware developments in nuclear cardiology have delivered many improvements.

• Iterative reconstruction algorithms for improved image quality and quantitative accuracy

• New detectors with improved high count rate performance, energy resolution and timing resolution

• Dedicated SPECT systems with improved sensitivity and spatial resolution

• Hybrid PET/CT and PET/MR systems with TOF and resolution modelling.

• All of these have already-established or potential benefits for cardiac imaging. Time will determine their ultimate role.
Reconstructing Attenuation Map from Emission data

MLAA
• Simultaneous iterative (maximum likelihood) reconstruction of attenuation and activity

• Both attenuation and activity derived from the measured emission data.
TOF-PET data determine the attenuation up to a constant

CT-based attenuation

TOF-PET-based attenuation
TOF-PET data determine the attenuation up to a constant

CT-based attenuation

TOF-PET-based attenuation

Exchanging contours reveals PET/CT mismatch
## Dose Reduction - D-SPECT Simulation

### Very-low dose stress MPS and reproducibility of TPD

<table>
<thead>
<tr>
<th>Counts in left ventricle</th>
<th>Gradually lowered count level (list mode reconstruction)</th>
<th>TPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.0 million</td>
<td></td>
<td>11%</td>
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<td>3.6 million</td>
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<td>12%</td>
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<td>2.0 million</td>
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<td>12%</td>
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<tr>
<td>1.3 million</td>
<td></td>
<td>12%</td>
</tr>
<tr>
<td>1.0 million</td>
<td>Effective dose 1mSv</td>
<td>12%</td>
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<tr>
<td>0.7 million</td>
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<td>12%</td>
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<tr>
<td>0.5 million</td>
<td></td>
<td>9%</td>
</tr>
</tbody>
</table>

Methods: Tumor Phantom Model

Guerin and El Fakhri, Med Phys 2011
Tumor Phantom Results: Motion estimation

Source

Target

Estimated motion
Methods: Tagged MR

GRE sequence

GRE sequence with tagging

Tagging patterns provide additional motion information.