New Software Developments to Shorten Scan Times for Gated Perfusion SPECT: A Critical Analysis

Tracy L Faber
Emory University

* Tracy Faber receives royalties from the sale of the Emory Cardiac Toolbox
Most important recent software development for reducing scan times is resolution recovery

- Modeling the collimator and detector physics within an iterative reconstruction algorithm to improve resolution

  coupled with

- Innovative noise reduction techniques

- Astonish
  - Philips Medical Systems, www.medical.philips.com

- Evolution
  - GE Healthcare, www.gehealthcare.com

- Flash 3D
  - Siemens Medical Solutions USA, www.siemens.com/medical

- nSpeed
  - DIGIRAD Corporation, www.digirad.com

- Wide Beam Reconstruction
  - UltraSPECT Inc., www.ultraspect.com
Why should resolution recovery allow reduced scan times?

- Low-count (due to short scan times) high resolution images (due to resolution recovery) can be filtered to remove noise – so that resolution and noise levels are similar to FBP.
- Resolution recovery actually reduces noise – so the same signal/noise as FBP could be attained in less time.
Resolution Recovery Decreases Noise

Resolution and Detector Response

Intrinsic Resolution
Extrinsic Resolution
Shorter source-to-collimator distance increases resolution

Shorter collimator holes decrease resolution

Wider collimator holes decrease resolution

Detector Response Extrinsic Resolution
Summing Circuit

Output Current

Photomultiplier tubes

Crystal

Detector Response Extrinsic Resolution

Primary electron

Secondary electrons

γ
To correct for resolution

• Account for detector physics
  – Need to know the detector
    • Database of known detectors and their characteristics
    • Specific detector must be in the dicom header

• Account for the size, shape of the collimator
  – Need to know the collimator
    • Database of known collimators and their characteristics
    • Specific collimator must be in the dicom header

• Account for the distance of the detector from the patient
  • Orbit shape, radius, and/or distance from the patient must be in the dicom header
  • OR, distance must be estimated
MLEM

Image^{k+1} = Image^{k} \times \text{Correction factor}

MLEM:
Correction factor =
\frac{\text{Backprojection(Measured Projections/Reprojections of Image}^{k})}{\text{Normalization factor}}

MAP:
Correction factor =
\frac{\text{Backprojection(Measured Projections/Reprojections of Image}^{k})}{\text{Normalization factor + Local smoothing term}}
Reprojection/Backprojection without Detector Response

Reprojection/Backprojection with Detector Response
How do the different programs compare?

Includes detector specific modeling using a database of known detectors and information from dicom header

Astonish
Evolution
Flash3d
nSPEED
WBR

Includes collimator specific modeling using a database of known collimators and information from dicom header

Astonish
Evolution
Flash3d
nSPEED
WBR
• Includes patient-to-detector distance using information from dicom header
  Astonish
  Evolution
  Flash3d
  WBR
  nSPEED

• Includes patient-to-detector distance by estimating it from images
  WBR
Noise reduction

Adds a filter to MLEM iteration in the approach of MAP:
  Evolution
  WBR?

Adds a post-filter after reconstruction
  Flash3D
  nSPEED

Uses the same Hanning filter in each portion of the MLEM algorithm (the original projections, the reprojections, and the backprojected ratio)
  Astonish
Other Corrections:

• Can include scatter and AC
  – Astonish
  – Evolution
  – Flash3D

• Will include scatter and AC in the future
  – nSPEED
Implementation

• Disclosure varies greatly from company to company
• Resolution recovery is very time consuming so that most implementations may include simplifying assumptions to obtain speed
• No reason to believe all will perform similarly
Summary of Clinical and Research Studies

• All patient studies published in refereed journals
• Clinical studies published as abstracts unless superseded by papers
• Particularly interesting phantom study published in a conference proceeding
• Unpublished data from a particularly trustworthy source
WBR


- 50 patients
  - 36 rest Tc-99m 30s / stop (other 14 were Tl-201)
  - 50 stress Tc-99m 20s/stop
  - 50 stress Tc-99m 10s/stop
- Compared SSS,SRS,SDS in half-time WBR vs full-time FBP
- Compared extent of rest and stress defects in half-time WBR vs full-time FBP
- Compared functional parameters in half-time WBR vs. full-time FBP
Evolution and WBR:

Depuey et al., “Ordered subset expectation maximization and wide beam reconstruction “half-time” gated myocardial perfusion SPECT imaging: A comparison to “full-time” filtered backprojection”, JNC 2008, prepublication

- 82 patients/ same day rest/stress Tc-99m
- Full time rest imaging: 25s/stop; 14 minutes
- Full time stress imaging: 20s/stop; 12 minutes
- Half time stress imaging: 10s/stop; 7 minutes
- Compared Evolution and WBR to FBP:
  - Evaluated image quality and functional parameters
**WBR**


- 100 patients
  - Full time: 40s/stop, 30 stops
  - Half time: 10s/stop , 60 stops
- Full time reconstructed with FBP, half-time reconstructed with WBR
- Comparison between functional parameters: EDV, ESV, EF, SMS, STS
Evolution


- 54 Patients
- Same day rest /stress Tc-99m
- Full time imaging 12.5min compared to half time imaging 7.5min
- OSEM reconstructions compared to reconstruction with Evolution
- SSS, SRS, LVEF correlated between full-time OSEM and half time Evolution
nSPEED


• 448 patients- 10 sites
  – Using different cameras
• Standard imaging was compared to half-time reconstructed with nSPEED
• Differences in quality assessed
• Differences in defect severity analyzed
• Differences in LV function measured
Astonish

Venero, et al. Enhancement of nuclear cardiac laboratory efficiency – multicenter evaluation of a new post-processing method with depth-dependent collimator resolution applied to full and half-time acquisitions. ACC 2008 abstract

- 190 patients from 3 sites with cath or low-likelihood
- Full time acquisition: 64 projections, 20-25 seconds/stop
- Half time acquisition: 32 projections, 20-25 seconds/stop generated from the original set
- Full-time FBP and Astonish compared to half-time Astonish
- Analysis of Image quality, sensitivity and specificity
Flash3D


• Gated phantom study
  – 80 realizations of full-time
    • Included 64x64, 128x128, 8frames, 16frames, and EFs of 30,40,50,60%
  – 80 realizations of half-time (every other projection omitted to achieve this)
  – Functional variables compared to known truths
Flash 3D

Ficaro, Kritzman, Corbett, et al.

- 40 Patients
- Stress – Rest Imaging Protocol
- Symbia T6 SPECT/CT Acquisition
  - 128x128 matrix, 4.8mm pixels
  - 32 stops, RAO-to-LPO, @ 20s/stop (64 projections total)
  - NCO (non-circular)
- Half time acquisitions 10s/stop
- Compared normal distributions found with full time FBP and Flash3d vs. half-time Flash3d
Results – Image Quality

- Quality is *almost always* improved with resolution recovery applied to half-time acquisitions compared to FBP with full-time acquisitions

- Differences in quality do not affect diagnostic equivalence

- Quality is *always* degraded with half-time FBP compared to full-time FBP
Comparison of *Stress* Image Quality, Filtered Back Projection, Full time Astonish, Half Time Astonish

Comparison of *Rest* Image Quality, Filtered Back Projection, Full time Astonish, Half Time Astonish

Venero, et al.

FBP
FTA
HTA
FBP
FTA
HTA
FBP
FTA
HTA
SNM 2008 Annual Meeting
Stress Image Quality

- Ex/Good Perfusion: Full Time FBP (85), Astonish (95), Half Time (98), p < 0.001
- Fair/Poor Perfusion: Full Time FBP (0), Astonish (20), Half Time (40), p = 0.002

Percution Function

- Ex/Good Function: Full Time FBP (90), Astonish (98), Half Time (95), p < 0.001
- Fair Function: Full Time FBP (0), Astonish (20), Half Time (40), p < 0.001

Rest Image Quality

- Ex/Good Perfusion: Full Time FBP (80), Astonish (95), Half Time (92), p < 0.001
- Fair/Poor Perfusion: Full Time FBP (0), Astonish (20), Half Time (40), p < 0.001

- Ex/Good Function: Full Time FBP (61), Astonish (85), Half Time (42), p < 0.001
- Fair Function: Full Time FBP (0), Astonish (20), Half Time (40), p < 0.001

Venero, et al.
2D Full Stress (8 min) vs. 3D Half (4 min), Dual Head

Maddahi, J. et al SNM 2008
Diagnostic Equivalence of Blinded Visual Interpretation

3D Half vs. 2D Full (n=448)

99% Diagnostically Equivalent

Stress images

99% Diagnostically Equivalent

Rest images

Maddahi, J. et al SNM 2008
Results - Perfusion

- Defect severity in half time resolution recovery compared to full-time FBP is very similar
  - NSD, maximum 3% difference – Maddahi, nSPEED
  - rest defect extent differed by ~ -1.4% - Borges Neto, WBR
  - stress defect extent differed by ~ -.94% - Borges Neto, WBR

- Summed Scores not significantly different in half-time resolution recovery compared to full-time FBP
  - Correlations between SSS and SRS = ~.75. - Borges Neto, WBR
  - Correlations between SDS = ~.48 - Borges Neto, WBR
  - No significant difference between scores – Venero, Astonish
  - Correlations between SSS = ~.92 - Ali, Evolution
  - Correlations between SRS = ~.93 – Ali, Evolution
• Similar sensitivity, specificity with half time resolution recovery compared to full time FBP – Venero, Astonish
  – Sensitivity:
    • FBP: ~78%
    • Half-time Astonish ~ 88%
  – Specificity:
    • FBP: ~87%
    • Half-time Astonish ~ 81%
  – Normalcy:
    • FBP: ~95%
    • Half-time Astonish: ~ 91%
• No statistical difference in normal distributions between between full time FBP and half time Flash3d- Ficaro, Flash3D
FBP

Half-time WBR

Borges-Neto, et al.
Venero, et al.

Diagnostic Accuracy

<table>
<thead>
<tr>
<th></th>
<th>SENS</th>
<th>SPEC</th>
<th>NORMALCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Def/Prob abnormal vs. others in pts with CAD</td>
<td>p = 0.117</td>
<td>78</td>
<td>81</td>
</tr>
<tr>
<td>Def/Prob normal vs. others in pts without CAD</td>
<td>p = 0.321</td>
<td>87</td>
<td>79</td>
</tr>
<tr>
<td>Def/Prob normal vs. others in Low-likelihood pts</td>
<td>p = 0.581</td>
<td>95</td>
<td>90</td>
</tr>
</tbody>
</table>
### Normal Myocardial Distributions (Male)

<table>
<thead>
<tr>
<th></th>
<th>FBP</th>
<th>FT-IR</th>
<th>HT-IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>77.3±6.5</td>
<td>78.8±7.1</td>
<td>79.6±7.1</td>
</tr>
<tr>
<td>StDev</td>
<td>77.3±6.5</td>
<td>78.8±7.1</td>
<td>79.6±7.1</td>
</tr>
</tbody>
</table>

*Ficaro, et al.*
Results- Function

• EDV
  – EDV from half time resolution recovery correlates well with that from full time FBP
    • R=.95 for Evolution and WBR - Depuey
    • R=.91 for WBR – Borges-Neto
    • R=.99 for nSPEED – Maddahi
    • R=.96 for WBR - Pena
  – EDV may be less with half-time resolution recovery than with full time FBP
    • Significantly less (~15ml) with Evolution Depuey
    • Somewhat less (~3ml NS) with WBR - Depuey
    • Significantly less with WBR (~8ml) – Borges-Neto
    • The same with WBR (NSD) - Pena
    • The same with nSPEED (NSD) – Maddahi
    • The same with Astonish (NSD) - Venero
    • Less with Flash3D (7% compared to true value) - Zeintl
• ESV
  - ESV from half time resolution recovery correlates well with that from full time FBP
    • R=.96 for Evolution and WBR - Depuey
    • R=.83 for WBR – Borges-Neto
    • R=.98 for WBR - Pena
    • R=.99 for nSPEED – Maddahi
  - ESV may be different with half-time resolution recovery than with full time FBP
    • Significantly less (~4ml) with Evolution - Depuey
    • Significantly greater (~5ml) with WBR - Depuey
    • Somewhat less with WBR (~3ml, NS) – Borges-Neto
    • The same with WBR (NSD)- Pena
    • The same for nSPEED - Maddahi
    • The same with Astonish (NSD) - Venero
    • Somewhat less with Flash3d (9% compared to true value) - Zeintl
• EF
  - EF from half time resolution recovery correlates well with that from full time FBP
    - R=.89 for Evolution - Depuey
    - R=.91 for WBR - Depuey
    - R=.59 for WBR – Borges-Neto
    - R=.96 for WBR - Pena
    - R=.96 for nSPEED – Maddahi
    - R=.98 for Flash3D – Zeintl
    - R=.91 for Evolution - Ali
  - EF may be less with half-time resolution recovery than with full time FBP
    - Significantly less (4%) with Evolution Depuey
    - Significantly less (7%) with WBR - Depuey
    - Somewhat less with WBR ( .06%, NSD) – Borges-Neto
    - The same with WBR (NSD) - Pena
    - The same with nSPEED - Maddahi
    - Somewhat less with Flash3d using 64x64x16frames (.8% compared to true value) – Zeintl
    - Much less with Flash3D using 128x128x16frames (16% compared to true value) – Zeintl
    - The same with Astonish (NSD) -Venero
  - Difference in functional variables measured using half time with resolution recovery compared to full time FBP are less than the differences seen when measuring them with the various quantitative packages - Depuey
Depuey, et al.

Zeintl, et al. Slides are not to be reproduced without permission of author.
Measurement of LVEF (%) from Gated Stress Images

3D Half vs. 2D Full / nSPEED

\[ y = 1.005x \]

\[ R^2 = 0.957 \]
• Regional function is probably worse when visualized with half-time resolution recovery compared to full-time FBP
  – Thickening and wall motion scores correlate highly (~.95) but are significantly different - Pena
  – Wall motion is significantly worse with WBR – Depuey
  – Wall motion is somewhat worse with Evolution – Depuey
  – Identification of wall motion abnormalities is significantly worse with half-time FBP
½ - TIME
WBR

Depuey, et al.

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Conclusions

• Half time acquisitions reconstructed with resolution recovery:
  – Improves image quality over filtered backprojection
  – Provides perfusion data and analysis that is very similar to filtered backprojection

• But
  – Results in EDVs and EFs that can be significantly reduced compared to filtered backprojection
  – Results in higher appearance of wall motion abnormalities

• And
  – Requires knowledge of detectors, collimators, and orbit
  – Best protocol for reducing scan time is unknown
  – Interaction with other corrections (AC/scatter) not clear