

SPECT

image quality improvement with Astonish software

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Introduction

Nuclear medicine gamma camera images suffer from poor image quality due to low count statistics and low resolution. These effects limit the clinical application of nuclear medicine procedures, requiring long scan times for blurry images.

Overall SPECT image quality depends on total counts, system configuration (detectors, collimator, gantry geometry) and reconstruction method. For the past three decades, many researchers have been working on the same set of problems for gamma camera imaging: developing a variety of reconstruction methods incorporating scatter correction, resolution recovery, attenuation correction, noise control and detector distance optimization. Although each publication demonstrates advances in image quality in certain ways, few of these advances make it to routine clinical use. In fact, most clinics are still using filtered back-projection (FBP) for their clinical images. Until recently, many of the proposed technologies were not mature to the point of clinical use, requiring too much computing power and an accurate attenuation map. Another factor affecting clinical acceptance of specific techniques is that the problem set is too big, so that few research institutes can address every aspect of nuclear medicine imaging. For the past five years, the Philips R&D team has been working on the same set of problems and focusing on

the key issues in an effort to improve the reconstruction process in a clinically useful manner. We have addressed such concerns as accurate modeling of the system, computing speed, and noise-control methods; as a result, we have observed significant improvement in our gamma camera image quality. Several of these improvements have been implemented in our reconstruction software package, called Astonish. Figure 1 shows the flow chart of how each technology improvement ties together within the iterative reconstruction framework, including features in the current product and future work.

The Astonish SPECT algorithm has been incorporated into the Philips product, AutoSPECT 3.0 for JETStream Workspace as a new reconstruction method. In this white paper, we will use phantom data to demonstrate the quantitative improvements that can be achieved in SPECT data by using Astonish reconstruction. We will also show retrospectively processed patient data to illustrate how Astonish improves the clinical image quality of SPECT images. Finally, we will use patient data to illustrate that because of the improvements in signal-to-noise ratio, Astonish allows clinicians to acquire fewer total counts (that is, for a reduced amount of acquisition time) in cardiac studies while still achieving clinically acceptable images.

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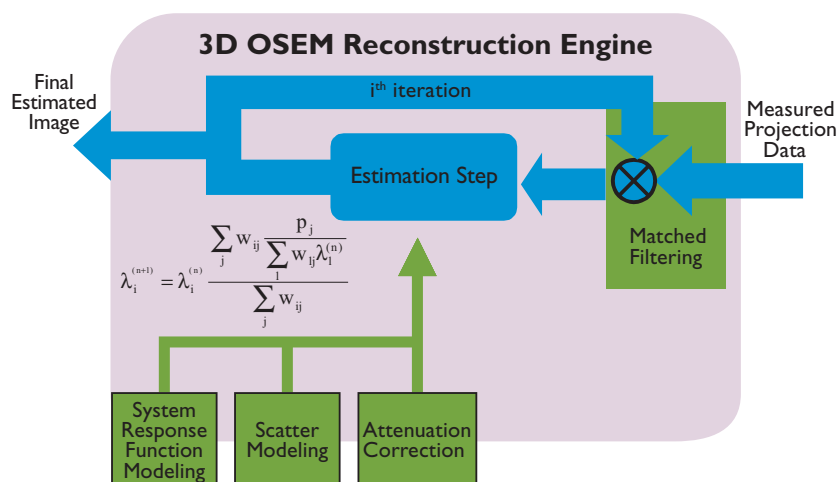


Figure 1. Schematic of Astonish reconstruction using the 3D OSEM iterative method with resolution recovery (system response function modeling), and optional attenuation and scatter modeling.

Techniques

Three-dimensional OSEM reconstruction

The Astonish software package uses a three-dimensional ordered subsets expectation maximization (3D-OSEM) algorithm for image reconstruction. As inherited from the MLEM algorithm, the 3D-OSEM algorithm models the Poisson noise for the counting statistics during data acquisition, avoiding the long-range noise texture (noise streaks, for example) usually seen in FBP reconstructed images. The three-dimensional implementation allows for the incorporation of three-dimensional resolution recovery during image reconstruction.

The major consideration in using an OSEM algorithm rather than an MLEM algorithm is the computational time. Both algorithms start from an estimation of the image, then use the acquired data to update the estimation in an iterative manner for a given number of iterations. For a single MLEM iteration, all the acquired data are used and the estimated image is updated once. For a single OSEM iteration, the acquired data are ordered to a number of subsets, and the estimated image is updated once for each subset. Therefore,

the estimated image is updated as many times as the number of subsets that make up a single OSEM iteration. Since each update in OSEM is equivalent to one update in MLEM, the overall computational time is much less for OSEM reconstruction than for MLEM reconstruction.

Convolution-based three-dimensional resolution recovery

The resolution of a gamma camera system is determined by the intrinsic resolution of the camera (mainly the crystal) and the geometric resolution of the collimator. The geometric resolution depends upon the collimator hole-size and hole-length and upon the distance from the object to the collimator surface. The farther the object is from the collimator surface, the poorer the resolution. The overall system resolution gets poorer with increased distance from the object to the detector surface (denoted as depth-dependent hereafter). The resolution of the detector/collimator combination is usually determined by measuring the full-width at half-maximum (FWHM) of point sources imaged at different distances from the collimator surface. The overall system resolution can also be influenced by camera geometry, and is measured by calculating the FWHM of line sources imaged in SPECT geometry at different SPECT radii.

To improve SPECT image resolution, a key consideration is the modeling of the resolution degradation factors, i.e., the depth-dependent resolution of the system. One approach de-blurs the acquired data by modeling the resolution at an averaged distance. It under-recovers the resolution for objects beyond that average distance and over-recovers the resolution for objects

within the average range. Another approach uses the frequency-distance principle (FDP) (Li et al 1999) to model the depth-dependent resolution of the system. However, this method is still an approximation, and works best with circular 360° orbits.

Astonish software uses the convolution method (Ye 1992) to model the varying resolution at different distances from the detector for three-dimensional depth-dependent resolution recovery. At each detector position, the distance from the detector surface to the image center is required for the accurate modeling of the depth-dependent resolution. The latest releases of the Philips gamma cameras Forte version 2.0, SKYLIGHT version 3.1, Precedence version 1.0, and CardioMD version 2.0, all include this information so that ideal resolution recovery can be performed. This approach allows for accurate depth-dependent resolution recovery as well as easy integration with non-uniform attenuation and scatter corrections.

Matched filtering

Achieving excellent resolution does not ensure a high quality image. To distinguish resolved features from the background, adequate noise suppression is also critical. However, in general, typical noise suppression approaches degrade the image resolution. The Astonish reconstruction method developed by Philips provides a powerful, proprietary new method for noise suppression that involves applying matched filters throughout the reconstruction process.

Given the fact that gamma camera imaging is a count-starved modality, three major approaches have been investigated by the

nuclear medicine community to suppress the noise in SPECT images in addition to the tremendous effort of improving SPECT system sensitivity (thus acquiring more counts). The first approach is to model the Poisson noise of the SPECT acquisition in the image reconstruction algorithms. This approach led to the emergence of maximal-likelihood expectation-maximization (MLEM) algorithms (Shepp and Vardi 1982, Lange and Carson 1984) that have largely replaced the filtered back-projection (FBP) algorithm in SPECT imaging. A related algorithm, the ordered subset expectation maximization (OSEM) algorithm (Hudson and Larkin 1994) was later developed to accelerate the reconstruction speed. MLEM and OSEM reduce reconstruction artifacts compared with FBP or other analytical reconstruction techniques, and allow incorporation of system response, such as attenuation, collimator blurring, and scatter. However, the noise in the image tends to be unacceptable by the time enough iterations have been used. Other approaches are usually incorporated to further suppress the noise. A second approach is Bayesian reconstruction (Liang et al 1989) that uses prior information in the reconstruction to control the noise. The prior information can be a simple assumption that the image is smooth locally or can be a CT image of the same patient. The third approach is to apply post-filtering to the images after reconstruction (Van Laere et al 2001), which can be used in conjunction with MLEM or OSEM reconstruction. There are many different filters that can be used for this post-filtering approach. The filter used for clinical applications is highly dependent upon the applications themselves, and needs to be optimized based on the specific applications (Durbin et al 2001). One of the most

commonly used techniques nowadays in SPECT image reconstruction is MLEM (or OSEM) reconstruction followed by post-filtering.

The Astonish reconstruction method uses a new method for noise suppression that involves applying matched filters throughout the reconstruction process. A simple non-negative filter is applied to the projections prior to reconstruction, and the identical filter is applied to forward projected data and just prior to back-projection during each iteration. Use of a pre-filter decreases the noise from the projection data. Matching that pre-filter during forward projection allows preservation of features that might otherwise have been smoothed past detectability. Finally, the use of the filter just prior to back-projection suppresses the build-up of noise that typically occurs with increased iterations.

Astonish allows the use of a Hanning filter for matched filtering. This filter is optimized for bone SPECT, brain SPECT, and cardiac SPECT imaging to achieve the best balance of resolution recovery and noise suppression in the images. The Hanning filter has a single controlling parameter, the cutoff frequency. A low cutoff frequency leads to smoother images. For the application-specific Astonish defaults provided with AutoSPECT, the filter was chosen by evaluating several clinical images.

Quantitative evaluation

NEMA SPECT resolution

To test the effect of Astonish reconstruction on system resolution, we acquired line source data in accordance with the SPECT reconstructed resolution without scatter test of the NEMA NU 1-2001 standard. We show the specifications for standard reconstruction and Astonish reconstruction (using a clinically relevant number of iterations and subsets) below:

Table 1. NEMA reconstructed resolution without scatter - specifications for FBP reconstruction (NEMA standard), and for Astonish reconstruction using 2 iterations and 32 subsets

	FBP	Astonish
FWHM, Central Transaxial	10.3 mm	4.4 mm
FWHM, Central Axial	10.9 mm	4.6 mm
FWHM, Peripheral Radial	10.5 mm	4.2 mm
FWHM, Peripheral Tangential	9.0 mm	4.3 mm
FWHM, Peripheral Axial	10.8 mm	4.7 mm

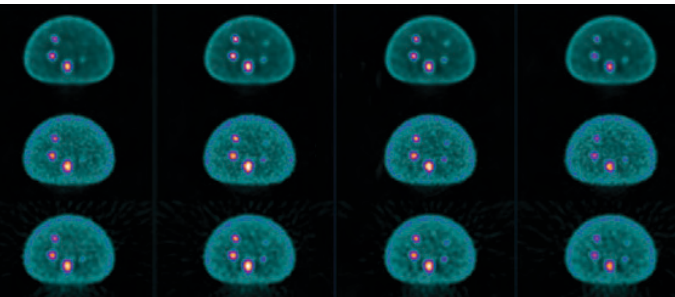


Figure 2. IEC phantom reconstructions - with Astonish (top), MLEM (middle) and FBP (bottom)

Contrast recovery ratio (CRR) and signal-to-noise ratio (SNR)

To test the effect of Astonish on contrast and signal to noise, we acquired images of an IEC 6-sphere phantom. The phantom has a roughly elliptical shape and contains six fillable spheres of varying sizes. The background and spheres of the phantom were filled with Tc-99m, with an activity concentration ratio of 8:1. Figure 2, below, shows the phantom as reconstructed using three different methods.

The background is clearly smoother for the Astonish-reconstructed images. However, to see the true benefit of Astonish reconstruction, it is necessary to look at quantitative values calculated from the images. Table 2, below, shows the contrast recovery ratio (CRR), a measure of how well the method recovers the true activity of the hot spot relative to the background.

Table 2. Contrast recovery ratio (CRR = 100 represents perfect recovery of the 8:1 contrast) for the five visible spheres in an IEC phantom, using three different reconstruction methods

Method	CRR-L1	CRR-L2	CRR-L3	CRR-L4	CRR-L5
Astonish	84%	82%	87%	36%	18%
MLEM	55%	49%	45%	26%	13%
FBP	58%	50%	44%	26%	13%

Table 3, below, shows the signal-to-noise ratio (SNR), a measure of how detectable a hot spot is against the background.

Table 3. Signal-to-noise ratio (SNR = lesion average divided by background standard deviation) for the five visible spheres in an IEC phantom, using three different reconstruction methods. A larger number is better.

Method	SNR-L1	SNR-L2	SNR-L3	SNR-L4	SNR-L5
Astonish	26	51	33	22	12
MLEM	17	27	22	12	8
FBP	14	28	18	10	8

The tables above demonstrate that Astonish improves both CRR and SNR, and the images in Figure 2 illustrate that this is achieved while reducing noise in the image.

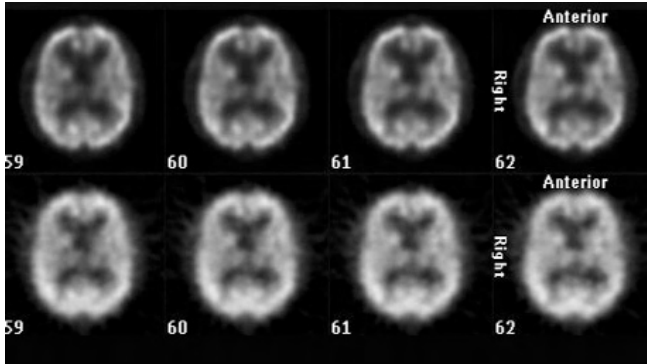


Figure 3. Clinical brain Tc-99m images reconstructed with (top row) Astonish, and (bottom row) standard clinical protocol (FBP)
 Images courtesy of University of Florence

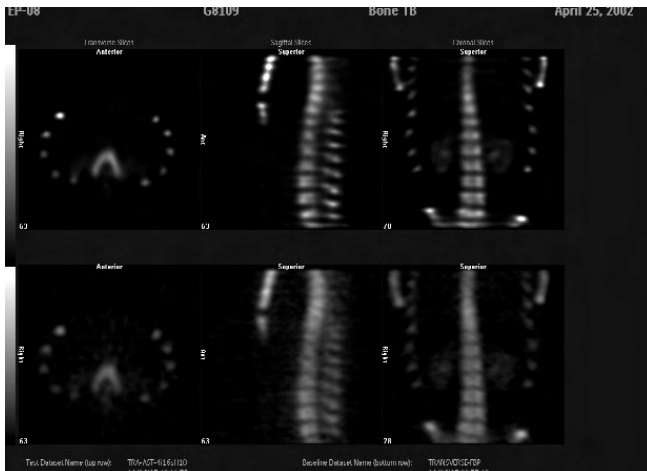


Figure 4. Clinical bone Tc-99m images reconstructed with (top row) Astonish, and (bottom row) standard FBP.
 Images courtesy of William Beaumont Army Medical Center

Patient studies

Brain imaging

Figure 3 shows a patient brain SPECT study reconstructed using the site's standard clinical protocol (bottom row) and reconstructed retrospectively using Astonish software (top row). Astonish reconstruction shows improved resolution over the clinical reconstruction and reduces the noise in the background. The clinical reconstruction protocol used FBP with a Butterworth filter. The Astonish reconstruction used two iterations and 16 subsets.

Bone imaging

Figure 4 shows a patient bone study reconstructed using the standard clinical protocol (bottom row) and Astonish software (top row). The Astonish reconstruction shows improved resolution over the clinical reconstruction and reduced noise in the background. The clinical reconstruction protocol used FBP with a Butterworth filter with order 8 and cutoff 0.7. The Astonish reconstruction used four iterations and 16 subsets. No matched filtering was performed because this was a high-count study that did not require additional noise control.

Reducing scan times

Reducing the acquisition scan time for SPECT images reduces the signal-to-noise ratio. Because Astonish provides improvement in signal-to-noise, therefore, it can provide acceptable image quality even when scan times are shortened. This is expected to be relevant for cardiac studies because by reducing patient imaging time, we can potentially reduce patient discomfort while allowing clinics to improve throughput. If patients have to hold still for only half the time, there is potential for them to move less, thereby reducing motion-induced artifacts. Clinics may also choose to continue acquiring for the standard amount of time, because of the gains in overall image quality possible when Astonish is used to reconstruct full-count images.

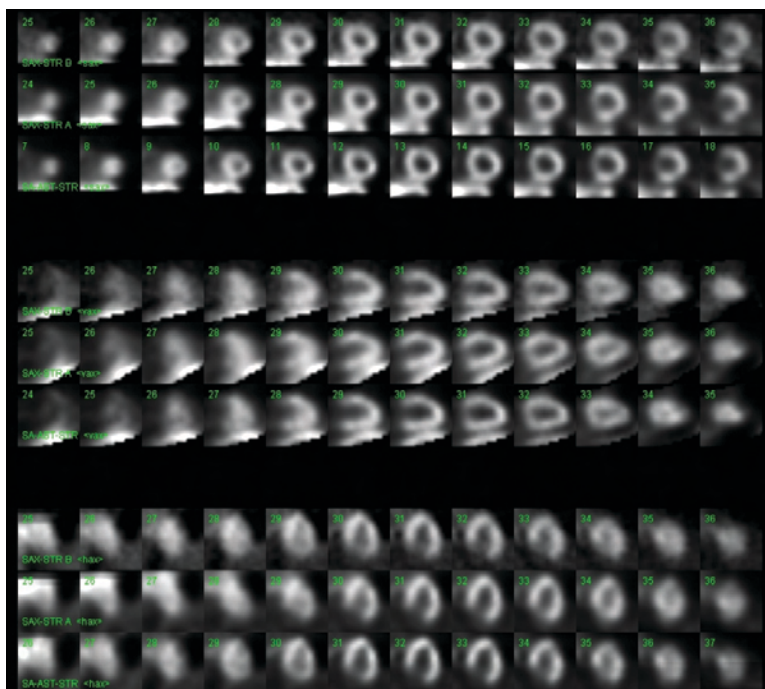


Image courtesy of Radiological Associates of Sacramento

Figures 5 and 6 show a comparison of cardiac images (Tc-99m Sestamibi and TI-201) demonstrating that Astonish reconstructions of half the counts produce images as good as (or better than) FBP reconstructions using all of the counts. They also show the improved resolution and signal-to-noise possible when all counts are used during Astonish reconstruction.

Figure 5. Typical clinical cardiac Sestamibi scan (169 lb female) processed with:

- (top row) FBP using all frames
- (middle row) Astonish using half frames
- (bottom row) Astonish using all frames

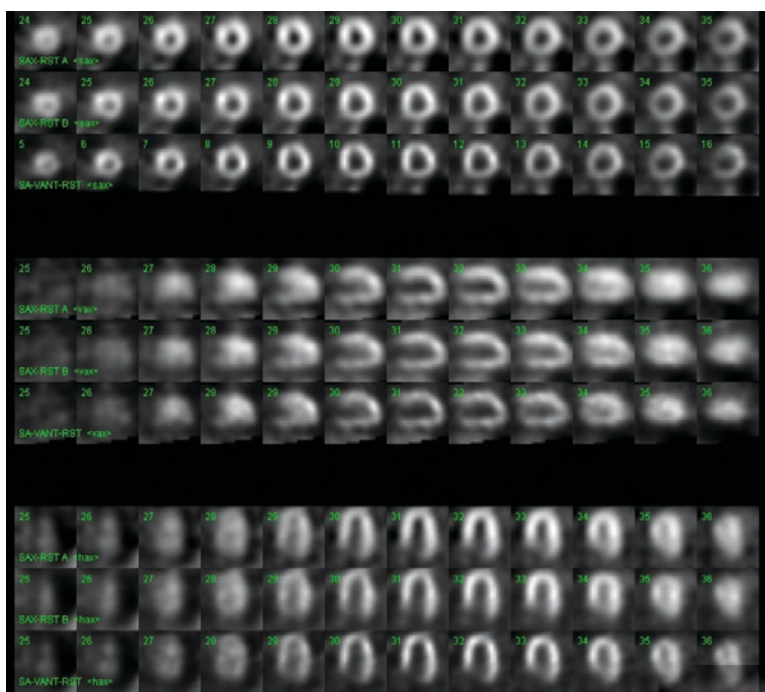


Image courtesy of Radiological Associates of Sacramento

Figure 6. Typical clinical cardiac TI-201 scan (181 lb male) processed with:

- (top row) FBP using all frames
- (middle row) Astonish using half frames
- (bottom row) Astonish using all frames

Discussion

Phantom measurements and NEMA calculations demonstrate that Astonish SPECT improves image resolution while keeping noise levels low, allowing better quantitative measurement of hot spot activity.

The patient images in this white paper illustrate that the application of Astonish to bone, brain, and cardiac SPECT imaging improves image resolution and reduces background noise. The overall balance of resolution and noise in the images is superior to that of the images reconstructed with FBP.

The quantitative improvements in image quality allow excellent myocardial images to be reconstructed from data gathered using half of the time used in standard cardiac acquisitions.

Acknowledgements

We would like to thank Mary Brodbeck and Albert Moreno, M.D., of William Beaumont Army Medical Center, as well as Michael Mix, Ph.D., and Ingo Brink, M.D., of the University of Freiburg for bone images and analysis. We would like to thank Alberto Pupi, M.D., of the University of Florence for brain images and analysis. We would like to thank Michael Haseman, M.D. and Richard Myers, M.D. of Radiological Associates of Sacramento for the cardiac images and analysis.

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Printed in USA.
4522 962 09351/882 * JAN 2006