Improving Image Quality and Imaging Efficiency Using nSPEED℠ Three-Dimensional Image Reconstruction in Cardiac SPECT

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With the growing competitive challenge from other modalities for perfusion and functional imaging, nuclear cardiology is facing tremendous pressure to achieve optimal image quality and faster imaging speed (higher imaging efficiency). Faster imaging usually leads to reduced acquired counts for a given system sensitivity, yet the quality of cardiac SPECT images is primarily limited by the acquired counts. Therefore the nuclear medicine community has reacted to the challenge from other modalities by enhancing imaging efficiency through the following approaches:

- To improve the system sensitivity so that one can acquire more counts in the same period of time or acquire the same number of counts in a shorter period of time. By doing this, one can reduce the acquisition time while maintaining the acquired counts (thus image quality); and

- To implement advanced software techniques so that one can improve image quality for the same acquired counts or obtain the same image quality with less acquired counts. By doing this, one can also reduce the acquisition time while maintaining the image quality.

Increasing system sensitivity is usually the most effective way to improve imaging efficiency, such as using a dual-head cardiac system instead of a single-head system for imaging. With the introduction of dual-head gamma cameras, the total acquisition time for a typical cardiac SPECT study can be reduced from 25-30 minutes to 11-14 minutes. Similarly, using 180° arc triple-head cardiac systems versus dual-head cardiac systems can further increase the system sensitivity and reduce the imaging time. For example, clinical studies showed that typical cardiac SPECT studies could be completed in about 7 minutes using the Cardius-3 series systems developed by Digirad (Digirad Corporation, Poway, CA 92064), as compared to about 11-14 minutes using a dual-head system (Lewin *et al* 2005).

The advanced software techniques for image quality improvement are mainly advanced image reconstruction algorithms. Examples include: (1) using iterative reconstruction algorithms (such as MLEM and OSEM) instead of the filtered-back-projection (FBP) algorithm to better model and suppress image noise (Bruyant 2002); (2) three-dimensional (3D) instead of two-dimensional (2D) image reconstruction for detector response modeling; and (3) using iterative reconstruction algorithms with the modeling of other image degrading effects (such as attenuation, scatter, and etc) (Tsui et al 1998). Such image quality improvement by using 3D reconstruction may allow one to reduce the acquisition time and maintain image quality as compared to using 2D reconstruction (DePuey *et al* 2006).

There are several different approaches for detector response modeling for 3D reconstruction. An effective and efficient one is the slice-by-slice incremental blurring model proposed by (Zeng *et al* 1998). In this technique, a slice of the reconstructed volume that is parallel to the detector surface is only convolved with a very small kernel (such as a 3x3 kernel) and the result is added to the next slice, which is closer to the detector surface. The result in the next slice is then convolved with another small kernel and then added to the next slice and so on. The small kernel is calculated from the different detector response functions of the two neighboring slices. This model significantly reduces the computational expense compared to non-incremental convolution based approaches.

In this work we developed nSPEED 3D-OSEM algorithm that uses a slab-by-slab approach (Bai *et al* 1998) derived from the slice-by-slice incremental blurring model described above. In this approach each slab that consists of several neighboring slices goes through the convolution process rather than each slice. This further reduces the number of convolutions and consequently the computational expense.

Line source studies based on NEMA procedure for reconstructed system resolution (NEMA NU-1, 2001, Section 2.6) showed resolution gain using Digirad's 3D reconstruction compared to 2D reconstruction. For a Cardius-2 dual-head system with CARD collimators (low energy medium-high resolution, parallel-beam collimators, bore hole diameter 1.5 mm, and bore thickness 27.0 mm), the reconstructed image of the center source had a FWHM of 12.5 mm in 3D reconstruction but 16.1 mm in 2D reconstruction.

Jaszczak resolution phantom studies also showed image quality improvement using nSPEED 3D reconstruction. For a Cardius-3 triple-head system with CARD collimators, 3D reconstruction showed better contrast of the cold rods and spheres than 2D OSEM reconstruction (Fig. 1). The finest rods that could be resolved were 9.5 mm in diameter. Anthropomorphic phantom (Data Spectrum Corporation, Hillsborough, NC) studies also showed improved resolution, chamber to myocardium contrast, and defect contrast (Fig. 2).

For 34 randomly selected stress/rest patient studies using Tc-99m on a Cardius-3 triple-head camera with CARD collimators, 3D reconstruction showed improved image quality as compared to 2D, such as resolution, myocardium to chamber contrast, and better liver to inferior wall separation. Fig. 3 shows an example of the patient studies in which resolution and myocardium to chamber contrast were improved using 3D reconstruction. Quantitative comparisons of the left ventricle ejection fraction (LVEF), end-systolic volume (ESV), end-diastolic volume (EDV), and regional perfusion defect severity (LAD, LCX, RCA) showed highly linear correlations between the 3D and 2D reconstruction (Table 1 and Fig. 4-6). Physician reading of the studies showed the same diagnostic outcomes for all the patients.

As a conclusion, the nSPEED 3D-OSEM reconstruction we developed in this work showed significant image quality improvement over 2D-OSEM reconstruction. The application of this algorithm to cardiac SPECT imaging may enable us to achieve the same image quality at reduced acquisition time. We are currently evaluating this application in extensive multicenter studies.

Table 1. Linear correlation (Y = kX, Y: 3D, X: 2D) of the quantitation of 3D and 2D images of the patient studies.

	Stress		Rest	
	k	**R^2**	k	**R^2**
LVEF	0.97	0.94		
ESV	1.02	0.99		
EDV	1.01	0.98		
LAD	0.97	0.75	0.98	0.76
LCX	0.96	0.87	0.98	0.81
RCA	0.97	0.84	0.99	0.84

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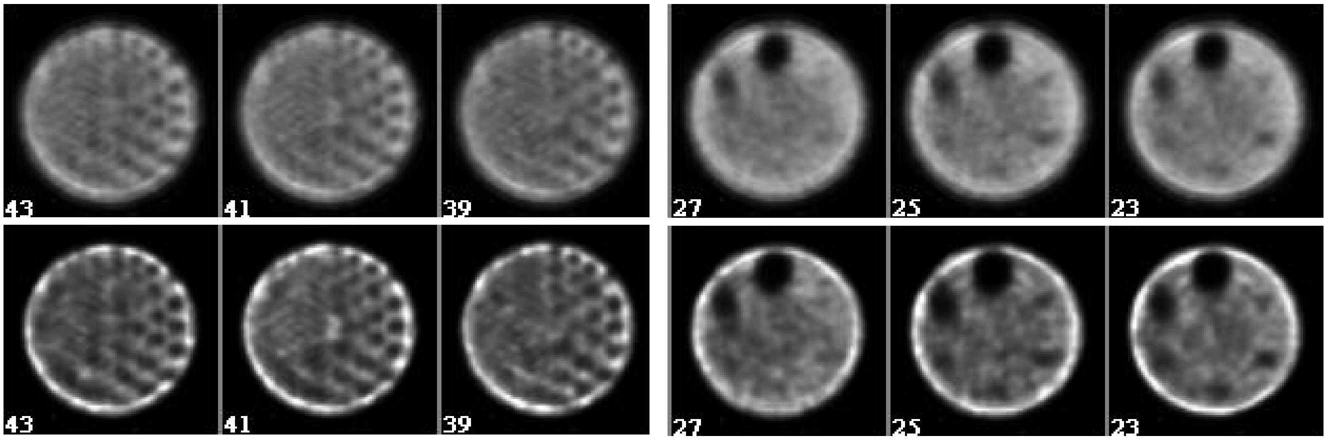

Fig. 1. Jaszczak resolution phantom studies showed improved contrast of the cold rods and spheres in the nSPEED 3D images (bottom row) over 2D images (top row). Left: slices of the cold rods; Right: slices of the cold spheres.

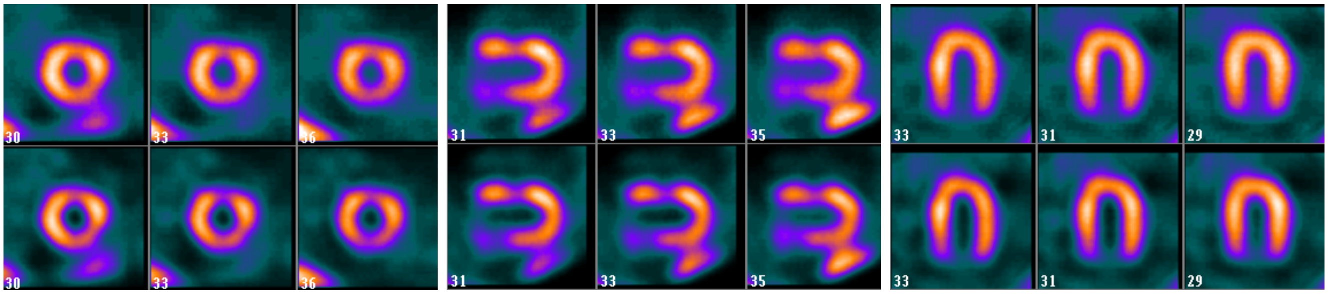

Fig. 2. Images of the cardiac insert with two defects showed improved myocardium-to-chamber contrast, defect contrast, as well as image resolution by using nSPEED 3D (Bottom row) versus 2D (Top row) reconstruction. Total activity was 10.8 mCi, total acquisition time was 13.3 minutes on a dual-head Cardius-2 camera using CARD collimators. No activity was introduced into the myocardium chamber.

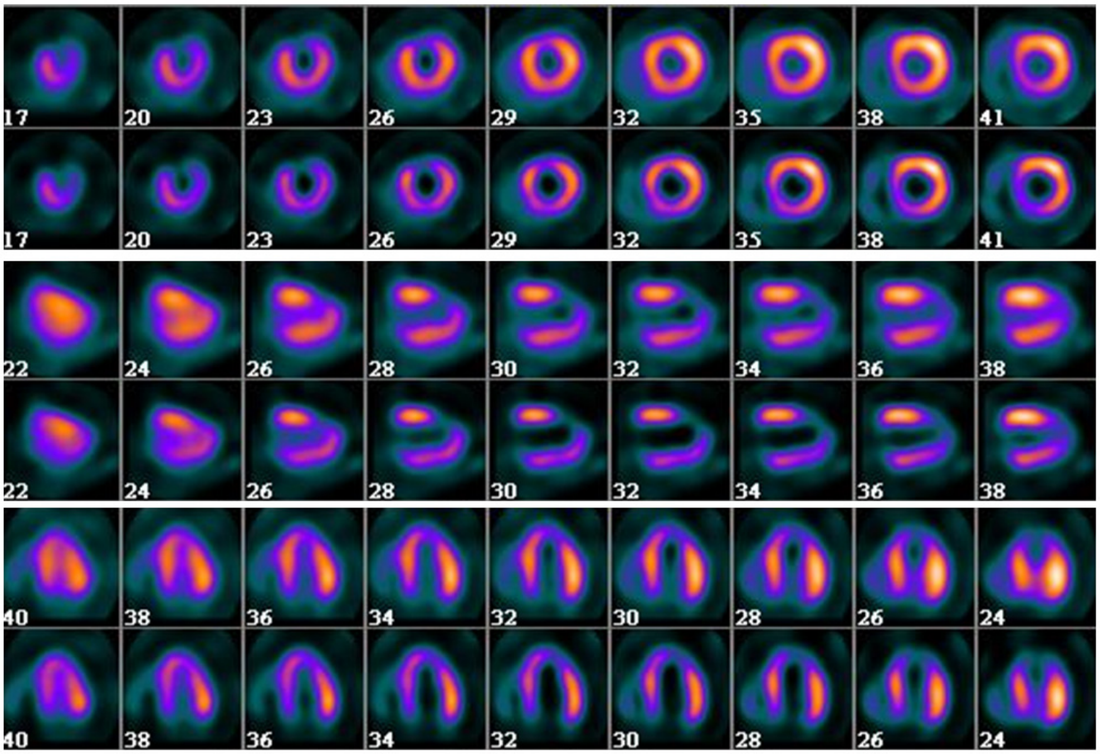

Fig. 3. Three-view of a patient study showed improved myocardium-to-chamber contrast, defect contrast, as well as image resolution by using nSPEED 3D versus 2D reconstruction (bottom row versus top row in each view).

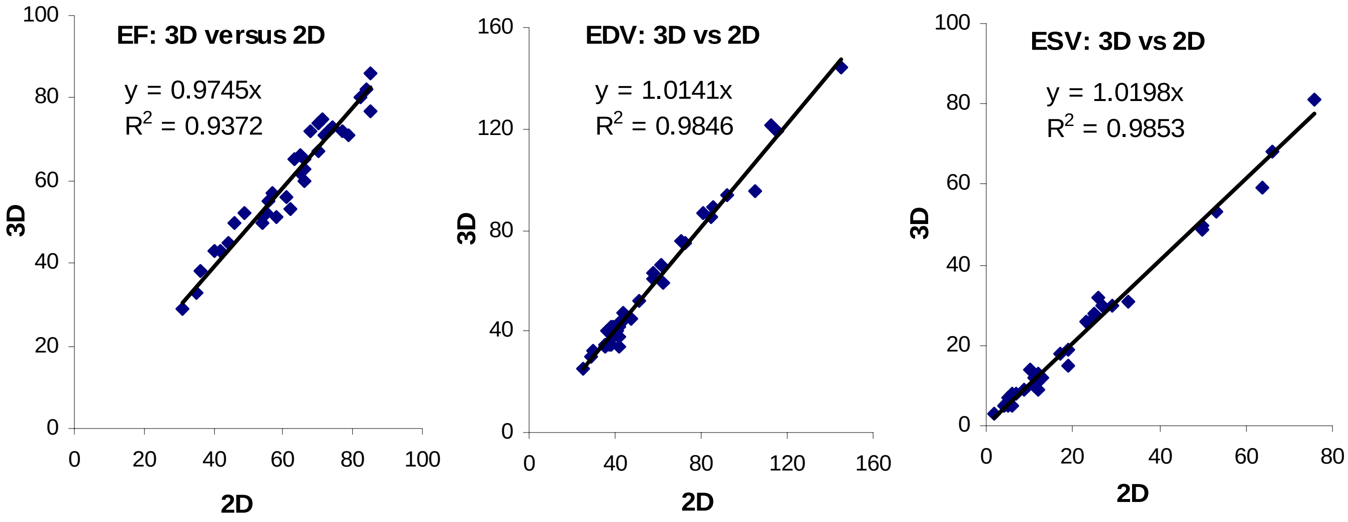

Fig. 4. Patient studies showed good correlation of the EF, EDV, and ESV in gated stress images between 3D and 2D reconstruction from full data.

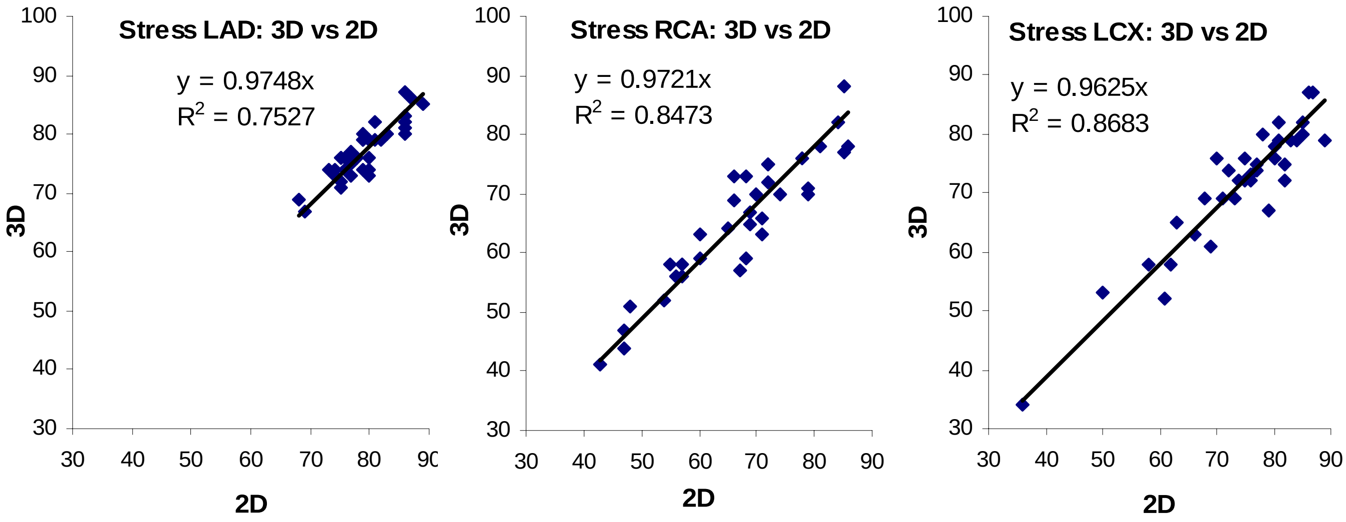

Fig. 5. Patient studies showed good correlation of the territory perfusion scores (% of the maximum pixel) in the summed gated stress images between 3D and 2D reconstruction from full data.

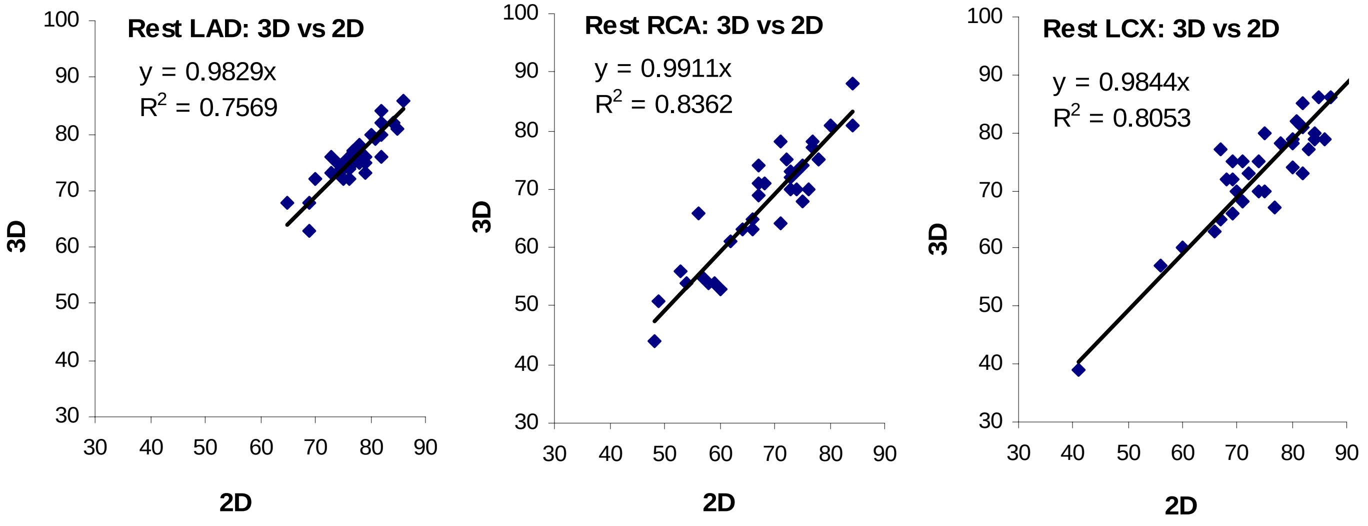

Fig. 6. Patient studies showed good correlation of the territory perfusion scores (% of the maximum pixel) in the rest images between nSPEED 3D and 2D reconstruction from full data.