Published in final edited form as:

IEEE Nucl Sci Symp Conf Rec (1997). 2010 October 30; : 3523–3526. doi:10.1109/NSSMIC.

2010.5874463

The Evaluation of Corrective Reconstruction Method For Reduced Acquisition Time and Various Anatomies of Perfusion Defect Using Channelized Hotelling Observer for Myocardial Perfusion SPECT

Taek-Soo Lee

Department of Radiology, Johns Hopkins University, Baltimore, MD, 21287 USA (telephone: 443-287-2006, tslee@jhmi.edu)

Benjamin M. W. Tsui

Department of Radiology, Johns Hopkins University, Baltimore, MD, 21287 USA, (telephone: 443-287-4025, btsui1@jhmi.edu)

Abstract

We evaluated the effect of conventional and corrective image reconstruction methods on reduced acquisition time for detecting a myocardial perfusion (MP) defect in MP SPECT using the Channelized Hotelling Observer (CHO). Using the 4D Extended Cardiac-Torso (XCAT) phantom, we simulated realistic transmural and endocardial MP defects in various location and size. Realistic Tc-99m Sestamibi MP projection data were generated using an analytical projector that included the effects of attenuation (A), collimator-detector response (D) and scatter (S) for various count levels simulating different acquisition times. They were reconstructed using the 3D FBP without correction and a 3D OS-EM method with ADS correction followed by a smoothing filter with various cut-off frequencies. The CHO followed by receiver operating characteristics (ROC) methodology was applied to the reconstructed images to evaluate the detectability of a MP defect in each method for different defect anatomies and count levels. Areas under the ROC curve (AUC) were computed to assess the changes in the MP defect detection. The results showed that the 3D OS-EM with ADS corrections showed significantly less changes in AUC value and gave overall higher AUC values than FBP at all cut-off frequencies of the post smoothing filter, count levels and MP defect sizes. The difference in AUC increased towards less smoothed images where the 3D OS-EM with correction was able to provide similar AUC values with 20 – 40% reduction in acquisition time compared to FBP. The AUC values for smaller MP defects were lower for both reconstruction methods with smaller differences. We concluded that the 3D OS-EM with ADS corrections provides higher performance in the MP defect detection task. It allows increased reduction of acquisition time without loss of MP defect detection in MP SPECT compared to the conventional FBP method especially towards less smoothed images.

I. Introduction

Emission computed tomography (ECT) techniques including single-photon emission computed tomography (SPECT) and positron emission tomography (PET), and more recently, SPECT/CT and PET/CT, have been firmly established as molecular imaging

techniques that are integral parts of diagnostic radiology and medicine. During the past decade, there has been tremendous growth of SPECT/CT and PET/CT in the commercial market and in clinical applications especially in oncology. Significant advances continue in ECT especially in terms of significant improvement in image quality. The improvements can be attributed to the advances in radiopharmaceutical, instrumentation and image reconstruction and processing methods. In particular, corrective image reconstruction methods that take into account statistical fluctuations of the acquired data and compensate for the image degrading effects of instrumentation and physical factors including photon attenuation and scatter have demonstrated unprecedented improvement in image quality and clinical diagnosis. Another notable advance is the steady reduction in acquisition time, which can be translated to a reduction in radiation dose to the patient [1], which is a direct consequence of this research.

We investigate the effect of corrective image reconstruction method on reduced acquisition time in myocardial perfusion SPECT using the channelized Hotelling observer (CHO) with respect to the task of detecting the perfusion abnormalities.

II. Method

A. The new 3D XCAT phantoms and simulated SPECT projection data

We chose Tc-99m Sestamibi myocardial perfusion SPECT study as a sample application. Using the 3D eXtended CArdiac-Torso (XCAT) phantom as shown in Figure 1 [2], we created a realistic model of perfusion defect (MP) in the anteroseptal and inferior locations. It allows the simulation of different sizes and degrees of regional myocardial perfusion defects including mid-sized and small sized ($=1/4$ volume of mid-sized) of transmural and endocardial defects in the left ventricular (LV) wall (Figure 2).

For each phantom, realistic noise-free projection data were generated using an analytical projector that includes the effects of non-uniform attenuation, collimator-detector response, and scatter (ADS). Poisson noise was subsequently added to the noise-free projection data to generate 256 noisy realization at various count levels corresponding to different acquisition time.

B. Reconstruction and Post Smoothing Filtering

The simulated projection data for various count levels were reconstructed using the 3D filtered back-projection (FBP) without ADS correction and the 3D OS-EM method with ADS correction both followed by the Butterworth smoothing filter. A wide range of cut-off frequencies of the smoothing filter was applied to the reconstructed images to determine the optimum post smoothing filter for maximum defect detection.

C. The channelized Hotelling observer (CHHO)

The channelized Hotelling observer (CHO) [3–5] was applied to the reconstructed images for each reconstruction method and cut-off frequency for the detection of a MP defect. The rating data were analyzed using the receiver operating characteristics (ROC) methodology and a software from University of Chicago [6–8]. Areas under the ROC curve (AUC) were

computed to determine the detectability of the MP defect. For each count level corresponding to an acquisition time, the cutoff frequencies of the post Butterworth smoothing filter for the 3D FBP and 3D OS-EM reconstruction methods and the number of iterations for the 3D OS-EM that gave the maximum AUC values were determined.

III. Results

A. Effect of update number in 3D OS-EM

Figure 3 shows the effect of the number of updates in the 3D OS-EM at 440% count level with respect to a reference acquisition time. The result indicates that lower number of updates provides higher AUC values for the detection of a mid-size transmural MP in antero-septal location using the CHO. The AUC values of 16 updates (2 iterations with 8 subsets) were higher than those from higher updates in 3D OS-EM with ADS correction at all cut-off frequencies. Future study will be performed with fewer number of subsets, such as 4 subsets for the complete optimization of the iteration number.

B. Comparison of reconstruction methods in detecting antero-septal MPP defects

Figures 4 (a) and (b) show comparison of the detection by the CHO of an endocardial and a transmural MP defect in the antero-septal location in reconstructed images obtained using the FBP without ADS corrections and the 3D OS-EM of 16 updates with ADS corrections. The results indicate that the 3D OS-EM with ADS corrections showed significantly less changes in AUC value across the different cut-off frequencies. It also provides overall higher AUC values especially for lower count level, and the difference in AUC increases towards less smoothed images where the 3D OS-EM with correction provides similar AUC values with 20 – 40% reduction in acquisition time compared to the FBP.

Given the same acquisition time and the defect location and contrast, it is easier to detect transmural than endocardial MP defect. No difference is found in heavily smoothed images of both endocardial and transmural MP defects in the antero-septal location.

C. Comparison of reconstruction methods in detecting inferior MP defect

Figures 5 (a) and (b) show comparison of the detection by the CHO of an endocardial and a transmural MP defect in the inferior location in reconstructed images obtained using the FBP without ADS corrections and the 3D OS-EM of 16 updates with ADS corrections.

The results show the same trends as those from the antero-septal MP defect. In addition, they demonstrate that it is easier to detect the antero-septal MP defect than the inferior MP defect.

D. Comparison of detecting MP defects of different sizes

Figures 6 (a) and (b) show comparison of the detection by the CHO of MP defects of two different sizes. Given the same acquisition time, the smaller defect gives an overall lower detectability and its maximum detectability occurs at the cutoff frequency of ~ 0.4 cycle/cm for the post Butterworth smoothing filter used in the 3D OS-EM with ADS corrections. The difference in detectability increase towards less smoothed images as well.

IV. Conclusion

In general, the 3D OS-EM with ADS corrections provides higher performance in the detection of MP defect than the FBP without correction in MP SPECT. It is less sensitive to the cut-off frequency used in the post smoothing filter than the FBP reconstruction method. Also, it allows a reduction of acquisition time without loss of the detectability of MP defects especially towards less smoothed images and small defect sizes. The reduction of acquisition time can be traded for the reduction of radiation dose to the patients.

From the results of this study, we conclude that corrective image reconstruction methods, such as the 3D OS-EM with ADS corrections, provides improved detectability of MP defects as compared to those without correction. The improved detectability can be traded for reduction in acquisition time or radiation dose to the patients without loss of defect detectability in MP SPECT. The amount of reduced acquisition time or radiation dose depends on various factors, such as count level, cut-off frequency of the post smoothing filter use in the reconstruction methods, size and location of the MP defect and patient anatomy. Future study will include more accurate model of the simulated data using Monte Carlo methods, inclusion of anatomical variations in the 3D XCAT phantom to more realistically simulate a patient population, and comparing the CHO performance to that of human observers.

Acknowledgment

This work was supported by the Public Health Service grant R01 HL68075 and R01 EB 000168.

References

- [1]. He X, Links JM, Frey EC. An investigation of the trade-off between the count level and image quality in myocardial perfusion SPECT using simulated images: the effects of statistical noise and object variability on defect detectability. *Phys. Med. Biol.* 2010; 55:4949. [PubMed: 20693615]
- [2]. Segars W, Tsui BMW. The Evolution of 4D Computerized Phantoms for Imaging Research. *Proceedings of IEEE.* 2009; 97:1954–1968.
- [3]. Hotelling H. The Generalization of Student's Ratio. *The Annals of Mathematical Statistics.* 1931; II:360–78.
- [4]. Smith WE, Barrett HH. Hotelling trace criterion as a figure of merit for the optimization of imaging systems. *Journal of the Optical Society of America. A.* 1986; 3:717–25.
- [5]. Wollenweber SD, Tsui BMW, Frey EC, Lalush DS, LaCroix KJ. Comparison of human and channelized Hotelling observers in myocardial defect detection in SPECT. *Journal of Nuclear Medicine.* 1998; 39:771A.
- [6]. Metz CE. Basic principles of ROC analysis. *Seminars in Nuclear Medicine.* 1978; 8:283–298. [PubMed: 112681]
- [7]. Metz CE. ROC methodology in radiologic imaging. *Invest Radiol.* 1986; 21:720–733. [PubMed: 3095258]
- [8]. LaCroix KJ, Tsui BMW, Frey EC, Jaszczak RJ. Receiver operating characteristic evaluation of iterative reconstruction with attenuation compensation in 99mTc-Sestamibi myocardial SPECT images. *Journal of Nuclear Medicine.* 2000; 41:502–513. [PubMed: 10716326]

Fig. 1. Left ventricle model of XCAT phantom with endocardial septal-anterior (yellow mesh) defects ((a) short axis view, (b) long axis view).

Fig. 2.

Short-axis views of four MP defects from an inferior MP defect models of the 3D XCAT phantom, (a) a transmural defect with mid defect size, (b) an endocardial defect with mid defect size, (c) a transmural defect with small defect size, and (d) an endocardial defect with small defect size.

Fig. 3. Plot of AUC values from the detection of the mid-size transmural MP defect in the antero-septal location by the CHO in the 3D OS-EM reconstructed images with ADS correction as a function of cut-off frequency of the post Butterworth smoothing filter at three different update numbers.

Fig. 4.

Comparison of the detection by the CHO of (a) an endocardial and (b) a transmural MP defect in the anteroseptal location in reconstructed images obtained using the FBP without and the 3D OS-EM of 16 updates with ADS corrections. The legend of (a) is the same as that of (b).

Fig. 5.

Comparison of the detection by the CHO of (a) an endocardial and (b) a transmural MP defect in the inferior location in reconstructed images obtained using the FBP without and the 3D OS-EM of 16 updates with ADS corrections. The Legend of (a) is the same as that of (b).

Fig. 6. Effect of defect size in 3D OS-EM and FBP for inferior MP defect. ((a) Endocardial perfusion defect, (b) Transmural perfusion defect)