Respiratory-motion matched attenuation correction for dual-gated cardiac SPECT

Christina Xing[1], Shiwei Zhou[1], Hendrik Pretorius[2], Yongyi Yang[3], Michael A. King[2], and Mingwu Jin[1]

[1]Department of Physics, University of Texas at Arlington, Arlington, TX 76019

[2]Department of Radiology, University of Massachusetts Medical School, Worcester, MA 01655

[3]Department of Electrical and Computer Engineering, Illinois Institute of Technology, Chicago, IL 60616

Abstract

Cardiac and respiratory dual-gated single-photon emission computed tomography (SPECT) is a promising technique for minimizing the motion artifacts in myocardial perfusion imaging using SPECT. However, attenuation correction (AC) for dual-gated SPECT using an attenuation map averaged over the respiratory cycle may lead to mis-matched attenuation correction artifacts. In this study, we propose a respiratory motion-matched attenuation correction (RMM-AC) to further improve dual-gated SPECT. For each respiratory gate, RMM-AC uses an attenuation map that matches the SPECT image in 4D reconstruction. 4D reconstruction with the attenuation map averaged over all respiratory gates (AVE-AC) are used for comparison. We used the NCAT phantom and SIMIND Monte Carlo simulation to simulate dual-gated cardiac SPECT using ^{99m}Tc-sestamibi. An ischemic lesion with 20% uptake reduction at four locations of the left ventricle wall was used for a channelized Hotelling observer (CHO) study. Three methods were quantitatively evaluated using the root mean squared error (RMSE) and the area under the receiver operating characteristic (ROC) curve (Az) of CHO. RMM-AC outperforms AVE-AC in both metrics, which reflects improvements on both reconstruction accuracy and lesion detectability. This study paves the way for the clinical adaptation of dual-gated cardiac SPECT.

Introduction

Myocardial perfusion imaging (MPI) using single photon emission computed tomography (SPECT)

- MPI SPECT is a primary tool in diagnosis and prognosis of coronary artery disease (CAD) (5~7 million exams/year and >90% cardiac gated exams).[1]
- The presence of image artifacts, arising from factors such as noise, attenuation, scatter, and motion, has a detrimental effect on diagnostic accuracy.[2]

Dual gated cardiac SEPCT (D-SPECT)[3]

- Cardiac and respiratory motions are both synchronized and controlled through list-mode data to minimize motion artifacts and enhance diagnostic lesion detectability.
- Challenge: 1. limited photons in each cardiac and respiratory phase; 2. **Mismatch between CT images (for AC) and SPECT images**
- Solution: 1. motion-compensated reconstruction; 2. **motion matched AC**

Methods

- A NURBS-based cardiac-torso (NCAT) phantom[4] with cardiac motion (8 phases) and respiratory motion (8 phases) was used to compare the performance of averaged and motion matched AC.
- The dimensions of the NCAT phantom were 64×64×64 with a voxel size of 6.34×6.34×6.34 mm^3.
- SIMIND[5] was used to simulate D-SPECT imaging with ^{99m}Tc -Sestamibi.
- Poisson noise of 8x10^6 photons for all phases, resulting in only 15,625 photons (8 million/64) per respiratory and cardiac phase.
- To evaluate the lesion detectability performance of each method, a lesion with a 20% intensity reduction at four locations in the left ventricular myocardium was introduced.
- For reconstruction, two methods were compared: (1) 4D reconstruction with an attenuation map averaged over all respiratory gates (AVE-AC); 2) 4D reconstruction with an attenuation map respiratory motion matched with the SPECT image (RMM-AC).
- Idea reconstruction of noiseless without attenuation and scatter serves as the ground truth for RMSE calculation.

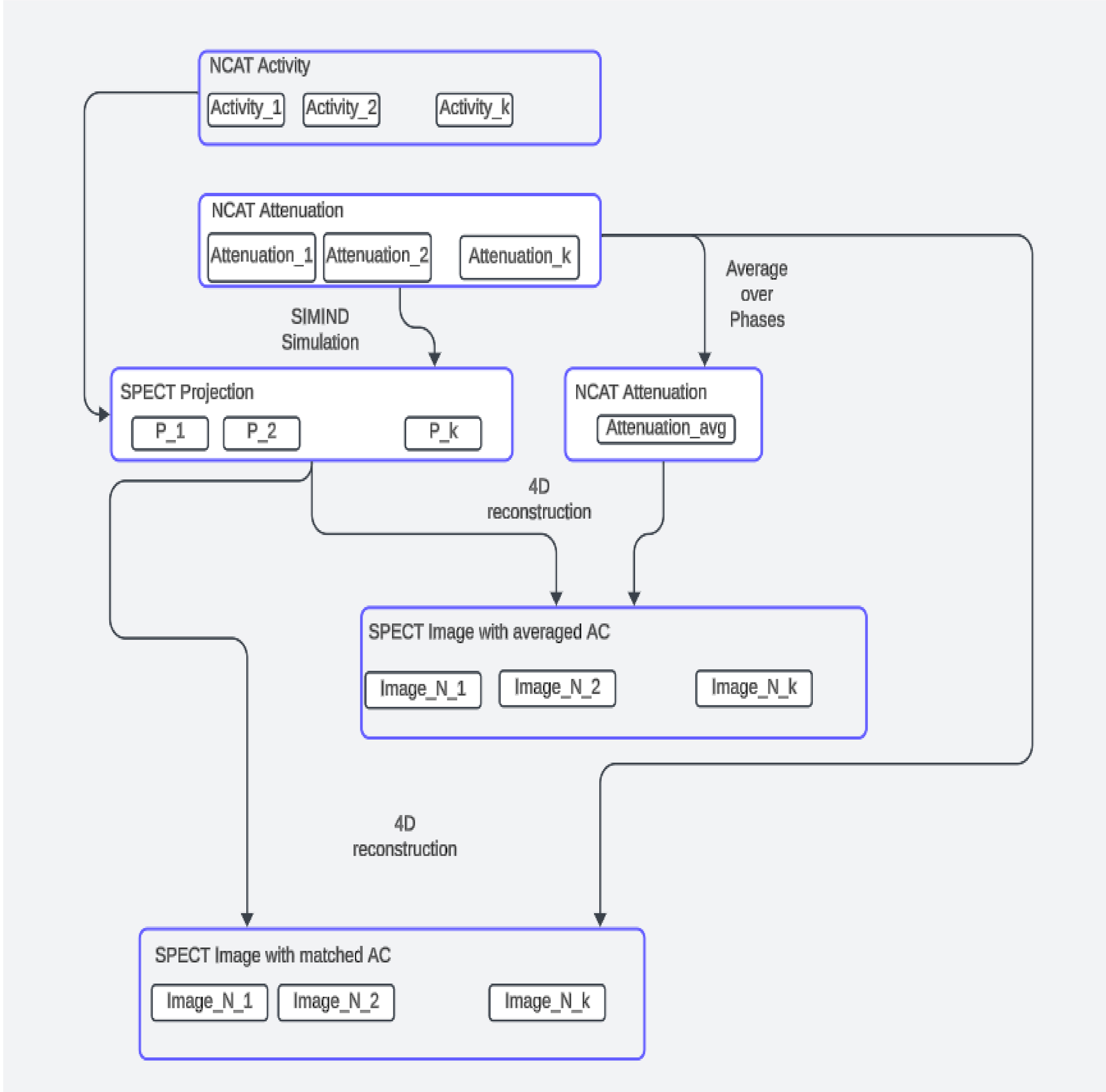
Evaluation criteria

- Reconstructed images
- Root mean square error (RMSE)
- Area under ROC curve (A_z) of Channelized Hoteling Observer (CHO)

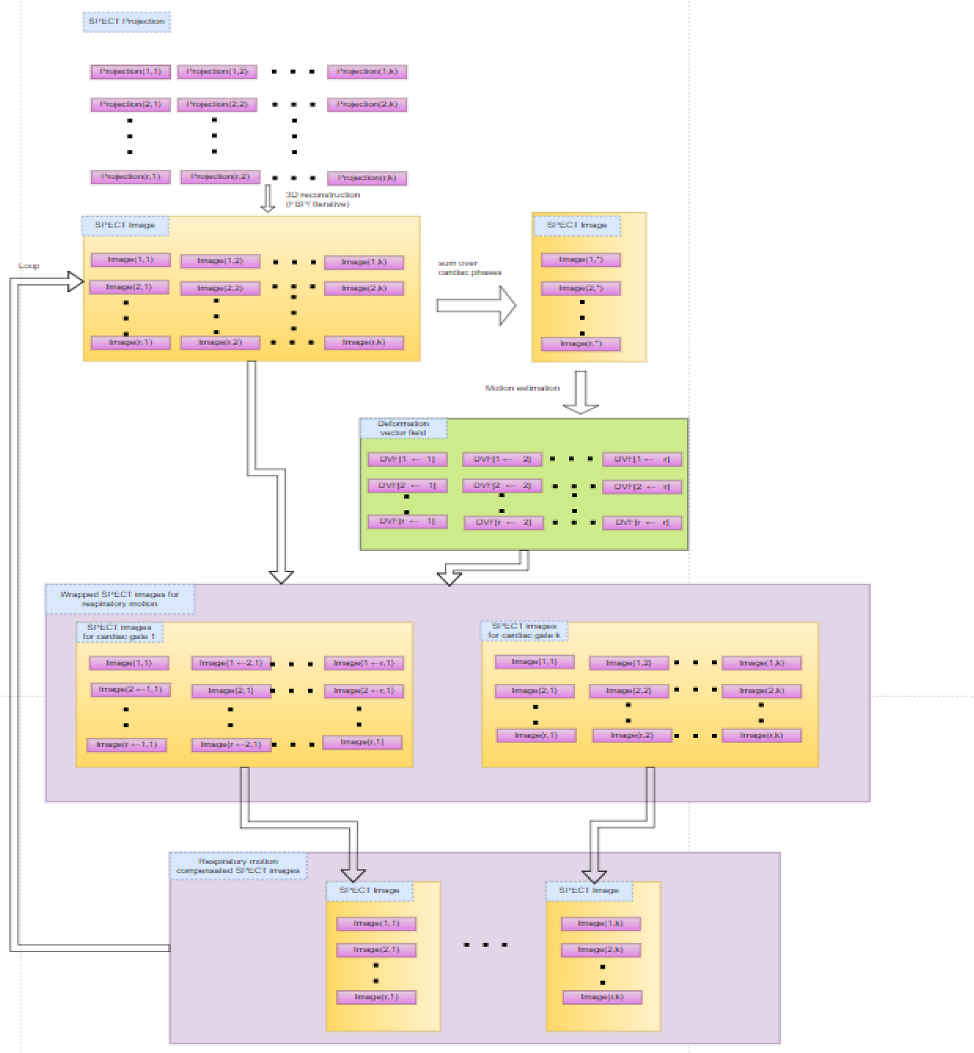
Summary and Future Work

In summary, we proposed a 4D cardiac/respiratory motion compensation reconstruction method with respiratory motion matched AC (RMM-AC). Our results indicate that it further improves image quality over 4D reconstruction with averaged AC (AVE-AC). In future, we will apply this method to real patient data and comprehensively evaluate its improvement on D-SPECT diagnostic accuracy.

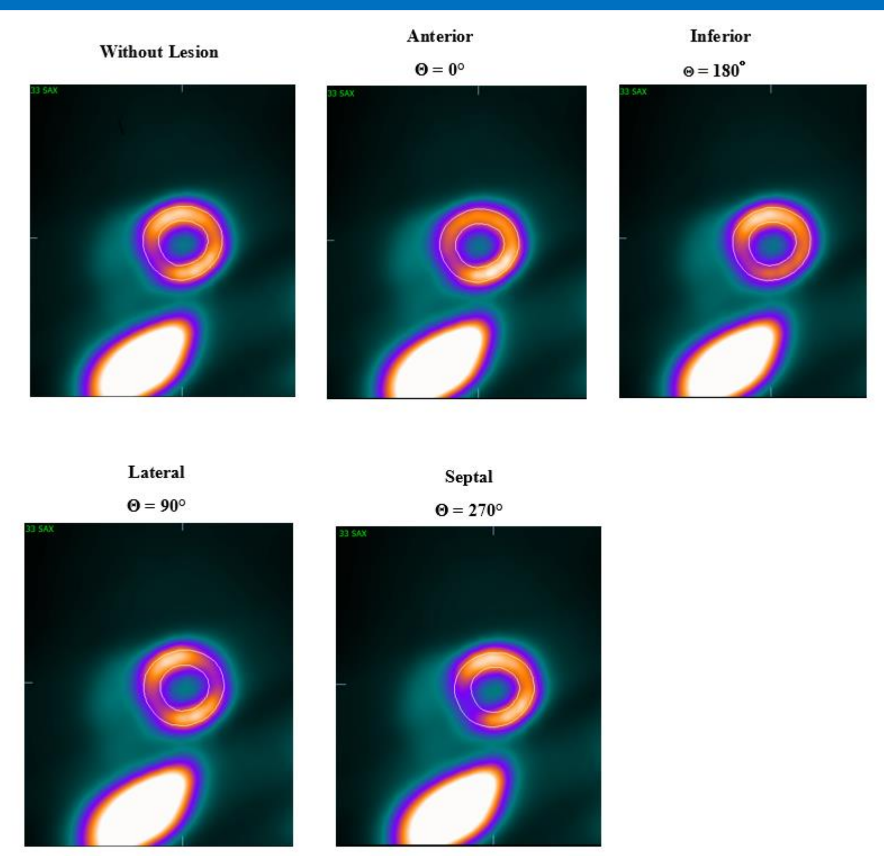
RMM-AC and AVE-AC for 4D Reconstruction



Post-recon temporal smoothing for D-SPECT



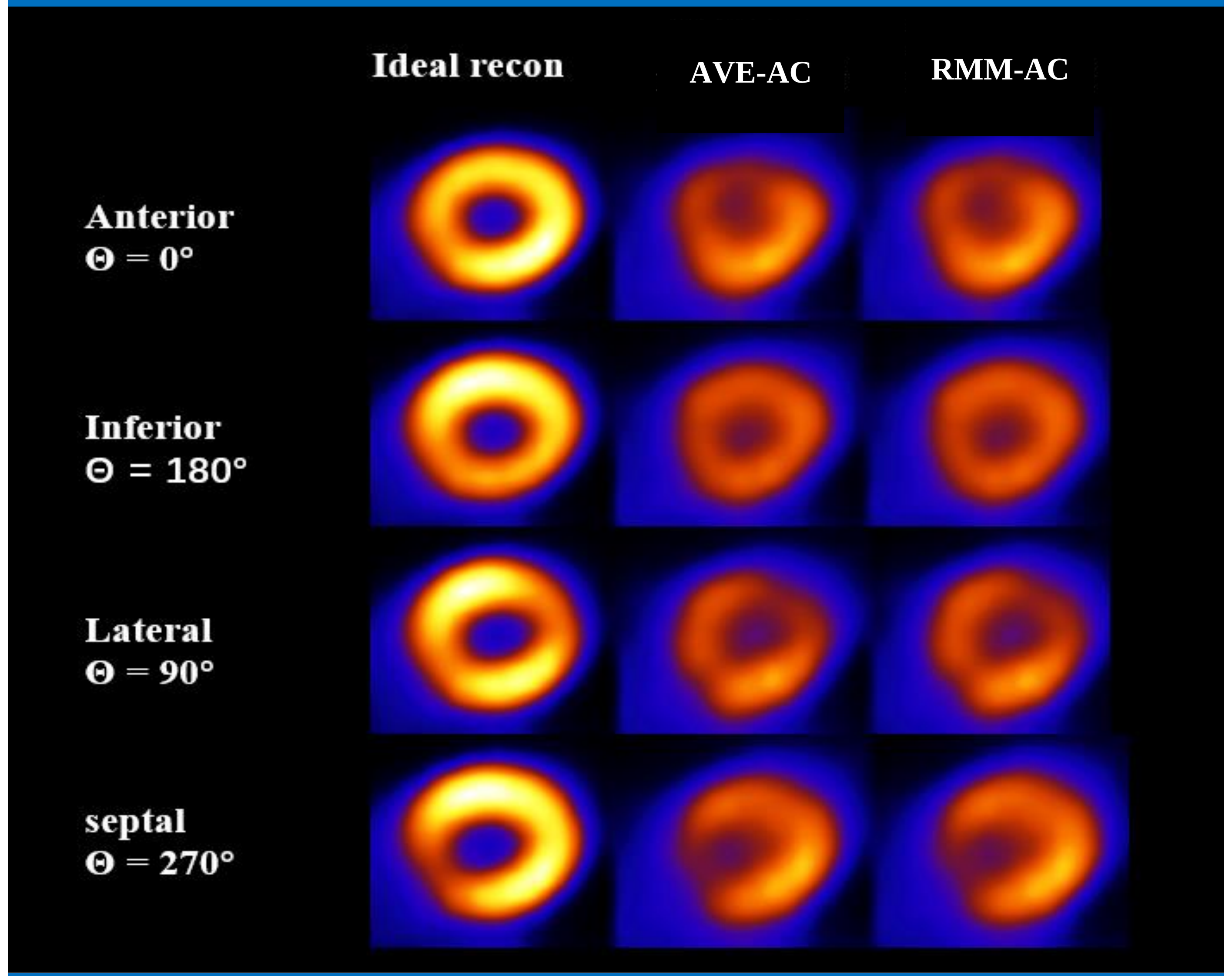
Four Lesion Locations



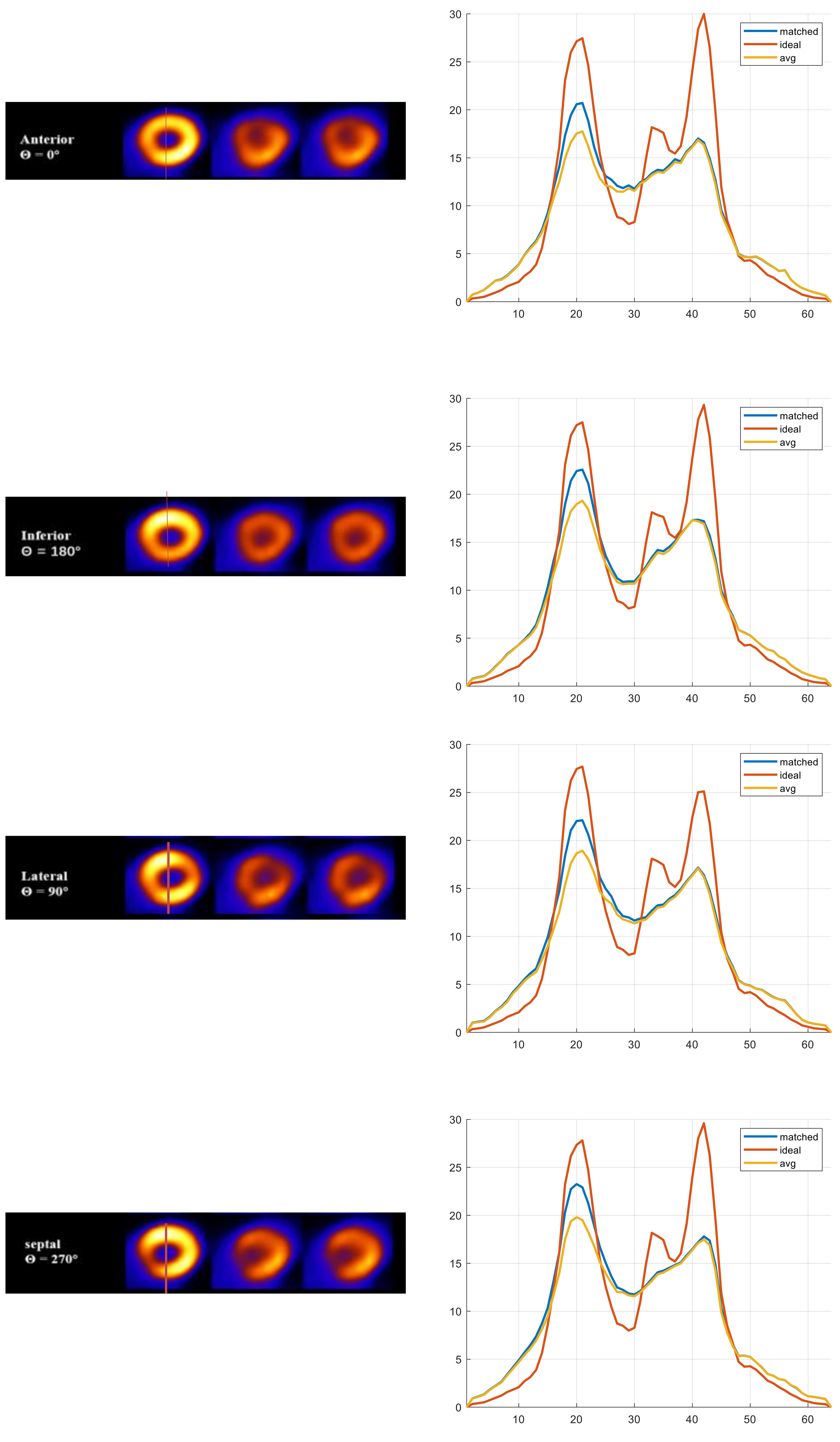
RMSE and CHO Results

Lesion Locations	Methods / Metrics	Averaged AC	Matched AC	Improvement
Anterior Θ = 0°	RMSE	8.1425	7.7134	5.270%
	Az	0.7081	0.7377	
Inferior Θ = 180°	RMSE	7.2904	7.0264	3.621%
	Az	0.789	0.791	
Lateral Θ = 90°	RMSE	7.2677	6.8345	5.961%
	Az	0.773	0.8351	
Septal Θ = 270°	RMSE	7.3653	6.9494	5.647%
	Az	0.7631	0.7869	

Reconstructed short axis images



Line Profile



Acknowledgments

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