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A Simulation Study of the Effect of Phase-Shift on Dual Gated Myocardial Perfusion ECT

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Abstract

We evaluated the effect of relative phase-shift of cardiac and respiratory (C&R) motions in myocardial perfusion (MP) ECT. Previously, we generated a set of realistic 3D XCAT (eXtended CARDiac Torso) phantoms that model simultaneous C&R motions for use in the study of new data acquisition methods and corrective image reconstruction techniques for improved gated MP ECT, including PET and SPECT. The respiratory motion (RM) over a respiration cycle was modeled using 24 equally-spaced time frames while the cardiac beating motion (CBM) over a cardiac cycle was divided into 48 equally-spaced time frames for each of the 24 RM phases. Almost noise-free projection datasets were generated separately from the heart, blood pool, lungs, liver, kidneys, stomach, gall bladder and remaining body at each of the 24×48 time points using Monte Carlo simulation techniques that include the effect of collimator detector response, photon attenuation and scatter. To demonstrate the effect of relative phase-shift, a typical ^{99m}Tc Sestamibi MP SPECT projection dataset were generated. They were then scaled and combined to model different degrees of relative C&R phase shifting and grouped into 6 respiratory-gates with 8 cardiac-gates. Each projection was reconstructed using a 3D OS-EM without and with attenuation correction using an averaged and phase-mismatched gated attenuation maps. The image artifacts of the reconstructed images were compared by visual inspection of the MP polar maps. The results showed significant changes of artifactual non-uniformity in the polar maps for off-phase of RM compared to those of CBM. The changes in the polar maps also demonstrated the effect of phase shifting accordingly. We conclude that the 4D XCAT phantom dataset with simultaneous C&R motions provides a powerful tool in the study of the effects of C&R motions with relative phase shifts, and development of C&R gating schemes and motion correction methods for improved ECT/CT imaging.

I. Introduction

It is well known that cardiovascular and respiratory motions are a major source of image artifacts in emission computed tomography (ECT) imaging. Although gating is a practical approach to reduce the effect of the motions for improved image quality, the issue initially received little attention due to the practical limitations of the methodology [1].

Recently, there have been clinical attempts for investigating the feasibility of dual cardiac-respiratory gating in emission computed tomography (ECT) acquisition [2, 3]. However, such a task is extremely complex due to the many parameters that it entails. Thus, we previously developed a realistic 4D simulation dataset that can model various cardiac and respiratory gating schemes to study the effects of the motions as well as to investigate optimal acquisition parameters, image reconstruction and correction methods for the dual gating study in ECT [4].

However, even for simultaneous cardiac-respiratory dual gating, irregular motions generate phase shift, resulting in artifacts in reconstructed images. Although phase-matched attenuation correction is recommended to minimize the artifact, it requires patient movement during PET & CT imaging and additional radiation exposure for gated CT. It is reported that misregistration occurred up to 40% of clinical cardiac PET/CT studies [5].

In this study, we evaluated the effect of relative phase-shift of cardiac and respiratory motions in myocardial perfusion (MP) SPECT with and without attenuation correction using the dual gating dataset which includes simultaneous cardiac and respiratory motions.

II. Procedure

A. The 4D Dual-Gating Dataset

The 4D eXtended CArdiac-Torso (XCAT) phantom was used to simulate a typical Tc-99m Sestamibi patient study (Fig. 1). XCAT phantom is widely used in the simulation studies of biomedical imaging research of different modalities, especially in SPECT and PET studies. The XCAT models cardiac motion based on a 4D cardiac gated and tagged MRI image dataset, and models respiratory motion based on a 4D respiratory gated CT image dataset.

The respiratory motion of the body excluding the heart was modeled by a total of 24 equally-spaced time frames of phantoms over a respiratory cycle (5 seconds). The body phantom includes six separate organs; lung, liver, stomach, kidney, gall bladder, and background body.

The beating heart which is consisted of myocardium and bloodpool was simulated separately with 48 equally-spaced time frames per cycle (1 second) for each of 24 respiratory phases so that we can generate any combination of cardiac-respiratory gating schemes. Table 1 shows summary of the dataset.

B. Generation of Projection Data

An almost noise-free projection dataset was generated separately for the entire 3D XCAT phantom which includes the heart, blood pool, lungs, liver, kidneys, stomach, gall bladder,

and remaining body using a long Monte Carlo simulation that include the effect of collimator detector response, photon attenuation and scatter. The separate projection datasets for body organs and the heart were combined to represent the complete torso of the body. Fig. 2 shows sample projection data.

The entire projection dataset is able to effectively model the simultaneous dual cardiac and respiratory gated ECT/CT. As shown in Fig. 3, each grid of the 24×48 matrix represents a frame of a specific phase of respiratory and cardiac cycle. Various kinds of respiratory and cardiac gating schemes can be generated from the master dataset by different combination of respiratory and cardiac phases, and some sample gating schemes are shown in Fig. 4.

C. Generation of Phase-Shifted Dataset

In this study, the entire 24×48 projection dataset was grouped into 6 respiratory gates with 8 cardiac gates to simulate dual gated myocardial perfusion SPECT data. To demonstrate the effect of relative phase shift, the projection data were then scaled and combined with different degrees of relative cardiac and respiratory frame shifting. Fig. 5 and Fig. 6 show phase shifting diagrams of cardiac and respiratory frames, respectively.

D. Reconstruction and Evaluation of the images

Each projection was reconstructed using a 3D OS-EM without and with attenuation correction using an averaged and phase-mismatched respiratory gated attenuation maps. The image artifacts of the reconstructed images were compared by visual inspection of the myocardial perfusion polar maps.

III. Results

The results of the cardiac and respiratory phase shifts with no attenuation correction were shown in Fig. 7 and Fig. 8, respectively. For each shifting case, there was not much difference in the cardiac polar map for the phase shift of cardiac beating motion, as shown in Fig. 7.

However, significant changes of artifactual non-uniformity in the polar maps were found for off-phase of respiratory motion, as shown in Fig. 8. In fact, phase shift of the artifacts in the polar map occurred with respiratory phase shift. For example, with the +2.5 second shift in which respiratory phase was completely reversed to the cardiac phase, EI-ED and EI-ES artifacts appeared in the 0-second phase shift were shown in EX-ES and EX-ED phases, respectively. Note that all the EX, EI, ED, and ES phases used in the various phase shift cases are determined based on the state of 0 second shift in which cardiac and respiratory phases are in-sync to each other. This makes it easier to identify the amount of phase shift in different phase shift cases compared to the 0 second shift.

Fig. 9 and Fig. 10 showed the results of the cardiac and respiratory phase shifts with attenuation correction using an averaged attenuation map. Compared to the results with no attenuation correction shown in Fig. 7 and Fig. 8, attenuation correction significantly reduced the attenuation artifact in both cardiac and respiratory phase shifts. The shift of the artifact due to the phase shift also occurred significantly with respiratory phase shift.

Fig. 11 and Fig. 12 showed the results of the cardiac and respiratory phase shifts with attenuation correction using phase-mismatched respiratory gated attenuation maps. In addition to the results found in the above without and with attenuation correction cases, phase-mismatched attenuation correction introduced increased artifacts at EI-ES and EX-ES phases with +2.5 seconds respiratory shift in which the mismatch between the activity map and attenuation map is nearly the maximum.

IV. Conclusions

The simultaneous dual cardiac and respiratory gating dataset using the 4D XCAT phantom is a realistic and powerful simulation dataset for investigating optimal imaging parameters and developing image reconstruction and correction methods for clinical ECT/CT dual gating study. It also provides a powerful tool in the study of the effects of cardiac and respiratory motions with relative phase shifts.

Sample study shows that the effect of phase shift in respiratory motion is significantly greater than that of cardiac motion. This implies irregular respiratory motion with different time period will result in different phase shifts and different degree of artifact.

Attenuation correction using an average attenuation map can reduce the artifacts. While attenuation correction using respiratory matched attenuation map provides minimum image artifact, attenuation correction using phase mismatched attenuation map results in increased image artifact.

Acknowledgments

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References

1. Ter-Pogossian MM, Bergmann SR, Sobel BE. "Influence of cardiac and respiratory motion on tomographic reconstructions of the hearts." implications for quantitative nuclear cardiology. J Comput Assist Tomogr. 1982; 6(6):1148–1155. [PubMed: 6983534]
2. Klein GJ, Reutter BW, Ho MH, Reed JH, Huesman RH. Real-time system for respiratory-cardiac gating in positron tomography. IEEE Transactions on Nucl Sci. 1998; 45(4):2139–2143.
3. Cho K, Kumiata S, Okada S, et al. Development of respiratory gated myocardial SPECT system. J Nucl Cardiol. 1999; 6:20–28. [PubMed: 10070837]
4. Lee, T-S.; Paul Segars, W.; Tsui, B. The Development and Application of a Realistic Simulation Dataset for Simultaneous Cardiac and Respiratory Gated ECT/CT. Nuclear Science Symposium and Medical Imaging Conference Record; Honolulu, Hawaii. 2007. p. 3656
5. Gould K, et al. Frequent diagnostic errors in cardiac PET/CT due to misregistration of CT attenuation and emission PET images: a definitive analysis of causes, consequences, and corrections. J Nucl Med. 2007; 48:1112–1121. [PubMed: 17574974]

Fig. 1. XCAT phantom (a: anterior view of the XCAT torso, b: heart phantoms with end-systolic (left) and end-diastolic (right) phases, c: sample activity map, d: sample attenuation map)

Fig. 2.

Anterior view of the projection data generated using Monte Carlo simulation for different organs (a: myocardium, b: blood pool, c: lung, d: liver, e: stomach, f: kidney, g: gall bladder, h: background body)

Fig. 3.
The entire projection dataset for simultaneous dual gating study.

Fig. 4.

Various respiratory-cardiac gating schemes which can be generated from the dataset. Each different color block represents one frame. (a: ungated, b: No respiratory gating with 8 frames cardiac gating, c: 6 frames respiratory gating with no cardiac gating, d: simultaneous 6 frames respiratory and 8 frames cardiac gateings)

Fig. 5.

Phase-shifting of cardiac frames. (Red: cardiac frames, Blue: respiratory frames, a: 0 second shift, b: 0.25 seconds cardiac phase shift, c: 0.5 seconds cardiac phase shift, d: 0.75 seconds cardiac phase shift)

Fig. 6.

Phase-shifting of respiratory frames. (Red: cardiac frames, Blue: respiratory frames, a: 0 second shift, b: 1.25 seconds respiratory phase shift, c: 2.5 seconds respiratory phase shift, d: 3.75 seconds respiratory phase shift)

Fig. 7.

Left ventricle polar maps of the reconstructed images for different degrees of cardiac phase shifting for different cardiac-respiratory phases with no attenuation correction. (from the top, first row: End-Inspiration – End-Diastole, second row: End-Inspiration – End-Systole, third row: End-Expiration – End-Diastole, fourth row: End-Expiration – End-Systole)

Fig. 8.

Left ventricle polar maps of the reconstructed images for different degrees of respiratory phase shifting for different cardiac-respiratory phases with no attenuation correction. (from the top, first row: End-Inspiration – End-Diastole, second row: End-Inspiration – End-Systole, third row: End-Expiration – End-Diastole, fourth row: End-Expiration – End-Systole)

Fig. 9.

Left ventricle polar maps of the reconstructed images for different degrees of cardiac phase shifting for different cardiac-respiratory phases with attenuation correction using an averaged attenuation map. (from the top, first row: End-Inspiration – End-Diastole, second row: End-Inspiration – End-Systole, third row: End-Expiration – End-Diastole, fourth row: End-Expiration – End-Systole)

Fig. 10.

Left ventricle polar maps of the reconstructed images for different degrees of respiratory phase shifting for different cardiac-respiratory phases with attenuation correction using an averaged attenuation map. (from the top, first row: End-Inspiration – End-Diastole, second row: End-Inspiration – End-Systole, third row: End-Expiration – End-Diastole, fourth row: End-Expiration – End-Systole)

Fig. 11.

Left ventricle polar maps of the reconstructed images for different degrees of cardiac phase shifting for different cardiac-respiratory phases with attenuation correction using phase-mismatched respiratory gated attenuation maps. (from the top, first row: End-Inspiration – End-Diastole, second row: End-Inspiration – End-Systole, third row: End-Expiration – End-Diastole, fourth row: End-Expiration – End-Systole)

Fig. 12.

Left ventricle polar maps of the reconstructed images for different degrees of respiratory phase shifting for different cardiac-respiratory phases with attenuation correction using phase-mismatched respiratory gated attenuation maps. (from the top, first row: End-Inspiration – End-Diastole, second row: End-Inspiration – End-Systole, third row: End-Expiration – End-Diastole, fourth row: End-Expiration – End-Systole)

TABLE I

The 4D Dual-Gating Dataset

	Cardiac Dataset	Respiratory Dataset
Phantom	Heart only (myocardium, blood pool)	Lung, liver, stomach, kidney, gall bladder, background body
Frames/cycle	48/1 second	24/5 seconds
Possible Gating Schemes	8, 16, 24 equally space time gates/cycle	3, 4, 6 equally space time gates/cycle