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Investigation of Respiratory Gating in Quantitative Myocardial SPECT

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Abstract

The purpose of this study is to investigate optimal respiratory gating schemes using different numbers of gates and placements within the respiratory cycle for reduction of respiratory motion (RM) artifacts in myocardial SPECT. The 4D NCAT phantom with its realistic respiratory model was used to generate 96 3D phantoms equally spaced over a complete respiratory cycle modeling the activity distribution from a typical Tc-99m Sestamibi study with the maximum movement of the diaphragm set at 2 cm. The 96 time frames were grouped to simulate various gating schemes (1, 3, 6, and 8 equally spaced gates) and different placements of the gates within a respiratory cycle. Projection data, including effects of attenuation, collimator-detector response and scatter, from each respiratory gate and each gating scheme were generated and reconstructed using the OS-EM algorithm with correction for attenuation. Attenuation correction was done with average attenuation maps for each gate and over the entire respiratory cycle. Bull's-eye polar plots generated from the reconstructed images for each gate were analyzed and compared to assess the effect of RM. RM artifacts were found to be reduced the most when going from the ungated to the gated case. No significant difference was found in attenuation compensated images between the use of gated and average attenuation maps. Our results indicate that the extent of RM artifacts is dependent on the placement of the gates in a gating scheme. Artifacts are less prominent in gates near end-expiration and more prominent near end-inspiration. This dependence on gate placement decreases when going to higher numbers of gates (6 and higher). However, it is possible to devise a non-uniform time interval gating scheme with 3 gates that will produce results similar to those using a higher number of gates. We conclude that respiratory gating is an effective way to reduce RM artifacts. Effective implementation of respiratory gating to further improve quantitative myocardial SPECT requires optimization of the gating scheme based on the amount of respiratory motion of the heart during each gate and the placement of the gates within the respiratory cycle.

Keywords

Imaging; motion compensation; simulation; single photon emission computed tomography (SPECT)

I. INTRODUCTION

QUANTITATIVE myocardial single photon emission computed tomography (SPECT) has received increased acceptance in clinical nuclear medicine. Corrections of attenuation, collimator-detector response and scatter are becoming available in clinical SPECT image processing and reconstruction software. As image artifacts caused by these important image

degrading factors are significantly reduced, effects from other image degrading factors become important. Examples are patient motions during data acquisition including voluntary motions such as patient shifting and involuntary motions such as cardiac and respiratory motions.

Respiratory motion (RM) has been known to cause artifacts in myocardial SPECT images. These artifacts, which appear as a reduction in the myocardial activity estimate in the area of the inferior and superior walls of the left ventricle, mimic perfusion abnormalities indicative of patients with coronary artery disease and therefore, can lead to the misdiagnosis of patients. RM artifacts are caused by the up and down motion of the heart and diaphragm during the course of image acquisition [1]–[3]. The diaphragm and heart typically move 1–2 cm during normal tidal breathing and up to 10 cm during heavy exercise [4].

One method used to minimize the effects of respiration is respiratory gating [5]–[12]. In respiratory gating, image acquisition is performed during a portion of the respiratory cycle (gating period) in which the extent of motion of the heart and diaphragm is reduced. In this manner, respiratory gating reduces the motion blur caused by respiratory motion, but it also leads to an increase in image noise in the gated images due to the smaller number of detected counts within a gated frame. Respiratory gating, therefore, involves a tradeoff between motion artifact reduction and increased image noise. In order to reduce image noise, one would want the gating period to be as long as possible (allowing more respiratory motion) without introducing significant motion artifacts.

In order to perform respiratory gating, a method is needed to track the respiratory motion. One common method to track the motion involves monitoring a pressure signal from a belt (pneumatic bellows) taped to a patient's chest or mid-abdomen [7], [10]. A second technique uses infrared tracking of markers attached to the patient [11]–[13]. Other approaches include pressure sensors or thermometers [14] to monitor the breathing airflow of the patient. The data collected from these tracking methods provides an indirect assessment of the interior motion of the heart and diaphragm.

In a previous study [6], we utilized the 4D NURBS-based Cardiac-Torso (NCAT) phantom [15]–[17], with its realistic model for the respiratory motion (Fig. 1), to investigate the efficacy of using respiratory gating to correct for respiratory artifacts in myocardial SPECT images. We found that in order to keep image noise at a minimum and to reduce motion artifacts, the gating intervals in a respiratory gating scheme should be as long as possible, but include a respiratory motion of less than 1 cm for the heart and diaphragm for minimum motion artifact. This study only investigated a single placement for the gates for a particular gating scheme. In this work, we investigate optimal respiratory gating schemes using different numbers of gates and placement within the respiratory cycle.

II. METHODS

Using the 4D NCAT phantom, 96 3D NCAT phantom sets modeling the radioactivity concentrations and attenuation distributions in the different organs were generated equally spaced time intervals over a complete respiratory cycle. The distribution of radioactivity concentration in different organs was set to model that of a typical Tc-99m Sestamibi patient study (Table I) as measured in SPECT images [18]. The heart and diaphragm were set to move a maximum of 2 cm during respiration. An average beating heart motion was simulated for each of the 96 time frames. Each generated 3D phantom (activity and attenuation) was stored in a $128 \times 128 \times 128$ array with a pixel size and slice thickness of 0.3125 cm. The 3D phantom sets were grouped and summed to divide the respiratory cycle into various gating schemes (1, 3, 6, and 8 equally spaced gates) and different placements of

the gates within a respiratory cycle (Fig. 2). The respiratory curve of Fig. 2 is based on a volume curve for normal respiration as determined from West's *Respiratory Physiology* [4]. This curve forms the basis for respiration in the NCAT as described in [15].

Emission projection data was generated from the 4D NCAT phantom modeling each respiratory gate of each gating scheme using the SimSET Monte Carlo code. A large number of counts were used so the projections would be relatively noise-free. A complete projection dataset over the typical 180° arc (45° RAO to 45° LPO) around the patient was generated. The emission data included realistic models of the effects of attenuation, scatter, and collimator-detector response [19]–[22]. A low-energy high-resolution (LEHR) collimator with a thickness of 4.1 mm and hexagonal holes with a flat-to-flat size of 0.19 mm was simulated. The 60 128×128 simulated projection images were collapsed to 64×64 to simulate sampling used in clinical data acquisition.

The emission projection data were reconstructed using the iterative OS-EM reconstruction method with compensation for attenuation. Attenuation correction was done with average attenuation maps for each gate (gated attenuation map) and an average attenuation map for the entire respiratory cycle (ungated attenuation map). The 128×128×128 attenuation phantoms were collapsed to 64×64×64 (0.625 cm pixel width and slice thickness) to match the resolution of the emission projection data. The emission projection images were reconstructed into 64×64 arrays with 64 slices and a pixel width and slice thickness of 0.625 cm. The reconstructed transaxial images for each respiratory gate in a gating scheme were reoriented into short-axis (SA) images. The SA images were smoothed using a Butterworth filter with a cutoff of 0.2 and bull's-eye polar plots (Fig. 3) were generated from them for each gate. Two regions-of-interest (ROI₁ and ROI₂) were placed over the inferior (prominent location for RM artifacts) and lateral (no visible artifacts) walls of the left ventricle in each bull's-eye polar plot. The average intensity for each region was calculated. The intensity ratio (IR) was then determined by the following equation

$$IR = \frac{ROI_1}{ROI_2}. \quad (1)$$

An intensity ratio that deviates from 1 indicates a non-uniformity artifact caused by the respiratory motion. A representative bull's-eye plot for each gating scheme was also generated by summing the individual polar plots for each gate composing the gating scheme. The intensity ratios were compared for each gate and each gating scheme.

III. RESULTS

Without using any compensation, respiratory motion (RM) artifacts were seen as decreased intensities in both the superior and inferior walls of the left ventricle (Fig. 4). A gated attenuation map was used for reconstruction of the case without motion while an ungated attenuation map (containing the average motion) was used in the case with motion. The intensity ratio (IR) was reduced from 0.9 in the case without motion to 0.65 in the case with an average respiratory motion of 2 cm. For the motion-free case, the IR value is still lower than 1. This can be attributed to the data generation and image reconstruction methods used in the study. We used Monte Carlo simulation methods to generate the SPECT projection data that included the effects of photon attenuation and scatter, and the collimator-detector blur. However, in image reconstruction, only attenuation correction was applied. Other contributing factors include the realistic nature of the NCAT phantom (the heart is based on patient data and the LV walls are not uniform) and the amount of smoothing used in the bull's-eye plots.

Respiratory gating was found to be an effective means to reduce these artifacts. Fig. 5 shows the representative bull's-eye polar plot generated for each different gating scheme (3, 6, and 8 gates) and placement (A, B, C, and D) using ungated and gated attenuation maps for attenuation correction of the reconstructed images. As mentioned above, the representative bull's-eye plot for each case was obtained by summing the individual plots created for each gate in the particular gating scheme. The RM artifacts were found to be reduced the most when going from the ungated to the gated case with 3 equally spaced gates. Further improvement is seen going from 3 to 6 gates. However, very little improvement is seen from 6 to 8 gates. No significant difference can be seen in the attenuation compensated images between the use of gated and ungated attenuation maps.

An optimal gating scheme with 3 gates was evaluated for its effectiveness to minimize the RM artifact. The gates were arranged so as to minimize the respiratory motion of the heart in each. Gates on the rising and falling edges of the respiratory volume curve were summed into one gate ($\text{Gate2} = \text{Gate2A} + \text{Gate2B}$) while the remaining two gates covered the transition from inspiration to expiration and vice versa, Fig. 6. The three gates divided the respiratory cycle uniformly in time. The optimal gating scheme was found to produce comparable results to those obtained using 6 and 8 gates.

Fig. 7 explores the effectiveness of each gating scheme in more detail. The IR values calculated from the bull's-eye polar plots created for each respiratory gate of each scheme is plotted as a function of the diaphragm motion occurring during that gate for the different gating schemes. The results obtained using gated attenuation maps for attenuation correction are shown. Similar results were found using ungated attenuation maps (results not shown). The effectiveness of respiratory gating can be seen to be dependent on the amount of respiratory motion of the heart. However, it also is dependent on the placement of the gates within the respiratory cycle. For 3, 6 and 8 gates, a fork in the graph appears where gates with very little respiratory motion have higher IR values in their polar plots as compared to other gates with a similar reduced motion. The gates with lower IR values (less uniform polar plots) are located on or near the end-inspiration portion of the respiratory cycle (Fig. 2) while the other gates with similar motion and higher IR values (more uniform polar plots) are located near end-expiration. This difference can also be seen in the IR values calculated for the optimal 3 gate scheme. The IR value for gate 1 located within end-expiration was 0.87 as compared to 0.81 for gate 2 on the rising and falling edges of the respiratory curve and 0.81 for gate 3 located within end-inspiration.

Fig. 8 shows how detectable these differences are in the individual bull's-eye plots. The figure shows the bull's-eye plot for gate 3 of the 3C gating scheme versus gate 2 of the 3A gating scheme, gate 6 of the 6C gating scheme versus gate 3 of the 6B gating scheme, and gate 8 of the 8C gating scheme versus gate 4 of the 8B gating scheme. In each comparison, the two gates contain a similar amount of heart and diaphragm motion, but are located at opposite portions of the respiratory cycle, end-expiration versus end-inspiration. Differences can be seen in the comparison of each pair of polar plots. Gates located near end-inspiration appear to have reduced activity in the inferior wall of the left ventricle.

Using an increasing number of gates can limit the dependence on the placement of the gates. As seen in Fig. 7, the IR values for the gates ranged from 0.69 to 0.87, 0.78 to 0.89, and 0.79 to 0.89 for the 3, 6, and 8 gate schemes respectively. The decreased variability means that there is less of a dependence on the placement of the gates. The greatest improvement is seen going from 3 to 6 gates. The optimal 3 gate scheme does show a comparable improvement in variability to that of 6 and 8 gates. The IR values for its three gates ranged from 0.81 to 0.87.

IV. CONCLUSION

Using the 4D NCAT phantom, we investigated various respiratory gating schemes using different numbers of gates and placement within the respiratory cycle for reduction of respiratory motion artifacts in myocardial SPECT. Respiratory gating was found to be an effective means to reduce RM artifacts. The artifacts were reduced the most when going from the ungated to the gated case.

Our results indicate that the placement of the gates is an important factor in determining the effectiveness of a gating scheme. RM artifacts were found to be less prominent in gates placed on or near end-expiration and more prominent in gates on or near end-inspiration. This is likely due to the increased attenuation that occurs due to the lower diaphragm position during inspiration. Attenuation compensation does not appear to fully compensate for this. Therefore, if it is desired to acquire only a single gate, the best possible placement for the gate would be centered over end-expiration and not including over 1 cm of motion within the gate.

In comparing the gating schemes, the RM artifacts were found to decrease when going to higher numbers of gates. The most improvement was seen going from no gating to 3 gates; little improvement was seen from 6 to 8 gates. The effect of the placement of the gates was also found to decrease as more gates were used. The difference in the IR value for the best gate (near end-expiration) and the worst (near end-inspiration) can be seen to decrease (Fig. 7). The best gate placement for each scheme was found to be D, D, and B for 3, 6, and 8 gates respectively with the average IR values being 0.79, 0.83, and 0.84 (Fig. 5). Respiratory motion was reduced in these schemes due to more gates being centered over end-expiration and end-inspiration and not falling on the steep portions of the respiratory curve (Fig. 2). Based on these results, a minimum of ~6 equally spaced gates is effective in reducing RM artifacts with less dependence on their placement scheme. However, it is possible to devise an optimal 3 gate scheme (uniform in time) that would produce results similar to those using a higher number of gates. To implement this scheme, gates on the rising and falling edges of the respiratory curve are summed into one single gate so as to minimize the respiratory motion. The average IR value for the 3 gates of this scheme was found to be 0.84 (ranging from 0.81 to 0.87). Therefore, the optimal 3 gate scheme would appear to be the best due to the inclusion of less image noise (longer gates) and less RM artifacts (less motion within the gates). In our results, we found no significant difference between reconstructed images using ungated and gated attenuation maps for attenuation compensation.

The results of the study indicate that effective implementation of respiratory gating to further improve quantitative myocardial SPECT requires optimization of the gating scheme based on the amount of respiratory motion of the heart during each gate and the placement of the gates within the respiratory cycle. In this study, we have a known respiratory motion pattern that is uniform over time with constant amplitude. In reality, the respiratory motion is unknown and often irregular with variable timing intervals and amplitudes. In order to perform effective respiratory gating in the clinic, tracking methods such as those mentioned in the Introduction are required. These methods have been shown to be good indicators of the respiratory motion of the heart and have been effective in minimizing RM artifacts. We believe that further improvement is possible using our results to guide respiratory gating procedures that use these tracking devices.

In this study, an average beating heart motion was simulated for each gate; therefore, we did not consider cardiac gating. Cardiac gating is useful in providing cardiac images with higher resolution at the expense of increased image noise in the gated images. It is important in providing information on myocardial wall abnormalities and other cardiac functions such as

ejection fraction. It is not as important in determining perfusion in myocardial SPECT as the beating heart motion does not significantly affect the perfusion distribution of the myocardium. Respiratory motion, on the other hand, can introduce significant artifacts in perfusion distribution, especially when the respiratory amplitude is 2 cm or larger, that can affect clinical diagnosis. Hence, compensation for the effect of respiratory motion, such as using respiratory gating, is the most important in improving clinical diagnosis.

Combined ECG and respiratory gating will provide information on both perfusion distribution and regional motion of the myocardial wall with minimum image artifacts that can affect clinical diagnosis [23]. However, the combined ECT and respiratory gated images will have greatly reduced counts and increased image noise. Further studies are needed to investigate different combinations of the gated images to obtain different clinical information from a single study for improved diagnosis and patient care. Also, new image reconstruction and processing methods are under investigation that will significantly improve gated myocardial SPECT images [24] for further improvement in image quality.

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REFERENCES

- [1]. Tsui BMW, Segars WP, Lalush DS. Effects of upward creep and respiratory motion in myocardial SPECT. *IEEE Trans. Nucl. Sci* Jun;2000 vol. 47(no. 3):1192–1195.
- [2]. Ritchie C, Crawford CR, Godwin JD, King KF, Kim Y. Correction of computed tomography motion artifacts using pixel-specific back-projection. *IEEE Trans. Med. Imag* Jun;1996 vol. 15(no. 3):333–342.
- [3]. Wang Y, Riederer S, Ehman R. Respiratory motion of the heart: Kinematics and the implications for the spatial resolution in coronary imaging. *MRM* 1995;vol. 33:713–719.
- [4]. West, J. *Respiratory Physiology*. 5th ed. Williams and Wilkins; Baltimore, MD: 1995.
- [5]. Cho K, Kumiata S, Kumazaki T. Development of a respiratory gated myocardial SPECT system. *J. Nucl. Cardiol* 1999;vol. 6:20–28. [PubMed: 10070837]
- [6]. Segars WP, Tsui BMW. Study of the efficacy of respiratory gating in myocardial SPECT using the new 4-D NCAT phantom. *IEEE Trans. Nucl. Sci* Jun;2002 vol. 49(no. 3):675–679.
- [7]. Klein GJ, Reutter BW, Ho MH, Reed JH, Huesman RH. Real-time system for respiratory-cardiac gating in positron tomography. *IEEE Trans. Nucl. Sci* Aug;1998 vol. 45(no. 4):2139–2143.
- [8]. Kovalski G, Israel O, Keidar Z, Frenkel A, Sachs J, Azhari H. Correction of heart motion due to respiration in clinical myocardial perfusion SPECT scans using respiratory gating. *J. Nucl. Med* 2007;vol. 48(no. 4):630–636. [PubMed: 17401102]
- [9]. Livieratos L, Rajappan K, Stegger L, Schafers K, Bailey DL, Camici PG. Respiratory gating of cardiac PET data in list-mode acquisition. *Eur. J. Nucl. Med. Molecular Imag* 2006;vol. 33(no. 5):584–588.
- [10]. Livieratos L, Stegger L, Bloomfield PM, Schafers K, Bailey DL, Camici PG. Rigid-body transformation of list-mode projection data for respiratory motion correction in cardiac PET. *Phys. Med. Biol* 2005;vol. 50(no. 14):3313–3322. [PubMed: 16177511]
- [11]. Vedam S, Keall P, Kini V, Mostafavi H, Shukla H, Mohan R. Acquiring a four-dimensional computed tomography dataset using an external respiratory signal. *Phys. Med. Biol* 2003;vol. 48:45–62. [PubMed: 12564500]
- [12]. Nehmeh S, Erdi Y, Rosenzweig K, Schoder H, Larson SA, Squire O, Humm J. Reduction of respiratory motion artifacts in PET imaging of lung cancer by respiratory correlated dynamic PET: methodology and comparison with respiratory gated PET. *J. Nucl. Med* 2003;vol. 44:1644–1648. [PubMed: 14530480]

- [13]. Beach R, Pretorius PH, Boening G, Bruyant P, Bing F, Fulton R, Gennert M, Nadella S, King MA. Feasibility of stereo-infrared tracking to monitor patient motion during cardiac SPECT imaging. *IEEE Trans. Nucl. Sci* Oct;2004 vol. 51(no. 5):2693–2698. [PubMed: 19081781]
- [14]. Wang Y, Baghaei H, Li H, Liu Y, Xing T, Uribe J, Ramirez R, Xie S, Kim S, Wong W-H. A simple respiratory gating technique and its application in high-resolution PET camera. *IEEE Trans. Nucl. Sci* Feb;2005 vol. 52(no. 1):125–129.
- [15]. Segars WP, Lalush DS, Tsui BMW. Modeling respiratory mechanics in the MCAT and spline-based MCAT phantoms. *IEEE Trans. Nucl. Sci* Feb;2001 vol. 48(no. 1):89–97.
- [16]. Segars WP, Lalush DS, Tsui BMW. A realistic spline-based dynamic heart phantom. *IEEE Trans. Nucl. Sci* Jun;1999 vol. 46(no. 3):503–506.
- [17]. Segars, WP. Ph.D. dissertation. Dept. Biomed. Eng., Univ. North Carolina; Chapel Hill: May. 2001 Development of a new dynamic NURBS-based cardiac torso (NCAT) phantom.
- [18]. Jaszczak R, Gilland D. An experimental phantom based on quantitative SPECT analysis of patient MIBI biodistribution. *J. Nucl. Med* 1996;vol. 33:451–457.
- [19]. Tsui BMW, Hu H-B, Gilland DR. Implementation of simultaneous attenuation and detector response correction in SPECT. *IEEE Trans. Nucl. Sci* Feb;1988 vol. 35(no. 1):778–783.
- [20]. Frey EC, Ju Z-W, Tsui BMW. A fast projector-backprojector pair modeling the asymmetric, spatially varying scatter response function for scatter compensation in SPECT imaging. *IEEE Trans. Nucl. Sci* Aug;1993 vol. 40(no. 4):1192–1197.
- [21]. Frey EC, Tsui BMW. A practical method for incorporating scatter in a projector-backprojector for accurate scatter compensation in SPECT. *IEEE Trans. Nucl. Sci* Aug;1993 vol. 40(no. 4): 1107–1116.
- [22]. Zeng, GL.; Gullberg, GT. Frequency domain implementation of the three-dimensional geometric point response function correction in SPECT imaging. presented at the IEEE Nucl. Sci. Symp. Med. Imag. Conf.; Santa Fe, NM. 1991;
- [23]. Lee, T-S.; Segars, WP.; Tsui, BMW. The development and application of a realistic simulation dataset for simultaneous cardiac and respiratory gated ECT/CT. presented at the IEEE Nucl. Sci. Symp. Conf. Rec. (NSS); Honolulu, HI. 2007;
- [24]. Lee, T-S.; Segars, WP.; Tsui, BMW. Study of parameters characterizing space-time Gibbs priors for 4D MAP-RBI-EM in gated myocardial perfusion SPECT. presented at the IEEE Nucl. Sci. Symp.; Puerto Rico. 2005;

Fig. 1. Respiratory model of the 4D NCAT phantom. During inspiration, the ribs rotate upward and outward and the heart and diaphragm move downward to expand the chest volume causing the lungs to inflate. The dotted line indicates the top of the diaphragm at end-expiration.

Fig. 2. Respiratory gating schemes with (a) (b) and (c) equally spaced respiratory gates. In each group of respiratory gates, A, B, C and D represent 4 different placements of the respiratory gates within a respiratory cycle.

Fig. 3. (Left) Bull's eye plot. A bull's eye plot is a 2D representation of the 3D perfusion in the LV myocardium. The plot consists of concentric rings representing the myocardial activity of a reconstructed transaxial slice. The apex region of the LV is located at the center of the plot while the base region is located at the periphery. (Right) ROI's examined from a bull's-eye polar plot.

Fig. 4.
Bull's-eye polar plots generated from the NCAT simulations without (left) and with (right) an average respiratory motion.

Fig. 5.

Summed representative bull's-eye polar plots showing the effect of different respiratory gating schemes with (a) 3, (b) 6, and (c) 8 gates using ungated (top row) and gated (bottom row) attenuation maps. Columns 1–4 show gate placements A–D respectively as labeled at the top of the figure. IR values calculated for each scheme are shown. (a) 3 gates, (b) 6 gates, (c) 8 gates.

Fig. 6. (Left) Optimal 3 gate respiratory gating scheme. (Right) Representative bull's-eye plot generated by summing the plots for the individual gates. IR value calculated from the polar plot is shown. Result is comparable to those obtained using 6 and 8 gates.

Fig. 7. Plots of intensity ratio versus diaphragm motion for (a) 3, (b) 6, and (c) 8 gate respiratory gating schemes. Results were obtained using a gated attenuation maps for attenuation correction. Bull's-eye plots for the labeled gates for each gating scheme are shown for comparison in Fig. 8. (a) 3 gates, (b) 6 gates, (c) 8 gates.

Fig. 8.

Comparison of the bull's-eye polar plots of two respiratory gates with similar motion of the heart and diaphragm, but located at opposite ends of the respiratory cycle, one near end-expiration (left) and one near end-inspiration (right). A comparison is shown for the use of 3, 6, and 8 gates.

TABLE I

THE RELATIVE RADIOACTIVITY CONCENTRATIONS OF THE DIFFERENT ORGANS FOR TC-99M SESTAMIBI AS MODELED IN THE NCAT PHANTOMS

Organ	Uptake ratio relative to the background
Heart myocardium liver and kidneys	75.0
Body, stomach, rib, and spine	2.0
Lungs	4.0
Spleen	60.0