Iterative 4D reconstruction of dynamic SPECT images

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Introduction

Kinetic modeling of biological processes has been a very active research area for many years in PET and it is starting in SPECT too. Quantitative kinetic analysis of dynamic cardiac single-photon emission computed tomography (SPECT) data provides unique information that can enable improved discrimination between healthy and diseased tissue, compared to static imaging. In particular, compartmental model analysis can provide quantitative measures of myocardial perfusion, viability, and coronary flow reserve. Conventional kinetic parameter estimation is carried out after a previous reconstruction of a dynamic sequence of 3D images from complete projections acquired in relatively short times. Kinetic parameters are then obtained by fitting compartimental kinetic models to time-activity curves generated by overlaying regions of interest on the temporal sequence of reconstructed images.

Since dynamic single photon emission computed tomography (SPECT) data acquisition involves gantry motion and the distribution of radiopharmaceutical changes during the acquisition, projection data at different angles come from different tracer distributions. Images reconstructed from these inconsistent projections can contain artifacts that lead to biases in the estimated kinetic parameters.

To overcome this problem, several groups are researching the estimation of time-activity curves estimation and kinetic parameters directly from projection data, modeling the spatial and temporal distribution of the radiotracer inside the field of view. Reutter at al. presented recently the extension of their work to fully 3-D single-photon emission computed tomography (SPECT) image reconstruction by extending the support of spatial B-spline basis functions into the time dimension. In their last work they obtained estimates of time-activity curves for the left ventricular blood pool and myocardium directly from projections for a human dynamic 99mTc-sestamibi cardiac SPECT/CT study.

The present work presents a new approach for the 4D reconstruction algorithm for dynamic SPECT in a parallel ray geometry based on B-splines including attenuation map from CT and geometry efficiency correction. In this work we make use of 4 piecewise piecewise quadratic temporal splines and a reconstruction algorithm based on the iterative maximization of Poisson likelihood. Results on a Tecnetium (99mTc-Teboroxime) canine study are shown.

Material and methods

The main goal of this work is to obtain the time activity curves and kinetic parameters directly from the projection data to describe the input and wash out of the tracer in the heart. In order to achieve this goal, we first obtain a 4D reconstruction data set which is composed by the 3D emission image for each time frame. The algorithm is based on modeling the distribution of the radiotracer inside the field of view with a B-spline grid both in spatial and temporal dimensions and performing an OSEM algorithm.

In order to reduce the dimensionality of the problem (too high if we include in the model every stage in time, which is 144 points in this case), we model the whole time variation by means of four piecewise quadratic B-spline basis functions. The result of the reconstruction process is then the coefficients for each of these four basis functions.

We obtained a late data static image ignoring the information of the first gantry rotations. The static image volume was reconstructed from data in 64 x 9 subframes of the 72 summed views acquired during the last 22 gantry rotations. The 3-D B splines were piecewise tri-linear in space and were organized on a 64 x 64 x 9 3-D spatial grid that provided uniform sampling of 8.84 mm x 8.84 mm 917.7 mm along the x-, y-, and z-axes, respectively.

Finally a dynamic image volume was reconstructed from data in 64 x 9 sub-frames of the 144 dynamic views per head acquired during the first two gantry rotations. The 4-D B-splines were piecewise tri-linear in space and piecewise quadratic in time. The splines were organized on a 32 x 32 x 4 3-D spatial grid that provided uniform sampling of 17.7 mm x 17.7 mm x 17.7 mm along the x-, y-, and z-axes, respectively, where x and y are transverse coordinates and z is the axial coordinate; and on a 1-D temporal grid with 4 piecewise quadratic temporal B-splines for the first two gantry rotations.

The algorithm was tested on a Dynamic 99mTc-Sestamibi Cardiac SPECT/CT canine study. Emission data were acquired using parallelhole collimators on a dual-head GE Millennium VH Hawkeye SPECT/CT scanner. A 30 min dynamic scan was performed, subsequent to pharmacologically induced stress as part of a rest/stress protocol.

During the scan, the gantry performed 24 360-deg rotations, acquiring 72 views per head per rotation at 1 sec per view. Projections at each view were binned into frames of 64 x 64 pixels, with pixel size 8.84 mm x 8.84 mm. Images were reconstructed from projections of the heart obtained in 64 (transverse) x 9 (axial) subframes of the data. An X-ray CT scan was performed with use of the integrated Hawkeye system to obtain an attenuation map. Attenuation and depth-dependent collimator response were modeled, but not scatter.

Results

Figure 1 shows the smoothed attenuation map acquired by the Hawkeye CT system and the static image reconstruction.

Figure 2 top shows time samples of a transaxial mid-ventricular cross-section through the fully 4-D dynamic reconstruction. The radiotracer is seen primarily in the right ventricular blood pool at 15 sec

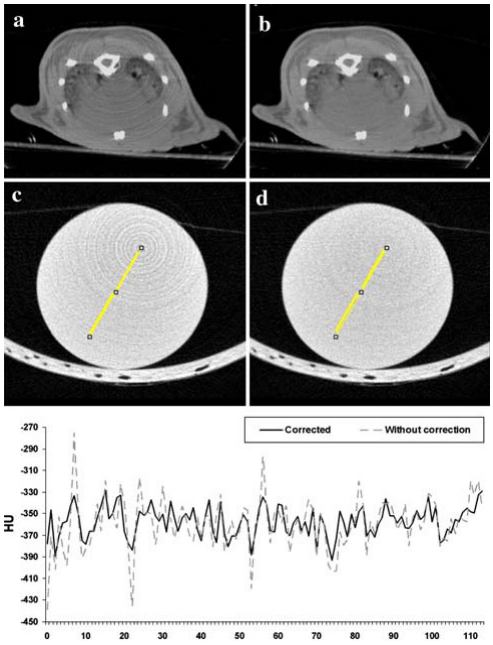

Fig. 1 Left: Attenuation map from CT. Right: Fully 3-D Reconstruction of Summed PET Late Data (summed 2–30 minutes)

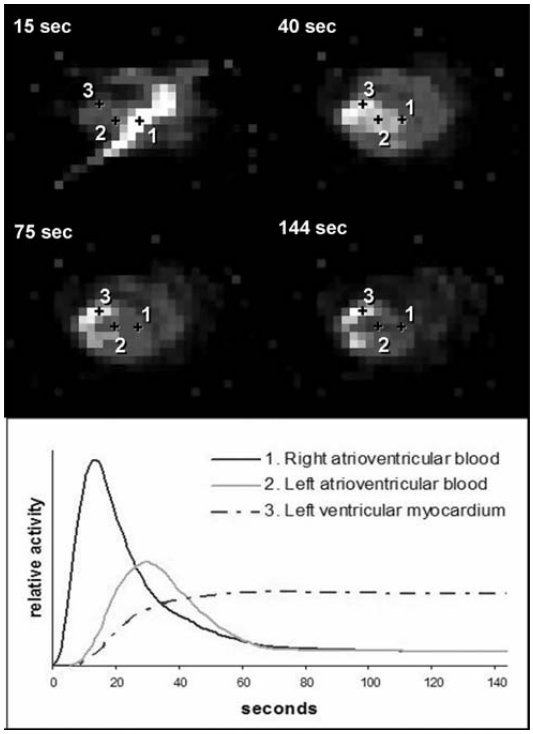

Fig. 2 Top: Central slice of the fully 4D reconstruction of Dynamic early data (32x32x9 pixels) at four different times. Bottom: Time

activity curves for Right atrio-ventricular blood pool, left atrioventricular blood pool, and left ventricular myocardium corresponding with points 1, 2, 3

post-injection (Figs. 2a, cross labeled ‘‘1’’). At 40 sec, radiotracer is seen primarily in the left ventricular blood pool (Figs. 2b, cross labeled ‘‘2’’). Retention of radiotracer in the left ventricular myocardium is evident at 75 sec and 144 sec (Figs. 2c and 2d, cross labeled ‘‘3’’), as well as in the fully 3-D reconstruction of late summed data (Fig. 1, left). The bottom part of Figure 2 shows time activity curves obtained from the 4D reconstructed volume for the three points.

Discussion

We have presented a fully 4D reconstruction algorithm for dynamic SPECT in a parallel ray geometry with a gantry rotating at less than one revolution per minute. The method is based on modeling the spatial and temporal distribution of the radiotracer inside the field of view with spatial tri-linear B-spline and 4 piecewise quadratic temporal B-spline basis functions. The reconstruction is performed by means of the iterative maximization of Poisson likelihood, with and OSEM algorithm.

For the fully 4-D dynamic 99mTc-sestamibi cardiac SPECT reconstruction, the use of non-uniform time sampling with 4-D B-splines that varied quadratically in time yielded smooth time activity curves that captured the relatively fast rise and fall of radiotracer in the right and left blood chambers, as well as uptake and retention of radiotracer in the left ventricular myocardium