Kernel-based Reconstruction of Cardiac PET Images Using MR Information

Zahra Ashouri, Chad R. Hunter, Benjamin A. Spencer, Guobao Wang, Richard M. Dansereau and Robert A. deKemp

2020 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC) | 978-1-7281-7693-2/20/$31.00 ©2020 IEEE | DOI: 10.1109/NSS/MIC42677.2020.9507993

Abstract: **Positron emission tomography (PET) is used to observe processes within the human body using radioactive tracers. Quality of PET images is compromised by statistical noise, especially in the heart where cardiac and respiratory motion occur. Image prior information is generally useful for improving PET image quality. Sources of prior anatomic information include computed tomography (CT) or magnetic resonance imaging (MRI). In this work, we used MR information in the kernel framework to help reconstruct cardiac PET images and compared it with the kernel reconstruction from PET data only. The kernel-based reconstruction method [1], incorporates prior information in the reconstruction algorithm with the use of kernels. Our results show kernel-based image reconstruction using MR prior anatomic information gives numerically equivalent results to the original kernel method that uses composite frames to reconstruct dynamic PET images.**

***Index Terms*—PET image reconstruction, kernel method, MRI.**

I. Introduction

DYNAMIC PET imaging is used to track the spatiotemporal distribution of a tracer in a tissue region, but it suffers from high noise. One method to compensate for noise is to use the kernelized expectation maximization (KEM) reconstruction algorithm [1]. KEM PET image reconstruction incorporates prior information into the expectation maximization algorithm. In the original KEM [1], a set of features is identified for each pixel and the pixel intensity in the final reconstructed image is considered a function of these features in the transform space. For dynamic PET, the features have been extracted from a dynamic series by summing multiple time frames.

The kernel method has been extended to incorporate anatomical information into the PET reconstruction model [2]. Unlike other anatomically aided PET image reconstructions which incorporate anatomical information as a penalty term, incorporating anatomical information with the use of kernels is simpler and amenable to ordered subsets implementation [3].

In our work, kernel is defined in a similar way as described by Hutchcroft, et al [2] with the focus on the difference between this method and the standard kernel method [1]. Also, we compare the m[1]ethods using cardiac imaging where cardiac and respiratory motions are present and evaluate these methods in the presence of these effects. Our results show that MR based kernel reconstruction works almost equally in these cardiac images and therefore can be used to improve PET image quality for clinical cases where dynamic PET imaging is not feasible because of patient throughput.

II. Method

In the original KEM for dynamic PET, multiple time frames are summed to form composite frames. The pixel values in the composite frames are the feature vector [1]. The difference between the pixel intensity in the composite frames and their neighboring pixels in a defined neighborhood is calculated using a Gaussian radial kernel and the mean value over all composite frames to form the kernel matrix K. Then the EM update using the kernel method is:

$$\alpha^{n+1} = \frac{\alpha^n}{K^T P^T 1_M} \cdot \left(K^T P^T \frac{y}{PK\alpha^n + r} \right) \quad (1)$$

where M is the total number of lines of responses, y and P are projection data and detection probability matrix, respectively, α is the coefficient image in the kernel space and r is the expectation of random and scatter events. When α is estimated in the iterative update of the EM algorithm, the reconstructed image $x = K\alpha$ is calculated.

In this work, we assign the feature vector as the pixel values from a co-registered MR image. The kernel matrix K is formed by using the Gaussian radial function to calculate the difference between pixel intensities of the co-registered MR image in a defined neighborhood. This kernel is then used in the EM algorithm in (1). With this method of creating the feature vector no dynamic imaging is required and still comparable results can be produced.

III. Patient Study

This study was produced without the use of a commercial PET-MR scanner, therefore PET and MRI are not acquired simultaneously and as a consequence registration is required. Registration was performed using the Elastix software [4].

The study population for this work includes dynamic PET scans acquired from 3 patients with the ^{11}C-hydroxyephedrine (HED) tracer. The HED tracer has an isotope half-life of 20 minutes. Patient scans were acquired with a GE D600 PET/CT scanner. The scan time was 60 minutes split into 25 dynamic time frames defined as follows: 9×10s, 3×30s, 2×60s, and 11×300s. MR images are acquired at a different time with the

Manuscript received December 10th, 2020. Research supported by Natural Sciences and Engineering Research Council (NSERC) of Canada.

Zahra Ashouri is at Ottawa Heart Institute and Carleton University. e-mail: zashouri@ottawaheart.ca). Chad Hunter is at Ottawa Heart Institute. Benjamin A. Spencer is at UC Davis medical center. Guobao Wang is with the Department of Radiology, UC Davis. Richard M. Dansereau is with the Department of Systems and Computer Engineering, Carleton University. Robert DeKemp is at Ottawa Heart Institute and Ottawa University.

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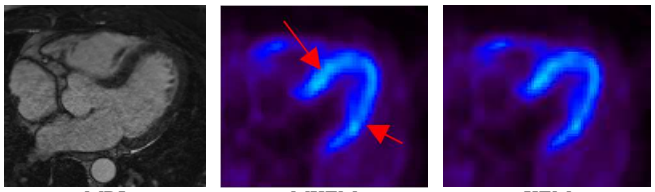

MRI MKEM KEM

Fig. 1. A Transaxial slice of the heart for a late frame showing reconstructed image for MKEM and KEM ad the corresponding MR image.

Siemens Aera which has magnetic field strength of 1.5 T. The acquisition protocol chosen was the steady-state free precession (SSFP) and the image was acquired at end-expiration and end-diastole using respiratory-navigators and ECG-gating. SSFP was chosen since it gives a good contrast between left ventricle wall and blood cavity. MR images were registered to the PET images and then used for PET image reconstruction. We compared the MRI-based kernel reconstruction method (MKEM) with the original KEM reconstruction method and ordered subset expectation maximization (OSEM) reconstruction [3]. The purpose of this study is to evaluate the quality of these reconstruction methods in the left ventricle (LV) wall which is the target region of interest (ROI). To compare these three reconstruction methods, the signal-to-noise ratio (SNR) and contrast are defined for this ROI as:

$$SNR = \frac{Mean(LV)}{std(LV)} \quad (5)$$

$$Contrast = \frac{Mean(LV) - Mean(Blc)}{Mean(LV)} \quad (6)$$

where Blc is the blood cavity of the left ventricle and is used to calculate contrast. The segmentation for the left ventricle wall is done using our clinical in-house software FlowQuant™. Kinetic modelling was achieved using a one-tissue compartment model for left ventricle (tissue of interest). The compartment model is used in parametric imaging to quantify tracer absorption and distribution in organs [5]. The one compartment model assumes a homogeneous distribution throughout the volume of interest with unidirectional transport of the tracer from blood to left ventricle, this rate is K_1.

The average SNR and contrast for all three patients over last four uptake frames are presented in Table I. As stated in the table these values are very close for MKEM and KEM, which means that quantitively MKEM can perform as well as original dynamic PET KEM, therefore MKEM can be used to reconstruct uptake images of perfusion when dynamic scans are not available. However, the reconstructed images show some subtle differences between the two methods. Figure 1 shows some improvements for MKEM on the left ventricle wall shown by arrows, which is due to the fact that MKEM may be better

Table I: SNR and contrast values for the late uptake frames averaged over all three patients.

	KEM	MKEM	OSEM
SNR	6.16	6.09	4.71
Contrast	78.27%	78.43%	78.26%

at preserving high intensity values. This is in agreement with the results from [2] which claims KEM with MR prior information preserves fine details.

The kinetic parameter, K_1, depends on perfusion. Polar map images of the K_1 value for KEM and MKEM along with OSEM reconstruction are given in Figure 2. This rate is almost unchanged for all three reconstruction methods, meaning that the rate quantification in this study is not affected by the image reconstruction methods. This is not surprising because the injected dose already provides good image quality and the

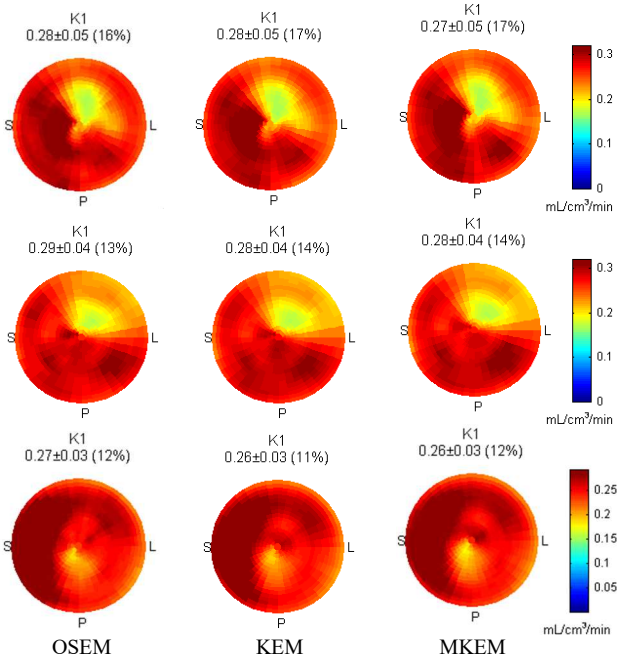

Fig. 2. K_1 values for three reconstruction methods and all three patients. Each patient is shown in one row.

kinetic quantification was performed for regions in which a number of voxels are involved.

IV. Conclusion

Kernel-based PET image reconstruction using MR prior information is compared to the original kernel method that use composite frames to reconstruct dynamic PET images and to standard OSEM reconstruction. Results show that the two kernel-based reconstruction methods work almost equally in these cardiac images. The use of MR images as a feature vector eliminates the need for dynamic imaging and could therefore be an option for cases where no dynamic imaging is obtainable and still produce comparable results.

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