Impact of Time-Of-Flight Image Reconstruction in PET Parametric Imaging

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Abstract— **Kinetic parameter estimation in dynamic PET imaging requires reconstruction of multiple time frames. Due to the limited counting statistics and reduced signal-to-noise ratio (SNR) in each frame, parametric maps suffer from reduced accuracy and precision. Therefore image reconstruction strategies improving upon the SNR are particularly important in the context of parametric imaging. Time of flight image reconstruction has been shown to improve the SNR and increase the effective sensitivity. However so far the benefit of TOF has only been demonstrated in static imaging applications with potentially substantial benefits when used in dynamic pharmacokinetic imaging applications. Using traditional dynamic 3D as well as direct 4D image reconstruction algorithms we evaluate the benefit of TOF on kinetic parameter estimation using various TOF resolutions, kinetic models and count levels. Initial data suggest that both bias and variance in the kinetic parameters are reduced, with improvements depending on the kinetic model and becoming more significant at increased TOF resolutions. Incorporating TOF within direct 4D image reconstruction and combining the respecting SNR gains results in substantial improvements in parametric maps compared to traditional post reconstruction kinetic analysis.**

***Index Terms*—Time-of-flight, direct 4-D image reconstruction**

I. INTRODUCTION

Pharmacokinetic modeling of dynamic PET data allows targeted physiological parameters to be derived such as blood flow, metabolism and receptor occupancy, which are closely related to the underlying pathology [1, 2]. In many studies, such parameters are more informative, robust and less prone to variability compared to the standardized uptake values (SUVs), which remains the most widely adopted metric in static PET imaging [3, 4]. Generating parametric maps compared to regional analysis preserves the intrinsic spatial resolution of the scanner and allows spatial heterogeneity of the physiological parameters to be assessed.

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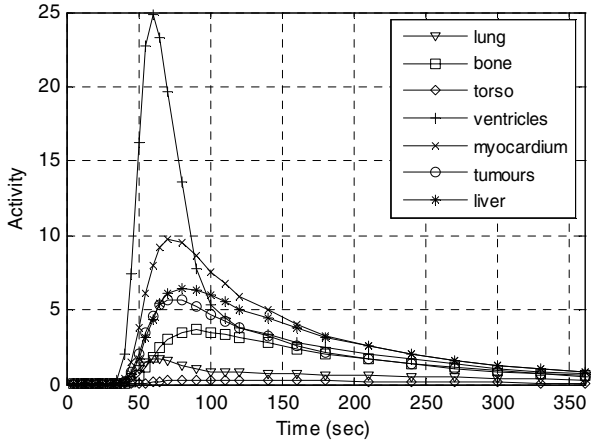
a)



b)

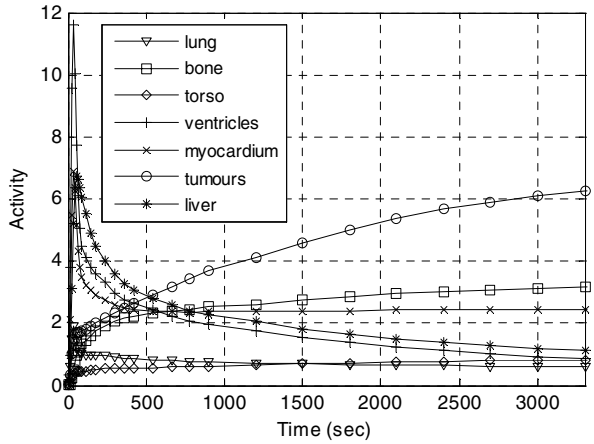


Fig.1 Two datasets were used, representative of a 1-tissue and 2-tissue models. A 360 seconds [^{15}O]H_2O scan binned into 28 non-uniformly sampled time frames [14×5 s, 5×10 s, 3×20 s, 6×30 s] was used for the one-tissue model (a) while a 3600 seconds [^{18}F]FDG scan binned into 29 non-uniformly sampled time frames [9×10 s, 3×30 s, 4×60 s, 4×120 s, 9×300 s] was used to represent a 2-tissue model (b).

Nevertheless modelling the time course of the activity distribution at the voxel level results in biased and statistically unreliable parameter estimates due to limited counting statistics and reduced signal-to-noise (SNR) ratio in each frame. One way though of improving upon the SNR and achieve noise/variance reduction in the reconstructed images

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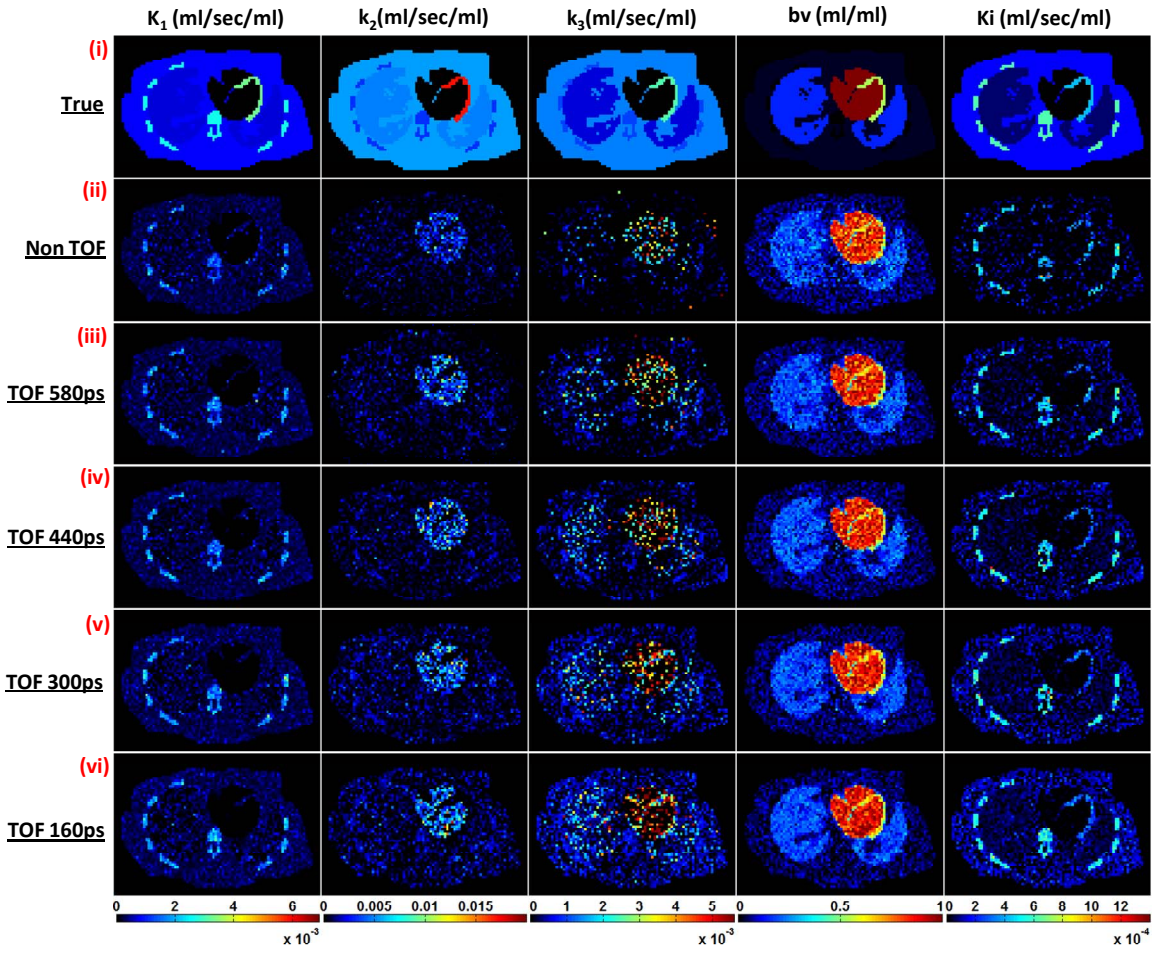

Fig.1 True (i) and estimated [^{18}F]FDG parametric maps using traditional post-reconstruction kinetic analysis at various TOF resolutions (iii-vi).

is by incorporating time-of-flight information within image reconstruction. Taking into account separate contributions to variance reduction from true and random events TOF gain can be given as:

$$\mathrm{SNR}_{\mathrm{TOF}} = \sqrt{\frac{D}{\Delta x}} \times \sqrt{\frac{1+\beta R_f}{1+\beta^2 R_f}}\mathrm{SNR}_{\mathrm{conv}}; \beta = D/D_{\mathrm{fov}}; R_f = R/T+S \quad (1)$$

where T, S and R are the true, scatter and random events, β is the object to field-of-view diameter ratio and R_f is the random fraction [5, 6]. The TOF gain in SNR can be considered as a gain in the effective sensitivity or as count booster. In static imaging this attribute has be exploited to improve image quality and achieve better lesion detectability, to minimise injected dose or to reduce the scan time. However in the context of dynamic pharmacokinetic imaging, no evaluation has been done to date. TOF information could substantially improve upon the existing methods by enhancing the effective sensitivity and improving the SNR in dynamic protocols, where extremely short-duration low-count frames are considered. Furthermore due to the dependence of the TOF SNR gain on the random fraction, parameters being derived from the early noisy frames which usually exhibit higher random fractions could benefit further. This TOF SNR improvement can be used in many ways in PET parametric imaging in the body, to either directly improve kinetic parameter bias and variance and generally image quality, to increase the temporal sampling and indirectly improve parametric maps or to even allow multi-bed dynamic protocols. In this work using simulated dynamic data we investigate the impact of TOF image reconstruction on parametric image quality and more specifically on precision and accuracy of kinetic parameters. Different kinetic models, noise levels and TOF resolutions are considered while parametric maps are estimated using both post-reconstruction kinetic analysis as well as direct 4D image reconstruction.

II. METHODS

Time-of-flight information were incorporated within a traditional dynamic OSEM 3D image reconstruction as well as a spatiotemporal direct 4D algorithm. The TOF 4D reconstruction is based on a previously derived 4D algorithm for direct parameter estimation in which the tomographic EM

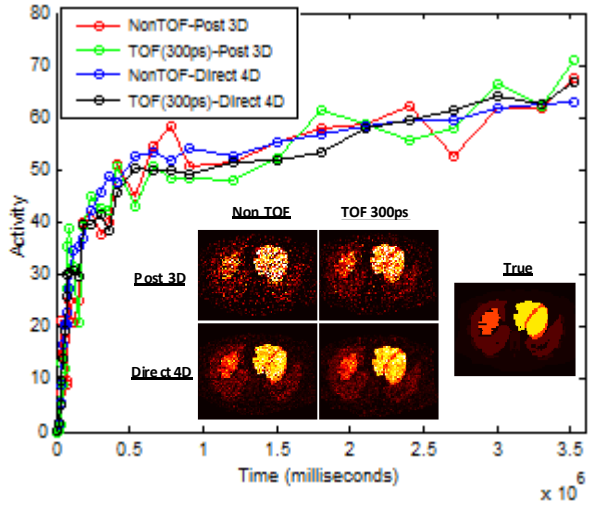

Fig.3 Time activity curves from an ROI in the lungs using 3d and direct 4D parameter estimation methods without and with TOF at 300ps.Image correspond to reconstructed dynamic emission data from an early frame.

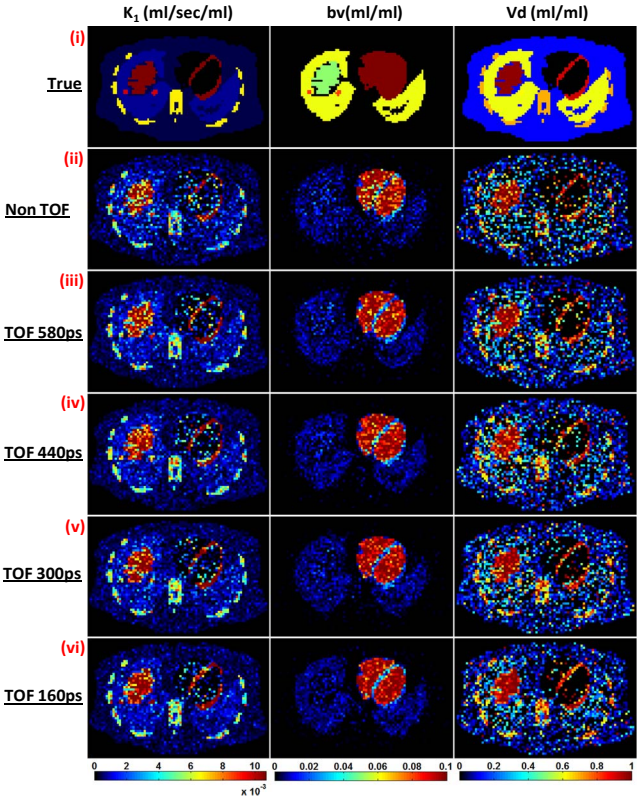

Fig.4 True (i) and estimated $[^{15}O]H_2O$ parametric maps using traditional post-reconstruction kinetic analysis at various TOF resolutions (iii-vi).

step has been extended to incorporate TOF information [7]. To evaluate the impact of TOF on kinetic parameter estimation, a realistic body phantom was used to simulate $[^{15}O]H_2O$ kinetics (6-minute scan, 28-frames) corresponding to 1-tissue 3 parameter model as well as $[^{18}F]$FDG kinetics (60-minute scan, 29-frames) corresponding to a 2-tissue 4 parameter irreversible model (Fig.1). Kinetic parameters were evaluated using post-reconstruction kinetic analysis as well as direct 4D image reconstruction both with and without TOF. Four different TOF resolutions were considered at 580ps, 440ps, 300ps and 160ps FWHM to evaluate current as well as future benefits while different count levels were considered (1.2×10^9 and 2.4×10^9 counts for $[^{18}F]$FDG and 2×10^8 and 4×10^8 counts for $[^{15}O]H_2O$). A virtual TOF scanner corresponding to the geometry of the mCT PET, was used to generate the dynamic TOF datasets. Kinetic parameters were estimated in both 3D and direct 4D image reconstruction using the generalized linear least squares (GLLS) method [8].

III. RESULTS

Fig 2 illustrates K_1, k_2, k_3, blood volume and K_i parameters generated from post reconstruction analysis of the $[^{18}F]$FDG data without TOF and with TOF at increasing TOF resolution. Due to different convergence rates between the different reconstructions, parameters are shown at matched contrast using the emission data (late frame). As the TOF FWHM reduces, so as the variance in the parameters. However comparing the reconstructed maps against the true parameters, a reduction in bias is also noticeable with accuracy improving by almost 15% in K_1 and k_2, 35% in k_3 and 30 % in Ki at 160ps TOF FWHM. To see the effect of TOF on dynamic data, time activity curves (TACs) from an ROI in the lungs are plotted in Fig.3 both for 3D and direct 4D reconstructions with and without TOF, with the corresponding inlet images taken from an early frame. TOF based reconstructions generate less noisy TACs in both parameter estimation methods. However as can be seen from the curves as well as the images, the SNR benefits obtained from the direct 4D reconstruction are greater than the ones achieved by TOF alone. Improvements are less dramatic on the $[^{15}O]H_2O$ parameters (Fig.4) but still noticeable even at 580ps.

IV. CONCLUSION

Initial results suggest that when TOF image reconstruction is used for kinetic parameter estimation, accuracy and precision on the kinetic parameters is improved. Incorporating TOF within direct 4D image reconstruction and combining the respecting SNR gains results in substantial improvements in parametric maps compared to traditional post reconstruction kinetic analysis. This study doesn't consider the effect of randoms and scatter. With the TOF gain varying in each time frame due to these contribution certain parameters could achieve differential improvements and is the subject of future investigations.

V. ACKNOWLEDGMENTS

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