Time of Flight Parametric Image Reconstruction from Variable Random Fraction Dynamic PET Data

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Abstract— **Dynamic PET imaging allows the time course of the activity distribution to be measured and modelled, therefore estimating parametric images of micro- or macro-parameters. Due to the need for increased temporal sampling, frames of low statistics are often reconstructed, leading to noisy dynamic data and subsequently to kinetic parameters of reduced precision and accuracy. TOF image reconstruction can substantially improve upon the kinetic parameter SNR. However, variable contributions to TOF variance reduction between true and random events, owing to their spatial distribution, results in SNR improvements depending on the random fraction and leading to variable TOF gains amongst temporal frames within a dynamic study. Such variable gains between early/late frames (high/low random fractions) are also expected to be more pronounced at increasing injected doses. Therefore, we hypothesize that certain kinetic parameters receive differential improvements depending upon the part of the time-activity curve they are estimated from. Using simulated dynamic [^{15}O]H_2O datasets at ever increasing doses and random fractions, we investigate the variable TOF gain in dynamic imaging and its effect on the kinetic parameters. Data are presented at improving TOF resolutions and using both indirect and direct methods to kinetic parameter estimation. Initial results suggest that kinetic parameter TOF gain is highly variable (increasing) at ever increasing injected doses, but such variation is different for each parameter based on the part of the dynamic data it is derived from, owing to the variable TOF gain within dynamic frames.**

***Index Terms*—TOF image reconstruction, random fraction**

I. Introduction

Time of flight iterative image reconstruction algorithms are becoming the standard method for parameter estimation in PET, whether to estimate activity concentrations or kinetic parameters. As a first approximation, the improvement in signal-to-noise ratio (SNR) which TOF image reconstruction can deliver, is proportional to the ratio $D/\Delta x$ (D=object diameter, Δx=spatial uncertainty given the system time resolution). However, such an expression considers that trues and randoms have the same contribution in the variance reduction due to TOF, which is not the case. The difference in the respective contributions arises from the fact that the randoms distribution spans the entire FOV as defined by the time coincidence window, as opposed to the trues distribution which are constrained within the scanned object. Taking into account this difference, the variance gain achieved in TOF-based image reconstruction becomes also dependent upon the random fraction, for a given object size, TOF resolution and time coincidence window/transaxial FOV [1]. The effect has been extensively evaluated in static imaging both for analytic and iterative TOF reconstruction algorithms demonstrating the differential TOF gain due to randoms, on activity concentrations [2-3]. However, such dependence on the randoms fraction has potential implications when TOF reconstruction algorithms are used in dynamic imaging to estimate parametric maps. As the activity concentration varies with time, so does the random fraction in each dynamic frame. Using TOF reconstruction, will result in reconstructing temporal frames having variable variance reduction compared to non-TOF reconstruction. Early frames, for which random fraction is higher, should gain more that late frames. Therefore, we hypothesize that in dynamic TOF image reconstruction, certain kinetic parameters should exhibit a variable gain compared to non-TOF reconstruction, depending on which part of the time activity curve they are derived from. Such an effect should be more pronounced at increasing injected doses where larger random fraction variations should exist between early/late frames. In this work, we investigate the effect of randoms contribution in TOF parametric image reconstruction, at variable injected doses and TOF resolutions using simulated dynamic [^{15}O]H_2O TOF datasets and realistic random fractions.

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II. Methods

To evaluate the impact of randoms on TOF-based kinetic parameter estimation, a realistic body phantom was used to simulate [^{15}O]H_2O kinetics (6-minute scan) corresponding to a 1-tissue 3 parameter model. To simulate representative random fractions on a current TOF-capable system (mCT PET/CT), data from a clinical study were used. Six consecutive dynamic [^{15}O]H_2O datasets from a clinical dose reproducibility study on the same patient, were utilized, to simulate varying random fractions at 6 ever increasing injected doses (172-552 MBq) (Fig. 1). Therefore, the effect of variable random fractions was assessed not only within a dynamic study but across dynamic scans of varying doses as well. For TOF image reconstruction, the 'estimated' TOF randoms were averaged and split equally amongst the TOF bins, similar to the current implementation on the mCT PET/CT since randoms have no TOF distribution. On the non-TOF reconstructed dynamic data, 2 cases were considered, simulating both noisy as well as noiseless random estimates

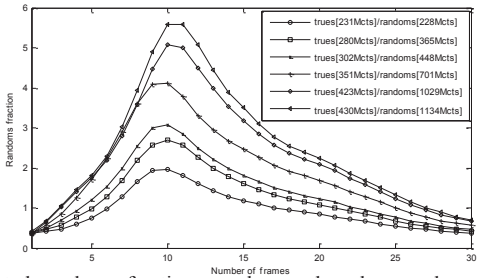

Fig.1 Simulated randoms fractions used were based on a dose escalating dynamic [^{15}O]H_2O patient scan.

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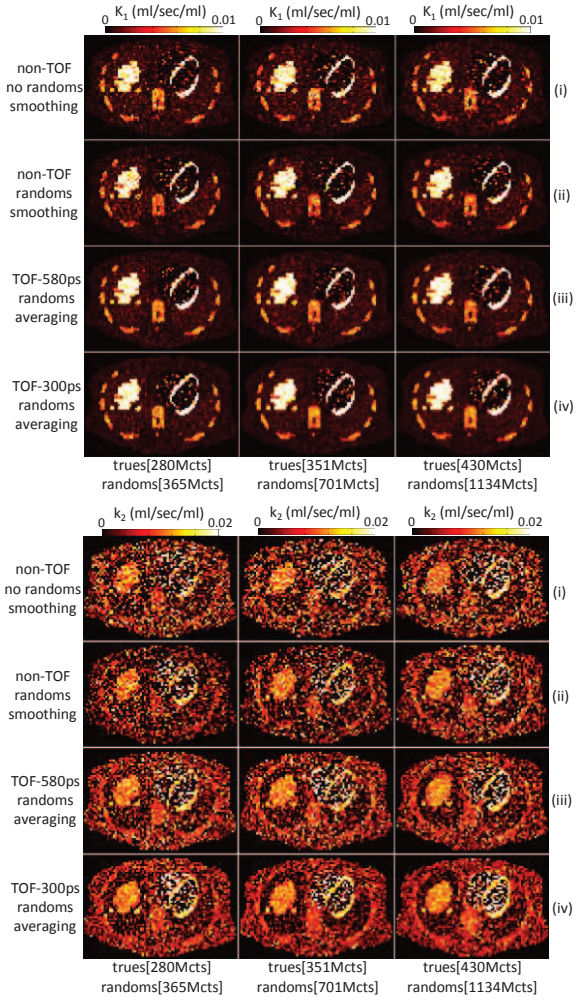

Fig.2 Parametric images of K_1 and k_2 for non-TOF image reconstruction using non-smoothed (i) and smoothed randoms (ii), as well as TOF-based image reconstruction at 300ps (iii) and 580ps (iv). Data are shown at matched tumour-to-background contrast using post-reconstruction kinetic modelling.

following random smoothing. Kinetic parameters were evaluated using post-reconstruction kinetic analysis as well as direct 4D image reconstruction while four different TOF resolutions were considered at 580ps, 440ps, 300ps and 160ps FWHM. A virtual TOF scanner corresponding to the geometry of the mCT PET, was used to generate the dynamic TOF datasets, while Poisson noise was also introduced. Following image reconstruction (8 iter - 21 sub), the GLLS method was used for kinetic parameter estimation.

III. Results

In Fig. 2 parametric images for 3 of the simulated doses are shown. Conventional non-TOF image reconstruction produced noisy parameters, however when random smoothing is used during reconstruction, noise is visibly reduced. Kinetic parameters following TOF image reconstruction appear improved with further variance reduction. However, looking at the parametric maps, it is difficult to deduce any conclusion amongst the different doses and varying random fraction dynamic scans. Therefore, quantitative analysis was performed to estimate the kinetic parameter TOF gain for all the simulated cases. The results are presented in Fig. 3 where the TOF gain is shown for 3 regions in the phantom (vertebra,

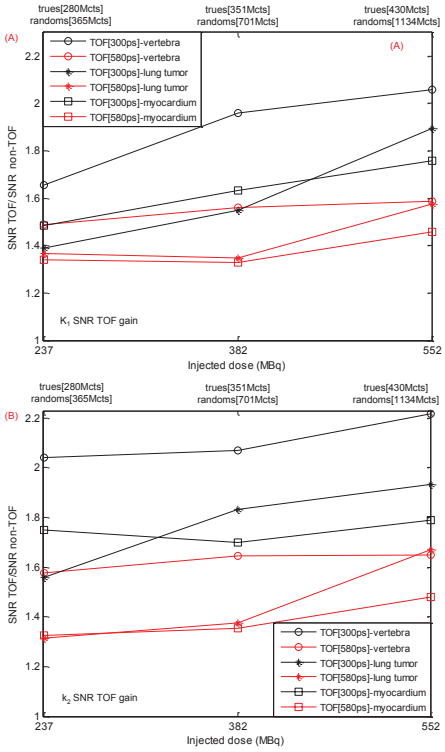

Fig.3 Estimated K_1 and k_2 TOF gain for 3 regions in the phantom, at 3 dose levels and for 2 TOF resolutions (against non-TOF no randoms smoothing).

myocardium and 2 lung lesions embedded in the right lung). As already seen in our previous work, TOF based kinetic parameters exhibit improved SNR compared to non-TOF with the gain as expected higher for higher TOF resolution. However, inclusion of randoms, shows that both K_1 and k_2 gain variably at increasing injected doses with differences of up to 25% in SNR gain between the 237MBq and 552 MBq at the 300ps TOF resolutions, owing to the variable random fraction. However, when comparing k_1 and k_2 for each corresponding regions is appears that K_1 gains slightly more compared to k_2 as the dose increases. For the vertebra at 300ps, K_1 gains 24% more going from 237 to 552 MBq while the corresponding k_2 gain variation with the dose is ~9%. This variation becomes more pronounced as the TOF resolution improves since the corresponding gain differences with dose are less pronounced at 580ps standing at 6.3% for K_1 and 4.6% for k_2. This could potentially be due to the non-linearity between the dynamic data and kinetic parameters from the iterative reconstruction and GLLS parameter estimation.

IV. Discussion - Conclusion

Initial results suggest that the variable TOF gain due to randoms, already seen in static imaging, results in variable TOF gain in kinetic parameter estimates. Furthermore, due to the variable activity, TOF gain amongst temporal frames, the corresponding TOF gain variation is not the same amongst kinetic parameters but depends on which part of the dynamic data each parameter is estimated from.

References

[1]M. Conti, IEEE Trans. Nucl. Sci. 5 1188–93(2006)
[2]L Eriksson and M. Conti, Phys. Med. Biol. 60 1613–1623(2015)
[3]G. Mettivier *et al* IEEE Trans. Nucl. Sci. 59 1948–57(2012)