Limited Field-of-View Dynamic PET Imaging from Truncated Time-of-Flight Sinograms

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***Abstract*— Time-of-flight (TOF) PET imaging enables a more precise localization of an emitted event along a given line-of-response (LOR). The additional temporal information could be used to restrict the effective coincidence window in the scanner to conform to the object being imaged. This can be achieved by truncating the sinogram bins along the TOF direction, keeping only those that contain LORs passing through the object, while further truncation can be done in the transaxial direction. When the region of interest (ROI) is localized and known, TOF sinogram truncation could then be used to exclude data not only outside the patient outline but further inside as well. One specific type of imaging which could substantially benefit from such an approach is dynamic imaging. By truncating the sinograms to conform to a specific ROI which is often needed in dynamic imaging, significant computation benefits could be obtained. Moreover, additional benefits could be realized through reduced propagation of errors specific to dynamic imaging. Using simulated and clinical studies, we investigate the feasibility and benefits of limited FOV imaging from truncated TOF sinograms in dynamic imaging.**

***Index Terms*—PET, time-of-flight, local image reconstruction**

I. INTRODUCTION

Recent advancements in hardware and software have allowed TOF capable scanners to be introduced in the clinic. TOF image reconstruction has been shown to improve signal-to-noise (SNR) ratio with the improvements depending on the object size, the scanner's TOF time resolution as well as the contribution from scatter and random events [1, 2]. Furthermore, at increasing TOF resolutions, TOF-based reconstruction is less sensitive to erroneous corrections while it speeds up the convergence rate of statistical reconstruction algorithms [3]. All these attributes make TOF-based reconstruction ideal in cases where counting statistics are limited. Therefore, its application to dynamic pharmacokinetic imaging is particularly of interest, since the reduced SNR in each time frame results in kinetic parameters of reduced precision and accuracy . One problem particular to the application of TOF image reconstruction in dynamic imaging is that the already substantial computational burden from reconstructing multiple time frames is increased due to the additional TOF sinograms as well as corresponding system matrix. This computational burden is further accentuated when higher TOF resolutions and more time bins are considered. As is often the case, in such dynamic protocols, whether for drug development or therapy response monitoring, analysis is restricted to a specific region already identified through screening from different modalities. In such cases, substantial gains could be achieved by using TOF bin truncation, thus rejecting the LORs that do not intersect the region of interest. Selecting the range of time bins to reconstruct, the effective coincidence window can be adjusted, resulting in the dynamic reconstruction and subsequent kinetic model to be restricted to a specific ROI. Such an approach has been proposed in static imaging applications both for analytical and iterative algorithm formulations [4-6]. However, no evaluation has been done in the context of parameter estimation in dynamic imaging where the benefits of such an approach could be even more substantial due the multiple time frames. Furthermore, additional benefits could be obtained in dynamic imaging especially when direct 4D reconstruction methods are used to reconstruct the kinetic parameters. When such methods are used, propagation of errors, due to kinetic modelling or voluntary motion between frames, to regions of interest, could be restricted by truncating the TOF sinograms.

In this work, we investigate the feasibility and benefits of limited FOV imaging from truncated TOF sinograms to dynamic imaging. Using simulated dynamic cardiac data, we compare the estimated kinetic parameters to full FOV dynamic TOF imaging at different TOF resolutions. Clinical studies are also considered. Moreover, using simulated data we investigate the benefits of TOF sinogram truncation in reducing the propagation of kinetic modelling errors, as well as inter-frame motion and attenuation errors in TOF direct 4D image reconstruction.

II. METHODS

Although limited FOV image reconstruction is applicable to any small structure in the body, this work is focused on dynamic cardiac imaging. Two cases of sinogram truncation were considered. In the first case, sinogram truncation was

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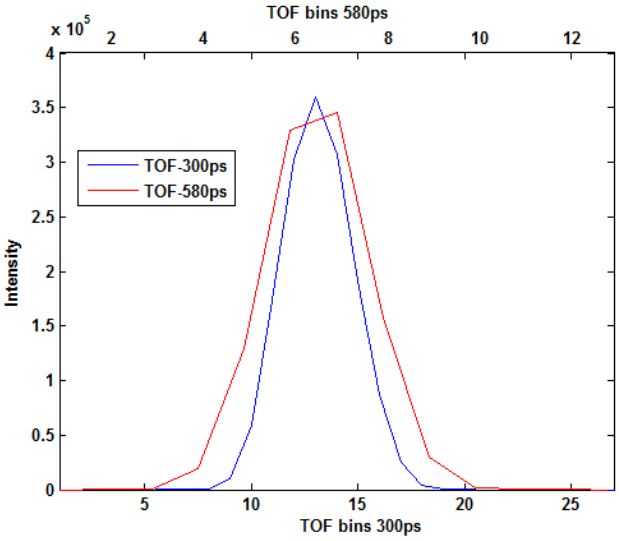

Fig.1 Simogram probability profiles across the TOF direction for an ROI mask encompassing the heart ventricles and myocardium, for 2 TOF resolutions (580ps and 300ps) sampled based on the number of the corresponding TOF bins used.

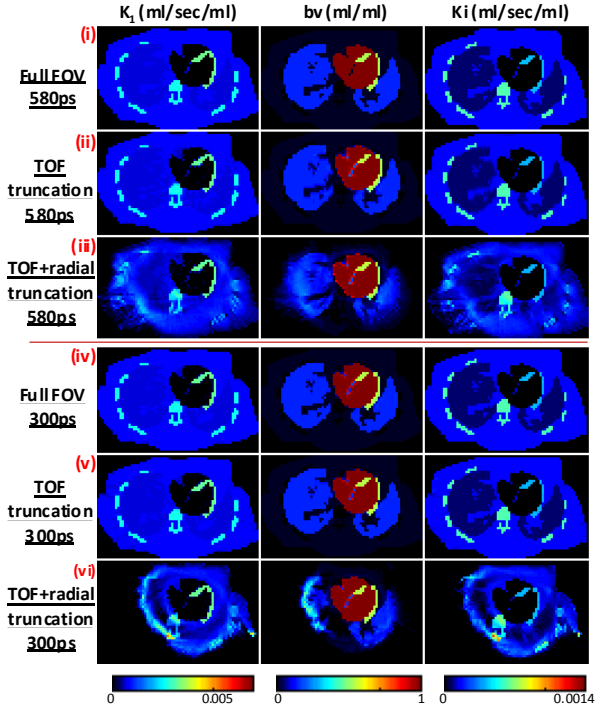

Fig.2 Parametric images of K1, blood volume and Ki for 580ps (i-iii) and 300ps (iv-vi) using all the sinogram data (i,iv), using TOF truncation (ii,v) and both TOF and radial truncation (iii,vi).

performed only in the TOF direction along the TOF bins, while in the second case additional truncation was performed in the transaxial direction along the radial bins. In order to truncate the sinograms, an initial mask of the region of interest is drawn on the CT or MR images if available, which is subsequently forward projected. Using this forward projected sinogram mask and summing the sinogram data for

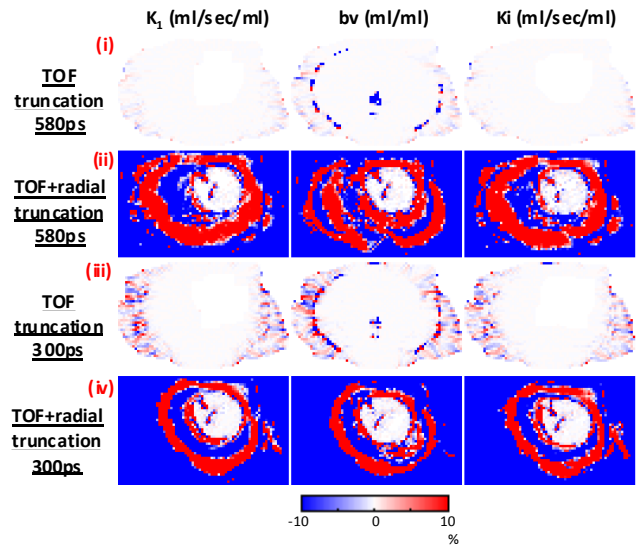

Fig.3 Bias parametric images of K_1, blood volume and Ki for 580ps (i-ii) and 300ps (iii-iv) using TOF truncation (i,iii) and both TOF and radial truncation (ii,iv). BIas is estimated against the full FOV parametric images.

each time bin, TOF bin truncation can be done on the bins that receive no contribution from the selected ROI (Fig.1). Furthermore, radial bin truncation can be done by directly applying the sinogram mask on the emission data. The limited FOV TOF reconstruction was applied on a simulated dynamic [^{18}F]FDG scan (29 time frames, 1h scan) and 2 TOF resolutions (580 ps and 300 ps), to evaluate the effect on kinetic parameters. A virtual TOF scanner corresponding to the geometry of the Siemens mCT scanner was used to generate the dynamic TOF datasets [7]. A 2-tissue model was used for kinetic modeling and parametric images of K_1, k_2, k_3 and blood volume (bv) were estimated using the generalized linear least squares method [8].

III. RESULTS

Parametric images of K_1, blood volume and K_i are compared in Fig.2 between the 2 limited FOV reconstructions and the one with no sinogram truncation. When only TOF truncation is used, changes in the image are not immediately apparent. At 580ps, a few bins (4 out of 13 time bins) could only be truncated due to the long overlapping tails of the TOF distribution corresponding to the heart ROI. Therefore, only a small portion of the data corresponding to the edges of the phantoms are discarded. Going to higher TOF time resolutions, a higher percentage of TOF bins can be excluded owning to less overlap between TOF bins. At 300ps, 10 out of 27 bins contained LORs passing through the heart, allowing more time bins to be excluded and the image to conform more to the ROI. This can be seen in the bias images shown in Fig.3 where at 300ps, errors appear further inside the torso as more time bins could be discarded. Crucially though in both TOF resolutions, the bias in the heart ROI compared to the non-truncated reconstruction is close to zero. Truncating the

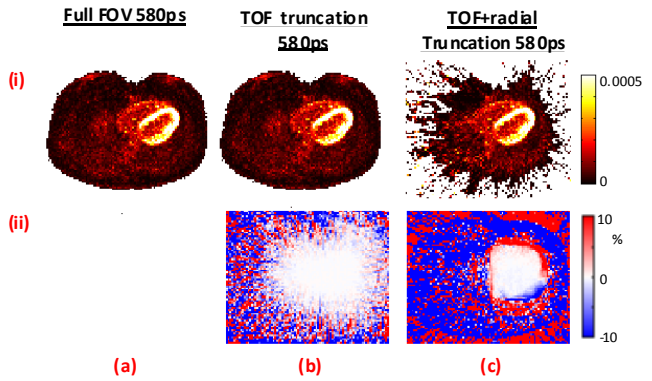

Fig.4 Emission data and bias with respect to full FOV reconstruction from a clinical [^{18}F]FDG scan on the mCT PET scanner at 580ps using all the sinogram data (a) TOF truncation (b) and both TOF and radial truncation (c).

sinogram in the TOF direction allows a broad region around the selected ROI to be reconstructed. Applying additional truncation in the transaxial direction restricts the data to reconstruct a region which conforms transaxially to the specified ROI as well as being consistent with the TOF information. Since the percentage of bins excluded through transaxial truncation is higher than the ones excluded by TOF truncation only, the impact of transaxial truncation on the parametric images is more apparent. Again though, the parameters in the heart ROI appear unaffected and quantitatively accurate compared to the non-truncated reconstruction. Finally, example emission data are shown from a clinical [^{18}F]FDG scan in Fig.4. The ROI was positioned to cover the myocardium and looking at the bias images, no bias in the ROI can be seen when truncation is used.

IV. DISCUSSION - CONCLUSION

Initial results suggest that when kinetic modelling is performed for a single region, whether for parametric imaging or ROI analysis, substantial computational benefits could be obtained from restricting the FOV to that specific region through sinogram truncation. Such an approach is particularly suited to dynamic imaging especially since constant improvements in TOF resolution make application of TOF reconstruction in dynamic imaging ever more challenging as more time bins are sampled, resulting also in a larger system matrix. Depending on the TOF resolution and the imaged ROI, the reconstruction time in dynamic applications could be more than halved. Furthermore, additional benefits due to reduced error propagation could be obtained through TOF sinogram truncation when 4D reconstruction methods are used. Such benefits are currently under evaluation.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

[1] M. Conti, "Effect of randoms on signal-to-noise ratio in TOF PET.," *IEEE Trans Nucl Sci,* vol. 53, pp. 1188-1193, 2006.

[2] M. Conti, "Focus on time-of-flight PET: the benefits of improved time resolution.," *Eur J Nucl Med Mol Imaging,* vol. 38, pp. 1147-1157, 2011.

[3] M. Conti, "Why is TOF PET reconstruction a more robust method in the presence of inconsistent data?," *Phys Med Biol,* vol. 56, pp. 155-68, Jan 7 2011.

[4] C. M. Kao, "Windowed image reconstruction for time-of-flight positron emission tomography," *Phys Med Biol,* vol. 53, pp. 3431-45, Jul 7 2008.

[5] G. Jinxia, K. Chien-Min, and X. Qinguo, "Evaluation of windowed image reconstruction for time-of-flight PET," in *IEEE Nucl Sci Symp Med Im Conf*, pp. 4162-4166, 2011.

[6] B. Zhang and C.-h. Tung, "Investigation of TOF 3D local tomography with various time resolutions using clinical datasets," *J Nucl Med meeting abstracts,* vol. 51, pp. 1382-, May 1, 2010 2010.

[7] B. W. Jakoby, Y. Bercier, M. Conti, M. E. Casey, B. Bendriem, and D. W. Townsend, "Physical and clinical performance of the mCT time-of-flight PET/CT scanner.," *Phys Med Biol,* vol. 56, pp. 2375–2389, 2011.

[8] D. Feng, S. C. Huang, W. ZhiZhong, and H. Dino, "An unbiased parametric imaging algorithm for nonuniformly sampled biomedical system parameter estimation," *IEEE Trans Med Imaging,* vol. 15, pp. 512-518, 1996.