

Multi-bed Tracer Kinetic Imaging of Micro-parameters from Dynamic Time-of-flight PET Data

Fotis A. Kotasidis, Nicolas A. Karakatsanis, Abolfazl Mehranian, and Habib Zaidi

Abstract— Compartmental modelling in dynamic imaging requires the full time course of the activity distribution to be sampled. Due to the need for increased early temporal sampling, leading to severely low signal to noise ratio (SNR) in those early frames, such protocols are restricted to a single bed. Time-of-flight (TOF) imaging has been shown to improve the SNR in static imaging applications. When used in dynamic imaging, the effective NEC gain could be used to generate TOF equivalent dynamic data with reduced frame duration and allow interleaving between adjacent bed positions to increase the axial extent from single bed to multi-bed acquisitions. Coupling this with the recent introduction of continuous bed motion acquisition modes, could make such a dynamic protocol feasible. Using simulated data based on the Siemens mCT, we propose an axially extended dynamic imaging protocol and demonstrate the feasibility of generating TOF equivalent dynamic data as well as extending kinetic parameter estimation using compartmental modelling from single- to multi-bed dynamic imaging.

Index Terms—TOF image reconstruction, dynamic imaging

I. INTRODUCTION

Dynamic pharmacokinetic PET can deliver physiological parameters of the subject under study by modelling the time course of the activity distribution. Unlike other methods, such as whole-body Patlak imaging [1-4], full compartmental analysis requires the full time course of the activity distribution to be acquired, in order for micro-parameter maps to be estimated. Coupling this with the short initial time frames needed to capture the rapidly varying activity distribution, restricts the axial FOV being scanned to a single bed. Two main problems exist when trying to extend such a dynamic protocol to multiple beds[5]. First, conventional step and shoot (S&S) imaging doesn't allow fast enough, efficient and comfortable for the patient, transition between beds. Second and most important, early time frames as short as 5-10 seconds are routinely used. Therefore the severely reduced SNR in those frames would be further

attenuated if frames of shorter duration were to be considered, in order to accommodate scanning additional bed positions within the same overall scan time. However, similar to static imaging and depending on the imaging task, TOF imaging can improve the SNR in the dynamic data, with the TOF gain used in different ways [6, 7]: (i) to directly improve the kinetic parameters, (ii) to reduce the frame duration while keeping the same SNR per frame and increase the temporal sampling therefore indirectly improving the estimated parameters, (iii) or more importantly to reduce the frame duration while keeping the same SNR per frame and same number of frames and extend the scanning protocol to adjacent axial positions in order to increase the scanned FOV. Generating 'TOF equalized' dynamic images allows the additional time 'saved' within each time frame to be used to scan additional positions, with the additional axial FOV depending on the NEC TOF gain and therefore on the TOF resolution [6]. However, taking into account the time needed for the bed to return to the initial position after each pass and based on the fact that this time is a significant percentage in the early short frames compared to late frames, differential TOF gains are needed to generate TOF equalized images for all frames. Furthermore, depending on the bed position, TOF gain could vary, with the largest differences occurring when transitioning from the torso to the head and neck region [3]. Therefore the maximum additional axial extent of the TOF equivalent dynamic scan will depend on equivalency based on these early frames and using the minimum achievable TOF gain within the scanned FOV. With such an equivalency, compartment modelling in dynamic PET imaging could be extended from single- to multi-bed acquisitions. Moreover, the recent introduction of continuous bed motion (CBM) which can mitigate the problem of fast and convenient transitioning between different axial positions, could make such a protocol feasible [8]. In this work, we propose an axially extended dynamic protocol from dynamic TOF data. Using simulated data based on the Siemens mCT TOF PET scanner, we demonstrate the feasibility of generating TOF equalized dynamic data and extending compartmental analysis from single- to multi-bed acquisitions.

II. METHODS

This work emphasizes on TOF equivalency in dynamic imaging and kinetic parameter estimation from axially extended data. Therefore for simplicity we considered traditional S&S acquisition. Using the XCAT phantom [9], a standard non-TOF single-bed 29-frame (9×10 sec, 3×30 sec, 4×60 sec, 4×120 sec, 9×300 sec) 1-hour dynamic [^{18}F]FDG

F.A.Kotasidis is with the Division of Nuclear Medicine & Molecular Imaging, Geneva University Hospital, Geneva, Switzerland and Wolfson Molecular Imaging Centre, MAHSC, University of Manchester, Manchester, UK.

A. Mehranian and N. A. Karakatsanis are with the Division of Nuclear Medicine & Molecular Imaging, Geneva University Hospital, Geneva.

H. Zaidi is with the Division of Nuclear Medicine and Molecular Imaging, Geneva University Hospital, the Geneva Neuroscience Centre, Geneva University, Geneva, Switzerland and the Department of Nuclear Medicine and Molecular Imaging, University of Groningen, University Medical Centre Groningen, Groningen, The Netherlands.

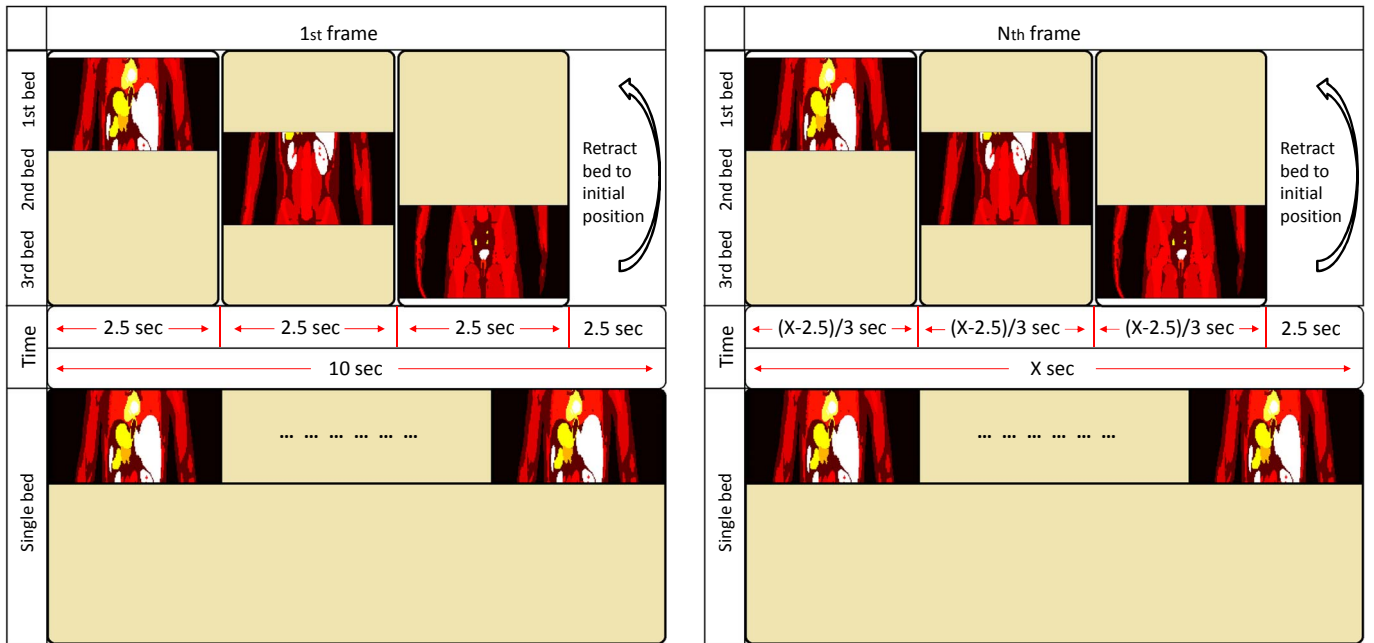


Fig.1 Comparison between a standard 1 bed dynamic protocol and the proposed 3-bed dynamic protocol. Each of the 29 3-bed passes and its overall time length are the same with each frame and the total scan time, respectively, of a 29-frame conventional single-bed dynamic scan. Each frame of the single-bed protocol was split equally amongst the bed positions of the 3-bed protocol considering also a 2.5sec gap after each full pass to simulate the bed return time.

scan was simulated. Moreover, using the same input function (ignoring delay and dispersion between beds) an axially extended dynamic scan was also simulated, corresponding to an equivalent 3-bed dynamic scan, with each bed consisting of 29-frames ($9 \times 2.5\text{sec}/\text{bed}$, $3 \times 9.2\text{sec}/\text{bed}$, $4 \times 19.2\text{sec}/\text{bed}$, $4 \times 39.2\text{sec}/\text{bed}$, $9 \times 99.2\text{sec}/\text{bed}$). The proposed protocol has been designed such that each of the 29 3-bed passes and its overall time length are the same with each frame and the total scan time, respectively, of a 29 frame conventional single-bed dynamic scan. In addition, the individual frame durations of the single-bed acquisition were split equally amongst the bed positions of our proposed multi-bed protocol. A 2.5sec gap after each full pass was taken into account also, simulating the bed return time (Fig. 1). Taking into account the phantom's diameter, TOF resolutions between 440-300ps would be needed to achieve the minimum necessary TOF NEC gain to equate the SNR compared to the single-bed scan[2]. Two TOF resolutions were simulated (440ps and 300ps) and the dynamic TOF dataset corresponding to the 3-bed protocol as well as the non-TOF single-bed one, were generated based on the geometry of the Siemens mCT TOF PET[10]. Post-reconstruction kinetic analysis was performed with the GLLS method[11]. Parameter estimation on the axially extended dynamic scan was performed in 2 ways; 1) using the entire axially extended dynamic image and the framing of the single-bed scan since the 2 scans are equivalent and each full pass in the extended scan matches the frame durations in the single-bed scan, 2) using each individual bed and the framing corresponding to it and then overlapping the parametric images to generate the axially extended parametric maps.

III. RESULTS

Fig.2 shows single frame emission data, using the single-bed and 3-bed protocol. At 300ps, the TOF gain can compensate for the SNR loss due to reduced scan time/counts per frame/bed and the first bed from the 3-bed scan is almost equivalent, if not better, to the single bed scan. At 440ps the reduced TOF NEC gain compared to the 300 ps is not enough to achieve SNR equivalency, with the data slightly noisier compared to the single bed. For comparison, the non-TOF 3-bed scan is shown. When non-TOF is used, the SNR drop due to having almost a 3-fold drop in counts is apparent. Using the single-bed and the equivalent 3-bed dynamic data, parametric maps were estimated and are shown in Fig. 3. Despite the equivalency in the dynamic data though, the parametric images in the single bed are substantially more biased compared to the 3-bed scan (Fig. 3(ii)) when parameters are estimated from each bed individually. In the single-bed scan and in regions with high K_1 , the framing is not sufficient to differentiate the tissue response from the blood volume which results in negative bias in K_1 and high positive bias in blood volume, while k_2 , k_3 and K_i are also negatively biased. However in the 3-bed scan such an effect is substantially reduced with the parameters more quantitatively accurate since although both scans have the same number of frames, the reduced frame duration per bed in the 3-bed scan, results in a more accurate temporal sampling. In order to demonstrate the effect of temporal sampling, parameter estimation on the 3-bed scan was additionally performed using the framing of the single-bed scan, since the time for a complete pass in the 3-bed scan is equal to the frame duration from the single-bed scan. As can be seen in Fig.3(ii-single bed framing) the same bias is observed in the parameters compared to the single bed

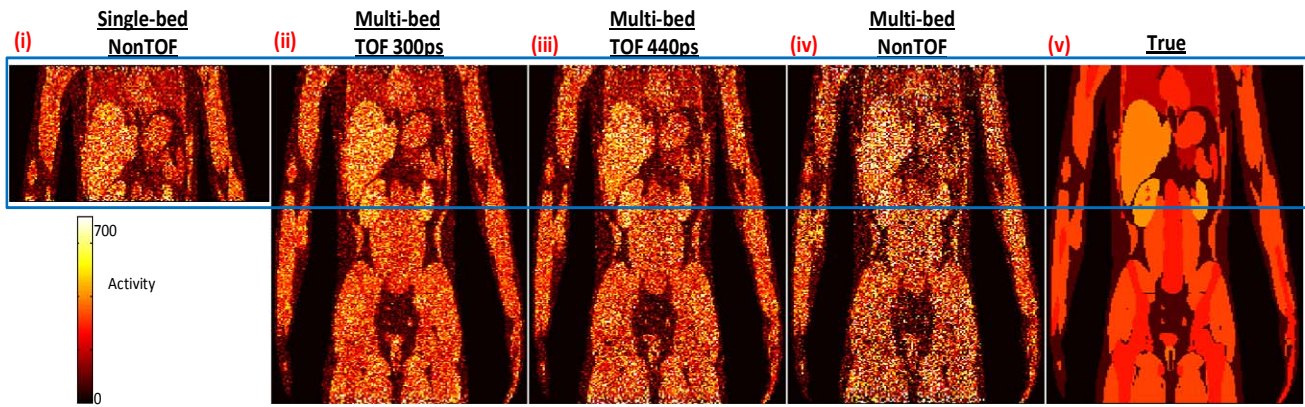


Fig.2 Dynamic emission data from a single frame at matched contrast using the single-bed non-TOF protocol (i), the 3-bed protocol (ii-iv) and the true image (v). At 300ps TOF resolution, (ii) the 3-bed protocol produces equivalent dynamic data to the single-bed scan, while for lower TOF resolutions (iii) no SNR equivalency exists as the TOF gain is not enough to counterbalance the reduced frame duration/counts. The extreme case of non-TOF 3-bed scan is also shown (iv).

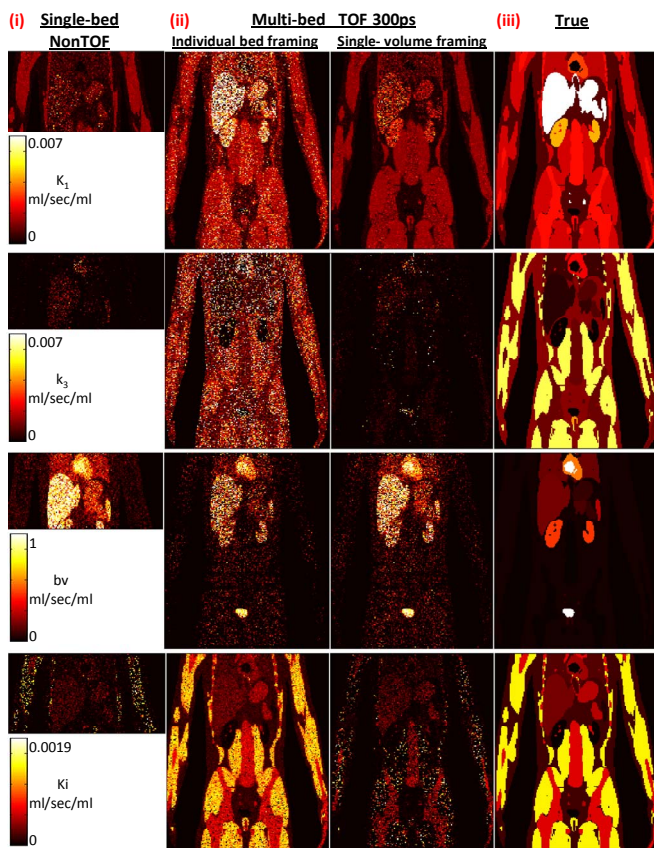


Fig.3 Parametric images of K_1 , k_3 , blood volume and K_i from the single-bed (i) and 3-bed protocols (ii) along with the true parameters (iii). The 3-bed parametric images (ii) were derived using the individual frame durations per bed (left) and the frame durations based on an entire pass through the beds (right) matching the single-bed framing.

though slightly less probably due to the fact that the TOF gain at 300ps results in the SNR not only equating but superseding the SNR of the single bed.

IV. CONCLUSION

Exploiting the SNR benefits of TOF, equivalent dynamic data can be obtained at reduced frame durations, allowing the scanned axial FOV to be extended. Furthermore, initial results show that improved parametric maps could be obtained due to more accurate temporal sampling. Such a 3-bed protocol could only become feasible in CBM modes, however, bed speeds in excess of 50mm/sec are needed (accounting also for a 50% overscan in CBM mode) and despite the ability of the bed to move at even faster speeds in the simulated scanner, the current maximum acquisition speed is limited to 10mm/sec. However, in CBM mode any axial extent can be acquired. Therefore, given the future improvements in the CBM speed and depending on the maximum available speed and TOF resolution (with resolutions of ~ 350 ps already available), dynamic scans could be axially extended accordingly.

V. ACKNOWLEDGMENTS

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