Impact of time-of-flight on quantitative accuracy and volume determination in non-uniform phantoms

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I. INTRODUCTION

In Nuclear Medicine (NM) images of functional processes are generated by injecting the patient with a molecule labeled with a radioactive isotope. By detecting the radiation from the radioactive decay of this isotope we can obtain an image of the distribution of the molecule in the body.

In NM two tomographic techniques are used: SPECT (Single Photon Emission Computed Tomography) and PET (Positron Emission Tomography). In SPECT the isotope is a single photon emitter while in PET we use positron emitters. The positrons emitted in PET annihilate with electrons into two coincident 511 keV photons emitted back to back. By measuring the two opposed photons in time coincidence one knows the line along which the annihilation occurred, or Line Of Response (LOR). The image can then be reconstructed through different kind of algorithms, all of which usually involve projecting and backprojecting the events along the LOR during the reconstruction process.

PET image quality is contaminated by statistical Poisson noise, and by noise coming from both random coincidences, created by photons coming from two independent annihilations, and scattered coincidences, created by photons coming from the same annihilation events but undergoing single or multiple scattering interactions before being detected. In practice these signal components are approximated and subtracted using different approaches (measurement, modeling or simulation) to obtain the final image from the true coincidences.

Using the most modern PET scanners it is possible to accurately measure the difference in Time-Of-Flight (TOF) between the two annihilation photons, and thus determine the position of the event along the LOR with a small error defined by the timing resolution. The additional time-of-flight information can be exploited to reduce the noise: instead of forward and backprojecting along a full LOR, one uses a Gaussian kernel (with FWHM equal to the space equivalent to the timing resolution) along the LOR. This smaller range limits the noise propagation which results in lower noise for the same number of counts compared to non-TOF PET. This property is used to reduce imaging time or to improve image quality.

A typical modern TOF scanner has a timing resolution of 600 ps, a high sensitivity and produces clinical images with better contrast recovery and lower noise level than non-TOF in shorter acquisition times, with beneficial effects maximized for obese patients. Today TOF PET is commonly used for oncological diagnosis and also radiotherapy planning and staging. In the latter case, it is common to measure the lesion volume by manual or automatic vol-
II. AIM

In this work we quantify TOF vs non-TOF PET image quality in terms of contrast, noise and volume definition. The Contrast Recovery Coefficient is commonly used as a figure of merit to assess the ability of a system to distinguish between different activity concentrations. The noise is usually defined as the ratio between the standard deviation and the mean of the reconstructed activity concentration values. The Contrast Recovery Coefficient depends on the lesions background. Identical lesions in different backgrounds (i.e., in the lungs and in the abdomen) can recover to different contrast values due to different convergence and spill in/out effects due to finite sampling. In this work we investigate the effects of using Time-of-flight PET reconstruction over identical lesions in different backgrounds in terms of both CRC and threshold based volume definition.

III. METHODS

A custom made phantom with lesions and organ inserts simulating an obese patient at high count rate was acquired on a Philips Gemini TOF-PET scanner. Identical lesions were placed both in hot and cold background. We performed listmode TOF and non-TOF reconstruction for varying scan times, for a range of clinically used reconstruction parameter, generating 10 realization per each combination of scan time and reconstruction parameters (30 and 60 s with 10 realizations each). We compared the performances of the TOF and non-TOF methods in measuring lesions volume by applying a 42% threshold method. CRC was calculated for all lesions in TOF and non-TOF.

IV. RESULTS

CRC calculated on the TOF image converges faster and to higher values for all cold and hot lesions except the biggest one, which converges to a value 10 % higher for non-TOF. However, for this lesion the difference between TOF and non-TOF CRC is less than 5 % at 3 iterations, the most used reconstruction in clinic. Identical lesions in different backgrounds were shown to converge to different values, the difference between the lesions being 20 % smaller for TOF reconstruction. Volume thresholding for lesions in the lungs gives up to a 30 % better volume estimation when using TOF.

V. CONCLUSIONS

TOF PET shows better characteristics for quantization tasks in different backgrounds and for volume definition for cold background lesions. In general, count and contrast recovery is less depending from the surrounding activity than with regular PET, allowing a more accurate evaluation of the lesions’ severity.