Introduction of the DOI capable Total-Body J-PET, a simulation study

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Background:

Positron Emission Tomography PET plays a fundamental role in medical diagnosis and oncological research. Due to exceptional performance of PET scanners and continuous advancement, their clinical availability is spreading [1]. The development of Total-Body PET technology is one of the most recent trends in the medical imaging field. Having large axial field of view (AFOV), they provide greater detection area and therefore an increased sensitivity [2]. Nevertheless, alongside many advantages over traditional PET tomographs they are more susceptible to the parallax error, which causes degradation of axial resolution. This is caused by the contribution of most oblique lines of response (LORs) in the acquired data. To overcome this problem the application of a cut – angular acceptance criterion – over such LORs has been recommended. Nonetheless, it causes a significant loss of scanner's sensitivity [3].

Jagiellonian PET (J-PET) collaboration from Krakow, Poland is currently developing novel PET tomographs based on the organic, plastic scintillators [4, 1]. Such unique design allows not only for the introduction of cost efficient Total-Body system, but also is able to solve challenges connected with such tomographs. The main aim of this study is to present a novel solution to overcoming the aforementioned problem of degradation in axial resolution in Total-Body scanners by introducing DOI capable detectors based on the J-PET technology.

Methods:

The presented study has been performed using GATE simulation software dedicated to medical imaging [5]. Two Total-Body tomographs designed based on the J-PET technology were simulated (see Figure 1). First scanner consists of two layers of scintillator strips separated by a layer of wavelength shifters (WLS) [6]. Second one possess an additional division of each plastic strip in radial direction. Their performance was assessed based on sensitivity and spatial resolution.

To investigate sensitivity, a 2 m long line source located at the radial center was simulated to evaluate the sensitivity profile over whole AFOV. In addition

the influence of acceptance criterion was determined. For that previously inspected 45° acceptance angle has been applied [3].

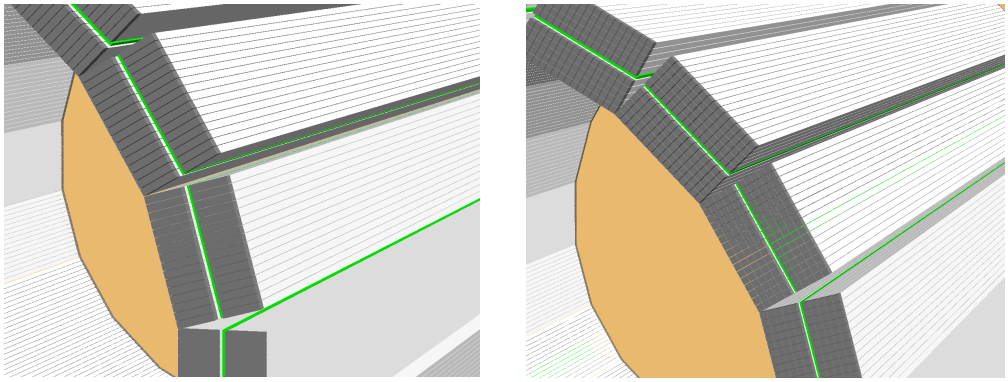

Fig 1. Standard Total-Body J-PET (left) and DOI Total-Body J-PET visualization, both consist of 24 modules in each layer and WLS between them. **This figures will be replaced with the zoomed one to have more visible structure**

In order to investigate spatial resolution a point source located at the scanner's center, which gives the widest range of LOR's obliqueness, was simulated. The image reconstruction was performed with the MLEM iterative algorithm using QETIR software [7]. The spatial resolution presented as full width at half maximum (FWHM) of point spread function was evaluated with and without 45° acceptance criterion.

Results:

The sensitivity possible to achieve with both tomograph's configuration is similar (see Figure 2). Since the only difference lies in an additional radial division the amount of scintillator material remains constant. Applying angular cut causes in both cases almost 30% reduction in the central part, which contributed to oblique LOR detection.

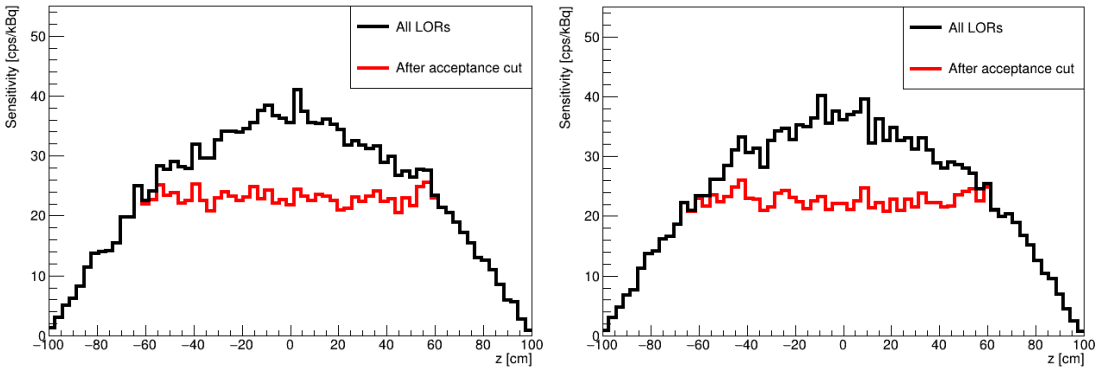

Fig 2. The sensitivity profiles of the standard Total-Body J-PET (left) and DOI Total-Body J-PET for all the coincidences (black) and after applying 45 degree of acceptance angle (red).

In case of spatial resolution the acceptance criterion gives 50% reduction in axial FWHM for standard TB J-PET (see Table 1). However, for DOI TB J-PET obtained resolution has no significant change and is already performing better than for non-cut standard TB-JPET.

	All coincidences	45 Degree of Acceptance Angle
Standard Total-Body J-PET Axial FWHM [mm]	9.4 ± 0.31	5.1 ± 0.25
DOI Total-Body J-PET Axial FWHM[mm]	3.6±0.33	3.53±0.16

Table 1. This tables shows the influence of the applying acceptance angle cut over the oblique LORs for standard Total-Body J-PET and DOI Total-Body J-PET

Conclusion:

The main aim of this study was to introduce a solution to overcome the axial resolution degradation problem in Total-Body J-PET systems. The presented results show that the commonly used method of applying angular criterion comes with a great reduction in sensitivity. However, based on the spatial resolution it was shown that the DOI configuration doesn't require acceptance angle application while having almost identical sensitivity as the standard TB J-PET. It reveals that the DOI Total-Body J-PET tomograph can be an almost parallax free system, hence the full detector coverage can be utilized while performing a scan.

Reference:

1- Moskal, P., Stępień, E.: Prospects and Clinical Perspectives of Total-Body PET Imaging Using Plastic Scintillators. PET Clinics 15(4), 439–452, (2020).

2- Vandenberghe S., Moskal P., Karp, J.: State of the art in total body PET. EJNMMI 7(35),(2020)

3- M. Dadgar, S. Parzych and F. Tayefi "A Simulation Study to Estimate Optimum LOR Angular Acceptance for the Image Reconstruction with the Total-Body J-PET," in MIUAOxford, UK, 2021, pp. 189–200.

4- P. Moskal, A. Gajos, M. Mohammed, J. Chhokar, N. Chug, C. Curceanu, et al. "Testing CPT symmetry in ortho-positronium decays with positronium annihilation tomography," Nat. Commun., vol. 12, no. 1, 2021.

5- P. Kowalski, L. Raczy nski, T. Bednarski, P. Białas, E. Czerwinski, K. Giergiel et al. "Determination of the map of efficiency of the Jagiellonian Positron Emission Tomograph (J-PET) detector with the GATE package," Bio.Algo. Med. Syst., vol. 10, no. 2, 2014.

6- Smyrski, J., Alfs, D., Bednarski, T., et al.: Measurement of gamma quantum in- teraction point in plastic scintillator with WLS strips. Nuclear Instruments and Methods in Physics Research A 851(5), 39–42 (2017)

7- Medisip Homepage, https://www.ugent.be/ea/ibitech/en/research/medisip. Last accessed 24 January 2022.