Abstract

This study aim is to evaluate the performance characteristics of the Modular Jagiellonian Positron Emission Tomograph (Modular J-PET) in accordance with the recognized standards established by the National Electrical Manufacturers Association (NEMA) for Positron Emission Tomography (PET) scanners. The Modular J-PET represents the latest prototype within the Jagiellonian-PET group, distinguished by its utilization of plastic scintillator strips optimized for the precise detection of back-to-back gamma quanta arising from electron-positron annihilations. The Modular J-PET comprises 24 individual modules arranged in a symmetrical 24-sided polygon circumscribing a circular configuration with a diameter of 73.9 cm. Each module is constructed from 13 scintillator strips, aligned adjacently, each measuring 50 cm in length and possessing a cross-sectional dimension of 6 mm × 24 mm. Dual-ended scintillation light readout is accomplished through analog Silicon Photomultipliers (SiPMs).

Data collected during the experimentation phase were subjected to analysis employing software known as the J-PET Framework. The average system sensitivity of the Modular J-PET was determined to be 0.768 ± 0.003 cps/kBq in the center with the peak sensitivity of 2.1 cps/kBq. The system sensitivity has improved by sixfold compared to the first generation of the J-PET prototype with 192 strips.

Radial spatial resolution for TOF image reconstruction methods was found to be 4.92 ± 0.56 *mm*, 7.37 ± 0.49 *mm*, and 6.94 ± 0.38 *mm* at positions 1 cm, 10 cm, and 20 cm from the detector center, respectively. Tangential spatial resolution for TOF image reconstruction methods was determined as 7.37 ± 0.51 *mm*, 7.37 ± 0.10 *mm*, and 14.67 ± 0.31 *mm* at the same positions, while axial spatial resolution was calculated as 30.73 ± 0.52 *mm* ,30.73 ± 0.64 *mm*, and 31.96 ± 0.29 *mm*. It is worth noting that the tangential and radial spatial resolution values of the Modular J-PET detector align closely with those of commercial PET devices. Future enhancements are anticipated in axial spatial resolution through an extended axial field of view scanner and the application of wavelength shifting (WLS) techniques. The determination of the scattered fraction based on single-scatter randoms background (SSRB) algorithms yielded a value of 41.68 ± 0.19 [%], which is consistent with that observed in commercial PET devices. To validate the experimental findings, GATE simulations were conducted.

The simulations included spatial resolution assessments using a sodium source, as well as evaluations of sensitivity and scatter fraction involving a phantom conforming to NEMA standards. The simulations indicated that the Modular J-PET achieves a system sensitivity of 1.324 ± 0.032 cps/kBq at the center of the detector's field of view and 1.313 ± 0.001 cps/kBq at a 10 cm offset from the tomograph center. The peak sensitivity at the center of the detector's filed of view to be 2.9 cps/kBq across various multiplicity cuts. Furthermore, the scatter fraction, computed utilizing SSRB algorithms, was established at (40.25 ± 2.3) % . Radial spatial resolution for TOF image reconstruction methods was found to be 4.80 ± 0.59 mm,7.26 ± 0.55 mm, and 6.67 ± 0.42 mm at positions 1 cm, 10 cm, and 20 cm from the detector center, respectively. Tangential spatial resolution for TOF image reconstruction methods was determined as 7.27 ± 0.47 mm, 7.27 ± 0.59 mm, and 15.1 ± 0.4 mm at the same positions, while axial spatial resolution was calculated as29.97 ± 0.49 mm, 30.53 ± 0.74 mm, and 31.78 ± 0.11 mm.

The Modular J-PET, characterized by its single-layer configuration with 50 cm scintillator strips, exhibits the potential for extension to an extended axial field-of-view through multi-layer arrangements. Consequently, the presented Modular J-PET prototype holds promise for the cost-effective development of a total-body J-PET system constructed from plastic scintillators.