JPET for proton beam range monitoring

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Introduction

Radiation therapy with accelerated protons offers a favorable, compared to photons, depth dose distribution with the maximum dose deposition at the end of their range. However, one of the major limitations of protons in the clinic is the uncertainty of their range, leading to the target volume underexposure or overexposure of the healthy tissue [1]. We present for the first time measurements performed with the J-PET detector [2,3,4] and therapeutic proton beams to demonstrate the feasibility of the J-PET to monitor the proton beam range.

Materials and Methods

The modular J-PET detector was arranged in a 3 layers dual-head setup with 24 modules as shown in Fig. 1A, 1B. The uniform, water equivalent gel phantom was irradiated with four, homogeneous 16 Gy SOBP fields of 100 mm, 104 mm, 110 mm, and 119 mm range corresponding to 117.77 MeV, 120.53 MeV, 124.23 MeV, 129.85 MeV distal proton beam energy, respectively (see Fig.1C). The continuous data acquisition during the beam on and between the subsequent field irradiations was performed. Processed data were formed in a coincidences list. PET images were reconstructed with the CASToR software [5] (MLEM, 10 iterations) including attenuation and sensitivity corrections. Reconstructed activity profiles for each field were compared to assess the feasibility of the modular J-PET for range monitoring.

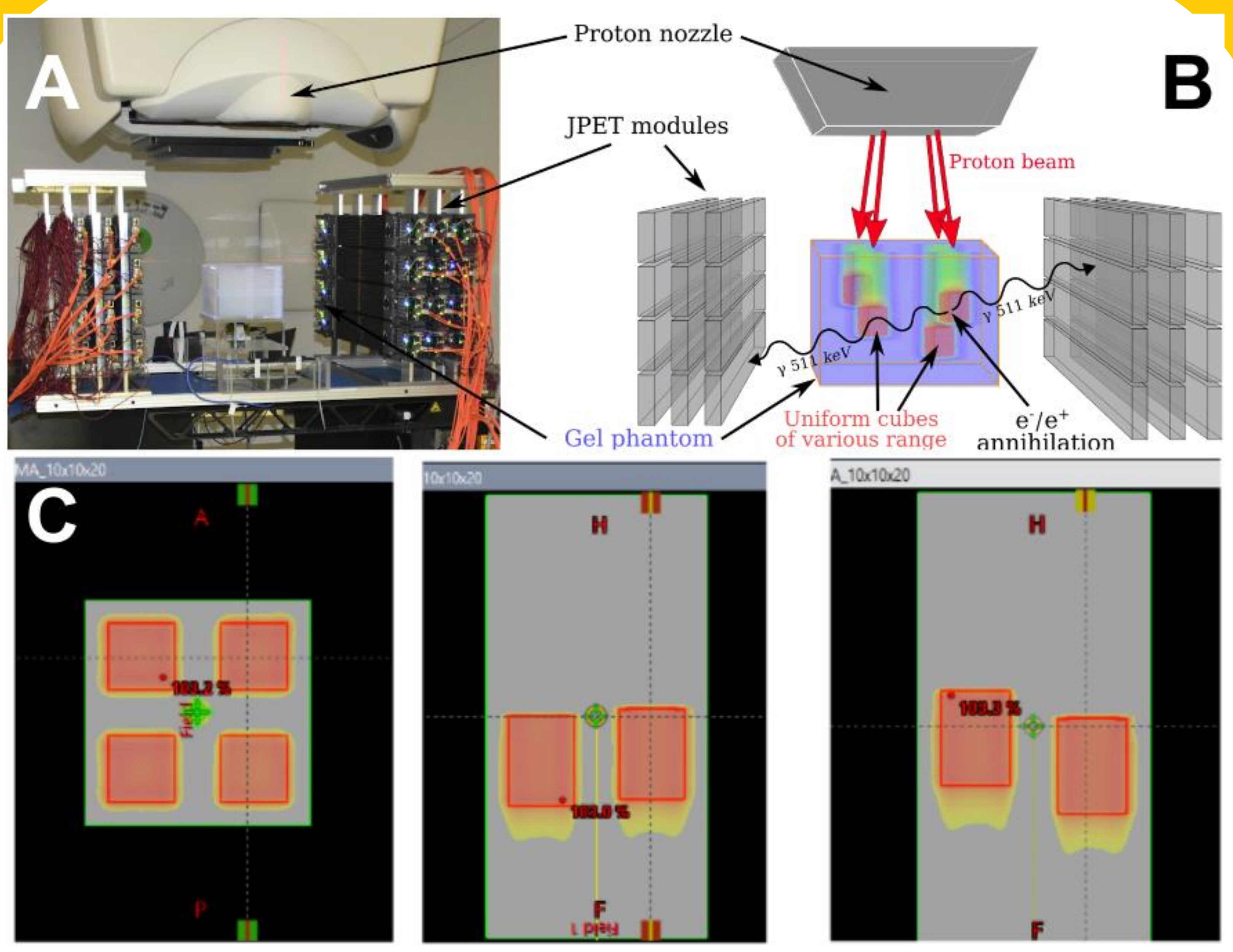
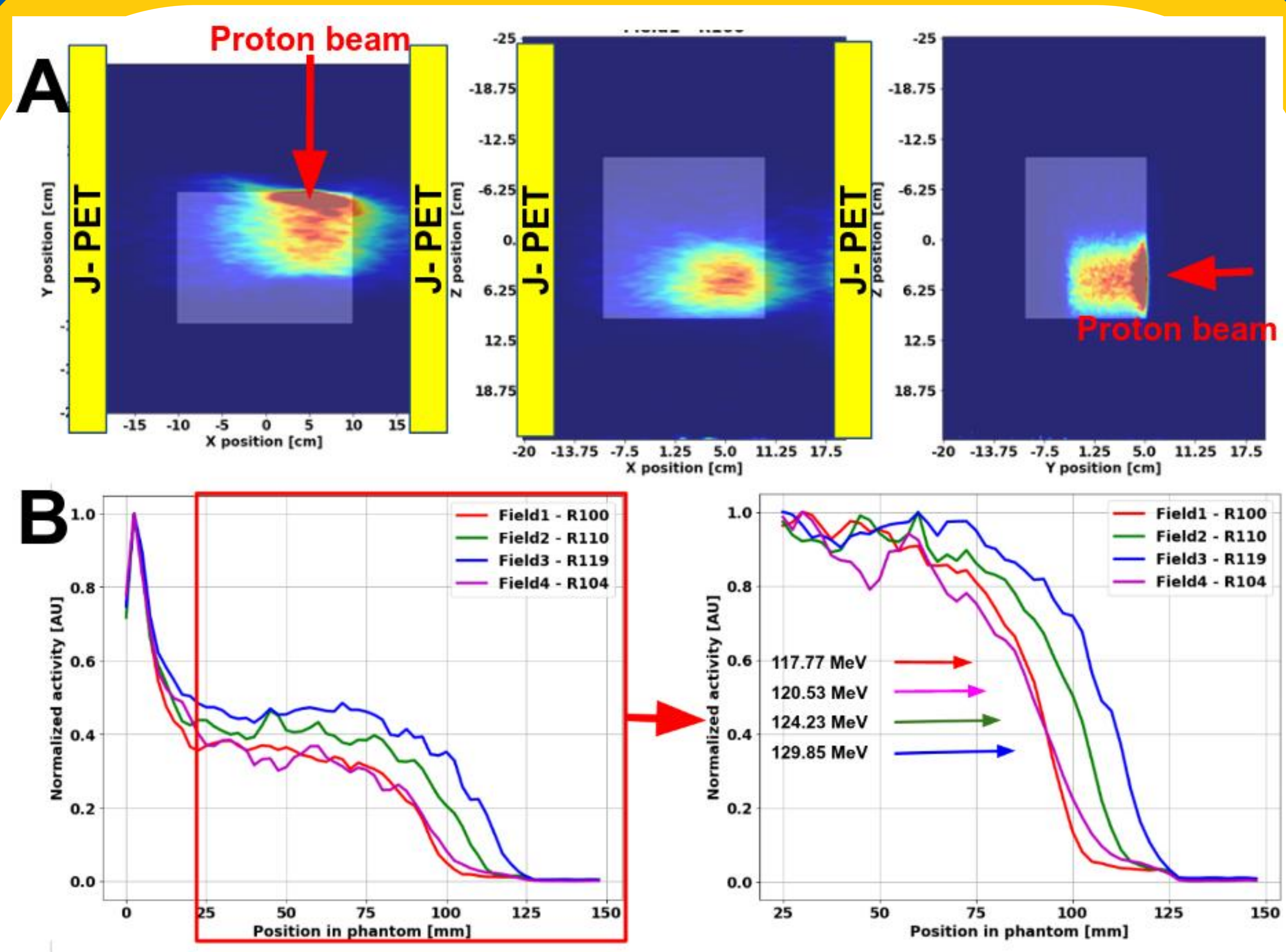


Fig.1. Panel A: The experimental setup with the J-PET detector, proton nozzle, and gel phantom. Each layer in the head has 4 modules. Each module consists of 13 50-cm-long scintillator strips. The annihilation gamma deposits its energy via Compton scattering producing the scintillation which is propagated to the ends of the strips, converted to the electronic signal by SiPM, and processed with FPGA. Panel B: scheme of the experiments indicating the position of the irradiation fields. Panel C: Irradiation plans of SOBP fields of different ranges.

Results

In Fig. 2A the exemplary reconstructed images of the activity gathered during the PET acquisition are presented for the SOBP field with the range of 100 mm. The reconstructed activity profiles along the beam direction for each of the fields are depicted in Fig. 2B. The differences in the proton beam ranges are clearly visible between Fields 1,2 and 3, demonstrating the feasibility of the J-PET system to detect beam range variations. The acquisition for field 4 was interrupted as ¼ of the scanner was not working properly due to the DAQ glitch and could be potentially biased. The PET image quality could be improved by applying normalization, random, and scatter corrections. A characteristic elongated activity distribution visible along the x-direction is due to non-cylindrical detector geometry; LORs were collected only by two opposing detector heads.



Panel A: The reconstructed PET activity distribution for the SOBP with the range of 100 mm. Positioning of the J-PET detector heads (yellow rectangular) and proton beam direction is indicated. Panel B: The normalized reconstructed activity profiles for SOBP fields of different ranges. Substantial differences in activity range between fields are noticeable.

Conclusions

The results show for the first time that the J-PET detector is feasible to acquire β+ signal produced during the proton beam irradiation and detect a few millimeter range variations of homogeneous dose fields in a uniform phantom. Further investigations include improvements in data processing, image reconstruction, and a more detailed assessment of the J-PET system precision for proton beam range detection in the clinical setting.

References

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