A proof-of-principle experiment of hybrid prompt gamma-positron emission tomography system for *in vivo* dose verification in proton therapy

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Purpose:
In proton therapy, the uncertainty over determining proton range may adversely affect on the actual dose distribution owing to the steep dose gradient at the distal edge of the Bragg peak. Accurate prediction for in vivo proton dose distribution is very important to improve the treatment quality by fully utilizing the potential advantages of proton therapy. In our previous study, we proposed a hybrid prompt gamma (PG)-positron emission tomography (PET)-based multi-modality imaging method by combining the advantages of PG imaging and PET to increase the accuracy in predicting the proton dose distribution using the Monte Carlo (MC) method. The purpose of this study is to experimentally verify the feasibility of the PG-PET system.

Materials and Methods:
Based on the detector geometry optimized in the previous MC study, we constructed a dual-head PG-PET system composed of 16×16 GAGG scintillator and KETEK SiPM array, 0.7 mm-thick $BaSO_4$ reflectors, and an 8×8 parallel-hole tungsten collimator. The performance of this system equipped with TOFPET2 readout system manufactured by PETsys electronics was evaluated using several test sources. For a proof-of-principle of the PG-PET system, we measured PG and PE distributions emitting from a 30×60×100 mm^2 PMMA phantom placed at two different positions for a 45 MeV proton beam (17 mm range in PMMA) with 1 nA current generated by an MC-50 cyclotron installed in the Korea Institute of Radiological and Medical Sciences. The PG distributions were obtained when the proton beam was turned on for 10, 50, 100, 500, 1000 seconds for the two different positions of the PMMA phantom.

Results:
As the results of performance evaluation with ^{133}Ba, ^{22}Na, and ^{137}Cs test sources, the mean energy resolutions of every channel for 356, 511, 662, and 1275 keV were 16.3%±2.9%, 13.5%±2.4%, 12.2%±2.4%, and 4.3%±2.9%, respectively. In the experimental study, we employed an in-house EW technique in the post-processing of the measured data to overcome the problems in applying the conventional EW technique to the DAQ system. As a result of the experiment using 45 MeV proton beam, the dual-head PG-PET system constructed for a proof-of-principle could successfully obtain PG and PE distributions. Following analysis of the measured distributions through the MC method, the PG and PE distributions had the advantage of assessing the proton range in the phantom and estimating the shape of the dose distribution, respectively. As following the results of measuring PG distributions, we report that 6.25×10^{10} protons are sufficient to clearly discriminate PG distribution.

Conclusions:
In this study, we confirmed that the PG distribution can be obtained by simply combining the 2-D parallel hole collimator and the PET detector module. In the future, we will perform further experimental studies with various proton energies and develop an accurate 3-D dose evaluation technique using deep learning algorithms based on the image sets of dose, PG, and PET distributions.

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proton therapy, prompt gamma imaging, positron emission tomography, in vivo dose verification, Monte Carlo