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# Performance improvement of Compton imaging of astatine-211 by optimizing coincidence time window

**Introduction**

Astatine-211 is a promising radionuclide for targeted α-particle radiotherapy of cancers. It is required to image the distribution of targeted radiotherapeutic agents in a patient's body before or during treatment for optimization of treatment strategies and determination of the suitability of a given agent for a particular patient [1]. Because the biodistribution of astatine-211 is different from that of iodine-131, it is important to image astatine-211 directly.

The astatine-211 and its daughter radionuclide polonium-211 emit gamma rays (570 keV, 687 keV, and 898 keV) at the total intensity of 0.9%. Recently, we have proposed to image astatine-211 with the gamma rays using a Compton camera and demonstrated the imaging capability of the camera in the experiments of a point-like astatine-211 source with a relatively wide coincidence time window of 160 ns [2]. Since random coincidence events by polonium K-shell x rays were dominant and seemed to cause saturation of counts in the experiments, optimization of the coincidence time window is important to reduce the random coincidence events. In this study, we optimized the coincidence time window and evaluated the performance of the camera.

**Materials and methods**

**A. Imaging system**

The Compton camera has two detectors: a scatterer and an absorber. The scintillator material of both the detectors is cerium-doped gadolinium aluminum gallium garnet (GAGG; Ce:Gd3Al2Ga3O12; Furukawa Co., Ltd.). The scatterer is a 20.8-mm x 20.8-mm x 5-mm GAGG array block coupled to a silicon photomultiplier S11064-050P (Hamamatsu Photonics K. K.). The size of a single GAGG element of the scatterer is 0.85 mm x 0.85 mm x 5 mm. The absorber is a 41-7-mm x 41.7-mm x 10-mm GAGG array block coupled to a flat-panel-type multianode photomultiplier tube H12700MOD (Hamamatsu Photonics K. K.). The size of a single GAGG element of the absorber is 0.85 mm x 0.85 mm x 10 mm. The distance between the front ends of the two GAGG array blocks is 15 mm. A commercially available data acquisition (DAQ) system [3] was diverted to the DAQ system of the Compton camera. It consists of weighted-summing amplifiers, 100-MHz free-running analog-to-digital converters, and a field-programmable gate array (FPGA). The FPGA detects coincidences of the two detector signals in a variable time window of 10 ns–160 ns. Detailed specifications for the camera can be found in Ref. [4].

**B. Optimization of coincidence time window**

A 0.6-MBq point source of barium-133 was placed at 6 cm in front of the camera and measured for 100 s each with changing the coincidence time window. We used barium-133 instead of astatine-211 to measure under the condition that there were few random coincidence events. The coincidence count rate was 120 cps when the coincidence time window was 160 ns for both the scatterer and absorber. The coincidence time window was optimized as narrow as the coincidence count rate didn't decrease apparently and preserved more than 85% of the maximum count rate. The optimized coincidence time window was 40 ns for the scatterer and 80 ns for the absorber, where the coincidence count rate was 108 cps.

**C. Performance evaluation**

A point-like source of an astatine-211 solution occupying a volume of 0.125 mL in a 0.5-mL conical vial was placed at 3 cm in front of the camera. First, the source (17.9 MBq at the measurement start) was measured for 600 s with the coincidence time window of 160 ns. Second, the source (14.5 MBq at the measurement start) was measured for 600 s with the optimized coincidence time window.

The measured coincidence events were filtered by the energy window of 687 keV ± 64 keV. The filtered events were imaged by list-mode maximum-likelihood expectation maximization algorithm. A detailed description of the implementation of the image reconstruction algorithm can be found in Ref. [4].

**Results**

The coincidence count rates in the energy window before and after the optimization of the coincidence time window normalized by the activity and measurement time were 21.2 cpm/MBq and 28.8 cpm/MBq, respectively. This means the sensitivity was improved by a factor of 1.4 due to reduction of the random coincidence events by the optimization of the coincidence time window. The spatial resolution of the $x$-profile was improved from 13.8 mm to 11.8 mm in full width at half maximum by the optimization of the coincidence time window.

**Conclusions**

We have optimized the coincidence time window of the Compton camera and improved the sensitivity and spatial resolution. Future research plans include the evaluation of image quality.

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