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Image quality of a pure Cherenkov TOF PET scanner: a simulation study

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In positron emission tomography, dense Cherenkov radiators provide an opportunity for high gamma detection efficiency and excellent CTR. However, because only a few tens of Cherenkov photons follow a gamma interaction in the radiator, the detection efficiency and the energy resolution of a pure Cherenkov detector are an issue. We study gamma detection efficiency and CTR of PbF_2 based detectors with different surface treatments and photo-detectors (SiPMs with realistic PDE and 70 ps FWHM SPTR) covering one, two, or all crystal faces. We investigate the potential performance of a full-size Cherenkov PET using the NEMA NU 2-2018 standard and compare image quality with a reference scanner - Siemens Biograph Vision PET scanner - with the geometry of Cherenkov scanners based on that of the reference scanner. Monte Carlo simulations were performed on a super-computing network using GATE, and CASToR was used for TOF-OSEM image reconstruction. Normalization, scatter, random, and attenuation correction factors were included in the reconstruction. Cherenkov scanner with 1-sided readout had similar TOF performance (˜210 ps CTR-FWHM) and achieved very similar image quality as the reference scanner. By using 2-sided (SiPMs at the sides of the crystal) or 6-sided detector designs with better coincidence detection efficiency and ˜120 ps CTR-FWHM, even better image quality was achieved. The main limitation of our simulation study is not including the noise in the simulation - especially the dark count events of the SiPMs. We demonstrate that even though pure Cherenkov scanners have basically no energy resolution, the scatter fraction is around 50%, compared to 33% with the reference scanner, and is not prohibitively large. Images comparable to the state-of-the-art clinical PET scanner can be achieved due to improved efficiency and CTR attainable with PbF_2. Low-cost Cherenkov detectors could become especially interesting for total-body scanners.

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