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Very high resolution PET techniques for small animal and human imaging

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Several years ago we presented the idea that PET resolution better than the intrinsic range of the positron at good sensitivity was achievable by placing a high resolution detector—ideally taking the form of a small diameter ring—within the bore of a conventional PET detector ring (J. Nucl. Med. Supp. 2000, 41(5):20P, 2001, 42(5):55P, 102P). While we examined constructing the inner detector from a number of materials that could potentially support high spatial resolution including cadmium zinc telluride and various scintillators, particularly intriguing was the fact excellent performance appeared achievable by using low proton-number (Z) materials such as silicon for the inner detector. Although nearly all interactions result in a Compton scatter, the Compton-scatter cross-section does not drop quickly with increasing energy. Furthermore, energy resolution is still possible by collecting the scattered photon in the outer ring. Detectors having high propensity for Compton interactions followed by escape of the scattered photon are capable of supporting extremely high spatial resolution that is limited by only the range of the Compton recoil electron. (Of course, photoelectric interactions are usable also). Although detector materials having higher Z are useful for packing more detection efficiency into a given volume, on the basis of the same detection efficiency, higher-Z materials suffer from more multiple interactions, which must be resolved to determine the correct coincidence line-of-response.

Various instrument configurations ranging from an intrarectal prostate imaging probe constructed using higher-Z LSO to a device for imaging mice at submillimeter resolution using a low-Z silicon inner detector are under active investigation. For the latter instrument simulation studies have shown that image resolution of ~350microns FWHM is achievable with good sensitivity (~1%) while ~1mm FWHM resolution can be achieved with outstanding sensitivity (9%). Both these figures include the effects of F-18 positron range and acolinearity. Resolution was estimated from images reconstructed using filtered backprojection, which has no intrinsic resolution recovery.

Results from such Monte Carlo investigations are encouraging and are presently being validated via experiment. To this end a single-slice proof-of-concept PET instrument was constructed using silicon and BGO detectors. Each 2.2cm x 4.4cm x 1mm silicon detector consisted of a 16 x 32 array of 1.4mm x 1.4mm pads. The silicon detectors were placed edgewise (for detection efficiency) on opposite sides of the 4.4 cm field-of-view and the source was collimated to a 1mm thick slice using thick tungsten plates. Measured efficiency was ~0.7x lower than Monte Carlo predictions which is fully explained by the detectors being biased slightly lower than depletion and by the coincidence timing window. Most encouraging was the spatial resolution which ranged between 700 to 800 microns FWHM across the field-of-view.

Even though the high spatial resolution predicted in simulation studies is borne out

by experiment, construction of an instrument supporting such resolution at high efficiency remains challenging but not outside the realm of practicality.

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