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Positron Range and prompt-gamma modeling in PET imaging

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Introduction: Besides the conventionally used radionuclides for PET (18F, 11C and 13N), alternative radionuclides such as 68Ga, 124I and 82Rb have been proposed for PET imaging and hundreds of PET radiotracers based on these radionuclides have been developed. Two challenges arise with the use of these radionuclides: their large positron range, which compromises the achievable spatial resolution of the system, and the emission of cascades of gamma-rays in coincidence with positrons, which complicates quantitative PET imaging. In this work we used the Monte Carlo simulation tool PeneloPET developed by our group to model the effects of positron range and prompt emissions in PET image quality. Later, we used this modeling to correct PET images for positron range and prompt gamma emissions effects. Further, a method for improving the quantification of PET images was also implemented and evaluated. Finally, we modified our simulation tool in order to simulate and analyze triple coincidences in PET.

Methods: We used PeneloPET to model positron range for different radionuclides in several biological tissues. Positron range (PR) distributions for each radionuclide-tissue combination have been determined and PeneloPET estimations have been compared with previous results found in the literature. In addition, a tissue-dependent and spatially variant positron range correction (TDSV-PRC) method has been developed and evaluated. We have modified PeneloPET to accurately simulate the decay cascades for non-pure emitters of interest for PET imaging, and we implemented and evaluated a local projection (LP) method for partial volume correction (PVC). Finally, we implemented a framework to simulate and analyze triple coincidences in PET. We validated our simulation tool by comparison of our simulated estimations against experimental measurements performed in a modified prototype of the Argus PET/CT scanner.

Results: The obtained PeneloPET PR estimations were consistent with previous literature. The TDSV-PRC yields artifact-free reconstructed images for large-PR radionuclides, like 124I or 68Ga, when range corrections are taken into account. The LP-PVC method, together with PRC, provides significant improvement in the quantification of PET images. Good agreement between the simulated and experimental double and triple coincidences spectra was obtained.

Conclusion: Monte Carlo simulations may guide the modeling and correction of the main effects that degrade image quality in PET imaging with non-conventional radionuclides.

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