Positron range distributions estimations using Monte Carlo simulations and U-Nets for PET Imaging

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Introduction

High-energy positrons emitted by PET radioisotopes such as ^{124}I can result in significant positron range (PR) effects, thus reducing contrast and inducing noise in the images.

Aim: Training and validation of a U-Net for the estimation of positron range kernels in different materials with high-energy positron emitters.

Materials and Methods

PR distributions of ^{124}I were simulated using Monte Carlo (MC) simulations in different material compositions: uniform, complex or spatially-variant CT derived combinations of bone, water and lung (Fig. 1). PR kernels were created by mapping the simulated annihilation points clouds to 3D matrixes, with sizes defined by the maximum PR in lung (~30 mm) and the PET voxel size (~2 mm).

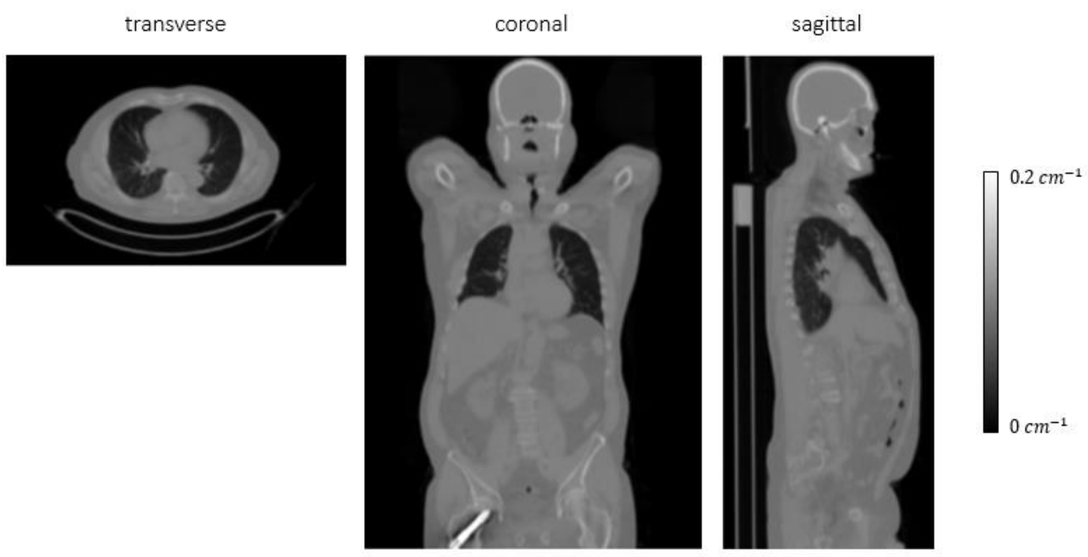

Fig. 1: CT attenuation map of a patient in transverse, coronal and sagittal views. Colour bar: linear attenuation coefficients, with a maximum threshold for bone at 0.2 cm^{-1}.

Material maps derived from the attenuation CT scan and the corresponding kernels with voxel sources were used as input pairs for the training of a U-Net (Fig. 2). The resulting distributions were compared to GATE results, which were regarded as ground-truth, using a percentage matrix difference.
The comparison was also repeated with a simple voxel-specific, material-dependent PR distribution method which was based on a material dependent combination of the respective homogeneous kernels (Fig. 3).

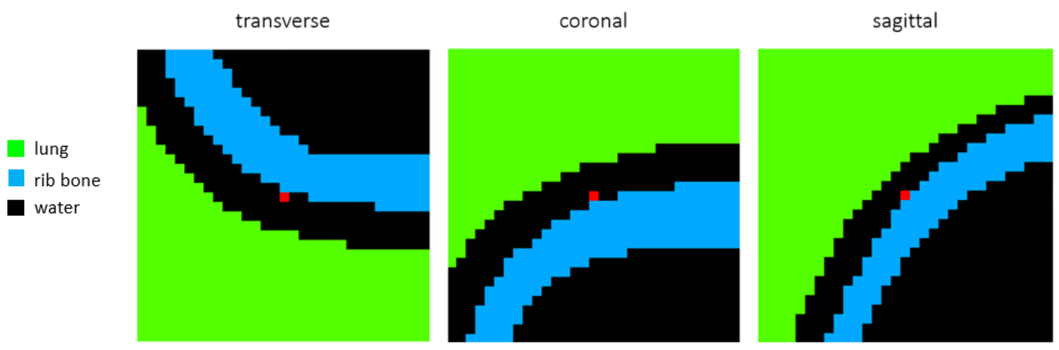

Fig. 2: Example of a spatially-variant phantom cropped from the CT derived material map. Three different materials are contained in the 3D matrix: water, lung and bone.

Results

The U-Net underestimated PR distributions in bone introducing image artefacts. However, PR distributions in water and lung as well as combination thereof were correctly estimated (Fig. 4). The network required just a fraction of the computational power needed for MC simulations.

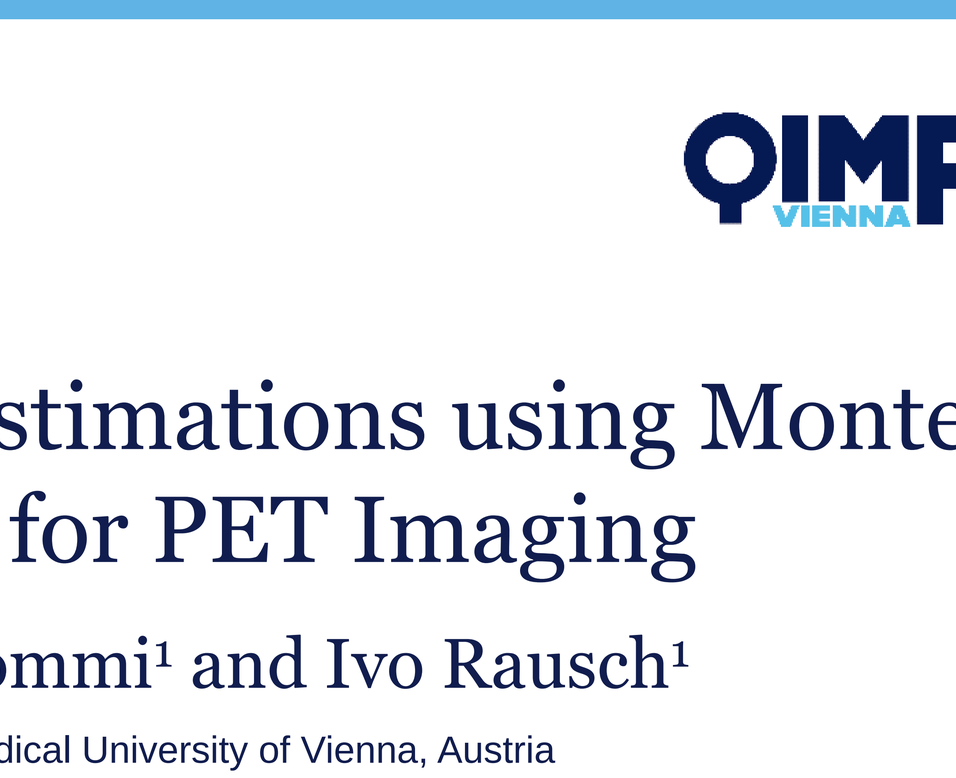

Fig. 3: A material map derived from the CT attenuation correction is cropped to obtain local material compositions. a) Tissue specific 3D kernels are combined accordingly to tissue-dependent uniform kernels. b) Central 2D slice of the material map obtained by the composition of the uniform water and lung kernels.

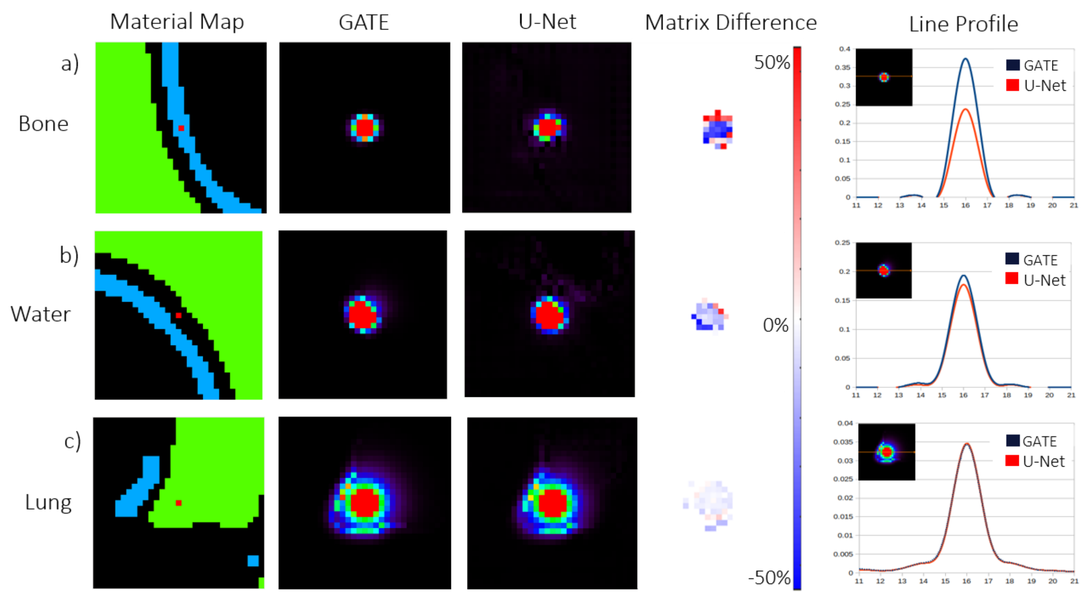

Fig. 4: Examples of positron range kernels in transverse view obtained with GATE simulation and U-Net training. Material maps composed of rib bone (blue), water (black) and lung (green). The percentage difference of the two 3D matrixes is also reported. In rib bone image artefacts are present and U-Net line profiles appears as underestimated, while in water and lung results are comparable.

Maximum Absolute Error

	GATE / U-Net	GATE / Sp. Var.
Bone	7.31×10^{-2}	5.37×10^{-2}
Water	1.13×10^{-3}	2.46×10^{-2}
Lung	5.74×10^{-4}	6.80×10^{-3}

Table 1: Maximum absolute errors between GATE and the positron range kernels derived for the material maps in Fig. 4 with the two described methods: U-Net and spatially-variant kernels construction.

Conclusion

U-Net seems a promising method for the estimation of PR distribution, with an accuracy similar to MC simulations and a much lower computational cost. With improvements in the implementation, the method could be used in image reconstruction for PR corrections.

References

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