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Voxel-based partial volume correction for accurate quantitative voxel values

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Abstract

Purpose: The accuracy of voxelized information in emission imaging is limited by spatial resolution (FWHM = 2.35σ) producing biases for objects smaller than 3 FWHM. If the signal distribution is non-uniform within 3σ of the voxel of interest then equilibrium does not exist and partial volume effect (PVE) compromises voxel accuracy. We propose a mathematical model to improve the accuracy of quantitative images of arbitrary distribution by bounding true voxel signal and estimating PVE for each voxel.

Methods: A monotonically increasing parametric dataset is created for each voxel of an emission image by radial integration from the voxel center to radius = 6σ. Each cumulative integration plot from r = 3σ to 6σ is fit to a function $A*4\pi/3*r^3 + B*\Delta V$ derived assuming a local uniform signal distribution (A) where ΔV is the voxel volume. The constant BΔV represents the converged within 3σ integral of PVE. B > 0 implies spill-out, B < 0 spill-in, and B = 0 no PVE. We tested the proposed model on simulations of 1D&2D datasets containing known signal distributions and 18F-PET/CT images of a 6cc lung lesion and bladder.

Results: Signal accuracy was > 99% in simulated 1D & 2D datasets. For the tumor, the original maximum value was 10kBq/ml. We obtained A = 3.5kBq/ml and B = 14kBq/ml for a total of 17.7kBq/ml. This yields (A+B)/original = 1.8 indicating substantial spill-out of ~80% and a large error for the original voxel value. For a voxel in the center of the bladder, the original value was 46kBq/ml with A = 44kBq/ml, B = 7kBq/ml. (A+B)/original = 1.11 indicating near-equilibrium at center of bladder and low spill-out of ~11% as expected. Local signal images (A) resemble low-pass filtered original image and (B) shows the magnitude and direction of PVE.

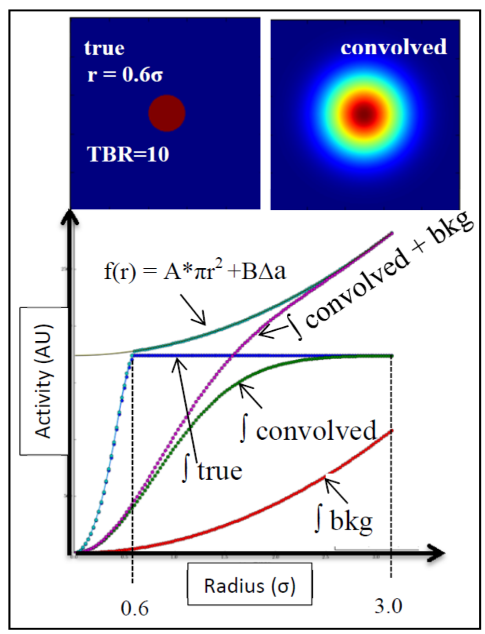

FIG 1: This figure illustrate our method in 2D for a disc source (r=0.6 σ) well below the spatial resolution (2.35σ). The integration is centered on a pixel at the center of the disc. *∫true disc signal* converges at r=0.6, the *∫convolved disc signal* converges (99.7%) at 3σ, and *∫background* in 2D grows as r^2. In addition, note that *∫convolved disc source + background* converged to *∫bkg* + *∫true* for r ≥ 3σ. Finally, fitting to points from 3σ to 6σ generates 2 fit parameters representing a local uniform activity areal concentration an additional activity areal concentration representing the spill-in/spillout in the pixel. Notice how B > 0 indicating spill-out. If B is zero, then the signal in the pixel becomes the local background.

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Conclusion: A new mathematical model to estimate the accuracy of voxels in quantitative images of arbitrary distribution has been developed. Analysis of additional patients is underway.

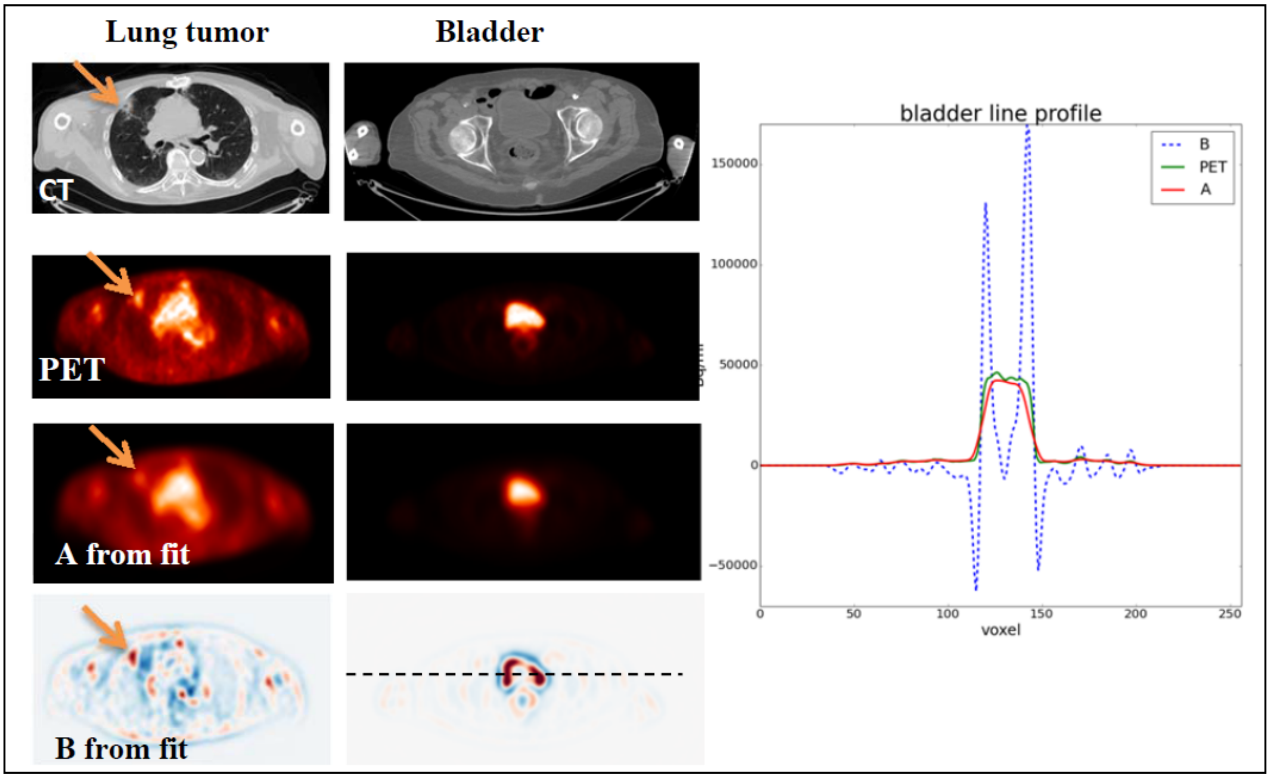

FIG. 2: This figure shows two slices from a full 3D implementation of our method. Top to bottom the CT, PET, our local background (A), and spill-in spill-out parameter (B). PET and A are on the same window scale (0-6kBq/ml for tumor, 0-50kBq/ml for bladder). Red colors in B represent B > 0 (spill-out), B < 0 are blue, and B=0 is white; the scale on these images range from (-18 kBq/ml to +18 kBq/ml for tumor and -100 kBq/ml to +100 kBq/ml for the bladder). Notice spill-out from the tumor near the chest wall as well as inside the bladder near the edge; a little spill-out can even be seen in the rectal wall on the bladder image. Spill-in (B < 0) can be seen around the patient and high activity heart as well as adjacent to the bladder and in the stool within the rectum which lies posterior (below) the bladder. Also note that in the center of the bladder, spill-in and spill-out is much closer to zero implying a voxel value there is near equilibrium and more accurate. This can also be seen on the line profile that shows the PET, A, and B. The B images will be useful in determining the bias from PVE in ROIs. To have no PVE bias in your activity measurement, the sum of B in the ROI should be zero.

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