Automatic optimization of bilateral filter parameters in clinical PET

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Motivation

- Gaussian filters are commonly used to improve signal to noise ratio (SNR) of PET images but reduces spatial resolution, thus increases partial volume effects.
- The edge preserving *bilateral filter* (BF) is able to overcome these shortcomings [1] but requires manual tuning of two free parameters σ_S and σ_I :

$$W(m,n) = \underbrace{\exp\left[-\frac{(\vec{P}_m - \vec{P}_n)^2}{2\sigma_S^2}\right]}_{\text{spatial domain } (W_S)} \cdot \underbrace{\exp\left[-\frac{(I_m - I_n)^2}{2\sigma_I^2}\right]}_{\text{intensity domain } (W_I)}$$

➡ This is time consuming and hampers clinical use despite attractive filtering properties.

➡ Development of a method for automatic filter parameter optimization.

Methods

- 552 low SNR image volumes from 69 clinical respiratory-gated PET/CT measurements (8 gates), three different tracer entities: [^{18}F]-FDG(N=33), [^{18}F]-LDOPA(N=25), [^{68}Ga]-DOTATATE(N=11).
- Delineated four 3D ROIs: one within liver (to assess noise), three in areas with elevated focal uptake (e.g. lesions).
- Generated 225 differently BF-filtered versions of each volume (sum: 124200) by varying σ_S and σ_I based on a 15x15 grid covering a logarithmic range from 2 mm to 8 mm for σ_S and from 0.1 to 10.0 SUV for σ_I.
- Optimization of σ_S and σ_I via objective function S:

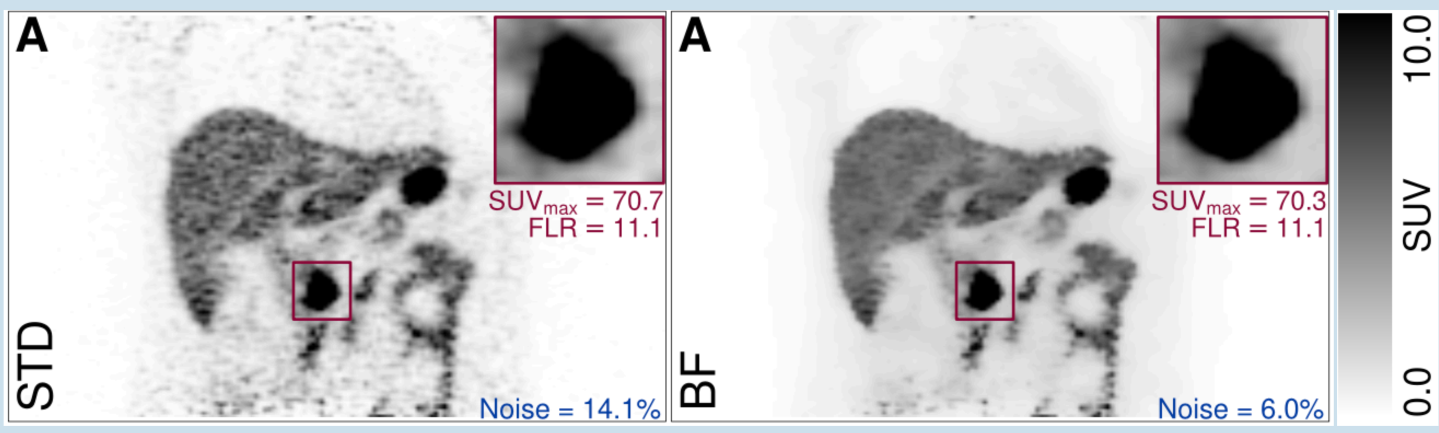
$$S(\sigma_S, \sigma_I) = \sum_{i=1}^{g} \sum_{j=1}^{l} \left[\Delta \mathrm{SUV}_{max}^{i,j}(\sigma_S, \sigma_I)\right]^2 + \sum_{i=1}^{g} \left[\Delta \mathrm{Noise}^{i}(\sigma_S, \sigma_I)\right]^2$$

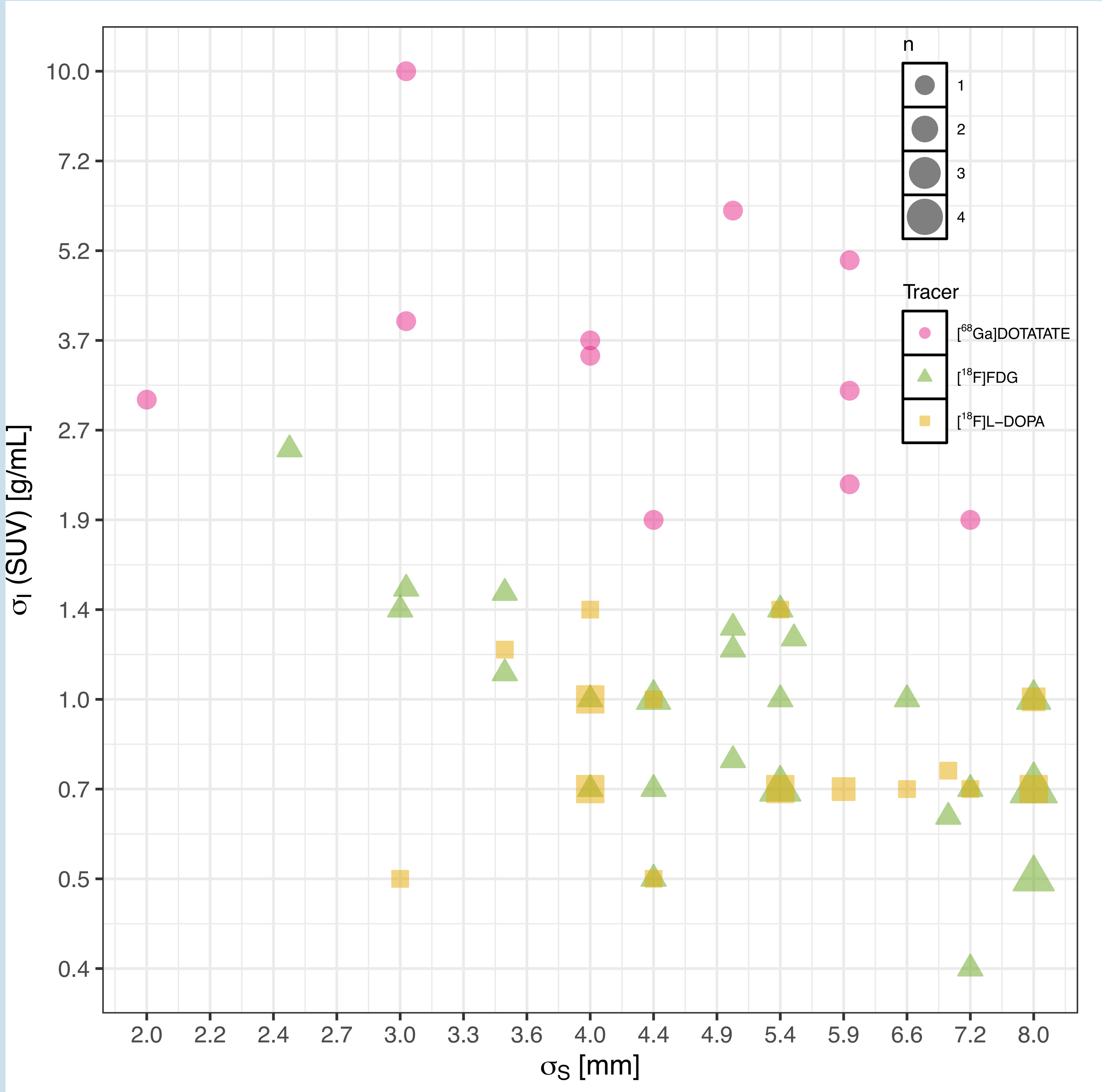
with $\Delta \mathrm{SUV}_{max}^{i,j}$ and $\Delta \mathrm{Noise}^{i}$ as the fractional differences between original (STD) and BF-processed gate-specific SUV_{max} and noise level.

Results

- For 19/69 datasets our method required manual parameter tuning (due to over-smoothed background or visible artefacts).
- Optimal parameter values varied over a substantial range (mean ± SD: σ_I = (1.4 ± 1.5) SUV and σ_S = (5.5 ± 1.7) mm)
- σ_I exhibits a pronounced tracer dependance (cf. figure)
- $\Delta \mathrm{SUV}_{max}$ of the focal uptake ROIs across all datasets was small (-0.5 ± 0.8) while substantial noise reduction was achieved by ΔNoise (-12.3±3.5) percentage points, although behaviour differed between tracers.

		[^{18}F]-FDG	[^{18}F]-LDOPA	[^{68}Ga]-DOTATATE	All
$\Delta \mathrm{SUV}_{max}$	[g/mL]	-0.33 ± 0.31	-0.26 ± 0.20	-1.63 ± 1.30	-0.51 ± 0.75
ΔNoise	[pp]	-12.7 ± 2.9	-13.0 ± 3.3	-9.6 ± 4.3	-12.3 ± 3.5





Conclusions

- Results demonstrate inter-individual and tracer-specific variability of optimal BF parameters
  - ➡ Underlines the need for careful parameter optimization.
- In 72% of all cases our automated method was able to perform parameter optimization without any user intervention.
  - ➡ More work needed to further improve the success rate.

➡ Our method already reduces workload when considering BF for routine use.

[1] F. Hofheinz, et al. *Suitability of bilateral filtering for edge-preserving noise reduction in PET.* EJNMMI Research 2011 1:23, doi: 10.1186/2191-219X-1-23